SANTA CATARINA: DISASTER RISK PROFILING FOR IMPROVED NATURAL HAZARDS RESILIENCE PLANNING

The World Bank

1818 H Street NW

Washington DC 20433

Telephone: 202-473-1000

Internet: www.worldbank.org

ACKNOWLEDGEMENTS

This report was produced by a team led by Frederico Ferreira Pedroso (DRM Specialist, GPSURR), and comprising Rashmin Gunasekera (DRM Specialist, GPSURR), Oscar Ishizawa (Senior DRM Specialist, GPSURR), Fernanda Senra De Moura (DRFI Consultant, GPSURR), Rafael Schadeck (DRM Consultant, GPSURR), Roque Alberto Sánchez Dalotto (GIS Specialist Consultant, GPSURR), Mario Saraiva (Consultant, GPSURR), Antonios Pomonis (DRFI Consultant, GPSURR), Maria Gaspari (DRFI Consultant, GPSURR), and Ambiental Technical Solutions Ltd. (Flood Modeling Consultancy). Niels Holm-Nielsen (Lead DRM Specialist, GPSURR) provided special guidance and comments that were crucial to the preparation of this study.

The report greatly benefited from data and information provided by the State of Santa Catarina through the Secretary of Sustainable Economic Development (SDS) and its Department of Climate Change Adaptation.

The team is thankful to the peer reviewers Joaquin Toro, Thadeu Abicalil and Josef Leitmann.

The team gratefully acknowledges the funding from the Japan-World Bank Program for Mainstreaming Disaster Risk Management in Developing Countries under the management of the Global Facility for Disaster Reduction and Recovery (GFDRR).

CONTENTS

ABBREVIATIONS AND ACRONYMS

AAL Annual Average Loss
AEP Aggregate Exceedance Probability
AMAX Annual Daily Maximum
BUC Basic Unit Cost
CAT Catastrophe
DRM Disaster Risk Management
DSM Digital Surface Model
DTM Digital Terrain Model
EP Exceedance Probability
IBGE Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*)
MDR Mean Damage Ratio
OEP Occurrence Exceedance Probability

EXECUTIVE SUMMARY

This report seeks to further the body of disaster risk management (DRM) knowledge in Santa Catarina by identifying flood asset exposure risks and consequently empower the state government and its institutions to include DRM practices and information in their daily operations and decision-making processes, respectively. In this context, a novel study was jointly designed and developed by the World Bank and Santa Catarina's state government with the ultimate aim to produce a state-level Catastrophe (CAT) model.

Following a well-established methodological process, the team has endeavored a number of activities that led to a successful and comprehensive CAT modeling as follows:

- A robust set of geo-spatial information plans were generated using national- and state-level databases, which were compiled in a single information technology application.

- Residential and nonresidential models were developed to allow both the estimation of building asset values and vulnerability to flooding events.

- A statewide flood model for different return periods was produced using available hydro-meteorological historical information and digital terrain and surface models. Climate scenarios were not considered as common assumptions used to define those would imply in a rather imprecise mathematical modelling attempt in the specific context of the CAT Model.

- A CAT model was derived using exposure, vulnerability, and flood models to produce general metrics (for example, Aggregate Exceedance Probability [AEP], Occurrence Exceedance Probability [OEP], Exceedance Probability [EP], and Annual Average Loss [AAL]) to improve the state's understanding of its asset and financial exposure to natural hazards.

The novelty and depth of the study allowed the team to draw a number of potential policy implications and possible decision making to improve the state's resilience to natural disasters. To the best of the team's knowledge, this is a first-of-its-kind study in Brazil and has potential direct applications to a wide body of professions and institutions in Santa Catarina. Finally, the proposed methodological approach was heavily based on the national census as well as on commonly accessible hydro-meteorological data and topographic information to ensure replicability in other Brazilian states or municipalities.

PART 01

INFORMED DRM PLANNING IN SANTA CATARINA

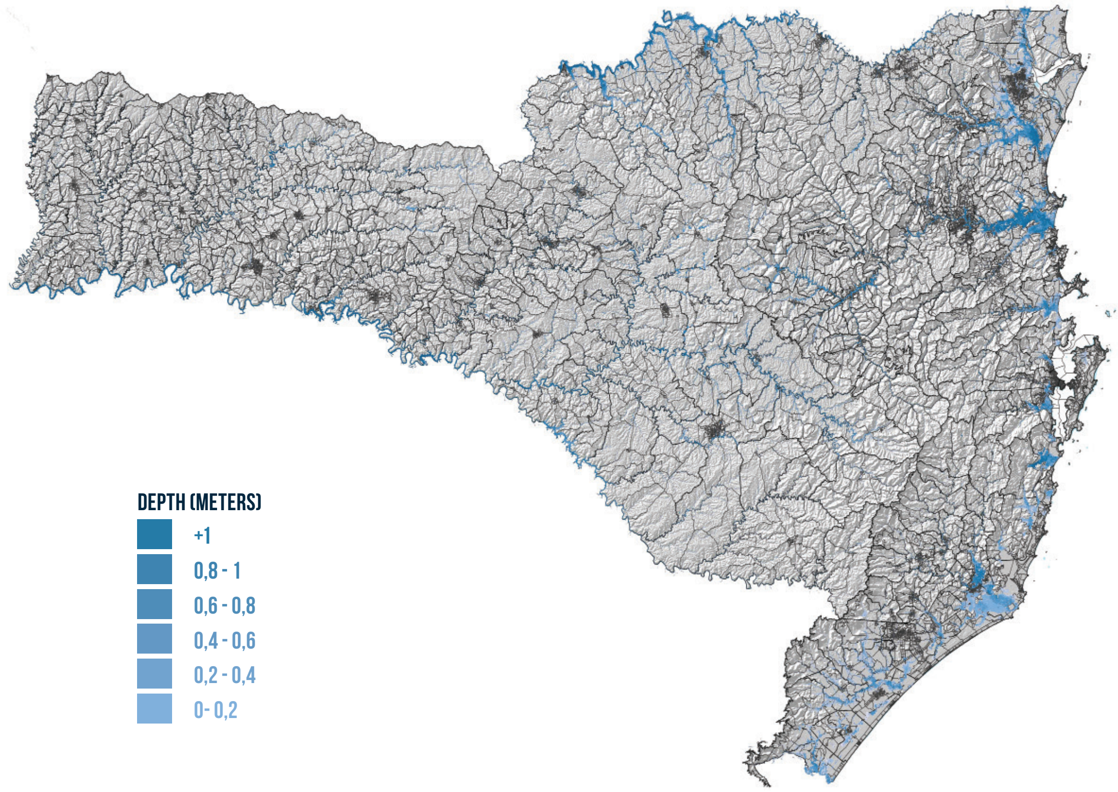
"Disaster Events are the materialization of Natural Hazards Risks, which ultimately generate economic loses and social impacts"

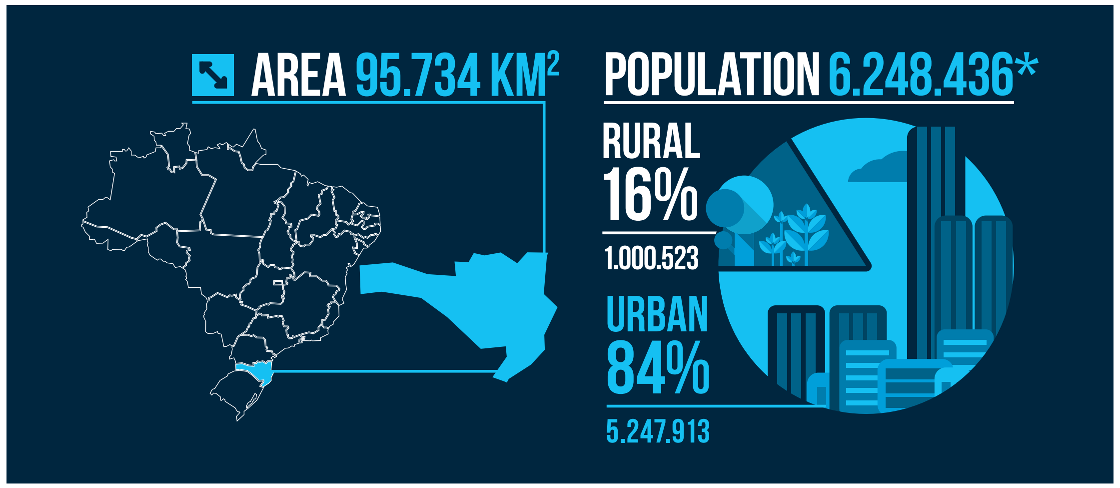
Omar Cardona - Sasakawa Award Winner

Santa Catarina flood map - 1 in 100 years return period

Flood maps can be used in combination with georeferenced datasets of assets of different types, like road networks, production plants, public infrastructure, real estate and so on.

As such, State or national institutions can benefit from the information provided in order to prioritize areas for DRM interventions and investment across the state or to promote private developments in safe zones, for example.





1. Historical Patterns of Natural Hazards in Santa Catarina

1.1 Recovering State-level Disaster Damage and Losses

The state of Santa Catarina, in Southern Brazil, covers an area of 95,346 km^2 and contains a population in excess of 6 million. The state is affected by a great diversity of natural adverse events: droughts, floods, flash floods, hail, mass movements, windstorms, tornadoes, and coastal erosions. The state was also affected by Hurricane Catarina, the only hurricane recorded in Brazil so far.

Floods and droughts are the most common events and most floods occur during the summer (December to February), which is the rainy season. From 1995 to 2014, damage and losses from natural disasters in Santa Catarina amounted to R$17.6 billion or 0.4% of State GDP per year (value adjusted to 2014), as reported by municipalities through 2,704 official records. On average, 135 records were submitted per year. From historical data, a slightly higher incidence of events in the western and in the southern regions of the state was noticed.

Over the 20-year period considered, significant annual peaks were observed in the number of records, which reflected events of greater magnitude such as the landslides and floods in November 2008, the 2004–2005 drought event, flooding in the Itapocu Valley in 2014, hail and thunderstorms in the west and mountainous regions in 2014, the 2004 Hurricane Catarina, and the flood events in the Itajaí Valley in September 2011. Table 1 presents specific data on these events to better scope the of their economic and social impacts.

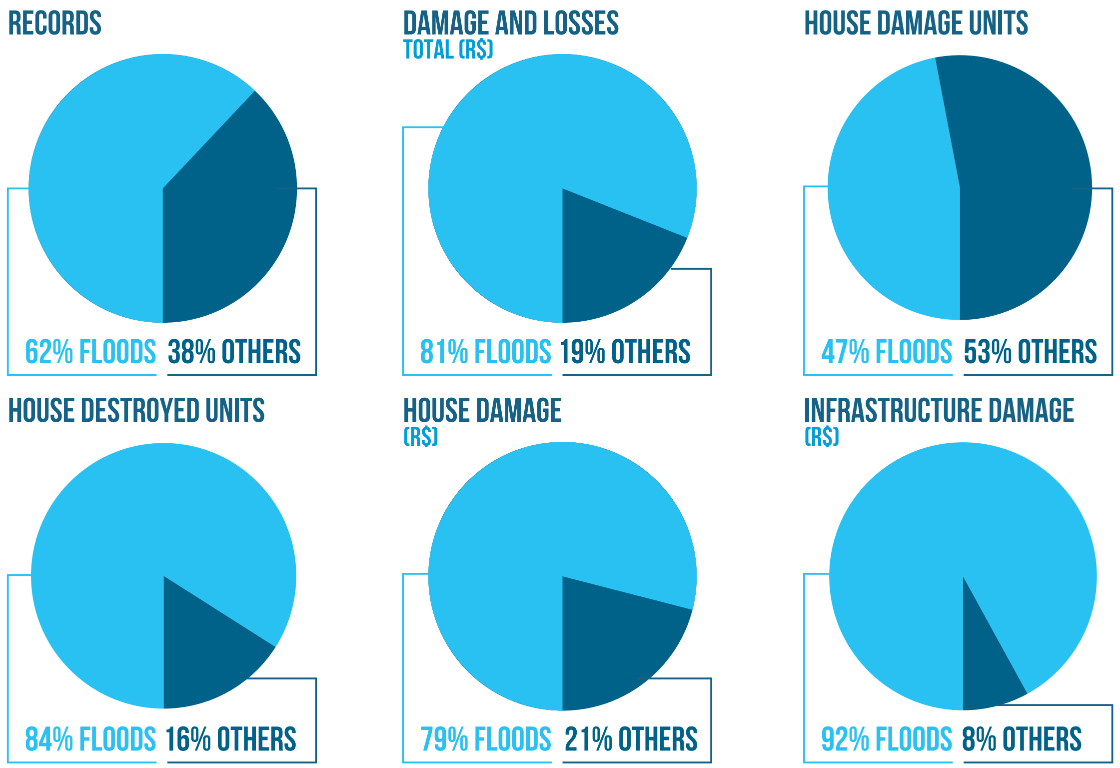
Table 1. Major Natural Disaster Events in the Recent History of Santa Catarina

	MUNICIPALITIES AFFECTED	DAMAGES AND LOSSES	POPULATION AFFECTED	HOMELESS AND DISPLACED	HOUSING DAMAGE
CATARINA HURRICANE 2004	14	US$ 116,2 MI	47.963	18.756	66.653
DROUGHT 2004 - 2005	163	US$ 544,1 MI	1.235.590	-	-
FLOODS VALE DO ITAJAÍ 2008	73	US$ 1.445,7 MI	1.528.2301	22.135	73.111
FLOODS SEPTEMBER 2011	58	US$ 337,5 MI	935.5172	01.338	34.126
FLOODS VALE ITAPOCU 2014	4	US$ 100,9 M	123.2621	7.9421	1.167

Among the events presented in table 1, the flooding in 2008 affected about 60 towns and over 1.5 million people. At least 135 people were killed, over 78,700 forced to evacuate their homes, 27,400 left homeless, 7,154 homes were completely destroyed (CEPED UFSC 2016), and 186,000 left without electricity for weeks (BBC 2008). Again in September 2011 the state was flooded, when 6 people died, 489,703 people were affected, 43,066 houses were damaged, and R$112 million of public losses were registered (CEPED UFSC 2016). Between 1980 and 2011, there have been 11 major episodes of flooding (Garcia et. al. 2011), and the recent flood events in 2014 (Smithsonian 2014) and 2015 (Floodlist 2015), suggest that flooding is a persistent and relevant hazard in the state.

Taking into consideration only flooding events between 1995 and 2014, property damages and losses are the most significant, representing about 53 percent in monetary terms and 43 percent of registered events as illustrated in figure 1.[1]

Figure 1. Flooding Impacts in Comparison to Other Disaster Events in the Recent History of Santa Catarina[2]

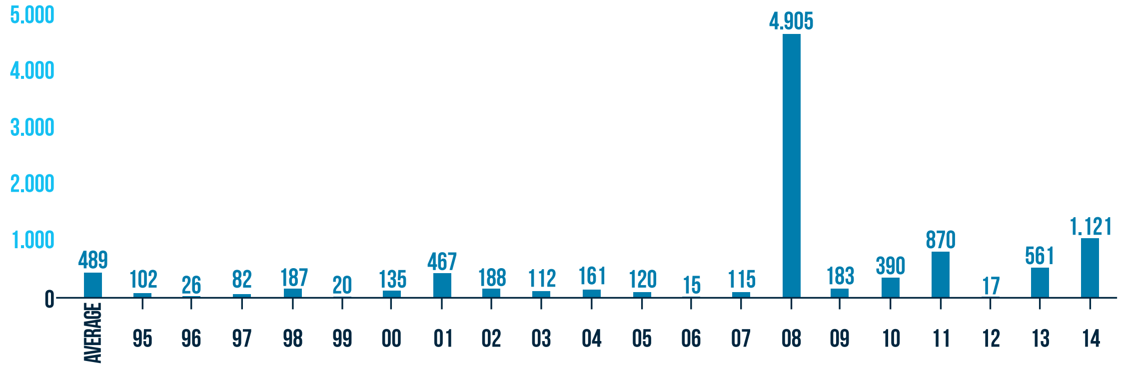


The municipalities informed flood-related losses of R$9.8 billion, with an annual average of R$489 million. Figure 2 presents the economic losses related to floods on a yearly basis. Given the magnitude of the 2008 events, this year has the highest flood-related loss of all years.

1 This percentage is in comparison with natural disasters reported, excluding drought events.

2 World Bank Estimates Based on Official Data

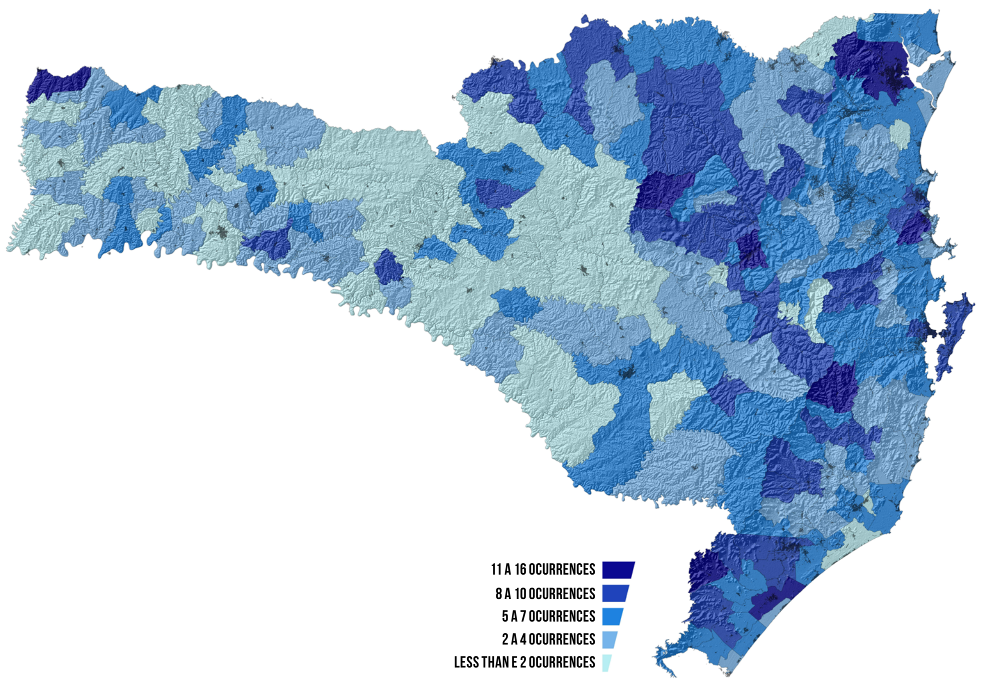
Figure 2. Economic Losses due to Flood Events[3]



Large events, such as the 2008 flooding, have caused high financial losses to the Government and the economic impacts, although not easily measured, are significant. For instance, in 2008, the associated cost of a single event represented approximately 2.6 percent of the state gross domestic product (World Bank, 2013). The port of Itajaí, the largest port in the region, was not operational for several weeks, thus causing economic disruptions throughout the region.

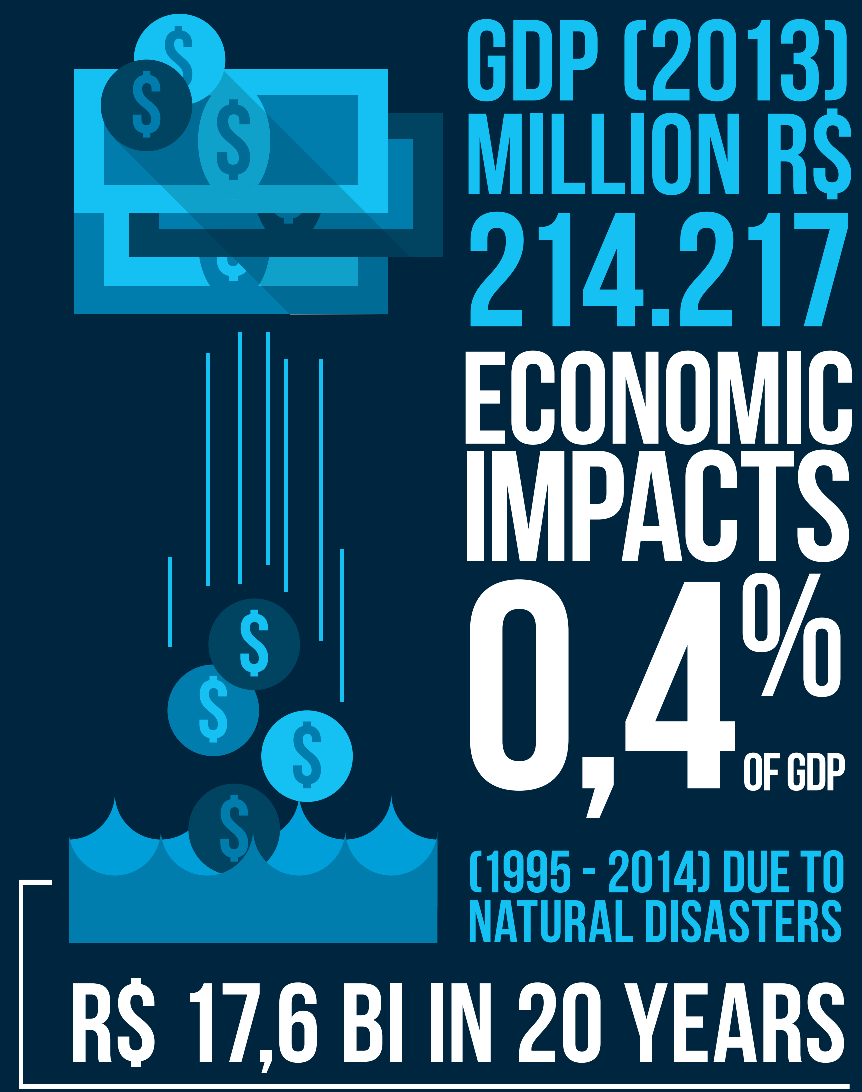
In the 20-year interval considered, 95 percent of municipalities reported losses related to flooding events at least in one occasion. Based on the geographical distribution of records as shown in map 1, it was concluded that these events occur with a higher incidence in the eastern portion of the state.

Map 1. Damage and Losses due to Hydrological Disaster Events



3 World Bank Estimates Based on Official Data

GDP AND THE FINANCIAL COSTS DUE TO NATURAL DISASTERS



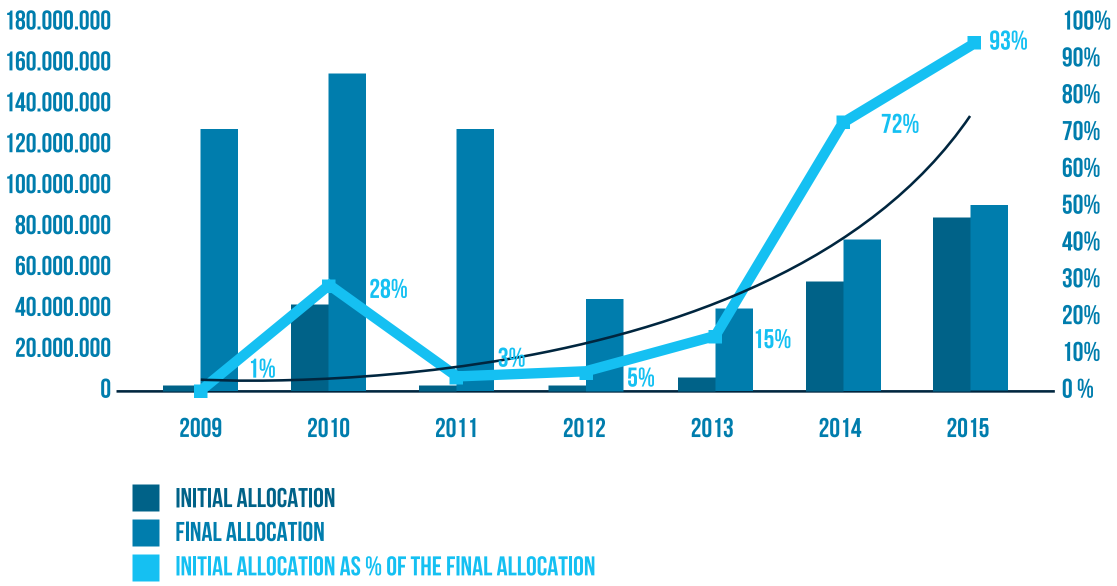
1.2 Financial Disaster Response Capacity in the Recent Past

Given the relevant damage and losses experienced by the state of Santa Catarina, a question that naturally follows is whether or not the state's financial response capacity in place was sufficient to avoid disaster response funding gaps. To investigate this issue, a set of disaster-related fiscal indicators was developed at the state level and a funding gap analysis was carried out.

From 2009 to 2015, disbursement of funds related to disaster response amounted to approximately R$400 million (see figure 3). Besides the low levels of disaster response funds disbursed, it is possible to see that during this period a large share of the response resources were mobilized through extraordinary credits, because the initial allocation of R$189 million was much lower than the revised amount (R$593 million). Moreover, with regard to budgetary execution, the numbers suggest that the main bottleneck refers to the state's commitment capacity. Whether this reflects difficulties in negotiating commitments or an expected lack of technical capacity to enable disbursements is an open question that goes beyond the scope of this study and needs further investigation.

However, over time, the initial allocation of funds for disaster response increased significantly, both in absolute terms and as a share of the final allocation, suggesting a shift toward ex ante sources of funding (figure 3).

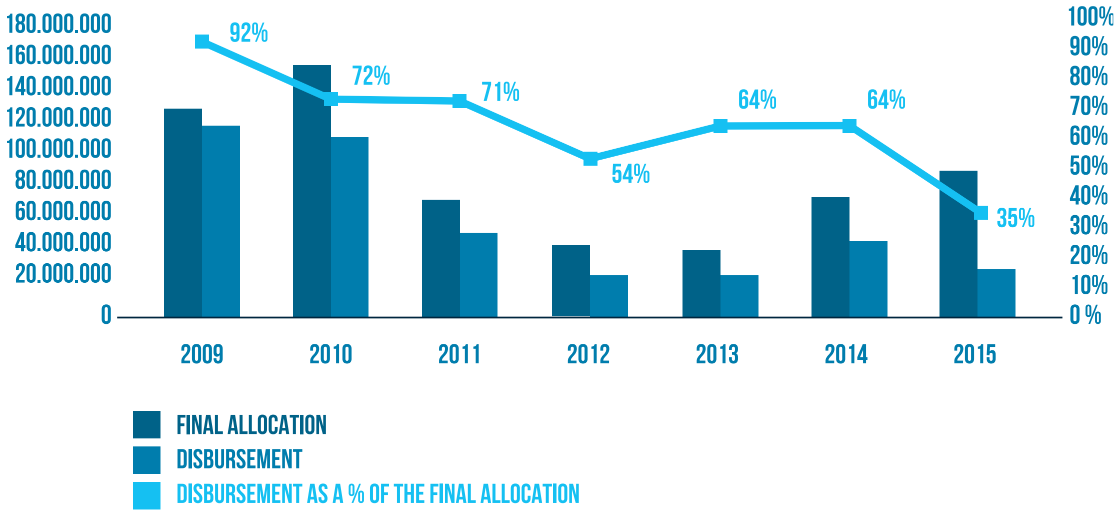
Figure 3. State-level Disaster Response in Santa Catarina (R$ current values)[4]



Regarding the disbursement performance, between 2012 and 2015, a decline in the funds disbursed as a share of the final allocation was observed, when compared to the numbers between 2009 and 2011 (figure 4). This could be explained by the fact that since 2012 the events that struck the state were not as severe as those in the 2009–2011 period were. Further arguments for this observation (from a speculative spectrum due to lack of evidence) might be the lack of agile and more flexible and disaster-specific instruments and processes.

4 World Bank Estimates Based on Official Data

Figure 4. State-level Disaster Response in Santa Catarina[5]



It is important to note that this only includes the spending executed by state-level institutions. Disaster response executed directly by the national government (instead of through transfers to the state) is not being considered as it was not possible to disaggregate the share of the disaster response funds (directly executed by the Federal Government of Brazil) allocated to each Brazilian state. However, the practice in many sectors is that the responsible line ministry transfers the response funds to the corresponding state-level secretariat, which then becomes the institution responsible for the planning, execution, and monitoring of the disaster response programs. Therefore, the execution of such funds is often included in the state budget.

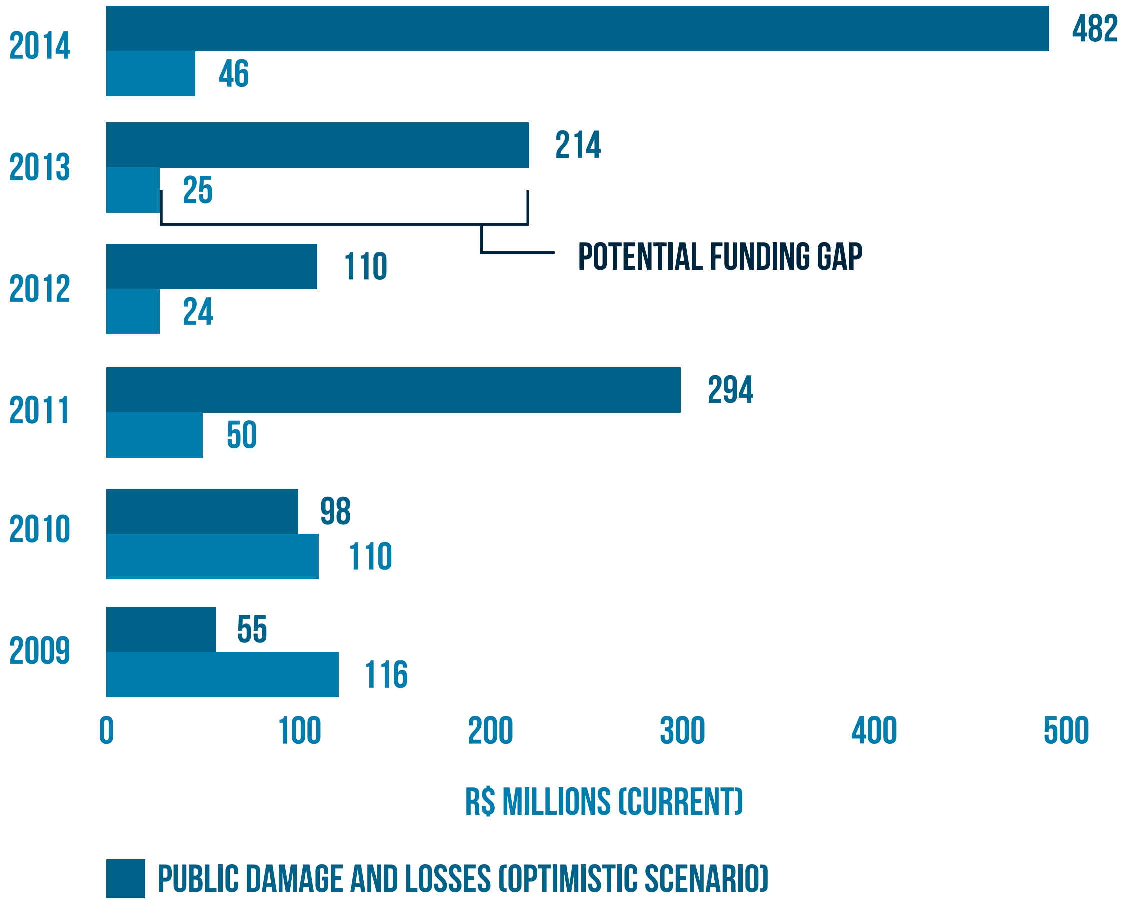
Moreover, it is possible that more general budget lines containing projects related to disaster response were not identified by the methodology that was employed. Therefore, given the limitations imposed by the nature of the available fiscal data, the fiscal variables presented in this section should be taken as proxies and as a basis for further in-depth analysis of the impacts of disasters on the state budget.

The next step is to compare disaster response funds with disaster public damages and losses to investigate to what extent disaster response funding gaps are a recurrent issue in Santa Catarina. In light of fiscal data availability, it was rather difficult to carry out this analysis which was done only for the 2009-2014[6] period.

5 World Bank Estimates Based on Official Data

6 From 2009, compulsory transfers dedicated to disasters were created; therefore, data availability has increased and facilitated our analyses.

Figure 5. Disaster Response in Santa Catarina, Potential Funding Gaps[7]



As show in figure 5, even under an optimistic scenario in which only 30 percent of the total damage and losses translate into state-level government liabilities, the disaster response funding gaps have been significant in the recent past. In addition, even though the numbers do not show a lack of resources for response in 2009, it is important to consider that the state experienced floods in November 2008, meaning that most of the response took place during the fiscal year of 2009. In other words, considering that the public disaster damage and losses amounted to over R$1 billion in late 2008, the disaster response disbursement of about R$120 million in 2009 was much below the response needs.

Unfortunately, because detailed fiscal data was available only from 2009, it was not possible to combine the years of 2008 and 2009 to get a clearer picture of the fiscal impacts of the 2008 floods. However, while the funding gaps presented above should be taken as preliminary estimates — and despite its limitations — the available information clearly shows that the financial gaps in disaster response are significant, with potentially major negative long-term impacts.

7 World Bank Estimates Based on Official Data

2. Knowledge Base for DRM Planning in Santa Catarina

As previously presented, Santa Catarina is exposed to recurrent disaster events, among which floods play a major role. The economic effects of such events as indicated by the historical damage and losses are significant and, at the same time, the state's financial response capacity is still limited. While over the years, the state has shown significant progress in DRM practices and has been, in fact, a benchmark in the country, there is still room to significantly improve its DRM strategy. In this context and while the historical records discussed above are extremely valuable for DRM planning, adopting a forward-looking approach is paramount for the design and update of a DRM strategy based on the following pillars of action: (a) risk identification, (b) risk reduction, (c) preparedness, (d) financial protection, and (e) resilient recovery.

With the above DRM framework in mind, this study combines an investigation of the historical patterns of natural hazards (and its effects) in Santa Catarina with a CAT flood risk model to deliver a state-level knowledge base for DRM planning. Figure 6 illustrates the proposed methodology used in the study, which is described as follows:

- Step 1. Disaster data (each municipality must submit a form informing the characteristics of the disaster event) available through the Integrated Information System on Disasters was analyzed to identify disaster loss patterns at the state level.

- Step 2. Geographic data was collected and analyzed for the state of Santa Catarina to generate information plans (geo-spatial layers) for a number of variables to build the information base for the study.

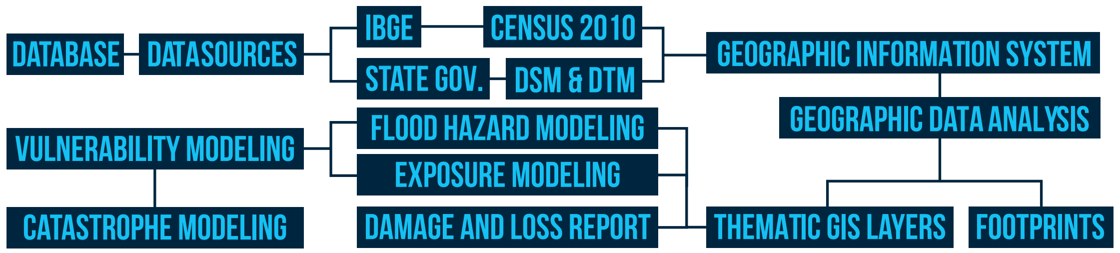
- Step 3. Residential and nonresidential exposure databases were created keeping the 2010 National Census as the main input to produce an estimation of built area, construction patterns, and building costs.

- Step 4. A state-level flood model (for different recurrence periods) was produced benefiting from historical hydro-meteorological data and hydrology and hydraulic modeling techniques.

- Step 5. A vulnerability model was derived from the exposure and flood models so physical damage and, consequently, economic impacts from the occurrence of flood events could be estimated.

- Step 6. A CAT model was generated by combining the vulnerability and flood models so AEP, OEP, EP curves, and related metrics could be produced.

Figure 6. CAT Modeling Methodological Approach



2.1 *Flood Hazard Modeling and Potential Policy Applications*

As presented in figure 6, one of the steps necessary to build a CAT model is to develop a hazard model, which in this particular study will display flood-prone areas in Santa Catarina (and its municipalities) for different return periods that can produce social and economic impacts.

In this context, the objective of the flood hazard model is to produce flood maps, at different levels (state, municipality, and census tract). In summary, the flood hazard model was built through four main stages as follows:

- The first step was to gather, refine, and analyze and data available: for example, rainfall records (1991–2010), historic flood records, fluvial features representing main rivers, river tributaries, drainage paths, and microdrainage basins) creating a knowledge base and input datasets
- The second step was to develop a hydrological model. In essence, hydrological modeling involves using a variety of techniques to figure out 'how much water' and 'where to put it' geographically speaking
- The third step comprised the hydraulic modeling using two-dimensional models, which involves modeling flow over the floodplain surface
- The final (fourth) step was focused on generating state-level flood maps as well as validating those against past-recorded events.

During the hydrological modeling stage, a sophisticated approach to model river flows was developed using a rainfall runoff model—based on the well-established Revitalized Flood Hydrograph approach for building hydrological models as used by the British Environment Agency. This method is suitable for global usage and is considered appropriate for Brazil.

This analytical process has improved the description of the hydrological processes underpinning the rainfall-runoff method, taking into account updated technique betterments and advances in computation. Moreover, the method is capable of predicting the baseflow as well as introducing more flexible unit hydrograph shapes to obtain a more accurate total runoff, improving other hydrological methodologies such as the rational method.

The methodology takes into account the interaction between direct runoff (flow of water that occurs when excess storm water flows over the surface) and baseflow (portion of stream flow from the sum of deep subsurface flow and delayed shallow subsurface flow).

The hydrological model consists of three main components. Figure 7 shows the connections between the model components together with the required input variables and model parameters. In addition to the main components, a soil moisture accounting model based on daily data was used to determine the state of the soil at the start of the flood event based on long-term series of antecedent rainfall.

Total Runoff hydrograph for a 1000 years return period

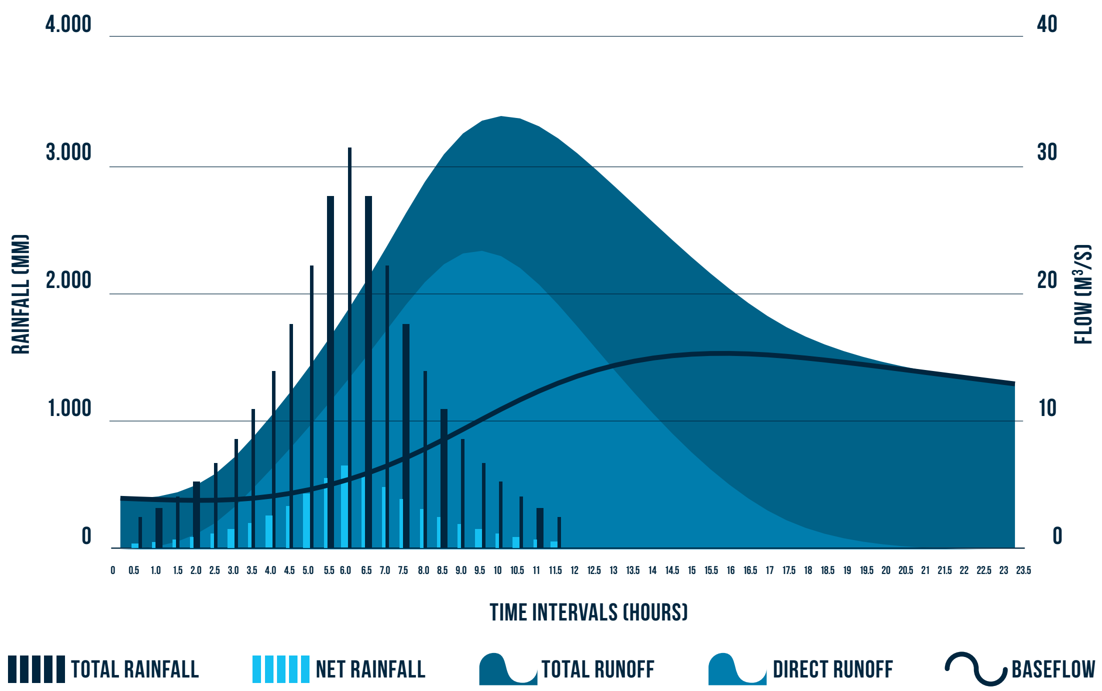
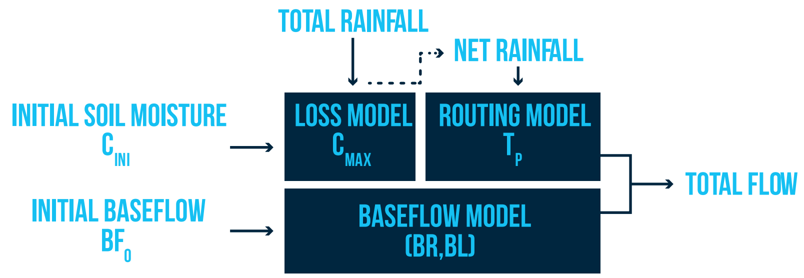


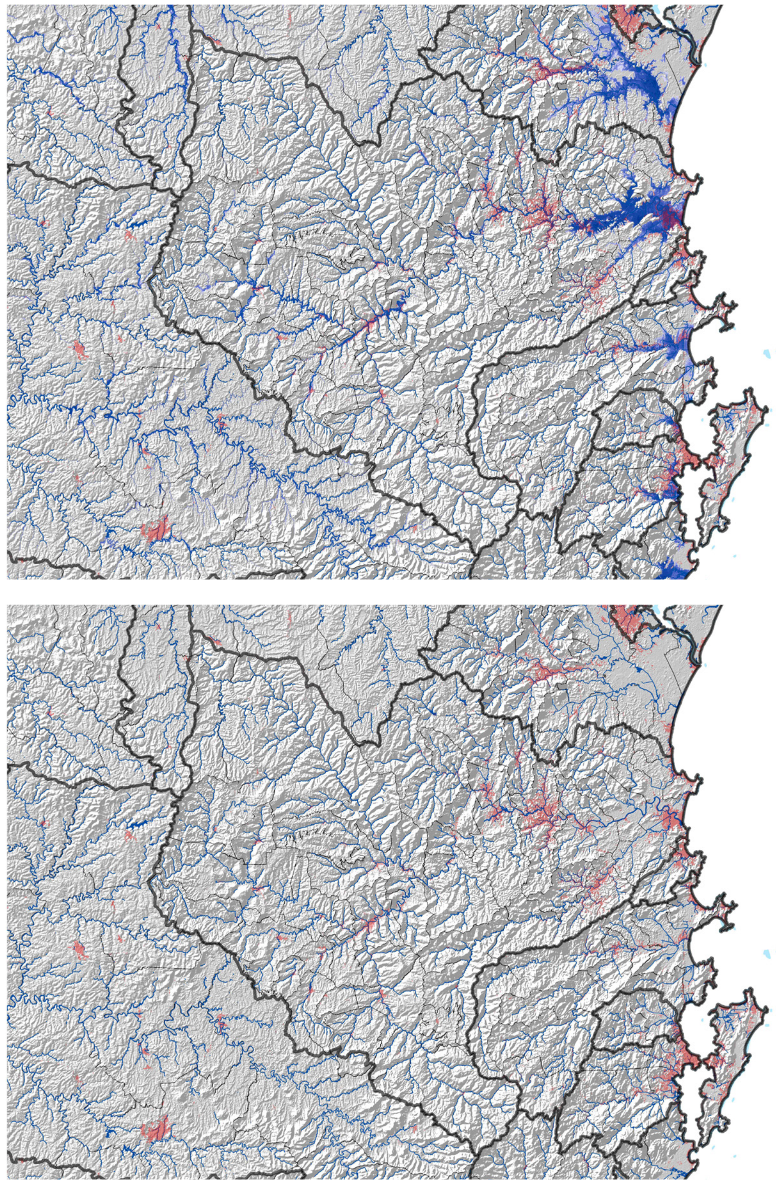
Figure 7. Flood Model Summary



When simulating a flood event, the loss model is used to estimate the fraction of the total rainfall volume turned into direct runoff. The direct runoff is then routed to the catchment outlet using the unit hydrograph convolution in the routing model and, finally, the baseflow is added to the direct runoff to obtain total runoff.

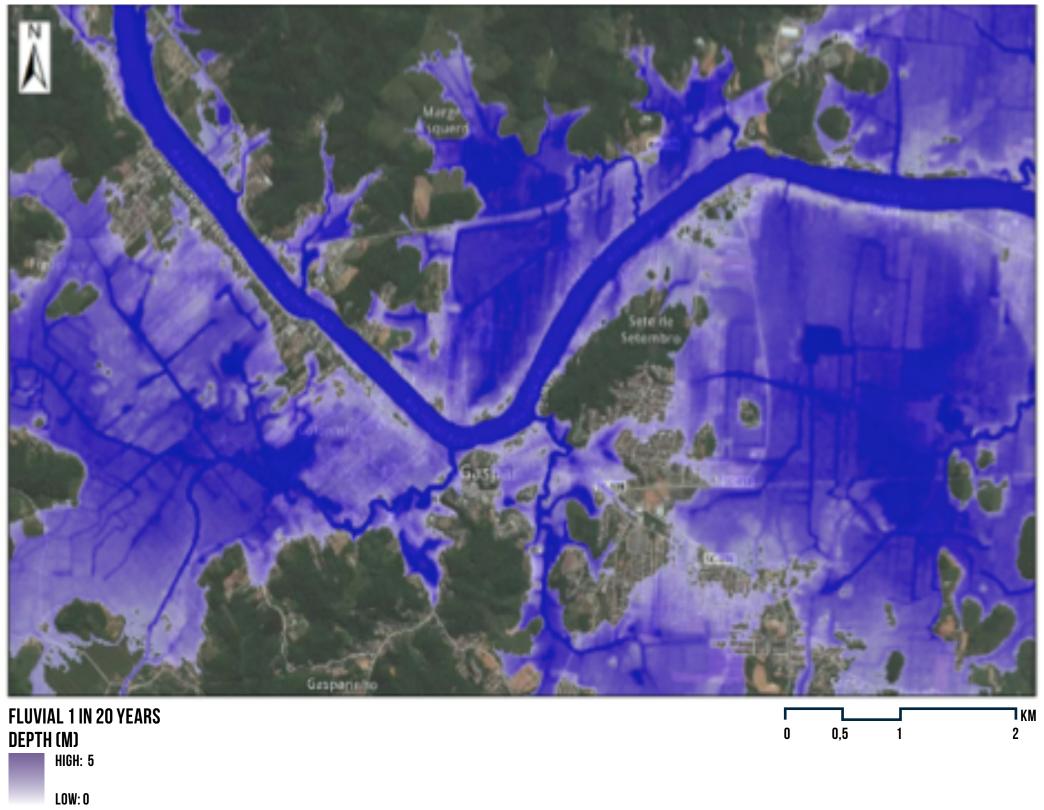
As an example of final products from the flood modeling exercise, map 2 shows the Itajai-acu basin drainage network in regular conditions (bottom) and under a 1,000-year return period flood as modeled. In addition, while the maps presented in this report are illustrative of the analysis carried out, the resolution of the original products is high enough to provide policy makers with very detailed information that will be useful in a variety of planning activities. Hence, it is expected that the results from this study will allow policy and decision makers to better address the DRM framework[1] promoted by the World Bank across the globe and agreed with many counterparts (for example, United Nations, national governments, and academia).

Map 2. Itajai-açu Basin Drainage Network Without Floods (bottom) and Subject to 1 in 1,000 Years (top) Floods



1 Global Facility for Disaster Reduction and Recovery pillars include (a) risk identification, (b) risk reduction, (c) preparedness, (d) financial protection, and (d) resilient recovery.

Map 3. Municipality of Gaspar Flood Map with Return Period of 20 Years



Furthermore, from a macro perspective at the state level, the combined flood map for Santa Catarina shows that even frequent events, with an annual probability of 20 percent, are associated with relevant floods, especially in the coastal region.

Map 4. Santa Catarina State One in Five Years Flood Return Period

At this level of thematic resolution, the information contained in the flood maps could be used by state or national institutions to prioritize areas for DRM investments across the state or to encourage and promote private investment in development prone areas instead of natural hazards exposed parcels, for example. More generally, at larger scales, the flood maps can be used in combination with georeferenced datasets of assets of different types, such as road networks, production plants, public infrastructure, and so on. Hence, the results from this study can become a key tool for improving the overall resilience of the state in different production sectors, public and private arenas, and infrastructure, among others uses.

2.2 *Exposure and Vulnerability Models*

The exposure module ultimately aims to determine the constructed value for residential and nonresidential buildings. Given the technical similarities, it is important to make a distinction between the concepts of exposure and vulnerability (see box 1 for a complete set of concepts). A building located in a flood-prone area does not imply that if an event takes place, the unit will be damaged. The exposure model only investigates how much it costs to repair or or replace the totality of the exposed buildings if a flood occurs, based on the predominant material used in its construction. It is hence focused on the physical characteristics of the asset and, in this particular study, the exposure modeling component focused on residential and nonresidential buildings.

Box 1: Conceptual DRM Framework

Natural hazard. Natural phenomena once triggered, have potential negative effects in a specific geographical location and within a determined length of time.

Asset or infrastructure vulnerability. Preexisting physical conditions that can be affected by the occurrence of a natural phenomenon will consequently negatively affect processes, services, and productivity, among others.

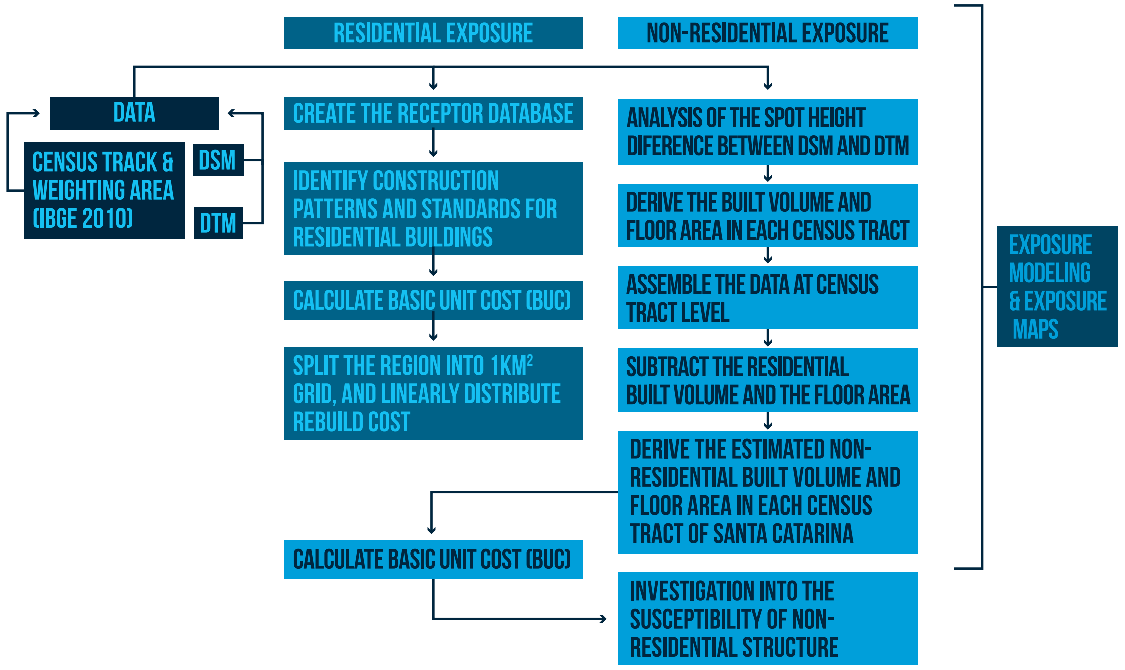
Exposure. An intrinsic geographical condition of an element given its location and possible geographical extent of natural phenomenon.

Susceptibility. The degree to which a given location is to be affected by a natural hazard.

Disaster risk. Likely economic and social losses that can happen due to the occurrence of a particular natural phenomena in a given period of time.

Two main outputs were sought when building the exposure model: (a) residential exposure and (b) nonresidential exposure. Sample data from the 2010 National Census provides significant information on the characteristics of each household residency, allowing for relatively accurate estimation of construction patterns, standards, and cost of built unit. On the other hand, data on nonresidential buildings for the state was scarce. To overcome this lack of data, the nonresidential built volume and floor area in each census tract of Santa Catarina was estimated. Then the physical vulnerability of each construction pattern was estimated and each pattern was cross referenced to its replacement cost (see figure 9).

Figure 9. Exposure and Vulnerability Modeling Methodological Approach



Residential Exposure

A database on residential buildings was required for the exposure model; to create the receptor database the urban area was extracted from the local land use database. This was checked against aerial mapping and deemed the best available dataset to represent concentrations of exposure.

As previously mentioned, data from the 2010 National Census [2] was used to identify construction patterns and standards for residential buildings according to the Brazilian Association of Technical Standards. Then, the basic unit cost (BUC) of the main construction patterns and standards for the state was calculated, according to the BUC

2 We used the sample data derived from the sample questionnaire (Questionário da Amostra) as it contains more details including building aspects of the household residence. The data characterizes weighting (or ponderation) areas.

index that is issued monthly by the Union of Construction Industry of Brazil. Through Geographic Information System processing, the rebuild costs were distributed equally across the urban area within each weighting area.

It was found that a significant number of houses across Santa Catarina state (approximately 28 percent of all households) were predominantly made of wood, and are not included in the standard construction patterns. To determine the value per square meter of such construction pattern (not specified by the Union of Construction Industry of Brazil), we prepared a unitary composition with the most common characteristics of wooden houses found in the state, particularly in rural areas. Such analysis allowed for the following findings: (a) average ground floor area of 74.0 m2, (b) two bedrooms, (c) one bathroom, and (d) one garage. The total construction cost for a house, predominantly built of wood, was R$62,217.41, representing a cost of R$840.78[3] per m^2.

To increase the precision of the flood analysis, the entire region was split into grids of 1 km^2 and the rebuild costs were distributed among the cells. To derive the proportion of each ‘receptor’ exposed to potential flooding, the 10,000-year flood map was exported and spatially analyzed against the exposure map to establish the share of each title exposed to potential inundation.

Residential Value of Built Area

As previously described, the households were classified according to the materials and construction standards, extracted from the variables available in the 2010 National Census. Using the number of rooms in each housing unit, the areas of residential buildings were obtained using the following equation:

RBFA = Dom x NMRooms x 17

Where:

- NMRooms (pcs) =Average number of rooms per household by weighting area;

- Dom (units): number of housing units per census tract; and

- RBFA (m2): Residential built area by census tract.

Repeating the process for all census tracts, the total residential floor area obtained was 198,749,558 m^2. Once the built area was established, the next step was to determine the constructed value for residential buildings. It is clear that the replacement or repair in any given damaged building was directly connected to the construction costs (see table 2 for the relative BUC for the different standard projects).

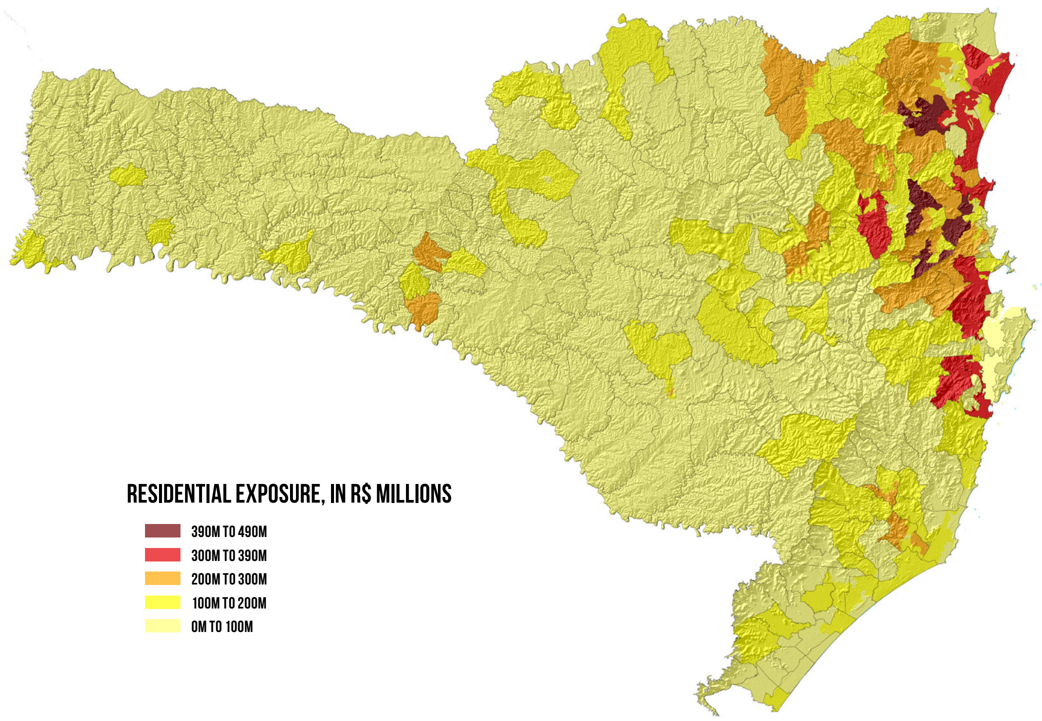
3 We used the National Costs and Indexes of Construction Research System composition sheets to calculate these amounts.

Table 2. Relative BUC for Different Standard Projects

TYPE	R$/M^2
RESIDENTIAL SINGLE FAMILY LOW STANDARD	1,306.46
RESIDENTIAL SINGLE FAMILY NORMAL STANDARD	1,553.53
RESIDENTIAL SINGLE FAMILY HIGH STANDARD	1,899.37
POPULAR/SOCIAL HOUSING	1,395.14
RESIDENTIAL MULTIFAMILY LOW STANDARD	1,159.13
RESIDENTIAL MULTIFAMILY LOW STANDARD	1,293.32
RESIDENTIAL MULTIFAMILY LOW STANDARD	1,533.79
WOODEN HOUSES	840.78
MEAN RESIDENTIAL BUC	1,453.79

The total residential floor area obtained for Santa Catarina was 198,749,558 m^2. Through the product of the built environment and the BUC for each standard design, we obtained the total value amount of R$247 billion. The average value per square meter was then estimated at R$1,243.36 per m^2 and the value of the total asset exposure per municipality is shown in map 5.

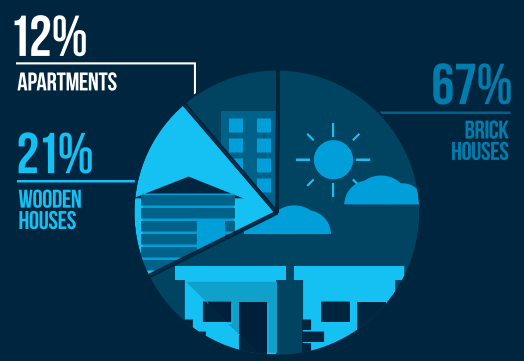
Map 5. Santa Catarina’s Residential Asset Exposure



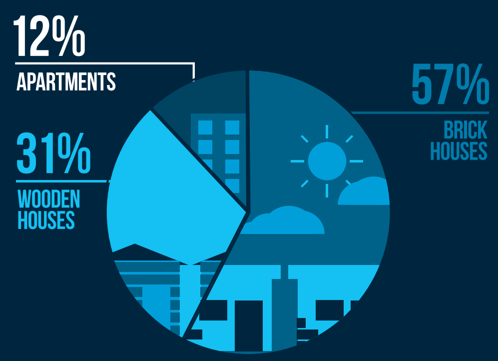
THE IMPACT OF A HAZARD WILL NOT BE EQUAL IN ALL CASES. IMPACT IS HIGHLY DEPENDENT ON THE CHARACTERISTICS OF THE ASSET AT ANY GIVEN LOCATION. SOME PROPERTY CONSTRUCTION TYPES ARE MORE VULNERABLE TO FLOODING.

EXPOSURE AND VULNERABILITY

BUILT VALUE*

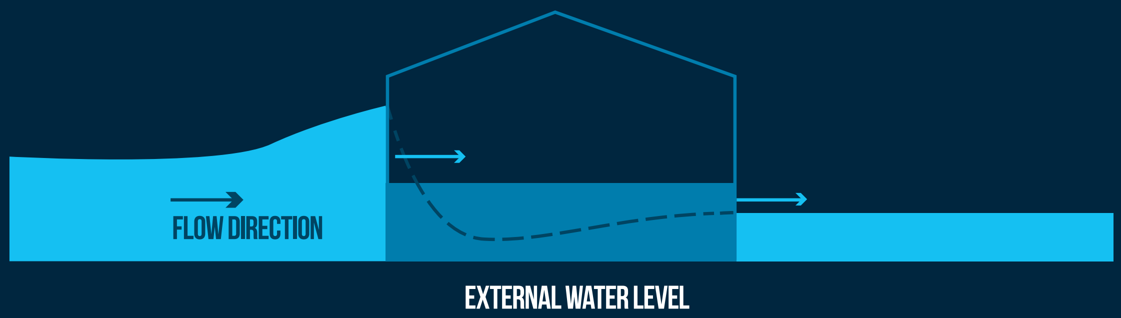


BUILT AREA - RESIDENCIAL

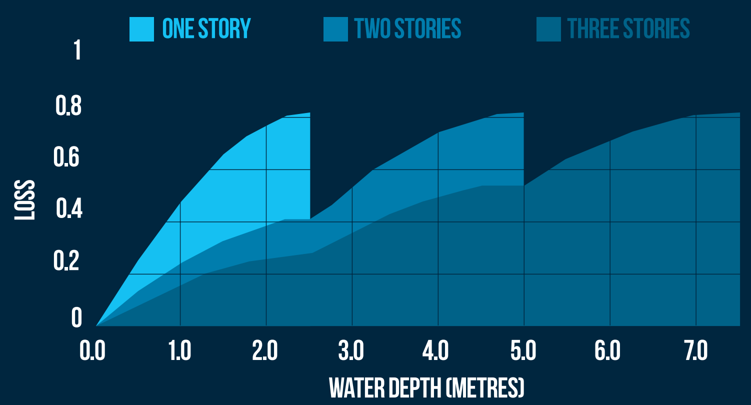


*PERCENTAGE OF THE TOTAL MONETARY VALUE OF REPLACEMENT/RECONSTRUCTION.

VULNERABILITY OF VARIOUS TYPES OF BUILDING



THE VULNERABILITY OF VARIOUS PROPERTY TYPES IN SANTA CATARINA WAS RESEARCHED. A SERIES OF CURVES RELATING MEAN DAMAGE RATIO (MDR) TO FLOOD INTENSITY (DEPTH) WAS PRODUCED. IT ALLOWS EXPOSURE PORTFOLIOS TO BE PARAMETERISED TO REFLECT CHARACTERISTICS OF INSURED ASSETS.



Nonresidential Exposure

The estimation of the nonresidential built volume and floor area was performed at the census tract level, using the Digital Terrain Model and Digital Surface Model imageries of Santa Catarina captured between 2011 and 2013, in conjunction with the August 2010 Census (Brazilian Institute of Geography and Statistics [Instituto Brasileiro de Geografia e Estatística, IBGE]). The approach was to derive the built volume and floor area in each census tract using the cell-level spot heights and then assemble the data at census tract level and subtract the residential built volume and floor area (estimated from the census 2010 data) to derive the estimated nonresidential built volume and floor area in each census tract of Santa Catarina.

Initially a feasibility study was carried out in a part of Florianopolis (7 weighting areas containing 143 census tracts), where the methodology and various hypotheses were developed and tested out. Then the methodology described above was applied across all the census tracts of Santa Catarina, which was possible in 10,029 (82 percent) of the 12,227 existing census tracts. The remaining census tracts could not be analyzed either because of a problem in the weighting area boundaries shape file of IBGE (concerning 412 census tracts) or because spot height data were not available (concerning 1,786 census tracts). The 10,029 analyzed census tracts contain 91 percent of the Santa Catarina population.

The next step was an investigation into the susceptibility of the nonresidential structures within the state. This involved a manual survey of 100 buildings, undertaken through Google Street View®, which encompassed urban, suburban, and rural areas. In each case, areas were chosen at random within three representative cities across the state. This analysis was intended to provide quantitative data to support or disprove the heroic assumption that there was a 50/50 split of susceptibility types.

Although 100 properties represent a relatively small sample size in proportion to the total relevant building stock within the state, the survey sample was deemed satisfactory to establish an initial assessment. The results obtained were stable when the sample size was halved. After the 100 observations were taken, no additional sampling was carried out as the established results did not vary significantly enough from the even split ratio assumption to warrant further investigation and because the impact on the loss modeling results would be very negligible.

The buildings chosen were all located within areas that were within the extent of the flood model footprint and deemed to be at risk of flooding by at least the 10,000-year return period flood. In each location, the first nonresidential building identified upon entering Google Street View was selected for the analysis. Subsequently, a new, nearby location was chosen and the process was repeated. For each nonresidential building, the following information was recorded: (a) door material, (b) interior quality, and (c) number of stories (1, 2, or 3+).

With such information, the susceptibility of nonresidential buildings was defined as high, medium, or low (see table 3). This decision was based on an analysis of the interior characteristics (to the extent to which this was possible) and then related to the most appropriate vulnerability curves.

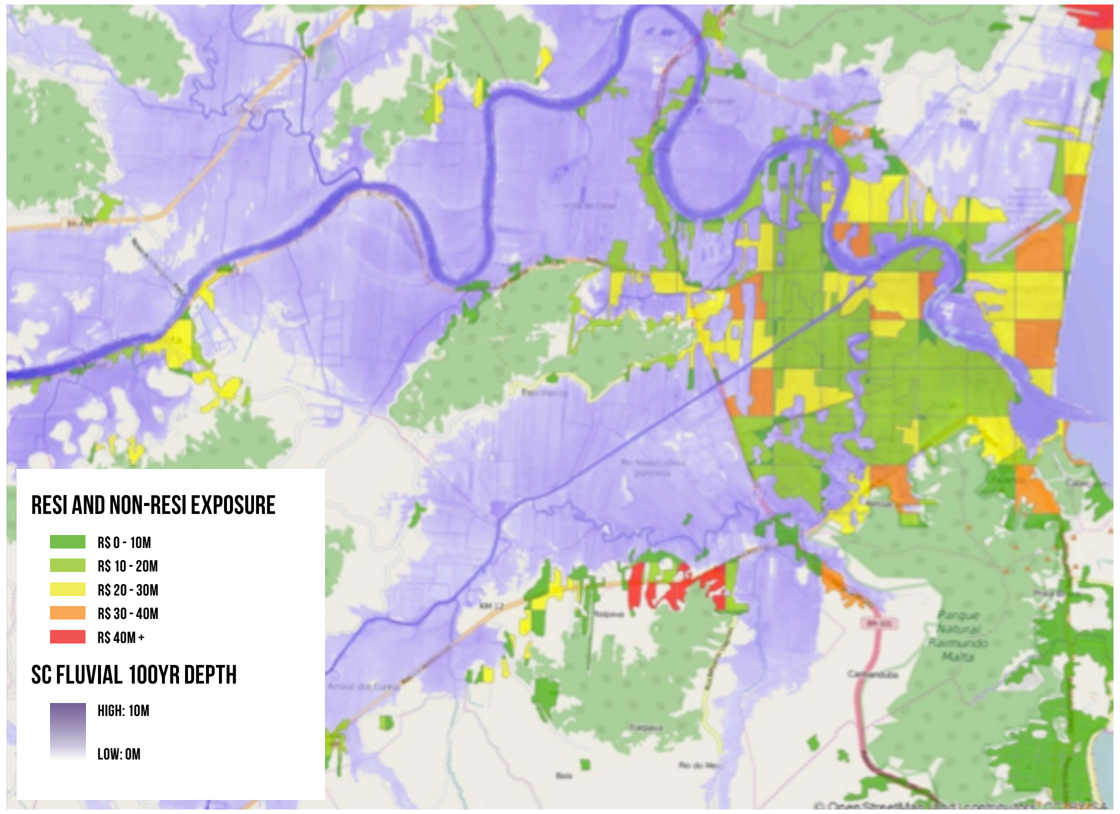
By referencing, an assessment describing the susceptibility of interior materials was made. The only reliable assessment criteria available were to make a selection based on (a) the door type and (b) the quality of the interior. From these criteria, the outcomes shown in table 3 were possible.

Table 3. Susceptibility Assessment for Nonresidential Buildings

DOOR MATERIAL AND INTERIOR QUALITY	SUCEPTIBILITY
METAL/GLASS DOOR + LOW QUALITY INTERIOR	LOW
METAL/GLASS DOOR + HIGH QUALITY INTERIOR	MEDIUM
WOODEN DOOR + HIGH QUALITY INTERIOR	HIGH
WOODEN DOOR + LOW QUALITY INTERIOR	MEDIUM

With both residential and nonresidential models and flood-prone areas mapped through the hazard modeling process, the study proceed with the vulnerability assessment step. For instance, map 6 presents how the modeled exposure (residential and nonresidential) in Santa Catarina, combined with the flood hazard maps, generates an estimate of the asset value at flood risk in the state.

Map 6. Santa Catarina's Asset Exposure in Flood-prone Areas



Adding information on the exposure of buildings to the flood maps is relevant, for example, to institutions in charge of allocating disaster risk reduction infrastructure investment. Thus, by knowing the value and the features of the assets located in the areas prone to floods, policy makers can be better informed about the target beneficiaries of such interventions and perform cost-benefit considerations before proceeding with investment decisions. From a social development viewpoint, the exposure module can be useful in profiling settlements exposed to flood risk and identifying critical areas where households are exposed to recurrent (low return period) events so specific programs can be designed for lower income.

While the hazard and exposure models are sufficient to indicate the areas and assets at risk, determining the proportion of damage as a function of the building typology and type of adverse events is part of the vulnerability analysis. Such a step is crucial as the level of damage as a function of natural events will provide the means to adopt soft and hard measures to manage disaster risks and therefore increase social and economic resilience.

Vulnerability in this context is an expression of the tendency of an element or a set of elements to suffer physical damage when subjected to a disaster event. It allows the intensity of the hazard to be translated into an estimated level of physical damage based on established understandings of the fragility of the element or the component set of elements. The model combines information from the flood hazard and exposure modeling stages, and produces a new result—the likely mean cost to replace or repair the asset given the flood event's intensity, in this particular case, depth of floods.

This study focused solely on the structural vulnerability of buildings and the financial losses associated with their damage because of flood hazards. It did not consider the contents within buildings, the welfare of the inhabitants, or the wider economic consequences of flooding through factors such as business interruption.

As a common practice, it was assumed that the impact of a hazard would not be equal in all cases. The impact is highly dependent on the physical characteristics of the asset at any given location. Additionally, some property construction types are more vulnerable to flooding (for example, a flood event will affect a low-set single storey building to a much greater extent than a high set multistory building—relative to the total value of the asset). Finally, mathematical modeling tools and limitations allow for a generalized approach toward physical damage estimation as flood models cannot anticipate the angle of impact, energy release, and debris influence, among others.

Through extensive research, the vulnerability of various property types in Brazil was determined and appropriate damage vulnerability curves were produced. Then we generated vulnerability functions that describe the overall ratio of damage that could occur to a property as a percentage of the total reinstatement cost. This indicates the amount of damage and resultant losses that may occur to a given property type at different hazard intensity levels. In other words, the relationship between event intensity and damage is described in the vulnerability curve.

The vulnerability component consists of a series of curves that relate the mean damage ratio (MDR) to a flood's intensity measure. The MDR calculates the ratio of the average cost of repair to replacement value. The following equation has been applied for MDR calculations:

$$\text{MDR} = \frac{\text{AVERAGE COST OF REPAIR}}{\text{COST REPLACEMENT VALUE OR SUM INSURED}}$$

Flood intensity measures are directly related to water depth. The models used in this study allow for 16 flood intensity increments (see annex 1 for full details on the vulnerability parameters and assessment). In summary, this study used the GeoScience Australia method, which provides a set of 47 damage curves covering various combinations of the following building parameters:

- Occupancy: residential, industrial, else
- Construction: adobe (clay), concrete, pole/beam, steel, and wood
- Height (stories): 1, 2, 3, low, medium, and high
- Elevation: non-elevated, elevated, and unknown
- Susceptibility (of interior): not susceptible, low-susceptibility, susceptible, high-susceptibility, and unknown

Damage curves for the different construction patterns, characteristics, and level of susceptibility of residential buildings in Santa Catarina were produced as previously mentioned. For all the vulnerability curves and detailed information refer to annex 1.

2.3 CAT Model and Potential Policy Applications

The CAT risk modeling stage of buildings was an important process in completing the Santa Catarina Disaster Risk Profiling. In this final stage of the study, we combined the individual products — hazard, exposure, and vulnerability models —and used them as inputs for the CAT modeling.

In this context, each of the previous models gave us vital information to calculate the risk and financial loss associated with different flood events.

- The exposure model data provides information on where the buildings are located and what their financial value is. In other words, this model produced geolocations and through an analysis of the construction patterns of buildings, a BUC was produced.
- The hazard model provides information on the core components of flood events including physical characteristics of the terrain.
- The vulnerability model helps understand how likely it is for buildings to be damaged (and what is the cost of repair/replacement) at a specific location given the hazard conditions and event's profile. This relationship is graphically represented by the vulnerability curves.

In spite of the models developed and previously presented, we still did not have a projection on how flood events would cause financial losses in Santa Catrina. This was obtained through the CAT risk model. Box 2 presents the commonly adopted terminologies for the sake of interpreting the results from any given CAT model.

Box 2. Terminologies Used for the CAT Model Results

Aggregate Exceedance Probability (AEP) represents the probability that the total cost of all events within a year will combine to exceed a certain threshold. These figures should be used when assessing gross loss ratios. Bigger flood events occur (and are exceeded) less often and will therefore have a lower annual probability.

- Occurrence Exceedance Probability (OEP) is the possibility that the most costly event in any one year will exceed a certain threshold. These figures are more relevant for CAT excess of loss reinsurance but were calculated in the analysis and thus are included for information.

Note that AEP and OEP refer to a loss being exceeded, and not the exact loss itself. This approach is favored for CAT modeling, as it is beneficial to identify attachment or exhaustion probabilities, calculate expected losses within a given range, or to provide benchmarks for comparisons between risks or over time. Calculating the probability of an exact financial loss is therefore of little value.

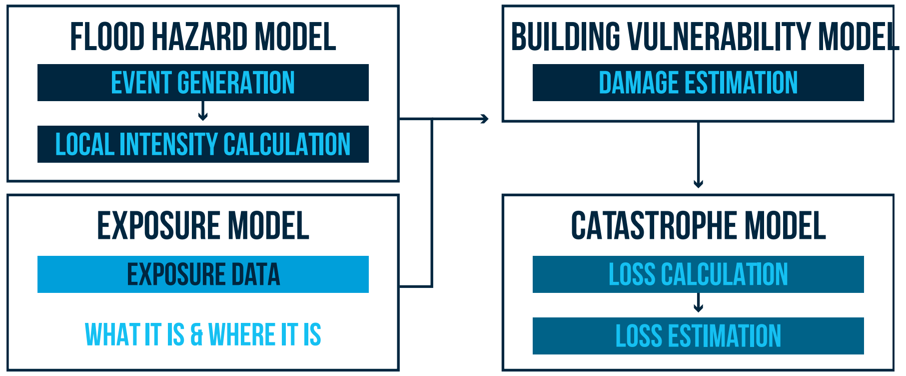
- Exceedance Probability (EP) curve communicates the probability of any given financial loss being exceeded. This may be based on AEP or OEP. It shows the likelihood of having either aggregate annual losses (AEP) or a single event (OEP) in excess of a given amount.

- Annual Average Loss (AAL) represents an average sum of the annual losses calculation. It is the mean value of a loss EP distribution. It represents the expected loss per year, averaged over many years. The one-year return period loss is expected to be equaled or exceeded every year. Its EP is therefore 100 percent.

Within the scope of this study, the CAT modeling activity is an automated system that generates a set of simulated events. Each simulation accounts for the magnitude, intensity, and location of an event to determine the amount of damage and calculate the financial loss resulting from a catastrophic event (Lloyd's Market Association 2013).

Although here we considered the previous models as individual products, some experts would consider them all as modules of the CAT model. Figure 10 summarizes the CAT model process.

Figure 10. Summary Diagram of a CAT Model



The process of generating a robust set of simulated events, with different levels of damage to simulate the possible financial loss is a rather complex one. Several steps are required to accomplish this task. This report provides only a general overview of the process, as it does not aim to provide the reader a systematic description of the CAT modeling process.

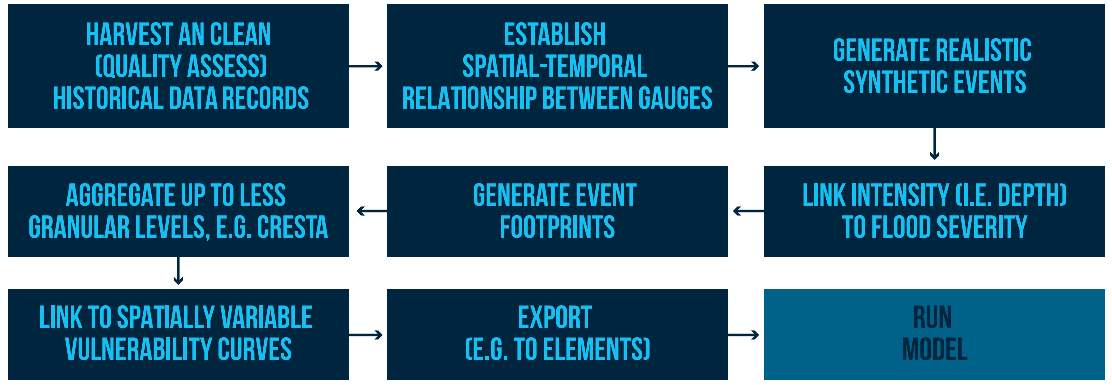
As such, using the historic rainfall records supplied, the annual daily maximum (AMAX) values were calculated for each year at each valid gauge location. This is formed into a series of files and is the primary input for the creation of a correlation matrix from which synthetic weather events are generated. Then 10,000 synthetic years of realistic event data for flood events in Santa Catarina were prepared. These synthetic events are stochastic—having a random probability distribution or pattern that may be analyzed statistically but may not be predicted precisely.

The first step in preparing synthetic events was to transform AMAX values into new, normally distributed variables. Then a 'co-variance matrix' was generated which describes the probability of significant rainfall/flow at gauge pairs at the same time (that is, dependency between AMAX values). Two correlation models were created; the first one was a correlation model fitted to describe how covariance reduces with distance between gauges; the second, a correlation model to generate a synthetic year of weather by interpolating to non-gauge sites to apply a more realistic spatial structure to the rainfall.

The next step was to transform annual event data into annual return periods for each of the 10,000 synthetic years of weather to relate the model to the underlying hazard data. Last, annual data were disaggregated into individual events and related back to the exposure database, and

water depth referenced against the hazard mapping return. Figure 11 illustrates the process.

Figure 11. Summary of the Stochastic Event Set Generation Process



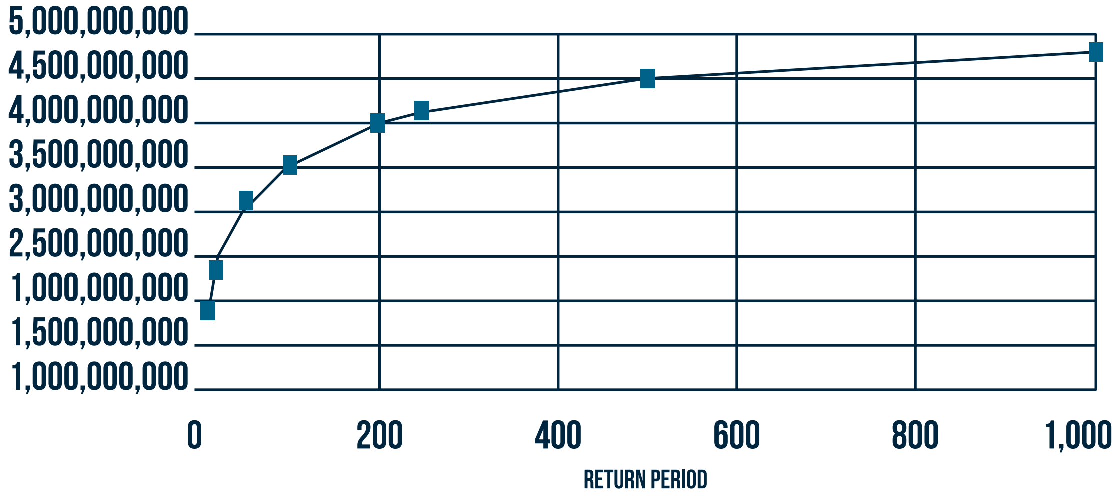
Once the model was ready, two analyses were run: a historic loss assessment using the data from three historic flood scenarios and a full probabilistic loss assessment using the full 10,000-year event set. Hence, the final exposure database was run against the complete 10,000 years of realistic synthetic event hazard data. This produced the key results of this study, which are presented in table 4.

Table 4. Summary of Key Outputs from Santa Catarina CAT Model

RETURN PERIOD	OEP IN R$	AEPS IN R$	AEP AS % OF GROSS DOMESTIC PRODUCT
10,000	3,187,533,953	5,335,498,814	2.49
5,000	3,130,487,859	5,248,577,898	2.45
2,000	2,961,037,662	5,041,813,079	2.35
1,000	2,829,424,099	4,798,717,501	2.24
500	2,712,547,009	4,482,340,660	2.09
250	2,563,276,409	4,105,352,668	1.92
200	2,504,873,263	3,972,822,872	1.85
100	2,340,205,404	3,041,295,048	1.65
50	2,150,395,407	3,041,295,048	1.42
20	1,822,799,614	2,369,292,826	1.11
10	1,484,396,030	1,829,110,336	0.85
AAL	645,100,611	645,100,611	0.30

The AEP results in figure 13 show the probability that the total cost of all events in a given year will exceed a certain threshold. Therefore, based on these results there is a 10 percent chance that all events within any given year will generate losses of R$1.8 billion or more. Events with a 20-year return period could generate losses of R$2.3 billion or higher.

Figure 12. AEP for Different Return Periods



It is also concluded from the CAT model that more frequent events could generate significant losses of over R$1 billion. It is important to note that the model considers only the losses associated with damage to buildings, which encompasses the direct effects of disasters in many sectors (for example, housing, education, and industry), but does not account for indirect effects associated with the estimated damages. Moreover, the model does not segregate ownership (public or private) of the exposed assets. In spite of such modeling limitations, even if only 10 percent of the associated losses translate into state-government liabilities, in the current scenario, the state's financial response capacity is not enough to avoid additional response funding gaps in the future.

Besides the AEP, as part of the risk assessment the OEP was also estimated. The OEP shows the probability of the largest loss in a given year, a metric that can be useful, for example, to insurance and reinsurance companies.

Figure 13. OEP for Different Return Periods

The OEP result shows that the most costly event in any given year will exceed a certain threshold. Therefore, based on these results there is a 0.01% chance that the most costly event in any given year will generate losses of R$2.3 billion or more.

In the context of this study, the CAT model results can also be used as a baseline to update the state-level strategy for financial protection against natural hazards. Based on the EP curve previously presented, it is possible to carry out scenario-based analysis of potential future funding gaps and, based on it, establish a portfolio of sources of fund that is adequate for the state's risk profile.

Moreover, besides the state-level EP curves, similar analysis were carried out at the municipality level, which means that based on the CAT model it is possible to have a general picture of how flood risk is spatially distributed across the state. Table 3 provides a ranking of Santa Catarina's municipalities which have AAL's greater than R$10 million.

Table 3. Ranking of Municipalities with Highest AAL in R$

MUNICIPALITY		AVARAGE ANNUAL LOSS
ITAJAÍ	1º	R$ 100,115,000
PALHOÇA	2º	R$ 42,905,000
BLUMENAU	3º	R$ 39,102,000
NAVEGANTES	4º	R$ 34,267,000
GASPAR	5º	R$ 29,454,000
JARAGUÁ DO SUL	6º	R$ 27,568,000
GUARAMIRIM	7º	R$ 24,355,000
JOINVILLE	8º	R$ 20,507,000
RIO DO SUL	9º	R$ 19,365,000
TIJUCAS	10º	R$ 13,357,000
TUBARÃO	11º	R$ 13,056,000

As such, table 3 lists the municipalities with a history of significant disaster damages and losses. These are also among the most populous municipalities in the state and, consequently, with more exposed assets and infrastructure. However, it is worth noting the counter-intuitive AAL for the municipality of Palhoça. Despite it is not being among the cities with a meaningful disaster history, the CAT model ranked the city as the second at the state. In this context, we would like to highlight the need to complement any modeling endeavor with field surveys to allow for a better assessment of whether (i) the flood model was not able to capture specific geographical features, or (ii) the exposure model was limited or erroneous, which can lead to a misleading CAT modelling attempt.

Potential modeling limitations might be related to lack of information on risk mitigation works and flood defenses installed in recent times and not accounted in the data bases used for modeling purposes. It should also be noted that in the 1995 the municipality of Palhoça, together with the entire metropolitan region of Florianópolis, was severely hit by heavy rains, which surely led to significant damages. However, the lack of official damage data on this specific event might have implied in lack of knowledge on how the city is prone to disaster loses and the model was able to capture such feature and therefore identify a blind spot previously unknown.

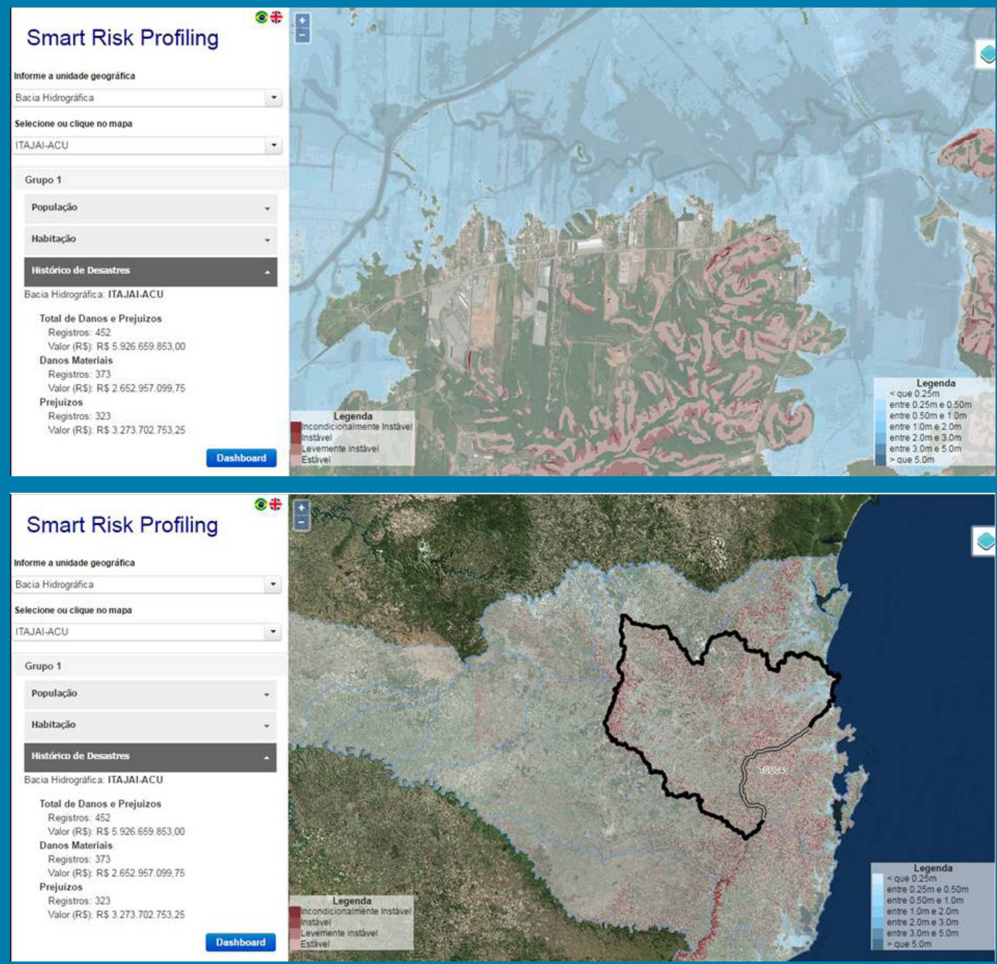
Finally, the disaggregation of the disaster risk profile knowledge for each municipality is not only useful as another criteria to be considered when prioritizing risk reduction investments, but also an instrument for both national and subnational governments to consider the possibility of adopting risk pooling or risk transfer (to the private sector) mechanisms to allow the state to improve its response capacity as well as its overall resilience against natural hazards. Such and other analyses are only possible due to geo-spatial features considered when first designing the study as well as by the development of the Smart Risk Profiling tool to allow future independent analyses by any given end user.

EXPECTED ANNUAL AVERAGE LOSS = R$ 645 MILLION

SMART RISK PROFILING

In addition, the products generated by this study were fully integrated into a geo-spatial application (Smart Risk Profiling) that allows specific queries to be performed by end users according to their individual needs (see figure 8). Such an initiative aimed at not only allowing for additional queries/analyses than the ones usually addressed in studies of this nature, but also to be a repository for DRM products at both national and subnational levels. Hence, a common platform for integration was developed, which will ensure continuity and sustainability of the numerous initiatives led by different institutions in Brazil.

Figure 8. Snapshot of the Smart Risk Profiling Tool



Complementarily, the level of detail of the study allows for both macro and microplanning as well as localized decision-making. For example, based on the localized flood maps produced, (see map 3) it is possible to identify low-risk areas for public or private investments or select high-risk areas to receive disaster risk reduction investments. Geo-spatial products can also be used as inputs in developing preparedness strategies as the flood depth and event recurrence are useful information to guide state institutions to better address risk mitigation and disaster preparedness in areas exposed to natural hazards.

LOOKING BACK

LOSSES REPORTED DISTRIBUTION OF DAMAGES

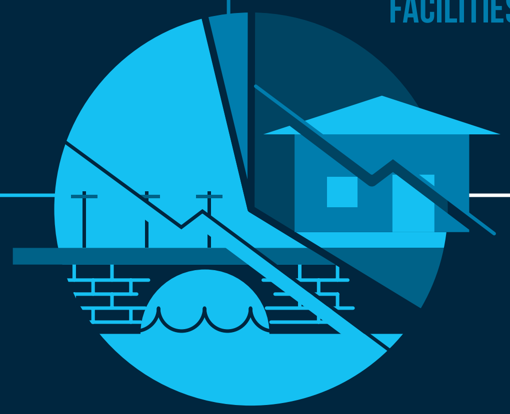
PER SECTOR

9% PUBLIC

91% PRIVATE

R$ 12,41 BI

BY TYPE



4% R$ 193,3 MI FACILITIES

63% R$ 3,28 BI INFRASTRUCTURE DAMAGES

33% R$ 1,75 BI HOUSING DAMAGES

R$ 5,23 BI

IMPACTS OF NATURAL DISASTERS FATALITIES, DAMAGES, AND ECONOMIC SHOCKS 1995 - 2014*

POPULATION AFFECTED

13,5 MILLIONS

POPULATION DIRECTLY AFFECTED, INCLUDING THE HOMELESS, DISPLACED PERSONS, DEATHS AND SICK.

HOMELESS AND DISPLACED

746 THOUSAND

746,600 PEOPLE NEEDED SHELTER OR HAVE BEEN DISPLACED FROM THEIR HOMES.

HOUSING DAMAGE

110 THOUSAND

11,200 HOUSES WERE DESTROYED AND 99,294 DAMAGED.

ECONOMIC LOSSES

R$ 17,64 BILLIONS

DAMAGE LOSSES AND MATERIALS REPORTED BY MUNICIPALITIES IN 2704 RECORDS. REAL AMOUNTS FIXED FOR 2014.

*NATIONAL SECRETARIAT OF PROTECTION AND CIVIL DEFENSE. DATA FROM DISASTER RECORDS REPORTED BY MUNICIPALITIES TO THE STATE CIVIL DEFENCE AGENCY OR THE NATIONAL PROTECTION BUREAU AND CIVIL DEFENSE - SEDEC. 6,464 RECORDS WERE EMPLOYED, OF WHICH 2,704 INFORMED ECONOMIC LOSSES.

AVERAGE ANNUAL LOSSES REPORTED AS GDP % OF MUNICIPALITIES

VARGEM 10,8%

ABDON BATISTA 9,3%

CELSO RAMOS 10,1%

ALTO BELA VISTA 7,4%

MUNICIPALITIES WITH GREATER REPORTED LOSSES

JOINVILLE R$ 345 MI

BLUMENAU R$ 1,8 BI

ITAJAÍ R$ 1,4 BI

GASPAR R$ 1,8 BI

PART
02

SANTA CATARINA

DISASTER RISK

PROFILE

POLICY AND

DECISION-MAKING

IMPLICATIONS

"The understanding of Disaster Risks is the first step towards providing sound solutions to disaster events…"

"… the absence of decisions once disaster risks are identified resonates as not complying with the basic principle from the first step."

Understanding Risk Brazil 2012

1. Potential Santa Catarina State Planning Implications

This section summarizes the findings and potential application of the Santa Catarina Disaster Risk Profile as well as from its specific products. As initially envisaged, the study aimed at providing knowledge to Santa Catarina's various institutions to contribute toward improved DRM.

In this backdrop, macro and complex state activities such as planning and investment decisions would benefit from additional strategic information on DRM that could lead to DRM informed decision making. Hence, the following potential applications (not a comprehensive list) from the study can be highlighted to the Santa Catarina state government and its institutions:

- Recommendations on future structural and nonstructural flood management options aimed at achieving a reduction in flood damage;
- Use flood maps and probabilistic loss estimates to direct future activity in flood risk reduction;
- The data products can be used to inform decision making to avoid people settling in flood-prone areas as well as reduce flood risks at established settlements;
- Hazard maps are useful for land use planning to enable zonation of land ensuring that highly vulnerable land use types are not developed within areas that may experience significant flood hazards;
- Flood hazard maps are important in disaster planning as it can inform evacuation plans, identify suitable refuge points, and provide detailed assessments of the risk to roads and other critical infrastructure;
- Inhabitants within hazard zones can be educated and sensitized on the risks they are exposed to and pre warned of an impending flood;
- Flooding hazard maps can be used to coordinate the disaster response across many stakeholders;
- Hazard and loss data provided can be used to identify locations that present maximum return on investment if flood reduction strategies were to be implemented (structural risk reduction decisions). For instance, it can be used as an instrument for identifying areas where spending on engineered flood defenses will provide real/measurable benefits;
- Inform the relocation of sensitive land uses away from the floodplain;

- A way of working with nature to develop effective catchment management strategies, which aim to delay the release of water into rivers. Upland catchment management can include the reforestation of deforested areas and restoring rivers to their natural state, therefore reducing disaster risks;

- Identify locations suitable for mangrove restoration to control sediment deposits as well as provide valuable habitats;

- A way of defining where to implement flood-monitoring technologies. By adding flow or level gauges to rivers a detailed data series can be captured which will ultimately improve the scientific understanding of the catchment characteristics as well as DRM practices at the state level;

- The data can be used to consider flood-forecasting technologies to predict floods before they happen and thus allow more time for disaster preparation and response, forewarning emergency responders as well as more time for the implementation of flood mitigation measures such as the erection of temporary barriers, relocation of expensive items to safer locations, and the evacuation of vulnerable populations;

- Consider use of remote sensing data such as Short Aperture Radar from high time resolution or rapid revisit satellites to capture meaningful flood extents and detect the emergence of flooding upstream. This can inform the understanding of the eventual consequence as water arrives downstream;

- Use the flood map and loss estimate products as an information source to guide better informed decisions regarding the management of reservoirs as a way of flood defense;

- Outputs can also be used as tools to drive societal changes, which can result in a reduction in flood risk. The tools can be used as ways to identify target areas for strategies, which improve education on flood hazards and the associated risks;

- The results of this study could also direct work, which aims to improve the resilience of communities and buildings to the impacts of flooding. By targeting the risk areas detected in this study with property-level flood protection, waterproofing, and the use of lower susceptibility interiors the overall potential for direct losses can be reduced along with quicker post flood recovery;

- State planning activities and investments decisions can incorporate the results from the study and therefore place Santa Catarina as the first Brazilian state to comprehensively address disaster risks in its strategic planning process;

- Future work is recommended to further explore the linkage between flooding and slope instability, as high rainfall intensities are linked to landslides as observed in the 2008 events;

- Pluvial (surface water) flooding has not been considered in this study and it is advised that this could be studied in future projects. Significant additional exposure to loss could be detected taking into consideration such an approach. Once a pluvial model is created, additional work could be enabled by exploring how site drainage can be improved to mitigate flooding through the use of Sustainable Urban Drainage Systems and macro-drainage plans;

- Tidal flood risk should also be considered given the high development in Santa Catarina's coastal areas. Although the state has a limited tidal range, the flat and wide coastal land could mean that the impacts of meteorological tidal flooding might be significant. Hence, a study investigating the impacts of storm surges could identify additional risk locations along the coast; and

- It is also recommended that climate change be considered. Over time, climate change could lead to rises in sea level, more frequent tidal storm surges, and potentially increases (or decreases) in rainfall, which will alter the risk profile in the longer term. Coupled with this, a further study of climatic oscillations could identify periods when the likelihood of flooding in any given year is higher and therefore ex ante decisions could be made to reduce the impacts.

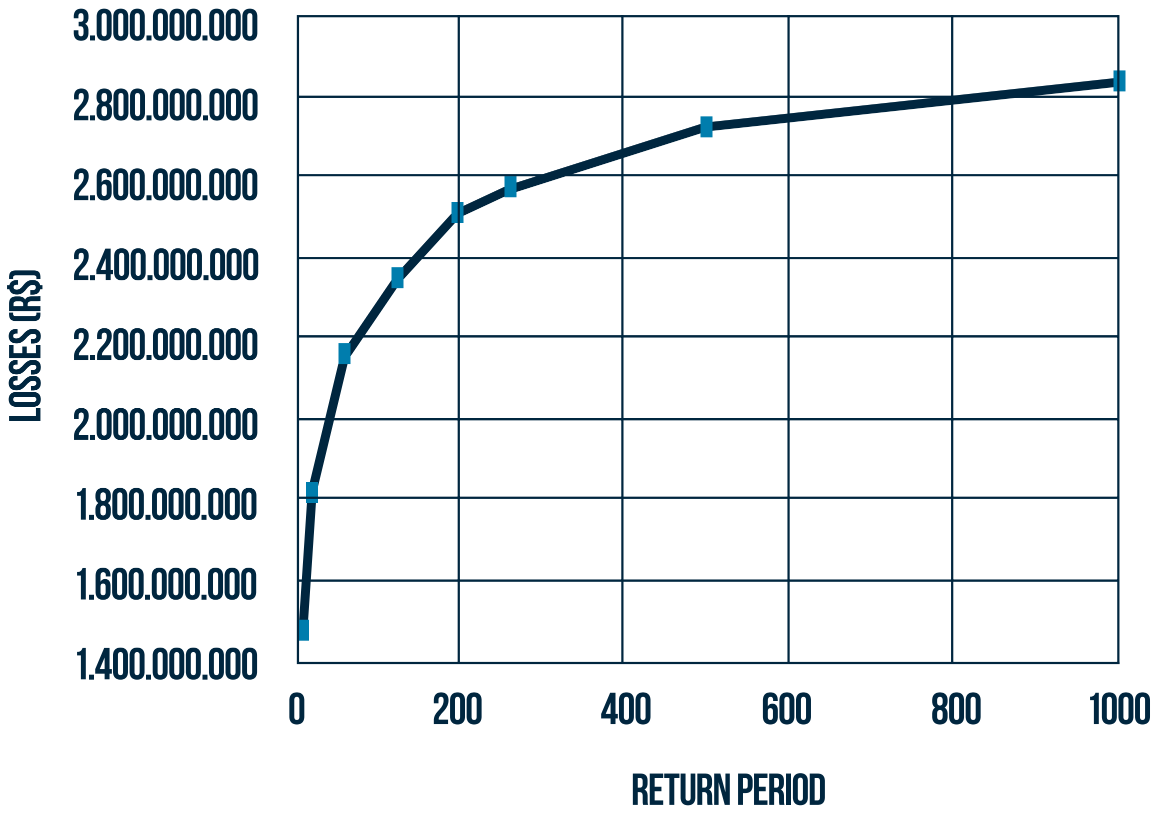
LOOKING TO THE FUTURE

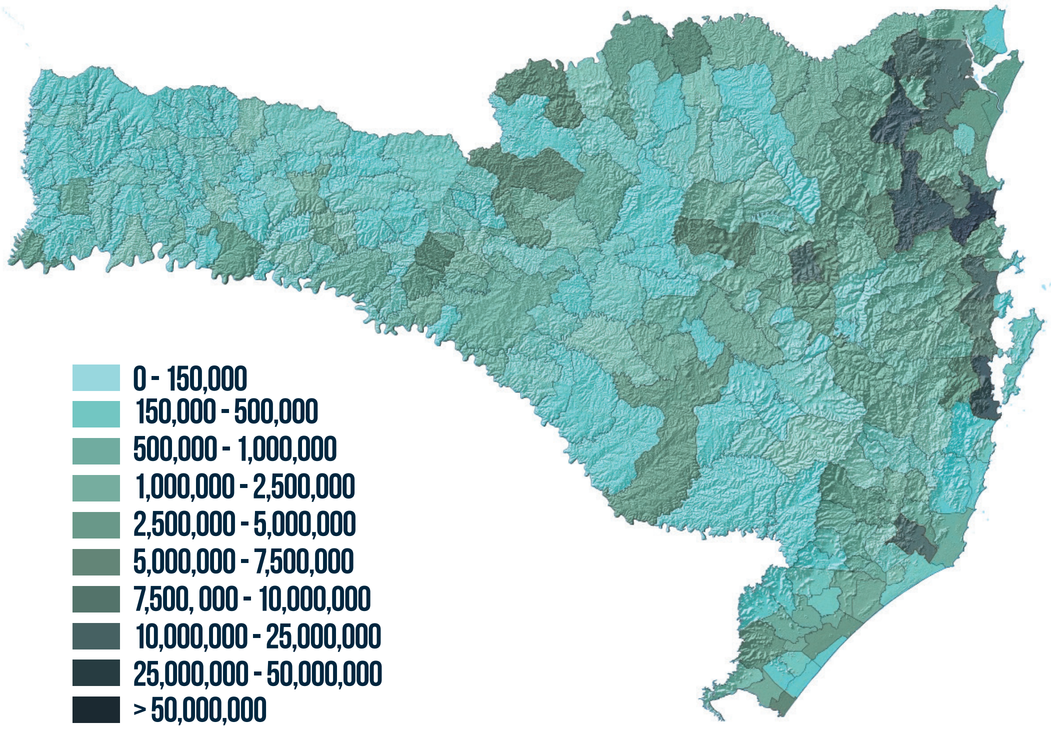
LOOKING FORWARD, HOW MUCH DO FLOODS COST AT DIFFERENT RETURN PERIODS?

THE AGGREGATE EXCEEDANCE PROBABILITY (AEP) REPRESENTS THE PROBABILITY THAT THE TOTAL COST OF ALL EVENTS WITHIN A YEAR WILL COMBINE TO EXCEED A CERTAIN THRESHOLD. THESE FIGURES SHOULD BE USED WHEN ASSESSING GROSS LOSS RATIOS. BIGGER FLOOD EVENTS OCCUR (AND ARE EXCEEDED) LESS OFTEN AND WILL THEREFORE HAVE A LOWER ANNUAL PROBABILITY. NOTE THAT AEP REFERS TO A LOSS BEING EXCEEDED, AND NOT THE EXACT LOSS ITSELF.

FLOODS AND FINANCIAL LOSS IN SANTA CATARINA

A CATASTROPHE (CAT) MODEL IS AN AUTOMATED MODEL THAT GENERATES A SET OF SIMULATED EVENTS. EACH SIMULATION CARRIES ESTIMATIONS OF THE MAGNITUDE, INTENSITY, AND LOCATION OF AN EVENT TO DETERMINE THE AMOUNT OF DAMAGE AND CALCULATE THE PROBABLE LOSS AS A RESULT OF AN EXTREME EVENT. (LLOYD'S MARKET ASSOCIATION 2013).





REFERENCES

BBC (2008) Flood deaths in Brazil rise to 84, http://news.bbc.co.uk/1/hi/7747456.stm, accessed 5/19/2016

CEPED UFSC (2016) Relatório dos Danos Materiais e Prejuízos Decorrentes de Desastres Naturais em Santa Catarina, World Bank – Brasilia, Brazil

Floodlist (2015) Brazil Floods – Over 200,000 Affected in Santa Catarina and Rio Grande do Sul, http://floodlist.com/america/brazil-floods-santa-catarina-rio-grande-do-sul, accessed 5/19/2016

Garcia, C.M., Roseghini, W.F.F. and Aschidamini, I.M. (2011) Environmental management planning – considerations about the events occurring in Santa Catarina – Brazil in November 2008, Procedia Social and Behavioral Sciences, 19, p.487-493

IBGE. Censo Demográfico 2010 – Características Gerais da População. Resultados da Amostra. IBGE, 2003. Disponível em ftp://ftp.ibge.gov.br/Censos/Censo_Demografico_2010/Resultados_Gerais_da_Amostra/Microdados/ , accessed 5/19/2016.

Kjeldson, T.R. (2007) Flood Estimation Handbook Supplementary Report No.1, The Revitalised FSR/FEH rainfall-runoff method, Centre for Ecology & Hydrology, Wallingford, UK

Lloyd's Market Association (LMA) (2013) Catastrophe Modelling, Guidance for Non-Catastrophe Modellers, available from-http://www.lmalloyds.com/Web/market_places/finance/Cat_Modelling_Guidance.aspx

Smithsonian (2014) Deadly flooding hits Brazil two days before World Cup begins, http://www.smithsonianmag.com/smart-news/deadly-flooding-hits-brazil-build-world-cup-180951697/?no-ist, accessed 5/19/2016.

World Bank (2013). Avaliação de Perdas e Danos: Inundações Bruscas em Santa Catarina.

ANNEX 01

VULNERABILITY ASSESSMENT

Table 1.1. Vulnerability Return Values for Elements Software

Depth (m)	Hazard Intensity	Elements' MDR Value'
0	0	n.a
0.1	1	1
0.2	2	1
0.3	3	2
0.4	4	2
0.5	5	3
0.6	6	3
0.7	7	4
0.8	8	4
0.9	9	5
1	10	5
1.1	11	6
1.2	12	6
1.3	13	7
1.4	14	7
1.5	15	8
1.6	16	8
1.7	17	9
1.8	18	9
1.9	19	10
2	20	10
2.5	21	11
3	22	11
3.5	23	12
4	24	12
4.5	25	13
5	26	13
6	27	14
7	28	14
8	29	15
9	30	15
10	31	16
12	32	16
15	33	16

Figure 1.1. Comparison of all Damage Curves for Different Building Heights Map

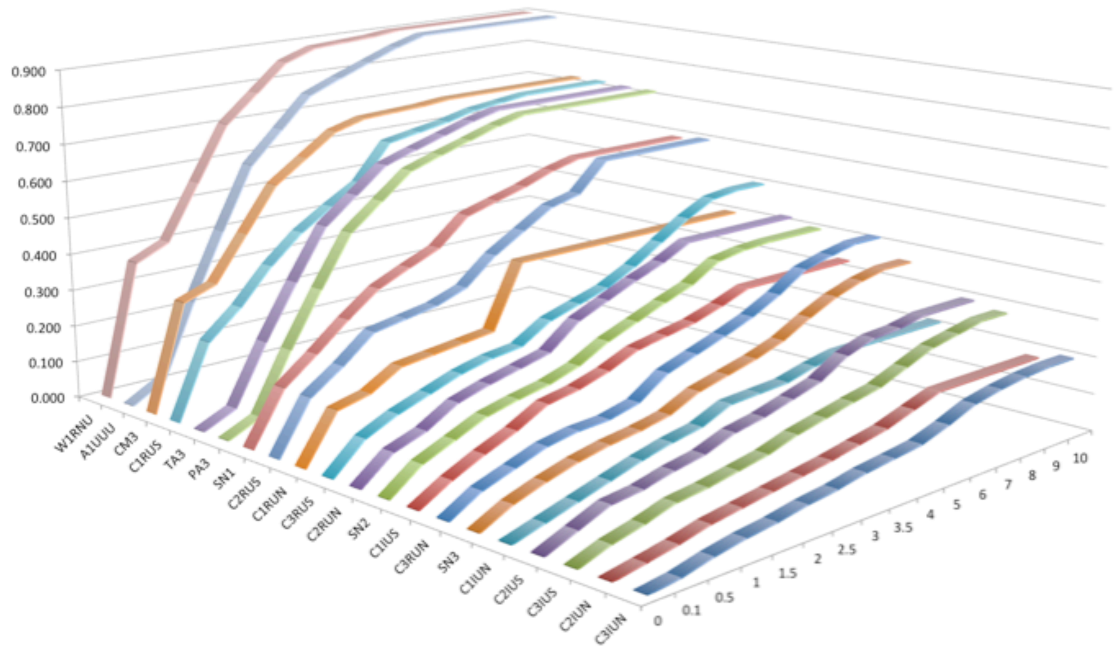


Table 1.2. Defined Relationship Between Susceptibility and Brazilian Census

ORIGINAL AMBIENTAL DEFINITION	BRAZIL CENSUS TYPE CODE	BRAZIL CENSUS TYPE DEFINITION
ADOBE, 1-STOREY	1_TA	HOUSE (CORTIÇO)
	2_TA	HOUSE (CORTIÇO)
	1_PA	HOUSE (STRAW OR OTHER MATERIAL)
	1_PA	HOUSE (STRAW OR OTHER MATERIAL)
CONCRETE, 1-STOREY, INDUSTRIAL, UNKNOWN ELEVATION, NON-SUSCEPTIBLE	1_InN	INDUSTRIAL
CONCRETE, 1-STOREY, INDUSTRIAL, UNKNOWN ELEVATION, SUSCEPTIBLE	1_InS	INDUSTRIAL
CONCRETE, 1-STOREY, RESIDENTIAL, UNKNOWN ELEVATION, NON-SUSCEPTIBE	1_R1N	HOUSE - NORMAL STANDARD
	1_R1A	HOUSE - HIGH STANDARD
	1_RnN	APARTMENTS - NORMAL STANDARD
	1_RnA	APARTMENTS - HIGH STANDARD
CONCRETE, 1-STOREY, RESIDENTIAL, UNKNOWN ELEVATION, SUSCEPTIBLE	1_RP1Q	HOUSE - POPULAR STANDARD
	1_R1B	HOUSE - LOW STANDARD
	1_RnB	APARTMENTS - LOW STANDARD
CONCRETE, 2-STOREY, INDUSTRIAL, UNKNOWN ELEVATION, NON-SUSCEPTIBE	2_InN	INDUSTRIAL
CONCRETE, 2-STOREY, INDUSTRIAL, UNKNOWN ELEVATION, SUSCEPTIBLE	2_InS	INDUSTRIAL
CONCRETE, 2-STOREY, RESIDENTIAL, UNKNOWN ELEVATION, NON-SUSCEPTIBE	2_R1N	HOUSE - NORMAL STANDARD
	2_R1A	HOUSE - HIGH STANDARD
	2_RnN	APARTMENTS - NORMAL STANDARD
	2_RnA	APARTMENTS - HIGH STANDARD
CONCRETE, 2-STOREY, RESIDENTIAL, UNKNOWN ELEVATION, SUSCEPTIBLE	2_RP1Q	HOUSE - POPULAR STANDARD
	2_R1B	HOUSE - LOW STANDARD
	2_RnB	APARTMENTS - LOW STANDARD
CONCRETE, 3-STOREY, INDUSTRIAL, UNKNOWN ELEVATION, SUSCEPTIBLE	3_InS	INDUSTRIAL
CONCRETE, 3-STOREY, RESIDENTIAL, UNKNOWN ELEVATION, NON-SUSCEPTIBE	3_R1N	HOUSE - NORMAL STANDARD
	3_R1A	HOUSE - HIGH STANDARD
	3_RnN	APARTMENTS - NORMAL STANDARD
	3_RnA	APARTMENTS - HIGH STANDARD
CONCRETE, 3-STOREY, RESIDENTIAL, UNKNOWN ELEVATION, SUSCEPTIBLE	3_RP1Q	HOUSE - POPULAR STANDARD
	3_R1B	HOUSE - LOW STANDARD
	3_RnB	APARTMENTS - LOW STANDARD
ADJUSTED W1RNU FOR 3-STOREY HEIGHT	3_CM	HOUSE (WOOD)
ADJUSTEDA1UUU FOR 3-STOREY HEIGHT	3_PA	HOUSE (STRAW OR OTHER MATERIAL)
AVERAGE OF 1-STOREY GAR CURVES	1_SN	UNKNOWN 1-STOREY
AVERAGE OF 2-STOREY GAR CURVES	2_SN	UNKNOWN 2-STOREY
AVERAGE OF 3-STOREY GAR CURVES	3_SN	UNKNOWN 3-STOREY
ADJUSTEDA1UUU FOR 3-STOREY HEIGHT	3_TA	HOUSE (CORTIÇO)
WOOD, 1-STOREY, RESIDENTIAL, NON-ELEVATED, UNKNOWN SUSCEPTIBILIY	1_CM	HOUSE (WOOD)
	2_CM	HOUSE (WOOD)

GFDRR

Global Facility for Disaster Reduction and Recovery

WORLD BANK GROUP