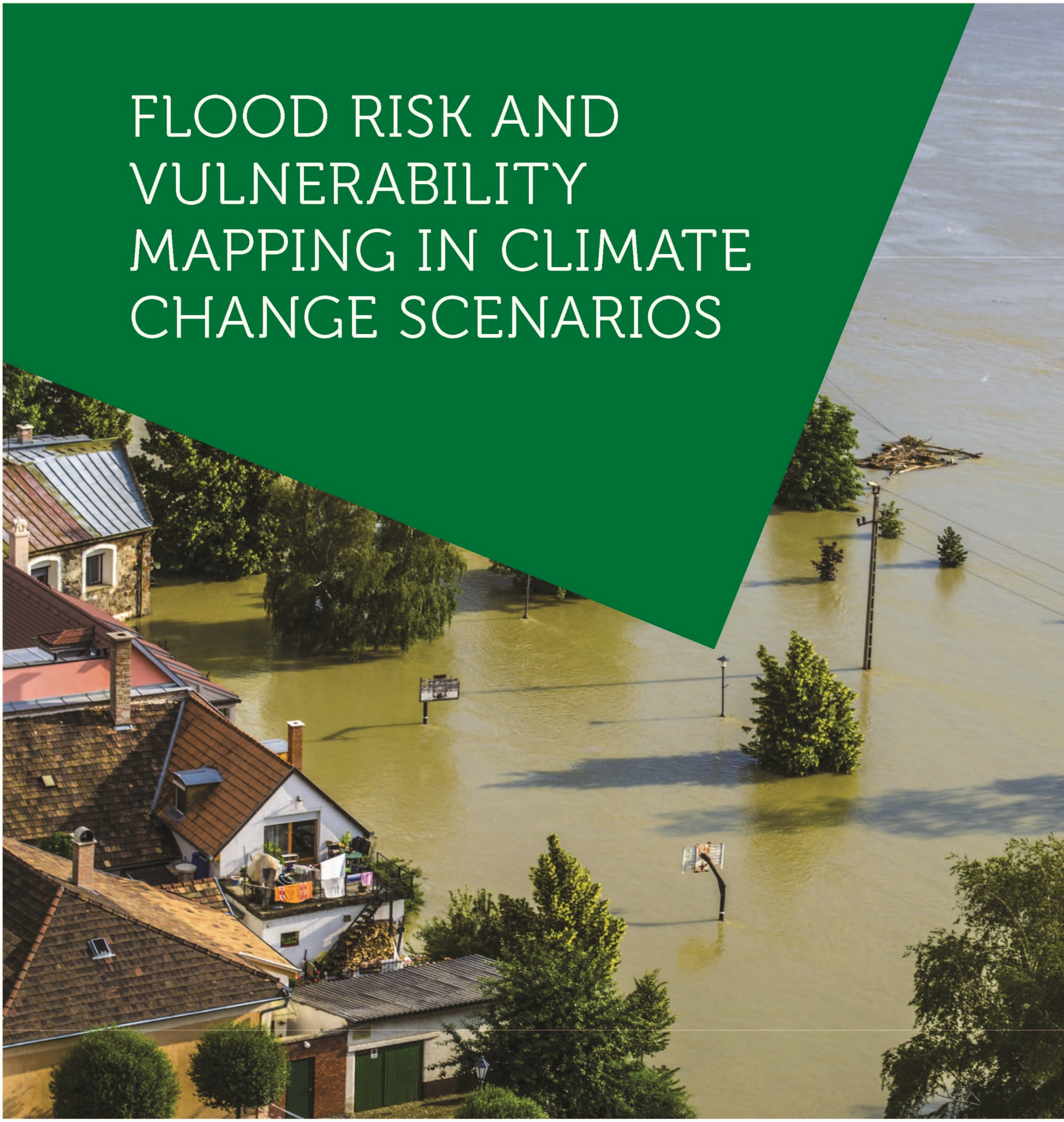
FLOOD RISK AND VULNERABILITY MAPPING IN CLIMATE CHANGE SCENARIOS



FLOOD RISK AND VULNERABILITY MAPPING IN CLIMATE CHANGE SCENARIOS

CARTAS DE INUNDAÇÃO E RISCO EM CENÁRIOS DE ALTERAÇÕES CLIMÁTICAS

fundação Faculdade Ciências Universidade Lisboa

CCIAM Centre for Climate Change Impacts Adaptation & Modelling

aps ASSOCIAÇÃO PORTUGUESA DE SEGURADORES

INTRODUCTION

“Nothing is softer or more flexible than water, yet nothing can resist it.”

Lao Tzu

About the Portuguese Association of Insurers (APS)

APS is a non-profit employers' association, founded in 1982, that congregates insurance and reinsurance companies operating in the Portuguese market, irrespective of their legal nature or country of origin. The members of APS presently account for 99% of the insurance market in terms of business turnover and human resources employed by the sector.

For more information visit *www.apseguradores.pt*

about CIRAC

PEDRO SEIXAS VALE
Chairman of Board of Direction
Portuguese Association of Insurers

Lisbon, March 2014

The Portuguese Association of Insurers (APS) and the Foundation of the Faculty of Science, University of Lisbon (FFCUL) developed a project that we consider of undeniable interest to the Portuguese society called Maps of Floods and Risk in Climate Change Scenarios (CIRAC).

It is our belief that CIRAC will be the source of reference information for the flood risk analysis in mainland Portugal.

It should be noted that currently there is a scientific consensus that climate change caused by the intensification of the greenhouse effect caused by some human activities will intensify throughout the XXI century. We know, therefore, that we will have to take measures for adaptation and mitigation to minimize the adverse effects of climate change and prevent the aggravation of their consequences for the population and the economy.

For the insurance industry, the CIRAC project is a tool to assess hazards that potentially will be held, which justifies its investment in the project, but it is also a contribution to the Portuguese society.

We intend that CIRAC will be widely divulged among insurers, reinsurers, scientific community, public entities and civil society sectors that demonstrate a recognized interest in the matter.

The European Union, the Directive 2007/60/EC of 23rd October 2007, transposed into Portuguese law by Decree-Law 115/2010, of 22nd October, establishes a framework for the assessment and management of flood risks that Member States should follow, providing relevance to the need for the "... creation of flood hazard maps and flood risk charts indicative of potential adverse consequences associated with different flood scenarios ...".

In Portugal, where until now there was no information in a structured and detailed manner, floods are responsible for huge losses, and significant changes are still expected in precipitation regimes, the frequency and intensity of weather phenomenon and extreme climate events, such as intense rainfall over short periods.

Portugal, due to its characteristics, is very exposed to floods and there is no doubt that our territory will suffer significant damage caused by this risk.

Over the past 40 years, there was a decreasing trend of rainfall and increased variability of accumulated rainfall in winter, with higher frequency of dry winters and rainy winters. The regionalized climate scenarios for Portugal, obtained through climate models, indicate the trend of increasing number of days with daily accumulated rainfall exceeding 50 mm in the north of the country until 2100.

The sea level rise, resulting from climate change, also contributes to a significant increase in the frequency and intensity of floods of marine origin. Due to the enormous complexity of the phenomena involved, opinions are divided with regard to the rhythms of the evolution of average sea level and respective magnitude. But there is no lack of consensus in the scientific community that the average sea level will continue to rise in the XXI century, which will affect the Portuguese territory with special intensity given its extensive coastline.

CIRAC allows the assessment of risk by providing benchmark indices that allow different types of vulnerability that assist the stakeholders in making strategic decisions.

The study area for this project was divided into two scales: a macro-scale, where were identified flood areas, with the possibility of analysis up to the parish or postcode and a micro-scale for regions considered vulnerable based on the criteria of probability of flooding and flood risk, defining the latter as the combination of the probability of flooding with the potential adverse consequences to human health, the environment, economic activities and cultural heritage.

Given the high number of recorded cases of floods and torrents, the two urban centers, Lisbon and Porto were analyzed in greater detail, as well as Algés, Vila Nova de Gaia and Coimbra.

With CIRAC, the insurance sector has a working tool of undeniable interest to society.

We hope that each of us learn how to use this tool in all its capacity so that together we can contribute to a better and more sustainable future for generations to come.

about CCIAM

FILIPE DUARTE SANTOS
Cathedratic Professor of the Faculty of Science, University of Lisbon

The Climate Change Impact, Adaptation and Modelling (CCIAM) Research Group has established itself as a reference European research and training centre on climate change integrated analysis, adaptation policy and modelling. The group brings together scientists from several scientific fields who conduct trans-disciplinary research on both national and international level. The main focus of CCIAM is to (i) improve our understanding of climate change-related processes and effects; (ii) develop integrative cross-sectorial methodologies to evaluate climate change impacts, risks and adaptation strategies; and (iii) design frameworks to improve science-society interfaces on climate change adaptation and sustainability.

It was a great privilege to develop the CIRAC project where the science and stakeholder needs were developed in a collaborative environment through regular meetings and workshops making this project unique and very challenging. We are certain that these findings will not only help and support the decision process in flood managing but will also help improve our understanding about our territory and ultimately minimize flood losses.

technical summary

Flood Vulnerability Analysis

Flood vulnerability can be defined as the extent of harm which can be expected under certain conditions of exposure, susceptibility and resilience. Therefore the term Exposure represents the values which are present at the location where floods can occur; the Susceptibility component is a physical characteristic of an area, given by its natural terrain configuration and occupation, which determines the propensity of the area to floods; and Resilience is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner. To explore the relationship between precipitation and floods a fourth component was added which aims to provide extra information about the precipitation geographical distribution, considering that in regions with more annual rainfall are most likely to gather all needed elements for flood events to occur.

A modular concept of flood vulnerability was developed that enables adding and removing different components providing flexible information that aims to reflect different user needs. Three main indexes were developed: (i) a Basic Flood Vulnerability Index (BFVI) that characterizes the exposed infrastructures in terms of propensity to floods due to the natural terrain configuration; (ii) a Flood Vulnerability Index (FVI) that characterizes the exposed infrastructures in terms of propensity to be affected by floods and the population's ability to cope with it; and finally (iii) a Combined Flood Vulnerability Index (CFVI) that gathers the physical susceptibility, exposure and precipitation characteristics in a combined index enabling the extraction of the contribution of each vulnerability component.

The national distribution of vulnerability to floods shows a large portion of the territory (≈85%) with a low flood vulnerability, associated with low population density and low or moderate physical susceptibility classes, such as the coastal and South regions of Alentejo, the North mountainous area of Algarve and most of the Center and North inland region.

The moderate vulnerability values cover about 14% of the territory and are concentrated in three distinct areas: a) the low exposure floodplains of major rivers like the Tagus, Mondego and Vouga; b) the center Alentejo and parts of Algarve, also with low exposure but higher physical susceptibility values related with a dense hydrographic network of smaller water courses and impervious soils (e.g., rock, clay) and; c) the peri-urban areas with moderate physical susceptibility, more visible along the coastal area between Setúbal and Viana do Castelo but also present in the vicinity of other major inland cities (e.g., Bragança, Vila Real, Castelo Branco).

Finally the high and very high flood vulnerability areas, covering approximately 2% of the Continental Portuguese territory, are mostly represented by high population density urban areas with high and very high physical susceptibility, usually associated with low soil permeability. These areas can be found in the Lisbon and Oporto metropolitan areas, the east part of Algarve as well as all major cities.

Flood Risk Analysis

The flood risk analysis aims to identify and quantify the expected damages resulting from this phenomenon. These damages vary over time and are due to several factors like land use changes, adoption of floods control measures or climate change extreme events.

For the first systematic study of flood risk integrating climate change in Portugal, five study areas were selected – Lisbon, Porto, Vila Nova de Gaia, Algés and Coimbra.

For all the areas, risk assessment methodologies widely used in the European context were applied, based on annual average risk maps. These were calculated using: a) flood maps containing the water height for different return periods, obtained by hydrological modeling; b) damage maps at the building scale calculated from damage curves, which relate the water height with the average potential damage. This assessment was performed for the present-day climate and for two global climate change scenarios. These scenarios were regionalized for each area from the HadCm3 model, excepting the Douro basin. This exception is due to the Douro river complexity and its flows being heavily regulated by dams.

The present-day climate risk assessment reveals that Coimbra has the largest number of elements exposed to floods with a total of 1278 buildings followed by the final section of the Douro with 1080 buildings, the basin of downtown Lisbon with 1001 buildings and downtown of Algés with 242 buildings. For the risk itself, the reality is completely different, being downtown Algés that has the higher values. Thus, in general terms, it can be said that after Algés, the areas with higher risk are the sub-basin of Avenida da Liberdade in Lisbon, followed by the South part of Coimbra, the sub-basin of Avenida Almirante Reis in Lisbon and the Central part of Coimbra.

The risk values for the future follow the behavior of the extreme events projected by the two regionalized scenarios. This regionalization was performed for the Lisbon and Algés areas and for the area of Coimbra, comprising projections for the short (2010 - 2039), medium (2040 - 2069) and long term (2070-2099). In Lisbon and Algés, the A2 scenario indicates a decrease of the extreme events over the XXI century, while the B2 scenario has a less linear behavior. The B2 scenario suggests an increase of the extreme events compared to the present-day climate, both on the short and long term, but a decrease in the period between 2040 and 2069. Thus the risk for sub-basins of downtown Lisbon, Avenida da Liberdade and Avenida Almirante Reis, decreases in the different periods of the A2 scenario, and increases in the short and long term in the B2 scenario. The risk for downton Algés has the same behavior of the Lisbon sub-basins on the long-term period. However, the A2 and B2 scenarios project an increase in the risk in that area, both in the short and medium term. This situation results from the features of the basin, where relatively low precipitation cause considerable damages, and both A2 and B2 scenarios project an increase in this type of precipitation.

In Coimbra both scenarios present a similar trend, i.e., extreme events diminish in the short and medium-term, and increase in the end of the century. As expected, the risk values projected for the future in both areas analyzed in this city, follow this behavior.

Being the first systematic study of flood risk integrating climate change in Portugal, there are several actions that can still be done to improve the base scientific data to ensure that the hydrological modeling and the flood maps are the most accurate and detailed as possible, like: improving the surveys of drainage networks, the detail and resolution of digital terrain models and the land use detail. Also, the information collection for the damage curves can be improved, by systematizing the collection of information and complementing it with key elements such as the height of the flood water inside the buildings allowing its relation with the caused damage. Finally, there is a future need to include different climate change scenarios, in order to obtain the uncertainty associated with these models, which is not possible using only one scenario. Despite these limitations and uncertainties, the methodology used to quantify the risk is robust and conclusive, allowing the definition of strategies for integrated flood risk.

GENERAL OVERVIEW

"Climate is what we expect, weather is what we get."

Mark Twain

what is a flood?

According to EU Directive 2007/60/EC on the assessment and management of flood risks, a flood is defined as "the temporary covering by water of land not normally submersed, which includes floods from rivers, mountain torrents, ephemeral water courses, and sea originated floods in coastal zones".

There are two main types of floods: (1) River floods, that result from persistent precipitation in a saturated soil within a watershed. The precipitation generates higher runoff, increasing significantly the river flow and promoting floods in river margins and adjacent areas. (2) Flash floods, as a combined consequence of heavy localized precipitation and impermeable soil. This type of floods tend to occur in relatively small areas of urban environments under rapid water accumulation. There is also coastal floods, when land is flooded by seawater, but they are outside the scope of this project.

what are the main flood impacts?

Floods can cause loss of life, population displacement, damage to property and the environment and harm business activities.

Extreme weather and climate events are responsible for about 80% of damage caused by natural disasters worldwide. Weather related catastrophes recorded worldwide have increased from an annual average of 335 events from 1980 to 1989, to 545 events in the 1990s and to 716 events for 2002-2011 (EASAC, 2013[1]). Floods alone affected more than one billion people in the last decade, causing thousands of deaths every year. The number of natural disasters and affected people has been growing as a result of an increase in exposure and vulnerability.

In Europe, about one third of the economic losses that result from natural disasters are caused by floods. In the European Economic Area hydrological events (floods and mass movements) were responsible for 31 of the 64% (regarding that 100% are total natural disasters) of total losses related to natural catastrophes between 1980 and 2011, EEA 2012 report on Climate change), of which 116 billion and 290 billion, respectively, were insured losses (Munich Re NatCatSERVICE[2]).

Flood risk has gained importance in recent decades, especially in urban areas, due to increasing human exposure and the occurrence of extreme rainfall events in short periods of time. In Portugal, floods have been responsible for significant economic and life losses. The DISASTER project identified 1524 occurrences related with flood events causing 968 deaths between 1900 and 2010. During the last decade 145 flood events were registered with 75 deaths. It's also important to highlight that during the period 1900-2008 the number

1 *Øystein Hov, Ulrich Cubasch, Erich Fischer, Peter Höppe, Trond Iversen, Nils Gunnar Kvamstø, Zbigniew W. Kundzewicz, Daniela Rezacova, David Rios, Filipe Duarte Santos, Bruno Schädler, Ottó Veisz, Christos Zerefos, Rasmus Benestad, John Murlis, M. Donat, Gregor C. Leckebusch, Uwe Ulbrich (2013). Extreme Weather Events in Europe: preparing for climate change adaptation. ISBN 978-82-7144-100-5*

2 *http://www.munichre.com/en/reinsurance/business/non-life/natcatservice/index.html*

of floods has been larger than landslides, except in the hydrological year of 1965-1966 (Quaresma, 2008[3]).

what are the links between floods and climate change?

According with the IPCC 5th Assessment Report the globally averaged combined land and ocean surface temperature has increased 0.85 [0.65 to 1.06] °C, over the period 1880–2012. The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72 to 0.85] °C. The main reason for these increases in temperature is very likely the increase in the atmospheric concentration of greenhouse gases, frequently measured in CO_2 equivalent (see Glossary), resulting from the anthropogenic emissions of such gases. It is worth noting that the present CO_2 concentration levels, which are above 400 ppmv (parts per million in volume), exceed those of the last 400 000 years, which includes an interglacial period between 129000 and 116000 years ago when the global average temperature was approximately 2°C higher than today. Since 1955,

3 *Quaresma (2008). Inventariação e análise de eventos hidro-geomorfológicos com carácter danoso em Portugal Continental. Dissertação de Mestrado, Faculdade de Letras da Universidade de Lisboa*

Flood risk has gained importance in recent decades, especially in urban areas, due to increasing human exposure and the occurrence of extreme rainfall events in short periods of time

CO_2 concentrations have risen 90 ppm and are continuing to increase, putting us very close to a concentration of 450 ppmv that could lead to a scenario where the global temperature is 2°C higher than the pre-industrial value. The 2°C increase in temperature is considered to be a threshold above which climate change impacts on human and environmental systems become very damaging and leading to high economic, social and environmental global costs.

To assess future climate, the scientific community developed socio-economic scenarios, broadly designated as SRES (Special Report on Emissions Scenarios of the IPCC[4]), based on a coherent and internally consistent set of assumptions about the world population growth, economic activity,

4 *IPCC Special Report on Emissions Scenarios (SRES) (2000) by N. Nakićenović, J. Alcamo, G. Davis, et al. edited by N. Nakićenović, R. Swart*

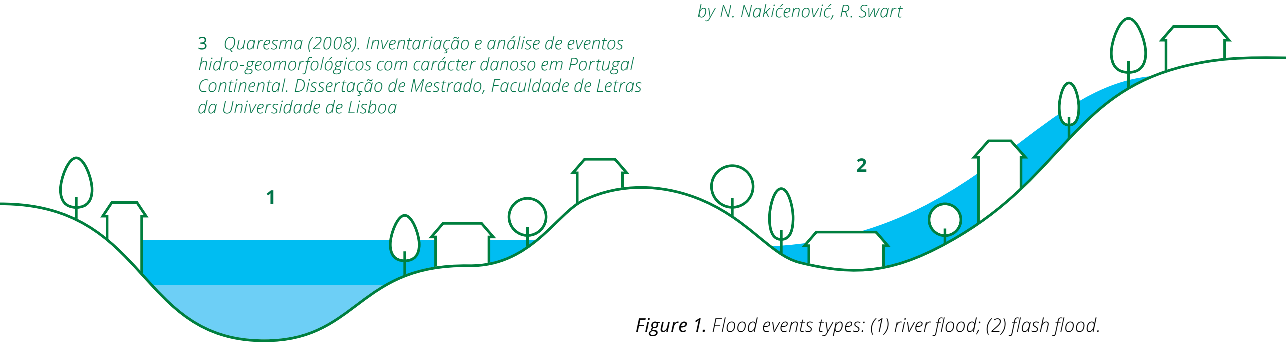


Figure 1. *Flood events types: (1) river flood; (2) flash flood.*

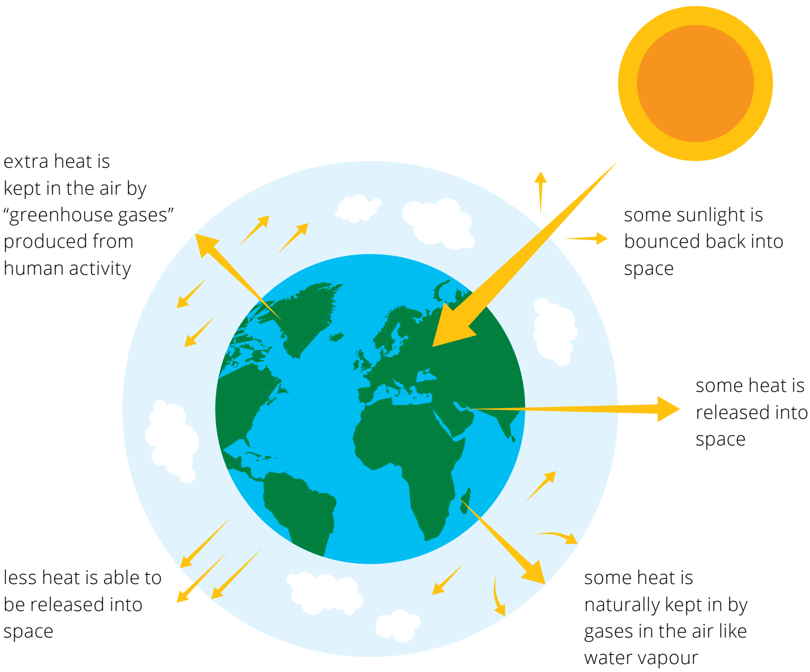


Figure 2. *Simplification of the earth energy balance to illustrate the increase in the greenhouse effect that results from the anthropogenic emissions of greenhouse gases.*

energy use and technological development. From the SRES scenarios it is possible to derive scenarios of greenhouse gases emissions that have their origin in various human activities. The emission scenarios are then introduced into Global Circulation Models (GCMs) that simulate the climate system. The GCMs lead to climate scenarios that can be used to assess the impacts of climate change on the various socio-economic sectors and biophysical systems. The climate scenarios give future climate projections but not future climate predictions since it is not possible to attribute probabilities to the various SRES socio-economic scenarios used in the GCMs. In the CIRAC project various SRES scenarios were used to assess the flood vulnerability and risk in Continental Portugal during the 21st century. There are four SRES scenario families called A1, A2, B1 and B2. The A1 scenario represents a globalised economy with rapid economic growth but low awareness of environmental problems. A2 is a scenario of a more fragmented world than in A1 where economic growth is regionally oriented. A2 is the scenario with greater similarity to the current global situation. Environmental issues are more important in the scenarios B1 and B2 than in A1 and A2, respectively. In B2 there is an emphasis on global solutions to achieve social, economic and environmental stability. B2 is a scenario more ecologically friendly than A2 but more fragmented and less centred on global issues than B1.

Based on insurance industry data, the number of loss-relevant weather extremes is becoming significantly larger globally and there is increasing evidence that at least part of the increase is associated with global warming.

The recent 5th Assessment Report of the IPCC (IPCC, 2013[5]) concluded that "warming of the climate system is unequivocal" and that "it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century". Warming of the atmosphere increases the water vapour content in the lower atmosphere, called troposphere. This increase feeds storm systems with additional energy which, when released as precipitation, amplifies the intensity of heavy rainfall events, thereby increasing the probability of floods. Based on insurance industry data, the number of loss-relevant weather extremes is becoming significantly larger globally and there is increasing evidence that at least part of the increase is associated with global warming. No single extreme event is solely caused by climate change associated with global warming. However, all extreme weather events include a manifestation of climate change because the environment in which they occur is warmer and contains more water vapour. The very likely increase of loss-relevant weather extremes in the future and in particular of floods poses serious risks to our society.

During the 20th century, the European continent has experienced an increase in mean annual rainfall between 10% and 40% in the northern part of the continent and a decrease of 20 to 40% in some regions of Southern Europe. Winter rainfall has decreased over Southern Europe and has increased further north. In recent decades Europe has experienced large floods and associated damages but there is no uniform pattern of change across Europe. Projections based on climate models indicate an increase in flood risk over a wide range of Europe owing to increases in the frequency and intensity of heavy rainfall (EASAC, 2013[6]). Projections of future climate also indicate an increase in windstorm-related risks for Western and Central Europe (EASAC, 2013). Low-lying coastal zones are particularly vulnerable to climate change, especially through sea level rise and storm surges associated with increasing storminess. The risk of inundation in low-lying coastal zones is very likely to increase along the 21st century.

Continental Portugal has experienced a small decrease in the average annual rainfall of around 30-60 mm per decade between 1961 and 2006 (EEA 2012 report on Climate change[7]). A decrease in the

5 *Stocker, Thomas F., Q. Dahe, and Gian-Kasper Plattner. "Climate Change 2013: The Physical Science Basis."Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers (IPCC, 2013) (2013).*

6 *Øystein Hov, Ulrich Cubasch, Erich Fischer, Peter Höppe, Trond Iversen, Nils Gunnar Kvamstø, Zbigniew W. Kundzewicz, Daniela Rezacova, David Rios, Filipe Duarte Santos, Bruno Schädler, Ottó Veisz, Christos Zerefos, Rasmus Benestad, John Murlis, M. Donat, Gregor C. Leckebusch, Uwe Ulbrich (2013). Extreme Weather Events in Europe: preparing for climate change adaptation. ISBN 978-82-7144-100-5*

7 *EEA 2012. Climate change, impacts and vulnerability in Europe. ISBN: 978-92-9213-346-7*

The more frequent and intense heavy precipitation events are very likely to lead to a higher frequency of floods with significant environmental and socio-economic impacts.

length of dry spells and a tendency towards drier climatic conditions for 1955-1999 has been observed over Southern Portugal. Furthermore a significant decrease in the number of light rainfall days has been observed in the same region over the period 1903-2003 (Gallego et al., 2011[8]). As regards the future, climate scenario projections for Continental Portugal indicate a decrease in the annual precipitation, particularly in the south (SIAMI, 2002[9]; SIAMII, 2006[10]). Future significant changes in the frequency and intensity of precipitation events are also expected. Extreme precipitation events are likely to become more frequent and intense, particularly in the region to the north of the central mountain range from "Serra de Montejunto" to "Serra da Estrela" The more frequent and intense heavy precipitation events are very likely to lead to a higher frequency of floods with significant environmental and socio-economic impacts. As regards the flood risk in the coast, 67% of the coastal zones in Continental Portugal have a significant risk of land loss (SIAMI, 2002; SIAMII, 2006), mainly due to erosion. Sea level rise, changes in the mean wave direction in the west coast and increased storminess are likely to increase the flood risk especially in the second half of the 21st century and beyond.

8 *M.C. Gallego, R.M. Trigo, J.M. Vaquero, M. Brunet, J.A. García, J. Sigró, M.A. Valente (2011). Trends in frequency indices of daily precipitation over the Iberian Peninsula during the last century Journal of Geophysical Research, 116 (2011) http://dx.doi.org/10.1029/2010JD014255*

9 *SIAM I - F. D. Santos, K. Forbes, R. Moita (2002). Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures. Gradiva, Lisbon, Portugal.*

10 *SIAM II - F.D. Santos e P. Miranda (2006). Alterações Climáticas em Portugal. Cenários, Impactos e Medidas de Adaptação. Gradiva, Lisbon, Portugal.*

can adaptation and mitigation change flood risk?

Responses to climate change can be of two broad and complementary types: adaptation and mitigation. Since the magnitude of climate change related impacts are uncertain, stakeholders/decision-makers require an adequate risk assessment to define the appropriate mitigation/adaptation strategy. Especially on floods, the risk should be managed taking into account the local communities and its social characteristics, science developments and the main guidelines of the international policy.

In order to respond to the risks and impacts posed by climate change, both mitigation and adaptation (M&A) measures are needed. The Intergovernmental Panel on Climate Change (IPCC) defines mitigation as "an anthropogenic intervention to reduce the anthropogenic forcing of the climate system" or, in simpler terms, as a set of action plans to reduce the emissions of greenhouse gases (GHG). On the other hand, adaptation is defined as an "adjustment in natural or human systems in response to actual or expected climatic

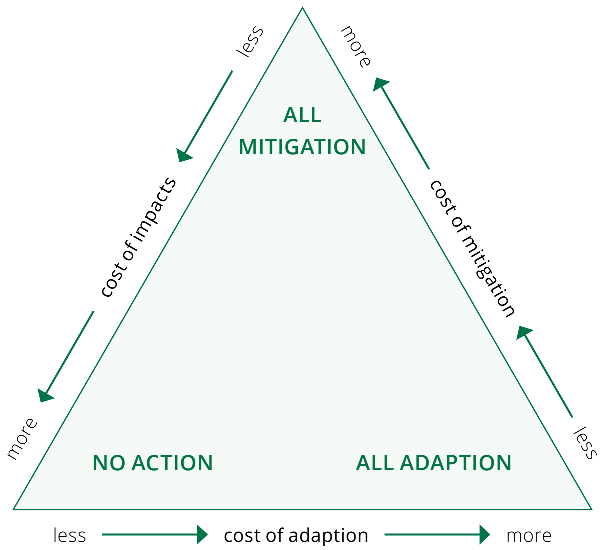


Figure 3. *Interrelationship between climate adaptation, mitigation, and impacts. Based on the concepts developed in Holdridge's life-zone classification scheme.*

stimuli or their effects, which moderates harm or exploits beneficial opportunities".

Generally, science and politics have treated M&A as separate domains, although they are responses to the same problem. However, as mitigation strategies aim to decrease GHG emissions, either by reducing its sources and emissions or by enhancing its sinks, adaptation can work to constrain climate change and its impacts. Therefore, both M&A are individually essential but not sufficient and should be viewed not as substitutes but as complements of the same strategy.

In fact, the IPCC considers that there are four types of inter-relationships between M&A: i) adaptation actions that have consequences for mitigation; ii) mitigation actions that have consequences for adaptation, iii) decisions that include synergies between M&A; and iv) processes that have consequences for both M&A.

As climate change and its negative impacts are inversely related to a reduction of damage, the more that is done to prevent these impacts the less is expected to be endured.

Both mitigation and adaptation aims to reduce the vulnerability but adaptation alone should increase the resilience of exposed systems. In this case, the selection of adaptation measures should be based

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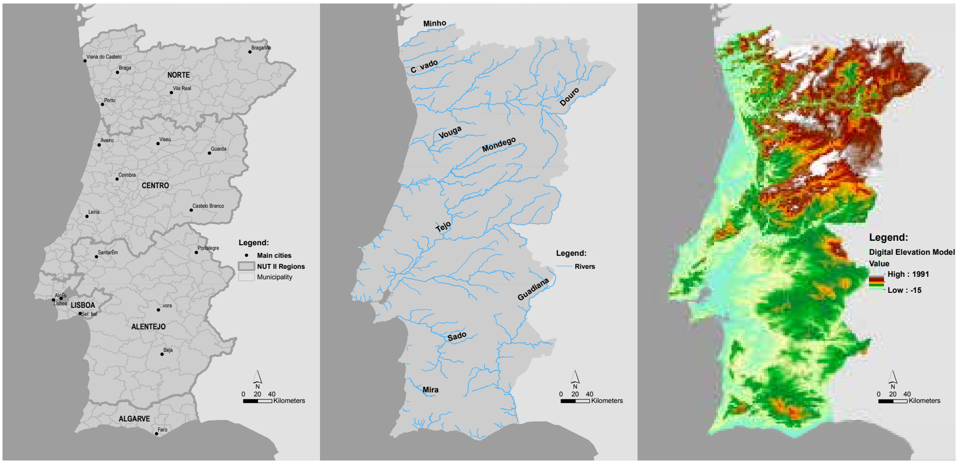

Figure 4. Characterization of the study area – Portuguese regions and main cities (i), Portuguese mainland basins and main river network (ii) and Digital Elevation Model (iii).

on strong data and cost-benefit analysis taking into account different time scales to ensure the irreversibility of the expected impacts.

how can the CIRAC project contribute to flood management in Portugal?

In mainland Portugal different kinds of hydrological extreme events occur, varying from those with slow spreading and large duration, normally extending to large areas (so-called progressive floods), and those with very fast spreading, short duration and concentrated impact (flash flood events). The flash floods events occur mainly on small watersheds or in urban areas and the progressive floods occur usually at a larger scale such as the Tagus, Guadiana, Mondego and Douro basins (Figure 4 ii). The topography of the Portuguese territory is steeper to the north of the Tagus River and in the south, on the Algarve region, and flatter in the Alentejo region between the rivers Tagus and Mira (Figure 4 iii).

The CIRAC project aimed to evaluate flood risk and vulnerability in Continental Portugal for present and future conditions (using climate change scenarios), trying to define a methodology to meet the objectives of DIRECTIVE 2007/60/EC of the European Parliament and of the Council of 23 October 2007. This directive establishes a framework for assessing and managing present and future flood risk. In this framework climate change should be taken in consideration, namely in terms of the definition of inundated areas for floods with an average frequency equal or higher than 100 years (point b of paragraph 3 of Chapter III). Ultimately, the definition of this

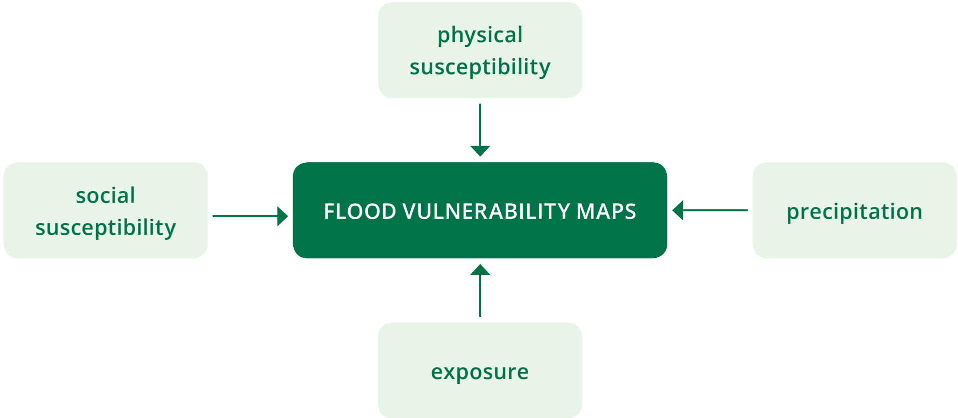

Figure 5. *Summary of the tasks and outputs of the Flood Vulnerability Index.*

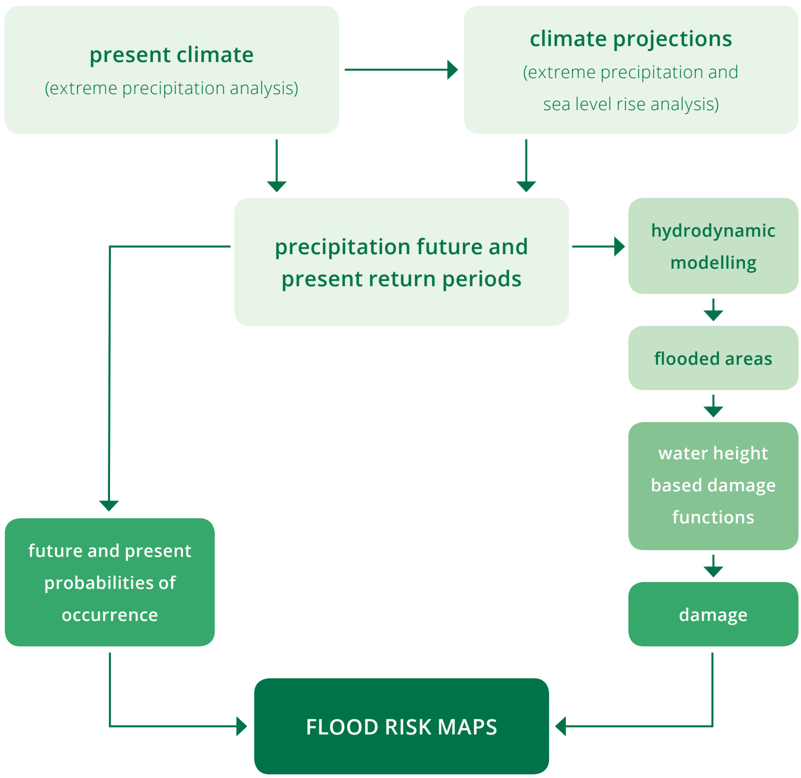

Figure 6. *Summary of the tasks and outputs of the Flood Risk Index.*

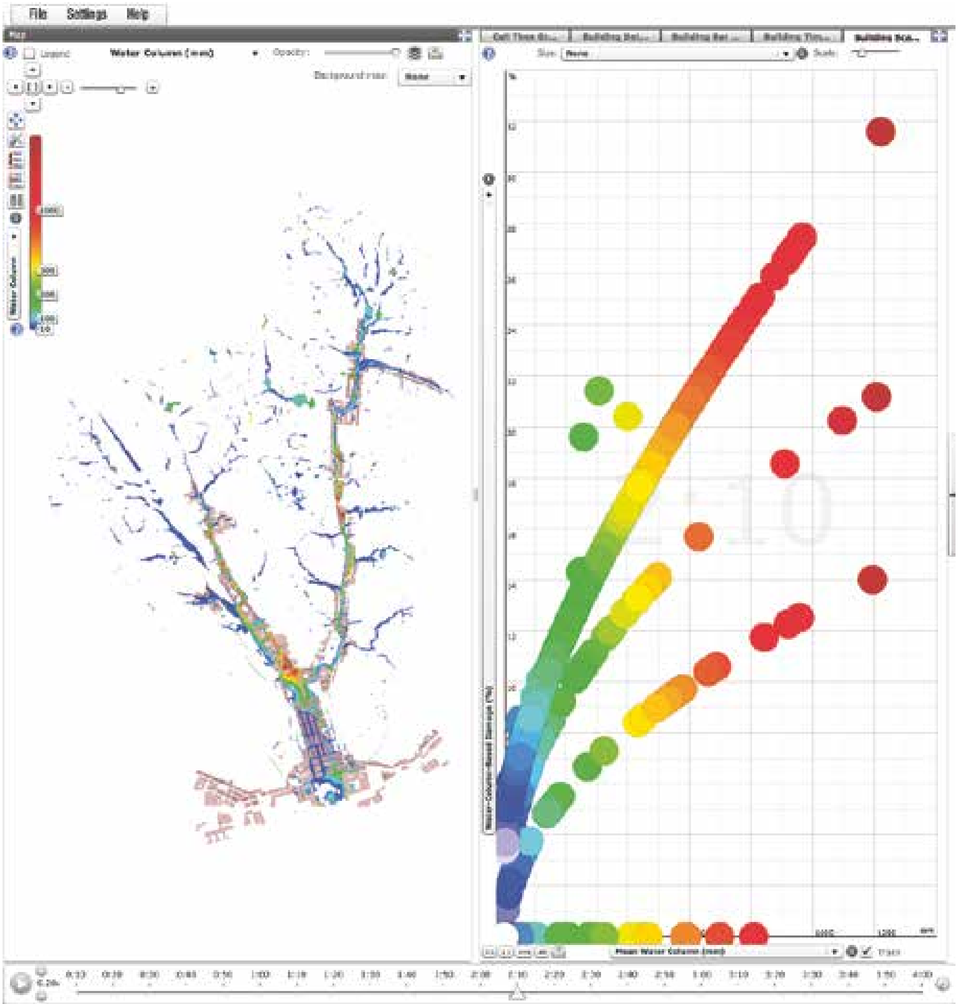

Figure 7. Flood visualization tool.

flood risk and vulnerability maps can help decision makers define more effective mitigation and adaptation strategies/pathways.

To assess flood risk and vulnerability two main approaches were developed. The first was a high resolution qualitative perspective to assess flood vulnerability at the national scale where several physical and social components characterize the exposed elements that in this case were buildings such as houses, schools or factories.

Simultaneously the project developed a risk assessment approach producing a very high resolution risk analysis to characterize the potential impacts and damage for Lisbon, Algés, Coimbra and Porto/Gaia where a multidisciplinary team was gathered to: (i) characterize climate extremes and future projections, (ii) characterize sea level rise, (iii) develop hydrodynamical models for the case studies, (iv) and develop risk maps. These tasks had the collaboration of the Geology department of the Faculty of Sciences of the University of Lisbon and the Portuguese company Action Modulers.

During these three years, the CIRAC project invited several institutions, like the Portuguese Environmental Agency, Civil Protection, insurance companies and local governments, to participate and evaluate the results. To engage in this multi-institutional interaction, a collaboration with the VA-4D[11] project, developed for the European Space Agency, was established to implement a collaborative platform that helps different stakeholders to take coordinated actions and planning activities before, during and after a flood event. This collaborative platform was presented in February 2013 in a workshop where the different stakeholders mentioned above were present. The main goal was to capture different perspectives on how to use this platform and what were the main functionalities that should be developed to address their different needs and at the same time promote the interaction between people that share responsibilities in flood risk management at different levels/scales. This tool can be found online at *http://siam..fc.ul.pt/cirac/floodvis/*

11 *http://goo.gl/U5SFdC*

Results from the workshop showed that several groups of stakeholders, like the local government and the Portuguese Environmental Agency, identified the need to couple the tool with a simulation model in order to experiment different types of solutions for their planning activities. In the other hand, institutions that work in emergency or prevention situations addressed the need to add real time visualization capabilities to be integrated in an early warning system.

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MAPPING FLOOD VULNERABILITY IN PORTUGAL

"Water is the driving force of all nature."

Leonardo da Vinci

Vulnerability is not an easy concept to define and is highly dependent on the topic where this term is applied. In the context of climate change, the IPCC definition of vulnerability is "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity." Focusing on floods, the UNESCO-IHE Institute for Water Education considers flood vulnerability "as the extent of harm, which can be expected under certain conditions of exposure, susceptibility and resilience" which can be translated by Equation 1 (Balica, S-F., 2012[12])

› Physical Susceptibility is a characteristic of an area, given by its natural terrain configuration and occupation, which determines the propensity of the area to floods.

› Resilience, as defined by UNISDR (2009)[14], is "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of an hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions".

From Eq.1, Resilience was addressed as Social Susceptibility, since it included only a socio-economic characterization of the population regarding factors such as age, income and education.

vulnerability = exposure + physical susceptibility - resilience **(1)**

vulnerability = exposure + physical susceptibility +
+ precipitation - social susceptibility **(2)**

This work adopted this last definition of vulnerability as a methodological framework to calculate flood vulnerability indexes for Continental Portugal with the following description of its components:

› Exposure represents the values which are present at the location where the floods can occur, such as: cultural heritage, infrastructure, goods, agricultural fields or people (Merz et al., 2007[13]).

To explore the relationship between precipitation and floods, a fourth component was added to take into account the geographical distribution of the mean annual precipitation. It's important to note that this component is based on the average data between 1961 and 1990, the Climate Normal used as international standard and climate change reference (see glossary), and its representativeness is specific for that period and doesn't consider possible trends and changes. Therefore flood vulnerability can be represented by Equation 2.

12 *Balica, S-F., 2012. Applying the flood vulnerability index as a knowledge base for flood risk assessment. CRC Press/ Balkema, ISBN ISBN: 9780415641579*

13 *Merz, B., Thieken, A. H., Gocht, M., 2007. Flood risk mapping at the local scale: concepts and challenges, in: Begum, S., Stive, M. J. F., Hall, J. W. (Eds.), Flood Risk Management in Europe. Innovation in Policy and Practice, Advances in Natural and Technological Hazards Research 25, Dordrecht, pp. 231-251.*

14 *United Nations Office for Disaster Risk Reduction (UNISDR) (2009). Global assessment report on disaster risk reduction. ISBN/ISSN: 9789211320282*

It should also be noted that coastal flood vulnerability was not addressed in this index. The following chapters aims to deeply describe these vulnerability components presenting the main results and conclusions.

physical susceptibility

Susceptibility to floods should be seen as the propensity of an area to be affected by floods and is given by the territory intrinsic characteristics such has slope, geology, river network, and land use. Physical susceptibility to floods is mostly derived from inherent characteristics of a specific basin.

The variables and respective datasets were based on three criteria: a) ability to incorporate parameters influence in both progressive and flash floods; b) minimization of the number of variables to contribute to index transparency and; c) dataset homogeneity (e.g., origin, spatial resolution) across the Portuguese territory. Three final variables were chosen: (i) flow accumulation; (ii) cost distance matrix (iii) flow number. The first two describe the water accumulation potential in the riverbed and adjacent areas, while the last assesses soil permeability based on land use and geology.

Based on historical flood spatial datasets the Physical Susceptibility index (PSI) was reclassified in four different classes to

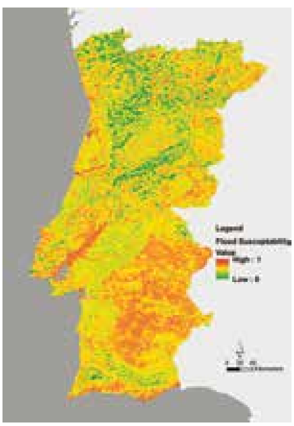

Figure 8. Flood Physical Susceptibility index.

Table 1. Flood physical susceptibility index classes

PSI	Area characterization	Physical characteristics
very high	› Differentiation of main water lines. › Some main urban areas.	› Water Lines and contiguous regions. › Regions of impervious soil (e.g. cities).
high	› Differentiation of adjacent flood plains in the main rivers.	› Flooding regions associated with large rivers. › Regions of permeable soil. › Regions with high water accumulation potential.
moderate	› Areas with increasing distance to water courses and steeper slopes.	› Regions of medium/low water accumulation. › Regions with significant water transport cost distance values. › Regions of permeable soil.
low	› Mountainous areas or with no water courses in their vicinity.	› Regions with no water accumulation potential. › Regions with higher soil permeability. › Regions with very high water transport cost distance values.

distinguish between higher water accumulation potential areas, like river margins and adjacent areas, from less susceptible flood areas, such as mountaintops.

The final physical susceptibility map identifies as highly susceptible the basins of the major Portuguese rivers (Tagus, Douro, Vouga, Mondego and Sado), specially the areas closer to their river mouths. Some major cities like Lisbon, Coimbra, Aveiro, Setúbal, Faro and Porto and some small basin areas in the south part of Portugal (Algarve) are also identified as highly susceptible to floods (classes 3 and 4). This showcases the index sensitivity to identify also flash flood prone areas, characterized by highly impermeabilized artificial surfaces situated in plain regions in the vicinity of relevant water courses. The Alentejo region is also classified as highly susceptible (class 3) due to its topographical and geological characteristics, since most of the territory is plain, with a high hydrographic network density and impermeable rocky (shale and marble) or clay soils. In this last case, this high physical susceptibility values may not be fully translated into a high floods frequency since this region is characterized by low precipitation regimes for most of the year.

The final physical susceptibility map identifies as highly susceptible the basins of the major Portuguese rivers (Tagus, Douro, Vouga, Mondego and Sado), specially the areas closer to their river mouths.

social susceptibility

Flood social susceptibility is defined as society's predisposition to be affected, resist, adapt or recover when exposed to a flood event. The Social Susceptibility Index (SSI) was developed based on a set of approximately 50 variables taken from the Portuguese census to describe the current functional and socioeconomic characteristics that determine a population's ability to cope with floods, such as, age, education, income, building function and typology and urban/rural background. From that original dataset, a smaller subset of 14 indicators was selected and aggregated according to their relevance to characterize three main components of flood social vulnerability: a) regional conditions; b) age; c) social exclusion conditions.

The social susceptibility component of the FVI shows a higher ability to cope with floods in coastal areas, mainly associated with more urbanized areas with higher education and income. Higher social susceptibility values are located in more inland regions, with a focus on the North and Center regions and the Northern and Southern part of Alentejo. As expected, the metropolitan areas of Lisbon and Porto have the lowest SSI values, mainly due to their higher per capita incomes, education and lower unemployment.

exposure

Exposure (E) is represented by the buildings density in the Portuguese territory derived from the data collected at the

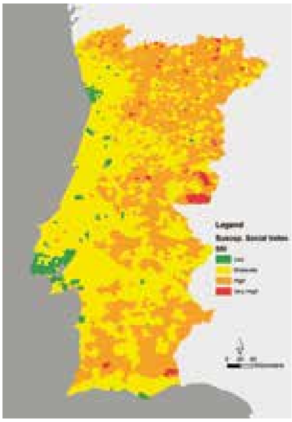

Figure 9. *Flood Social Susceptibility Index.*

Table 2. *Flood social susceptibility index classes*

SSI class/value	Class description
very high [-1.5; -0.75[	Highly susceptible populations with very low capacity to act or avoid consequences of flood damage and restore their environment into the same conditions prior damage.
high [-0.75; 0[	Susceptible populations with low capacity to act or avoid consequences of flood damage and restore their environment into the same conditions prior damage.
moderate [0; 0.75[	Population with a moderate level of susceptibility that is globally prepared to act with the consequences of flood damage and restore the environment into the same conditions before suffering damage.
low [0.75; 1.5]	Population with a low level of susceptibility that is more prepared to act with the consequences of flood damage and restore the environment into the same conditions before suffering damage..

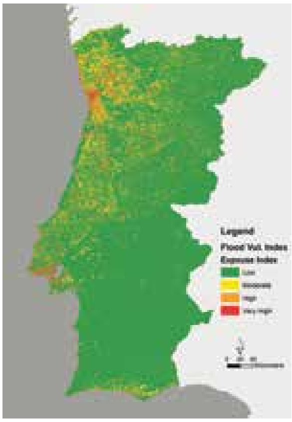

Figure 10. *Flood exposure index.*

Table 3. *Flood exposure Index classes*

E index	Class description
very high	Areas with high buildings density mainly representing urban areas.
high	Areas with medium buildings density usually villages and regions close to urban areas.
moderate	Areas with sparse buildings usually in rural areas.
low	Areas with scarce structures.

national census in 2001 by the National Statistics Institute (INE – Portuguese acronym). Each spatial statistical unit, which resembles a city block in urban areas, has the named of "Geographical Base of Referenced Information" (BGRI – Portuguese acronym).

The Exposure component highlights urban and peri-urban regions between Viana do Castelo and Setúbal, with higher incidence in the Lisbon and Porto metropolitan areas. It reflects two different urban morphology realities, in the northern coastal region higher exposure values are related to urban sprawl in the vicinity of major cities such as Porto, Aveiro, Braga and Viana do Castelo, whereas in the Lisbon metropolitan area they are associated with more compact and dense occupation.

precipitation

Portugal is generally characterized by the mediterranean climate but with the Atlantic influence due to its geographical position. In the Northern coast prevails the temperate Mediterranean climate with Atlantic influence and higher precipitation amounts, while the Northeast region is dominated by the Mediterranean climate with continental influence and consequently with less rainfall. In the South of Portugal the characteristics of the temperate Mediterranean climate are more pronounced reaching up to three times less annual precipitation than in the Northern coast.

The link between floods and precipitation depends on the type of flood (flash flood

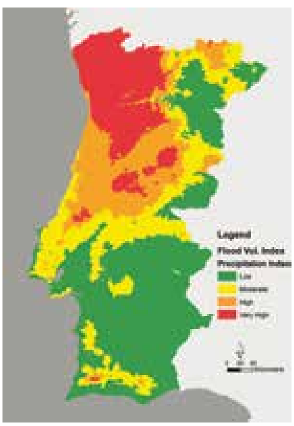

Figure 11. Annual average precipitation Index.

Table 4. Precipitation Index classes

Precipitation index	Annual precipitation (mm)	Class description
very high	[1270; 3500[	Areas with very high annual precipitation
high	[930; 1270[	Areas with high annual precipitation
moderate	[730; 930[	Areas with moderate annual precipitation
low	[380; 730[	Areas with low annual precipitation

or progressive flood), basin characteristics, soil saturation and in coastal areas tide height. The combination of these characteristics determines that for the same amount of rain is possible to have a flood event or not. The main difficulties in this work to link precipitation and floods was that in a general and qualitative approach is very difficult to put all these dependencies in an index since they aren't static in time.

The precipitation as a component of the Flood Vulnerability Index aimed to provide extra information about the precipitation normal (see climatological normals in the glossary) geographical distribution, considering that for regions with more annual rainfall are most likely to gather all needed elements to have flood events. This index represents the average of the total annual precipitation between 1961 and 1990 (see climatological normals in the glossary) divided in four classes reflecting the Atlantic and continental influences of the temperate Mediterranean climate and the effects of topography on precipitation.

where are we vulnerable? and why?

The advantage of having a modular index structure is that the different flood vulnerability components can be used in different combinations, depending on the information that each stakeholder requires or wants to extract. For instance, if a stakeholder selects only the Physical Susceptibility component the information given by the index reflects only the potential territorial vulnerability. By including Exposure, a second dimension is added to the final

The link between floods and precipitation depends on the type of flood (flash flood or progressive flood), basin characteristics, soil saturation and in coastal areas tide height. The combination of these characteristics determines that for the same amount of rain is possible to have a flood event or not.

index that considers not only potential vulnerability but also current vulnerability of existing structures and people. This combination defined a Basic Flood Vulnerability Index (BFVI) that provides a more physical approach to flood susceptibility, combining both terrain propensity to floods and human presence. Typically this index can be more interesting to better characterize insurance companies financial risk or to improve flood disaster operational management by Civil Protection authorities. If the stakeholder requires information about socioeconomic characterization, for instance, to improve social intervention measures or for strategic territorial planning purposes, Social Susceptibility can be added to this index. This component combination is what is generally referred as a Flood Vulnerability Index (FVI). For these two previous indexes, the final values were calculated by summing the different elements. This aggregation method may result in information loss regarding the contribution of each component to the overall flood vulnerability. Furthermore, adding the Precipitation component to the BFVI can

Table 5. Flood Vulnerability Indexes produced regarding its component.

Components	Basic Flood Vulnerability Index (BFVI)	Flood Vulnerability Index (FVI)	Combined Flood Vulnerability Index (CFVI)
SSI = Social Susceptibility Index		**FVI** (SSI + E + PSI)	
PSI = Physical Susceptibility Index	**BFVI** (PSI + E)		**CFVI** (PSI ∩ E ∩ P)
E = Exposure Index			
P = Precipitation Index			

Table 6. Summary table of the vulnerability indexes and their components for different applications and stakeholders.

Indexes or components name	Index characteristics	Target application / stakeholder
SSI= Social Susceptibility Index	Functional and socioeconomic characteristics that determine a population's ability to cope with floods, such as, age, education, income, building function and typology and urban/rural background.	(i) Social institutions (ii) Local public administrations
PSI= Physical Susceptibility Index	Propensity of an area to be affected by floods; territory intrinsic physical characteristics such has slope, geology, river network, and land use.	(i) Local public administrations; (ii) Territory planning (iii) Insurance companies (iv) Risk management
BFVI = Basic Flood Vulnerability Index = PSI+E	Characterization of the exposed elements in terms of propensity to be affected by floods due to their location.	(i) Local public administrations (ii) Territory planning (iii) General public; (iv) Civil protection
FVI = Flood Vulnerability Index = PSI+E+SSI	Characterization of the exposed elements in terms of propensity to be affected by floods and the population's ability to cope with it.	(i) Local and national public administration (ii) Civil protection
Combined Flood Vulnerability Index (CFVI) = CFVI (PSI ∩ E ∩ P)	Interception of the physical susceptibility, exposure and precipitation characteristics in a combined index. with this combined approach is possible to weight the contribution of each vulnerability component.	(i) Local public administrations (ii) Territory planning (iii) insurance companies

Flood Vulnerability Index (FVI)

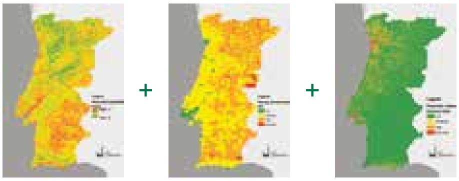

Figure 12. *Flood Vulnerability index components overlap - Exposure + Physical Susceptibility + Social Susceptibility (FVI=E+PSI+SSI)*

Basic Flood Vulnerability Index (BFVI)

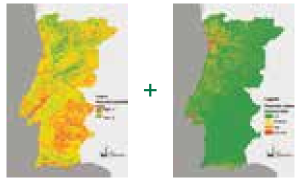

Figure 13. *Flood Vulnerability index components overlap - Exposure + Physical Susceptibility (FVI=E+PSI)*

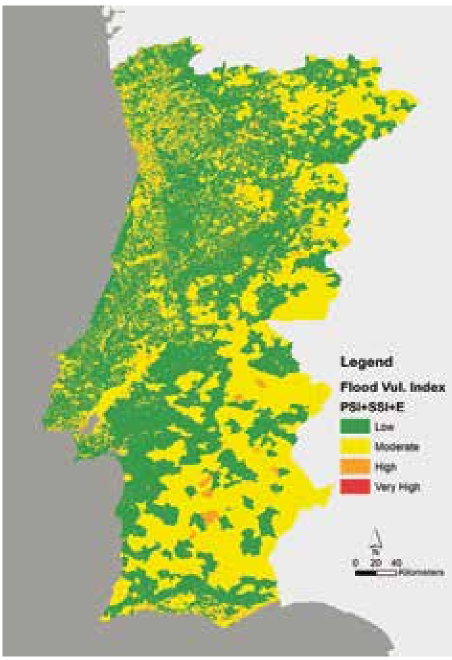

Figure 14. *Flood Vulnerability index - Exposure, Physical Susceptibility and Social Susceptibility (FVI=E+PSI+SSI)*

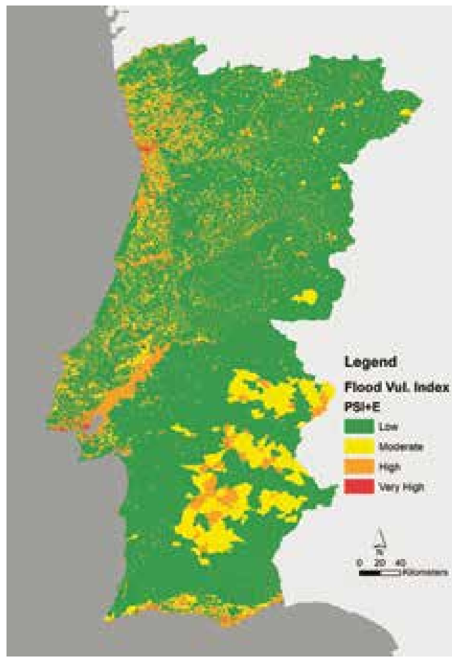

Figure 15. *Flood Vulnerability index - Exposure and Physical Susceptibility (FVI=E+PSI)*

Table 7. Flood Vulnerability indexes classes

Classes	E + PSI + SSI	E + PSI	Class description
very high	]10; 12]	]6; 8]	Areas very likely to suffer damage during flood events (E, PSI), with highly susceptible communities (SSI).
high	]7; 10]	]4; 6]	Areas likely to suffer damage during flood events (E, PSI) and with susceptible communities (SSI).
moderate	]5; 7]	]3; 4]	Areas unlikely to suffer damage during flood events (E, PSI), and where communities tend to be less susceptible (SSI).
low	[3; 5]	[2; 3]	Areas unlikely to have flood events (E, PSI), and where communities are less susceptible (SSI).

Table 8. Class description of the Combined Flood Vulnerability Index

CFVI	Description	PSI	E	P
8	High Physical Susceptibility, Exposure and Precipitation	[3,4]	[3,4]	[3,4]
7	High Physical Susceptibility and Precipitation and Low Exposure	[3,4]	[1,2]	[3,4]
6	High Physical Susceptibility and Exposure and Low Precipitation	[3,4]	[3,4]	[1,2]
5	High Physical Susceptibility and Low Exposure and Precipitation	[3,4]	[1,2]	[1,2]
4	Low Physical Susceptibility and High Exposure and Precipitation	[1,2]	[3,4]	[3,4]
3	Low Physical Susceptibility and Exposure and High Precipitation	[1,2]	[1,2]	[3,4]
2	Low Physical Susceptibility and Precipitation, High Exposure	[1,2]	[3,4]	[1,2]
1	Low Physical Susceptibility, Exposure and Precipitation	[1,2]	[1,2]	[1,2]

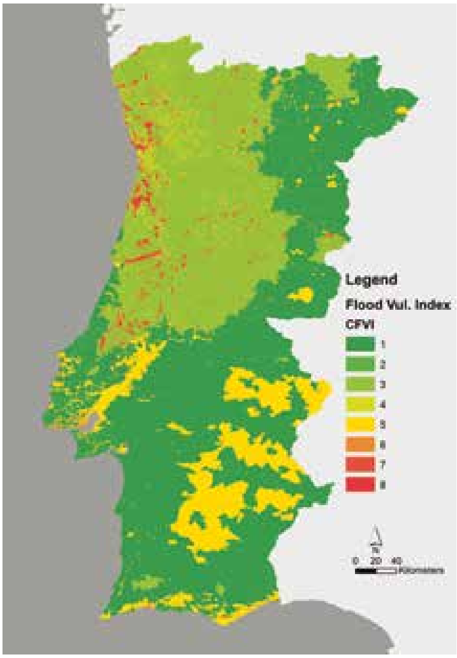

Figure 16. *Combined FVI with Exposure, Physical susceptibility and Precipitation (CFVI= E+PSI+P)*

help to distinguish flood propensity in areas with similar terrain physical characteristics. For this reason, a third index was developed, defining different vulnerability classes for different combinations of Exposure, Physical Susceptibility and Precipitation, designated by Combined Flood Vulnerability Index (CFVI). These different approaches are summarized in tables 5 and 6.

The national distribution of BFVI (Figure 15) shows a large portion of territory (≈85%) with a low flood vulnerability, associated with low population density and low or moderate physical susceptibility classes, such as the coastal and South regions of Alentejo, the North mountainous area of Algarve and most of the Center and North inland region.

The moderate vulnerability values cover about 14% of the territory and are concentrated in three distinct areas: a) the low exposure floodplains of major rivers like the Tagus, Mondego and Vouga; b) the center Alentejo and parts of Algarve, also with low exposure but higher physical susceptibility values related with a dense hydrographic network of smaller water courses and impervious soils (e.g., rock, clay) and; c) the peri-urban areas with moderate physical susceptibility, more visible along the coastal area between Setúbal and Viana do Castelo but also present in the vicinity of other major inland cities (e.g., Bragança, Vila Real, Castelo Branco).

Finally the high and very high flood vulnerability areas, covering approximately 2% of the Continental Portuguese territory, are mostly represented by high population density urban areas with high and very high physical susceptibility, usually associated with low soil permeability. These areas can be found in the Lisbon and

The national distribution of BFVI shows a large portion of territory (≈85%) with a low flood vulnerability, associated with low population density and low or moderate physical susceptibility classes, such as the coastal and South regions of Alentejo, the North mountainous area of Algarve and most of the Center and North inland region.

Porto metropolitan areas, the east part of Algarve as well as all major cities.

When comparing the BFVI and the FVI (Figures 14 and 15) we can clearly see that adding the Social Susceptibility component increases, as expected, flood vulnerability values in rural areas, while reducing it in coastal and urban regions. Another noticeable feature is that, in both maps, the level 4 (very high) areas are very similar.

As mentioned above, adding a third component (Precipitation) and combining their classes helps to describe the influence of the difference climatic regions and, at the same time, conveys better the contribution of each component (table 8). As shown in Table 8 its possible to explore the results from the perspective of the terrain physical characteristics, looking at classe 5, 6, 7 and 8, or from the exposure perspective (classes 2, 4, 6 and 8). The Precipitation component enhances, as expected, the vulnerability of the north coast while reducing it in the Alentejo region.

do the vulnerability indexes reflect reality?

During the CIRAC project a survey to the Portuguese insurance market was developed with two main goals. The first was to validate the vulnerability index based on the number of flood related claims between 2000 and 2011. The second was to characterize the geographic dispersion of the claim costs in relation to the total insured capital per zip code.

Figures 17 and 18 shows per zip code, respectively, the total number of claims and

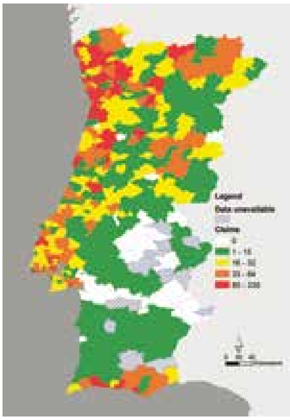

Figure 17. *Number of claims related to flood events between 2000 - 2011*

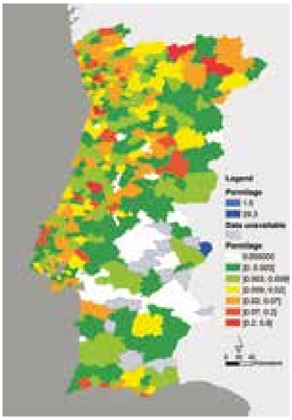

Figure 18. *Annual Average Permillage regarding the average policies enabled between 2000 - 2011 and the total sum insured in 2010*

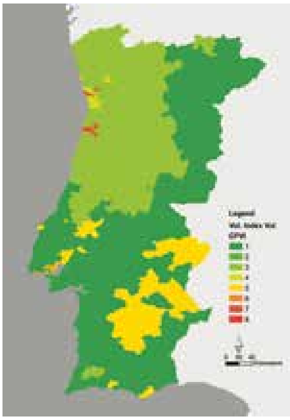

Figure 19. *Combined FVI of Exposure, Physical susceptibility and Precipitation (CFVI= E+PSI+P), by Zip code*

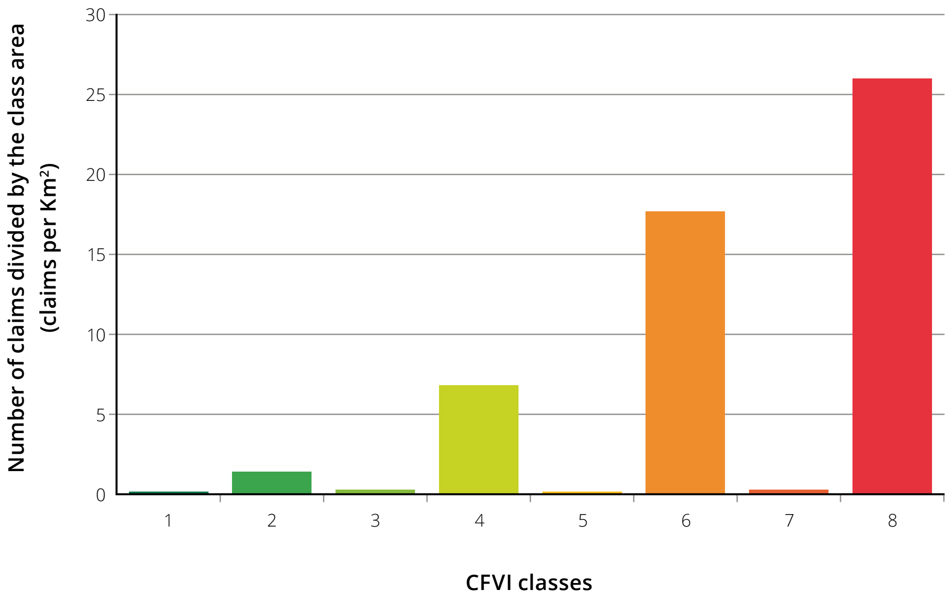

Figure 20. *Claims density per vulnerability class using the mode of the components.*

the annual average permillage, represented by the ratio between the claims costs and the total sum insured.

Although with different spatial resolutions and as expected, figure 17 and figure 16 (CFVI) are very similar. Both results highlight the Algarve region and the center and northern coast to be the most affected by flood events. To further go on this comparison the most common vulnerability values were aggregated to the zip code (Figure 19) of the combined Flood Vulnerability Index and the total number of claims per square kilometer was assigned to each vulnerability class (figure 20).

The analysis of figure 20 clearly shows that most of the insurance claims related with floods are in areas with high Physical Susceptibility and Exposure, class 6, or in areas of high Physical Susceptibility, Exposure and Precipitation, class 8. Although classes 5 and 7 are also characterized by high Physical Susceptibility, since they have low exposure values the number of insurance claims in those areas are very small. These results confirm the robustness of the national Flood Vulnerability methodology.

When comparing the BFVI and the FVI (...) we can clearly see that adding the Social Susceptibility component increases, as expected, flood vulnerability values in rural areas, while reducing it in coastal and urban regions.

MAPPING FLOOD RISK IN PORTUGAL

"The best thing one can do when it's raining is to let it rain."

Henry Wadsworth Longfellow

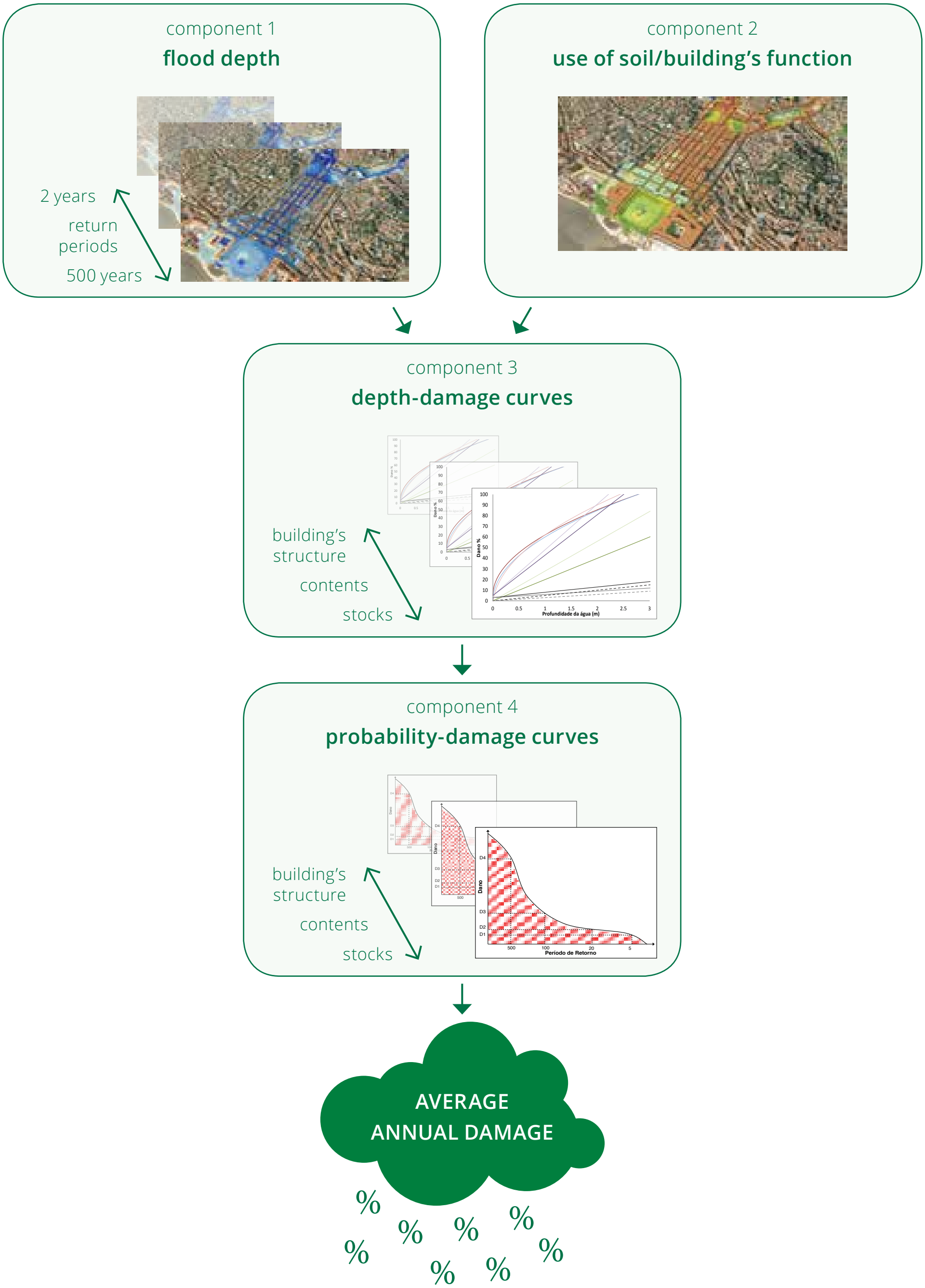

Figure 21. Methodological scheme for the assessment of flood risk by calculating the average annual damage.

The Risk is defined, in general terms, as the probability of harmful consequences or losses as a result of the interaction between the natural environment, or human-induced hazards, and conditions of susceptibility of the elements.

The calculation of risk consists of the product between the probability of occurrence of a phenomenon with a certain magnitude, and the consequences of this phenomenon (Equation 3).

risk = probability × consequence (3)

The probability was obtained through the return periods (see glossary) of precipitation or flow rates for different areas.

By modeling it is possible to obtain the extent of flooding and associated characteristics to different return periods (component 1 of Figure 21). With this information and using historical data of damage caused in exposed elements associated with different water heights, it creates depth - damage curves (component 3 of Figure 21). The application of these curves is associated with a consequence to the exposed elements in different return periods (component 2 of Figure 21). Finally and by multiplying the probability of a flood by the consequence that results in the elements, we obtain the risk for each return period analyzed. The sum of the risk associated with return periods corresponds to what is called the average annual damage (Component 4 of Figure 21). This average annual damage is the fraction of the total value of assets exposed to a certain category of buildings that is affected annually in average.

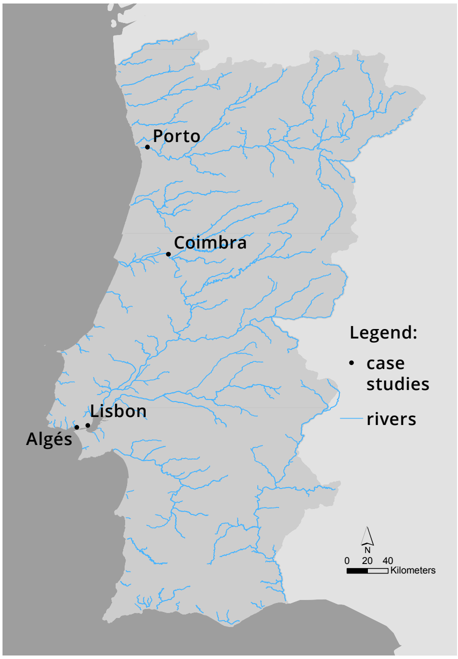

Figure 22. Location of case studies for the assessment of flood risk.

The calculation of risk consists of the product between the probability of occurrence of a phenomenon with a certain magnitude, and the consequences of this phenomenon

In this project the damage was assessed for four areas of study, and evaluated both the structure of the buildings and their contents, subdivided into Residential Inventory, Fixed Assets - Industrial and Non-Industrial - and Stocks (See glossary). This review only counts the average annual damage of buildings actually affected by floods and not all of the buildings standing on the assessed basin. The four areas evaluated were chosen by the large number of floods and torrents recorded, corresponding to Lisbon (Downtown Basin), Algés (Baixa de Algés), Coimbra (Downtown and the southern part of the city) and Douro (Porto and Gaia) (figure 22).

Lisbon case study

The city of Lisbon is often hit by floods. The most vulnerable areas are identified in various studies including the Municipal Director Plan of the City. In this city, floods occur as a result of heavy rainfall and short duration that result in floods or flash floods. These are aggravated due to the high level of impervious surfaces associated with a drainage system that is not always properly sized and through the occupation and the now artificial sections of the old water lines, which are mostly channeled. No less important is the interaction between the rainwater drainage network and the Tagus river. Taking into account its width, this river is not responsible for flooding resulting from rainfall in the city of Lisbon.

However, other phenomena such as storm surge, tides and rising sea level have a significant impact on urban flooding since they imply an increase in the water level of the river, causing a buffering effect in the city drainage system.

In the last decade the most significant flooding occurred in Lisbon on the 18th February 2008. On this day the weather station of the Geophysical Institute of the Infante Don Luis, active since 1836 surpassed the previous record of maximum

Figure 23. *Delimitation of the basin of downtown Lisbon*

daily precipitation, being the new absolute extreme 118 mm. However this was not the flood that caused the worst impacts on the population, being necessary to go back to November 25th, 1967 when, in the Lisbon region, floods were responsible for over 400 deaths (some sources report more than 700 victims). Despite the precipitation value being much higher than in 2008 many improvements have been made over the years. With relevance to the city of Lisbon it may be referred the improvements of the rainwater drainage systems, which although still present some undersized situations, have a capacity far more appropriate currently.

Annual average damage in building's structure (‰)	Return period (years)
0–10	2
10–20	5
20-30	10
30-40	20
40-55	50
assessed buildings	100
other buildings	500

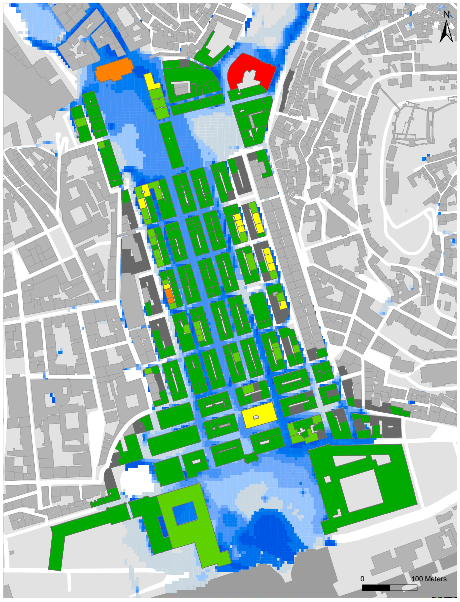

Figure 24. Flood risk. Annual average damage in building's structure. Sub-basin of downtown Lisbon.

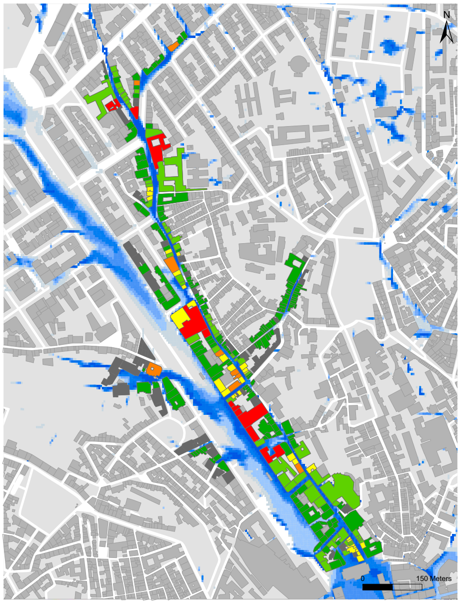

Figure 25. Flood risk - Annual average damage in building's structure. Sub-basin of Avenida da Liberdade, Lisbon.

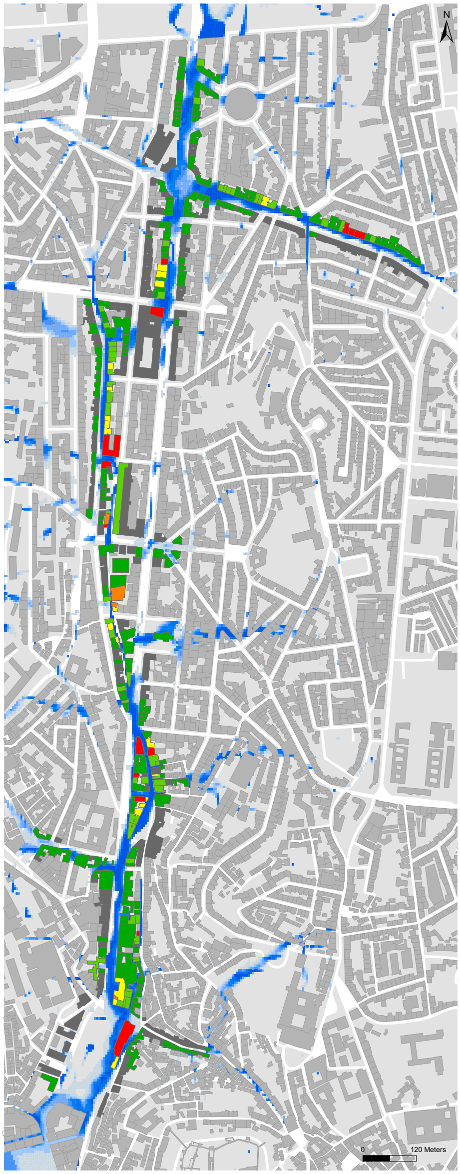

Figure 26. Flood risk - Dano médio anual na estrutura dos edifícios. Annual average damage in building's structure. Sub-basin of Avenida Almirante Reis, Lisbon.

Table 9. Annual average damage (AAD) as a consequence of flooding to the building structure and different occupations. Expected difference in annual average damages taking into account two scenarios of climate change. Sub-basin of Avenida da Liberdade, Lisbon.

SUB-BASIN OF AVENIDA DA LIBERDADE	Exposed Elements	Present	HadCm³	2010 2039	2040 2069	2070 2099
	nº	AAD (‰)	SRES	Changes to the AAD of 2010 (‰)		
Structure	285	2.95	A2	-0.25	-0.08	-0.81
			B2	+0.28	-0.23	+0.20
Residential Content Basement	1	0.41	A2	-0.32	-0.24	-0.35
			B2	+0.13	-0.28	+0.26
Residential Content Ground Floor	37	59.4	A2	-0.77	+0.99	-10.3
			B2	+3.74	-1.03	+1.51
Non-industrial Fixed assets Basement	9	59.7	A2	-3.49	-0.43	-15.4
			B2	+5.42	-3.38	+3.21
Non-industrial Fixed assets Ground Floor	230	105.7	A2	-4.92	+0.02	-25.1
			B2	+8.81	-4.87	+4.74
Industrial fixed assets Basement	0	—	A2	—	—	—
			B2	—	—	—
Industrial fixed assets Ground Floor	0	—	A2	—	—	—
			B2	—	—	—
Stocks Basement	27	38.3	A2	-2.30	-0.43	-9.40
			B2	+3.32	-2.22	+2.12
Stocks Groud Floor	220	45.9	A2	-3.40	-0.85	-12.2
			B2	+4.27	-3.19	+2.84

In Lisbon there are several drainage basins where flooding occur, namely the Alcantara valley, the Chelas valley or downtown Lisbon. The latter develops into North through the Avenida da Liberdade (old Ribeira de Valverde or Santo Antao) and Avenida Almirante Reis (old Ribeira de Arroios), being chosen for the assessment of flood risk (Figure 23).

For the purposes of risk assessment, the procedure was the modeling of runoff and drainage network and subsequently the basin was divided into sections in order to comparatively assess the risk of these different areas. The sections correspond to the: (1) area of downtown Lisbon (Figure 24), (2) Avenida da Liberdade (Figure 25) and Avenida Almirante Reis (Figure 26).

At present, the three areas assessed have different risk profiles when treated individually. The area with the highest values corresponding to the portion of the basin designated by Avenida da Liberdade where the drainage system is not as effective in situations of torrential rain, as several depressed and water accumulation areas, such as Rua das Pretas or Rua das Portas de Santo Antao, which is at a lower level of the surrounding areas. On the set of evaluated buildings, and at present, there is an average annual loss of slightly more than 100 ‰ in non-industrial fixed assets

Table 10. Annual average damage (AAD) as a consequence of flooding to the building structure and different occupations. Expected difference in annual average damages taking into account two scenarios of climate change. Sub-basin of Avenida Almirante Reis, Lisbon.

SUB-BASIN OF AVENIDA ALMIRANTE REIS	Exposed Elements	Present	HadCm³	2010 2039	2040 2069	2070 2099
	nº	AAD (‰)	SRES	Changes to the AAD of 2010 (‰)		
Structure	348	2.03	A2	-0.07	-0.01	-0.43
			B2	+0.15	-0.07	+0.08
Residential Content Basement	0	—	A2	—	—	—
			B2	—	—	—
Residential Content Ground Floor	64	64.9	A2	-1.97	+0.58	-13.5
			B2	+4.81	-2.08	+2.26
Non-industrial Fixed assets Basement	5	69.8	A2	-1.84	+1.12	-16.1
			B2	+5.72	-2.07	+2.44
Non-industrial Fixed assets Ground Floor	260	77.5	A2	-2.03	+0.93	-16.0
			B2	+5.71	-2.23	+2.55
Industrial fixed assets Basement	1	0.50	A2	-0.32	-0.22	-0.40
			B2	+0.14	-0.28	+0.22
Industrial fixed assets Ground Floor	0	—	A2	—	—	—
			B2	—	—	—
Stocks Basement	22	34.5	A2	-1.10	+0.19	-6.83
			B2	+2.43	-11.4	+12.1
Stocks Groud Floor	244	33.4	A2	-0.98	-0.32	-7.00
			B2	+2.49	-1.05	+1.16

located at the ground floor level, reducing this value in the remaining categories evaluated (Table 9).

Regarding the portion of the basin of the Avenida Almirante Reis water accumulation occurs mostly in Regueirão dos Anjos, where the primitive water line was located, and at the Largo do Intendente. For this sub-basin the category with the most damage at present corresponds to non-industrial fixed assets. However the value of annual average damage to the sub-basin of Avenida Almirante Reis has a lower value, of around 77 ‰ (Table 10).

In Lisbon there are several drainage basins where flooding occur, namely the Alcantara valley, the Chelas valley or downtown Lisbon. The latter develops into North through the Avenida da Liberdade (old Ribeira de Valverde or Santo Antao) and Avenida Almirante Reis (old Ribeira de Arroios), being chosen for the assessment of flood risk

Table 11. Annual average damage (AAD) as a consequence of flooding to the building structure and different occupations. Expected difference in annual average damages taking into account two scenarios of climate change. Sub-basin of Baixa de Lisboa.(Downton Lisbon)

SUB-BASIN DOWNTOWN	Exposed Elements	Present	HadCm³	2010 2039	2040 2069	2070 2099
	nº	AAD (‰)	SRES	Changes to the AAD of 2010 (‰)		
Structure	368	0.58	A2	-0.15	-0.09	-0.26
			B2	+0.09	-0.13	+0.11
Residential Content Basement	0	—	A2	—	—	—
			B2	—	—	—
Residential Content Ground Floor	2	59.2	A2	-1.29	+0.24	-9.10
			B2	+3.37	-1.44	+1.85
Non-industrial Fixed assets Basement	2	36.9	A2	-15.4	-8.78	-24.0
			B2	+7.83	-13.1	+9.06
Non-industrial Fixed assets Ground Floor	363	36.0	A2	-6.18	-3.07	-13.4
			B2	+4.61	-5.48	+4.34
Industrial fixed assets Basement	0	—	A2	—	—	—
			B2	—	—	—
Industrial fixed assets Ground Floor	0	—	A2	—	—	—
			B2	—	—	—
Stocks Basement	4	11.0	A2	-2.53	-1.30	-5.57
			B2	+1.96	-2.28	+1.96
Stocks Groud Floor	318	14.8	A2	-2.83	-1.50	-5.66
			B2	+1.96	-2.50	+2.00

Finally the area with lower associated risk is the Baixa (Downtown Lisbon). This relates primarily to the more efficient structure of the drainage system system in this area but also with its topographical situation, more favorable due to the enlargement of the area resulting in higher water spreading.

For this case and at present the highest risk value corresponds to the contents of the fractions dedicated to housing on the ground floor, with a value of around 60 % average annual losses. However and since there are only two buildings exposed to this feature, its value has a low representation in the rated universe. More relevant in comparison with the other areas assessed in this basin are the non-fixed industrial assets located on the ground floor, where the risk value corresponds to 36 % average annual losses. (Table 11).

The assessment of climate scenarios for these three sections shows a trend of relative stationarity or decrease of extreme events, depending on the scenario. In the A2 scenario there is a slight decrease in median damage in almost all categories assessed. In the B2 scenario results have no defined trend. Modifications designed for this climate scenario suggest an increase in extreme events by mid-century (until 2039), and in its end (2070-2099). However the intermediate period (2040-2069) shows a decrease of these events. It should be noted that the downward trend in the average annual damage observed in the A2 scenario is generally more significant than the increase in the B2 scenario (Tables 9, 10, 11).

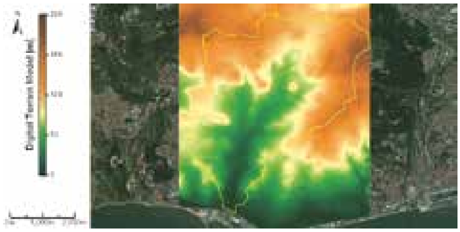

Figure 27. Delimitation of the basin of Ribeira de Algés.

Algés case study

Algés is located in Oeiras, on the border with the municipality of Lisbon. The final section of the stream of Algés is channeled underground through downtown Algés and flows into the Tagus. For this reason, the floods that occur quite frequently in this area, are strongly influenced by tides and other verified conditions in the river.

In the last decade two floods are of particular relevance that occurred within two months, specifically on the 19th December 2007 and 18th February 2008. In both cases several downtown streets of Algés were flooded and damages were significant in residential and commercial spaces.

For the purposes of risk assessment the procedure was the modeling of both surface runoff and drainage network. This modeling, despite being held for the entire river basin (Figure 27), is more detailed in downtown Algés, where the risk assessment (Figure 28) was performed.

The assessed area has the highest risk values, translated into average annual damages of all case studies due to the high number of occurrences of floods that occur here. With the exception of damage to the structure of the buildings, all damage categories assessed have an average potential loss above 100‰ per year, with

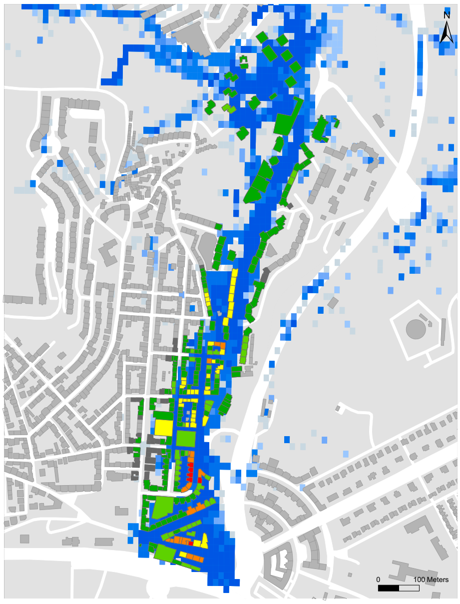

Figure 28. Flood risk - Annual average damage in buildings´ structure. Algés, Oeiras.

Annual average damage in building's structure (‰)	Return period (years)
0–10	2
10–20	5
20-30	10
30-40	20
40-55	50
assessed buildings	100
other buildings	500

Table 12. Annual average damage (AAD) as a consequence of flooding to the building structure and different occupations. Expected difference in annual average damages taking into account two scenarios of climate change. Algés, Oeiras.

DOWNTOWN ALGÉS	Exposed Elements	Present	HadCm³	2010 2039	2040 2069	2070 2099
	nº	AAD (‰)	SRES	Changes to the AAD of 2010 (‰)		
Structure	242	12.3	A2	+0.18	+0.44	-1.80
			B2	+0.66	+0.07	+0.10
Residential Content Basement	33	137.6	A2	+0.93	+4.80	-24.5
			B2	+8.95	-0.19	+2.06
Residential Content Ground Floor	134	170.2	A2	+2.12	+6.02	-26.2
			B2	+9.64	+0.69	+1.74
Non-industrial Fixed assets Basement	44	177.2	A2	+2.13	+6.21	-27.2
			B2	+10.0	+0.66	+1.81
Non-industrial Fixed assets Ground Floor	180	212.1	A2	+3.31	+7.61	-29.9
			B2	+11.1	+1.49	+1.60
Industrial fixed assets Basement	5	113.5	A2	+2.12	+4.28	-15.6
			B2	+5.79	+1.09	+0.67
Industrial fixed assets Ground Floor	1	130.1	A2	+2.77	+4.98	-16.6
			B2	+6.23	+1.57	+0.50
Stocks Basement	42	136.3	A2	+1.95	+4.94	-20.4
			B2	+7.52	+0.78	+1.21
Stocks Groud Floor	175	103.7	A2	+14.6	+3.69	-15.3
			B2	+5.64	+0.58	+0.91

special relevance to the damage category of non-industrial fixed assets where this value exceeds 200‰.

The changes projected by climate scenarios are identical to those found for the Downtown area where in the A2 scenario, the risk has a tendency to decrease, as well as extreme events, and in the B2 scenario, there are different behaviours depending on the analyzed period. Thus the changes projected by the B2 climate scenarios suggest an increase in extreme events by mid-century (until 2039) and at the end of (2070-2099) century. However the intermediate period (2040-2069) shows a considerable decrease in those events. These behaviours are reflected in the risk values calculated for each of these periods (Table 7).

Coimbra case study

In the city of Coimbra floods occur from different sources. They may occur as a result of the water overflow from the river Mondego, implying precipitation upstream of the river, or through local episodes of extreme rainfall, causing overloading of the rainwater drainage and / or significant increase of surface runoff systems, which cause floods or urban flooding.

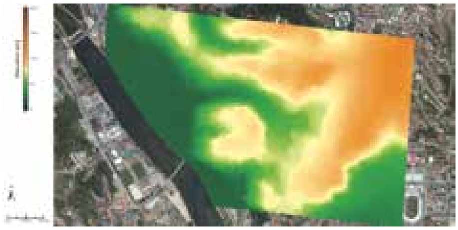

Figure 29. Delimitation of the assessed area. Downtown Coimbra

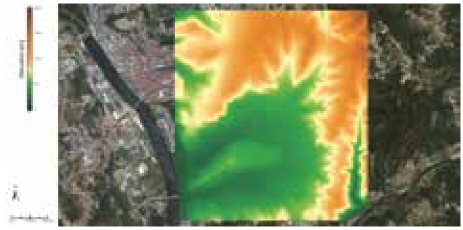

Figure 30. Delimitation of the assessed area. South Coimbra

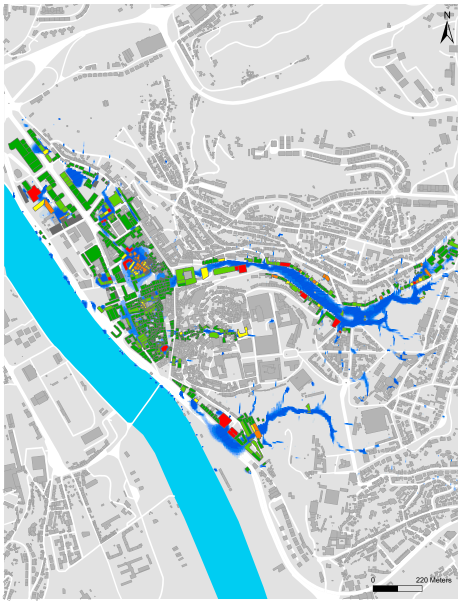

Figure 31. Flood risk - Annual average damage in buildings structure. Downtown Coimbra

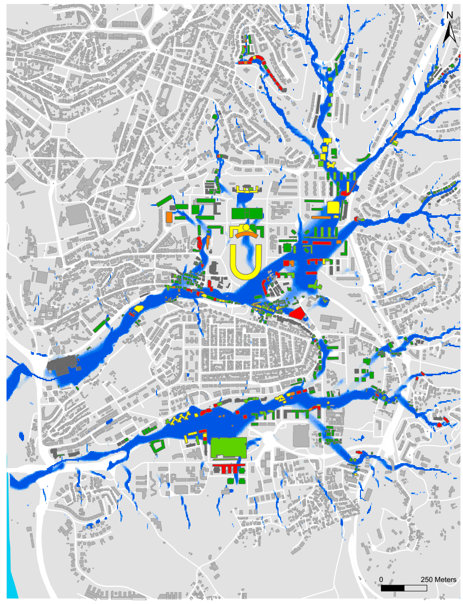

Figure 32. Flood risk - Annual average damage in buildings structure. Coimbra, South.

The evaluation performed in Coimbra focuses exclusively on urban flooding, responsible for damage in downtown and south areas of the stadium and Vale das Flores. As in Porto, there are progressive floods on the Mondego River, with a component of regularization of the flow through the dams upstream the city. As the factors that lead to changes in flow go beyond the weather it was decided not to

Annual average damage in building's structure (‰)	Return period (years)
0–10	2
10–20	5
20-30	10
30-40	20
40-55	50
assessed buildings	100
other buildings	500

Table 13. Annual average damage (AAD) as a consequence of flooding to the building structure and different occupations. Expected difference in annual average damages taking into account two scenarios of climate change. Downtown, Coimbra.

DOWNTOWN COIMBRA	Exposed Elements	Present	HadCm³	2010 2039	2040 2069	2070 2099
	nº	AAD (‰)	SRES	Changes to the AAD of 2010 (‰)		
Structure	692	2.29	A2	+0.18	+0.44	-1.80
			B2	-0.60	-0.08	+0.51
Residential Content Basement	16	21.5	A2	-3.61	-2.65	+8.05
			B2	-8.52	-1.51	+4.49
Residential Content Ground Floor	122	50.1	A2	-5.11	-3.14	+14.4
			B2	-13.1	-1.88	+10.2
Non-industrial Fixed assets Basement	15	46.2	A2	-4.79	-3.08	+12.9
			B2	-12.1	-1.88	+8.88
Non-industrial Fixed assets Ground Floor	529	60.8	A2	-6.11	-3.29	+19.6
			B2	-16.6	-2.04	+14.7
Industrial fixed assets Basement	0	—	A2	—	—	—
			B2	—	—	—
Industrial fixed assets Ground Floor	2	1.76	A2	+0.02	+0.52	+2.34
			B2	-0.81	+0.21	+2.59
Stocks Basement	46	40.6	A2	-3.78	-2.90	+7.78
			B2	-8.65	-1.62	+4.49
Stocks Groud Floor	480	22.8	A2	-2.17	-0.90	+8.26
			B2	-6.37	-0.62	+6.61

include this kind of phenomenon in the risk assessment carried out.

The largest recorded flood occurred in Coimbra on the 29th January 1948, the latter being closely related to the rising waters of the Mondego River. However, in the last decade two episodes of flooding resulting from concentrated rainfall occurred in the city on the 25th October 2006 and on the 21st September 2008.

Risk assessment of Coimbra is performed in two areas. The first comprises the downtown area including Avenida Sá da Bandeira, being a very urbanized area with steep slopes up to the downtown area. The second area corresponds to the south of the city (City of Coimbra Stadium and Vale das Flores) which has a more recent urban occupation and where the rainwater drainage network uses the pre-existing water lines that in the meantime were made artificial in several sections (Figure 29, 30).

For the purposes of risk assessment an hydrological modeling of superficial runoff for both basins and drainage network was carried out in areas where it is available (Figure 31, 32).

At the two evaluated areas the risk of flooding is quite different, being higher in the southern part of the city compared to the downtown area. The damage category with higher associated risk consists of the

Table 14. Annual average damage (AAD) as a consequence of flooding to the building structure and different occupations. Expected difference in annual average damages taking into account two scenarios of climate change. Coimbra, South.

COIMBRA SOUTH AREA	Exposed Elements	Present	HadCm³	2010 2039	2040 2069	2070 2099
	nº	AAD (‰)	SRES	Changes to the AAD of 2010 (‰)		
Structure	586	4.52	A2	-0.44	-0.40	+0.62
			B2	-0.90	-0.21	+0.22
Residential Content Basement	23	54.9	A2	-5.08	-4.45	+7.77
			B2	-10.6	-2.41	+3.16
Residential Content Ground Floor	238	66.3	A2	-6.81	-5.91	+10.8
			B2	-14.4	-3.20	+4.57
Non-industrial Fixed assets Basement	16	50.4	A2	-5.05	-4.24	+8.64
			B2	-10.9	-2.32	+4.13
Non-industrial Fixed assets Ground Floor	199	101.3	A2	-9.85	-8.94	+13.7
			B2	-20.2	-4.79	+4.54
Industrial fixed assets Basement	0	—	A2	—	—	—
			B2	—	—	—
Industrial fixed assets Ground Floor	7	22.8	A2	-2.35	-2.18	+3.02
			B2	-4.72	-1.16	+0.84
Stocks Basement	104	39.7	A2	-3.85	-3.48	+5.39
			B2	-7.89	-1.87	+1.83
Stocks Groud Floor	283	33.9	A2	-3.37	-3.02	+4.85
			B2	-6.95	-1.62	+1.74

non-industrial fixed assets located on the ground floor of buildings, corresponding to a value of average losses of around 100‰ per year in the southern part of the city and 60‰ on downtown. This difference relates primarily to an increased compliance of the Downtown drainage network as a result of several studies and interventions made over the years and combined with a smaller area of rain water drainage (Table 13, 14).

The changes projected by climate scenarios for the region of Coimbra suggest a decrease of extreme events by mid-century (until 2039) and a considerable increase in the end of the century (2070-2099). In the intermediate period (2040-2069) the events with smaller magnitude will occur less frequently and the ones of greater magnitude more frequently. Climate trends in the intermediate period do not have, however, a reflection on risk, since for the calculation of the annual average damage, events with higher frequency, and therefore of lesser magnitude, are those that contribute the most to its final value (Table 13, 14).

Porto case study

The cities of Porto and Gaia are often affected by floods resulting from progressive floods resulting from the water overflow of the Douro River. These cities are located at the mouth of the river where the tides, the weather and storms, when combined with

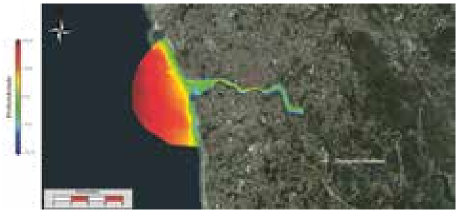

Figure 33. *Delimitation of the modeling section of the Douro river basin.*

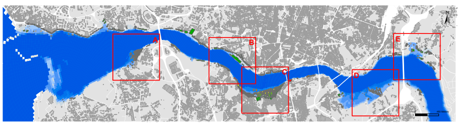

Figure 34. *Flood risk – Annual average damage in buildings structure. Douro - Porto/Gaia.*

flow rates influence the height of the river water. The floods that currently occur have a lesser impact than the ones recorded in the past, since the Douro stream is strongly regulated by existing dams. On the 23rd December 1909 there was one of the largest floods recorded in the last century, which killed over 120 people and the water height exceeded 10 meters (using the hydrographic zero as reference) on the area of Cais da Ribeira in Porto, corresponding to 4 meters high of water from the surface of that pier. This is not the worst flood on record, as there are many reports of extreme events prior to that date. In the last decade the most significant flood occurred on the 25th November 2006. Although it caused a lot of damage, it is not comparable to the one in 1909.

The risk assessment of this area is based on the values of the river flow and not precipitation, as in the remaining case studies. Although these flow rates are dependent on weather conditions, the Douro is strongly regulated by several dams. Therefore, its flow is to a great extent the result of human decisions, which does not allow a conclusive review of the floods in the context of climate change. Therefore, this case study only presents the results of the flood risk at present.

Table 15. *Annual average damage (AAD) as a consequence of flooding to the building structure and different occupations. Douro - Porto/Gaia.*

PORTO/GAIA	Exposed Elements	Present
	nº	DMA (‰)
Structure	1080	3.54
Residential Content Basement	3	108.2
Residential Content Ground Floor	544	41.5
Non-industrial Fixed assets Basement	2	3.29
Non-industrial Fixed assets Ground Floor	271	39.5
Industrial fixed assets Basement	0	—
Industrial fixed assets Ground Floor	12	1.95
Stocks Basement	7	4.61
Stocks Groud Floor	483	26.9

In Vila Nova de Gaia the higher risk of flooding is associated with the locations of São Pedro da Afurada (Figure 35a) and Areinho (Figure 35c) and the riverfront of Santa Marinha, where the wine cellars of Porto are located (Figure 35b).

On the Porto bank, the area of Alfândega (Figure 35d), Ribeira (Figure 35e) and the confluence of the rivers Torto and Tinto with the Douro (Figure 35f) are at greatest

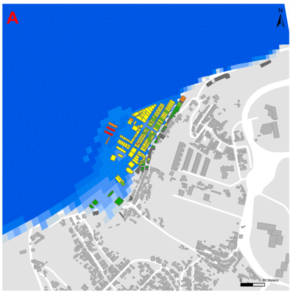

Figure 35a. *Flood risk – Annual average damage in buildings structure. São Pedro da Afurada, Gaia.*

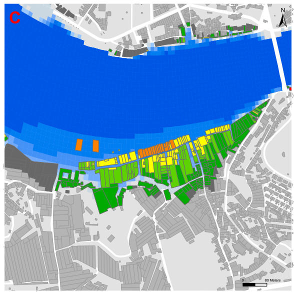

Figure 35b. *Flood risk – Annual average damage in buildings structure. Close to the Porto wine cellars – Riverfront of Santa Marinha, Gaia (South part in the Image).*

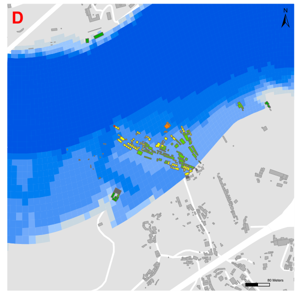

Figure 35c. *Flood risk – Annual average damage in buildings structure. Areinho, Gaia.*

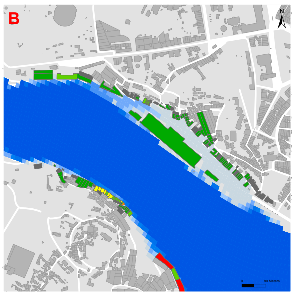

Figure 35d. *Annual average damage in buildings structure. Alfândega do Porto area (North part in the Image).*

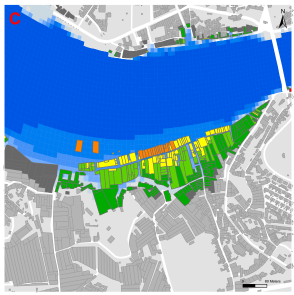

Figura 35e. *Annual average damage in buildings structure. Area of Ribeira, Porto (North part in the Image).*

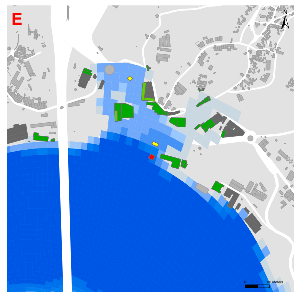

Figure 35f. *Flood risk - Annual average damage in buildings structure. Confluence of rivers Torto and Tinto with Douro.*

risk. It should be noted that the municipality of Vila Nova de Gaia is more exposed than Porto.

For both river banks, annual average damage is more significant in residential buildings, where the contents have an average loss of approximately 100‰ per year for basements and 40‰ for ground floors. Only three of the buildings exposed have housing in the basement. In this sense the representation of this category is quite low, as there is an overvaluation of the risk associated with the category, a result of the specific location of these three buildings (Table 15).

Annual average damage in building's structure (‰)	Return period (years)
0–10	2
10–20	5
20-30	10
30-40	20
40-55	50
assessed buildings	100
other buildings	500

GLOSSARY

"All water has a perfect memory and is forever trying to get back to where it was."

Toni Morrison

Annual Average Permillage
Ratio between the average compensation given between 2000-2011 and the insured amount for each Zip code in 2011.

Building structure
Contains in addition to the structural elements of the buildings, their walls, coatings, supply networks and other elements that are an integral part of the building.

Climate
The "average weather" described in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organisation (WMO).

Climate change
Statistically significant variation in either the mean state of the climate, or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or to external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate model
A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some its known properties.

Climate projection
A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based on simulations by climate models. As such climate projections are based on assumptions concerning future socio–economic and technological developments.

Climate scenario
A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change.

Climate variability
Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events.

Climatological normals
Climate "normals" are reference points used by climatologists to compare current climatological trends to that of the past or what is considered "normal". A Normal is defined as the arithmetic average of a climate element (e.g. temperature) over a 30-year period. A 30 year period is used, as it is long enough to filter out any interannual variation or anomalies, but also short enough to be able to show longer climatic trends. The current climate normal period is calculated from 1 January 1961 to 31 December 1990.» (World Meteorological Organization (WMO).

CO_2 equivalent
Is a measureing of the functionally equivalent amount or concentration of carbon dioxide (CO_2) as the reference. Converting all greenhouse gas (GHG) emissions into CO_2 equivalents they can be compared.

Exposure
Consists of the presence of people, assets or other elements potentially subject to damage where the flood occurs (see e.g. UNISDR, 2004, UNISDR, 2009, SEC, 2010), and it can be quantified by the number or value of the elements found within that area (Merz et al., 2007). Thus, a particular element very fragile to flooding but that is not exposed to this phenomenon, will always have a zero risk (Bruijn et al., 2009).

Extreme weather event
An event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary from place to place (and from time to time), but an extreme event would normally be as rare or rarer than the 10th or 90th percentile.

Fixed assets
Property located permanently within a fraction or building. They may be industrial if found inside a building/fraction whose activity is industrial or non-industrial in case they are located in a building/fraction associated with commerce, service, equipment or offices. Example of fixed assets are industrial machinery, computers and servers, refrigerated cabinets, etc.

Flood Risk
The combination of the probability of a flood event and the potential adverse consequences for human health, environment, heritage and economic activity associated with floods.

General Circulation Model (GCM)
A three–dimensional representation of the Earth's atmosphere using four primary equations describing the flow of energy (first law of thermodynamics) and momentum (Newton's second law of motion), along with the conservation of mass (continuity equation) and water vapour (ideal gas law). Each equation is solved at discrete points on the Earth's surface at fixed time intervals (typically 10–30 minutes), for several layers in the atmosphere defined by a regular grid (of about 200km resolution). Coupled ocean–atmosphere general circulation models (O/AGCMs) also include ocean, land–surface and sea–ice components. See climate model.

IPCC
Intergovernmental Panel for Climate Change.

ppm or parts-per-million
Is a units that pretends to describe small values of mani dimensionless quantities, e.g. mole fraction, mass fraction or volume fraction (ppmv or parts-per-million by Volume).

Residential inventory
All assets that are in a fraction with residential use.

Resilience
The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

Risk
Is generically defined as the probability of harmful consequences or losses (death, injuries, property, means of production, disruptions in economic activities or environmental impacts) that result from the interaction between the natural environment or human induced hazards and vulnerability conditions of the elements (UNISDR, 2004, ISO 31010, 2009). Thus the risk calculation consists of the product of the probability of occurrence of a phenomenon with a determined magnitude.

Risk management
A systematic approach to setting the best course of action under uncertainty, by applying management policies, procedures and practices to the tasks of analysing, evaluating, controlling and communicating about risk issues.

Return period
The context of this study states the average number of years between two successive events in which a determined amount of precipitated water or flow is exceeded.

Scenario
A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a "narrative story–line".

Stocks
Goods or products stored or contained in a fraction.

Susceptibility
In the context of a study the concept is associated with floods and torrents, the concept of susceptibility has several interpretations. For some authors susceptibility comes down to the predisposition of a given area to be affected by these phenomena. This assessment takes into account physical factors of the terrain, and does not include the probability of occurrence of floods (Julião et al., 2009).

The Hydrographic Zero
Corresponds to the value set in 1938, consisting of the lowest low tide recorded.

ISBN: 978-972-98847-5-7

TEAM

COORDINATION

Pedro Garrett, Filipe Duarte Santos
Centre for Climate Change Impacts Adaptation & Modelling (CCIAM)

MONITORING COMISSION

Tomé Pedroso, João Barata, António Teixeira
Companhia de Seguros Tranquilidade, S.A.

Rui Esteves, Carlos Ferreira Borges
Fidelidade - Companhia de Seguros, S.A.

Olga Germano
Consultora

Miguel Guimarães, Paulo Baptista, José Maria Lima
Associação Portuguesa de Seguradores

Pedro Castro Caldas
Ocidental – Companhia Portuguesa de Seguros, S.A.

TECHNICAL EXECUTION

Vulnerability Analysis
Nuno Grosso, Hugo Costa, Luís Dias, Rita Jacinto, Pedro Garrett
Centre for Climate Change Impacts Adaptation & Modelling (CCIAM)

Risk Analysis
Luís Dias, Hugo Costa, Nuno Grosso
Centre for Climate Change Impacts Adaptation & Modelling (CCIAM)

Extremes and Climate Scenario
Pedro Garrett
Centre for Climate Change Impacts Adaptation & Modelling (CCIAM)

Hydrodynamic Modelling
Frank Braunschweig
Action Modulers

COLABORATORS

Carlos Antunes, Rute Vieira
LATTEX, IDL

Eusébio Reis
RISKam

GRAPHIC DESIGN

vivóeusébio
www.vivoeusebio.com

PRINTING

Gráfica Maiadouro
Circulation: 500 copies

TRANSLATION

Susana Filipe

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