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The drivers of the cost of natural disasters: the role of climate change in France

RISKS

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Title: The drivers of the cost of natural disasters: the role of climate change in France

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Executive Summary

In a context of rapidly rising global temperatures (in geological terms), there are recurring questions about the impact of climate change on natural disasters, and about the need to anticipate future developments.

This study provides a brief overview of current economic analysis in relation to natural risks and climate change. It aims to provide a framework for interpreting past events and for understanding critical factors that will arise over the coming decades.

The study is based on the findings of various scientific publications. It constitutes a non-exhaustive summary of recent thought and research in this area, from both economists and technical experts. First of all, this scientific research will be used as a basis to explain the increased cost associated with natural risks in the 21st century, and to discuss the influence of climate change on this cost. Next, the study will seek to determine the potential consequences of climate change on natural hazards in France over the course of the current century. In the final section, the study will examine whether and how these potential future impacts can be quantified in economic terms.

I. Introduction

I.1. Scientific context

Since Arrhenius[1] published his first calculations in the late 19th century, the concept of the "greenhouse effect" has become widely accepted. Initially, the Swedish scientist established a link between the concentration of carbon dioxide in the atmosphere and the temperature at the surface of the planet. According to his theory, a doubling of the average CO2 concentration would result in a global temperature rise of 4°C. This link between concentration and temperature was subsequently established for other gases, known as greenhouse gases, such as methane, water vapour and chlorofluorocarbons (CFCs). The majority of these gases are naturally occurring, although some are artificially produced. These gases are permeable to solar radiation (either arriving directly from the Sun or reflected by the planet) and absorb terrestrial energy radiation (located in the infra-red spectrum). This energy is then released in the form of heat, resulting an overall rise in the temperature on Earth.

According to the most robust current scientific hypotheses, as reflected in the work of the Intergovernmental Panel on Climate Change (IPCC), human activity is causing the temperature of the planet to rise more quickly than normal, due to increased emissions of greenhouse gases[2]. On average, and all other things being equal, the global temperature is likely to rise by 1.8°C to 4°C (and up to 6.4°C under the worst-case scenario) by the end of the 21st century.

In this document, the term "climate change" will be used instead of "global warming", reflecting current debate on whether the changes that may occur are genuinely "global" in nature. Indeed, due to a series of indirect and complex effects, some regions of the world may actually experience a fall in average temperatures.

While human activity is cited as one of the primary causes of climate change, as a result of greenhouse gas emissions, this very same activity may be one of the first victims of this phenomenon. One of the numerous impacts of climate change announced by the IPCC is the potential for rising sea levels, which will vary in intensity in different regions of the globe. It also points to the possibility of more extreme events, caused by an increase in energy levels in the Earth's atmosphere. More generally, the human race needs to prepare for profound changes in its environment, brought about by a "rapid" rise in temperature (in geological terms).

As well as detailing ongoing climate-related scientific research, some articles discuss potential links between recent natural events and the phenomenon of climate change. Indeed, climate change has been a topic of discussion in relation all major natural disasters in recent times (Hurricane Katrina in 2005, Cyclone Nargis in 2008 and Storm Xynthia in 2010, for example). In the majority of cases, these events are measured in terms of the value of the associated (direct or indirect) economic losses. Other indicators may also be used, particularly for large-scale natural disasters (number of deaths, displaced people, etc.). In other words, the perceived intensity of these disasters is measured not in technical terms, but rather in socio-economic terms.

The aim of this document is to provide a brief overview of current economic analysis in relation to natural risks and climate change. It focuses on various natural hazards that fall within the scope of the French natural disaster compensation scheme, including wind damage and forest fires.

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1 "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground", S.A. Arrhenius, in *Philosophical Magazine and Journal of Science*, April 1896.

2 *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Intergovernmental Panel on Climate Change, Geneva, Switzerland, 2007.

It has been produced against a backdrop of recurring questions about the impact of climate change on natural disasters, and about the need to anticipate future developments. It aims to provide a framework for interpreting past events and for understanding critical factors that will arise over the coming decades.

This document is based on the findings of various scientific publications. However, it is not intended to contribute new knowledge about the changing nature of natural hazards. Nor does it contain new data about the consequences of climate change. Instead, it constitutes a non-exhaustive summary of recent thought and research in this area, from both economists and technical experts.

This document has three main aims. First of all, scientific research will be used as a basis to explain the increased cost associated with natural risks over recent decades, and to discuss the influence of climate change on this cost. Next, the study will seek to determine the potential consequences of climate change on natural hazards in France over the course of the current century. In the final section, the study will examine whether and how these potential future impacts can be quantified in economic terms.

I.2. Definitions

The term risk refers to a latent threat to a given target. This risk consists of a physical phenomenon, known as a hazard, generally characterised by its intensity or severity, as well as its likelihood of occurrence or *frequency*. If the event concerns takes place, it could threaten exposed elements, generally human in nature. These exposed elements may be characterised using two criteria: their importance and their vulnerability. The latter term defines the impacts of the event on the exposed elements. The "risk" is therefore the result of a combination of two factors (hazard and exposed element), each of which is characterised using different terms. If the frequency or severity of a hazard is zero, there is no risk. If there are no exposed elements or vulnerability, the risk will be treated as non-existent, even if a natural hazard with high frequency and intensity actually exists. This concept is therefore, by definition, centred on human societies.

Natural hazards – the exclusive subject of this report – cover a vast number of different phenomena. These include floods (rivers, run-off, rising groundwater, rising sea levels, etc.), earth movements (collapses, rockfalls, landslips or clay movements), storms, snowfall, avalanches, hail storms, volcanic eruptions, earthquakes, forest fires, etc. There is a long list of natural hazards that threaten human societies.

The risk can be divided into two main elements: hazard and exposed element. In this document, differentiation will be made between scientists working on these two dimensions, depending on their area of focus. The first group are "economists", whose work focuses on human society. The second group are "engineers", who study the occurrence of natural events from a more technical perspective. The purpose of this (highly formal) distinction is to clarify the scientific field to which a particular concept or discussion belongs.

II. Analysis based on past events

II.1. Knowledge and representation of past events

The vast majority of past event measurement and analysis work is based on the social or economic cost of the losses incurred.

Risk technicians generally measure natural events against a set of criteria such as flow rate (for floods), water level (for tidal flooding), or the number of days above a given temperature (for heatwaves). This list is not, of course, exhaustive. There is normally an accepted set of criteria for assessing a given type of event.

In addition to these measurable (or modellable) parameters, natural events are also assigned a "return period", i.e. the inverse of the threshold exceedance frequency. In other words, if an event described is a "100-year event" this means that, on average, the technical threshold that characterises the event will be reached or exceeded once every 100 years. For example, if a given river has a 100-year flood rate of 50 m^3 per second, this means that this flow rate (or a higher flow rate) will only be observed every 100 years on average. Or, in terms of frequency, there is a 1 in 100 chance that an identical or more significant event (i.e. at an equivalent or higher flow rate) will occur each year.

In order to compare and track changes across all natural disasters that occur from one year to the next, we first need to measure and quantify our definition of "all events". However, natural disasters are so diverse in nature that it is impossible to apply a single technical criterion to quantify all events that occur. Similarly, just as one cannot add together "chalk and cheese", so one cannot add together flood levels and heatwave durations. A common instrument capable of measuring the intensity of all natural events that occur is therefore required. This instrument may be based on the "rarity" of all events that occur each year, but there are several methodological barriers to this approach. This type of measurement does not currently exist, and cannot therefore be used as a point of reference.

Since the intensity of the hazard cannot be used as a common departure point for all natural risks, attention must therefore shift to the exposed element, and therefore to socio-economic indicators. This is a more natural approach to adopt, especially given that the scale of a natural event is generally judged by the number of deaths or the cost of the losses caused. A "1,000-year flood" in an uninhabited area will attract less attention than a single death from a "10-year flood", for example. Furthermore, this is the indicator that public authorities systematically use when making disaster risk prevention and management policy decisions. This information is generally available for any event that has resulted in losses.

II.2. How are the costs of these events structured?

When a natural disaster occurs, the losses are generally divided into multiple categories according to two criteria: direct or indirect, and tangible or intangible.

Types of loss

Direct losses: this category covers damage to property or assets (destruction, damage) caused by the physical impact of the flood (D4E, 2007).

Indirect losses: this category covers consequential losses incurred by business or the costs of replacing damaged property or assets (loss of business for a business following the destruction of its stock or production facilities) (D4E, 2007).

Tangible losses: this category covers damage to property or assets for which a replacement cost can be calculated, i.e. property or assets for which a market exists (e.g. furniture, real estate, etc.).

Intangible losses: this category covers damage to property or assets for which there is no *ad-hoc* market, and for which the cost is difficult to quantify with the information available; examples include stress, changes to the landscape, pollution, etc.

Figure 1: Examples of losses resulting from natural disasters

Type of loss	Tangible	Intangible
Direct	Destruction of property or assets	Loss of human life, destruction of a landscape
Indirect	Loss of business, interruption to an utility, rehousing of residents	Increased vulnerability among the affected population after the disaster

Source: CGDD

The headline loss cost figures given after natural disaster normally relate to tangible losses, while intangible losses are generally expressed in terms of non-financial indicators (number of deaths, displaced persons, etc.).

Generally speaking, insurance schemes (such as the natural disaster guarantee scheme in France) and compensation funds[3] only cover the costs of tangible losses (policies covering damage to property and assets, which may also cover loss of business). Other than a few rare exceptions, they do not cover intangible losses.

However, while we can postulate that all losses for which compensation is paid are tangible in nature, the reverse is not true: compensation is not paid for all tangible losses. There are several reasons for this non-reciprocal position.

Firstly, insurance policies may include (non-refundable) excesses, and many of these policies do not cover loss of business. The compensation payouts do not therefore cover all direct losses, and do not always cover indirect losses.

Furthermore, not all destroyed property and assets are covered by an insurance policy. In some limited cases, this situation may involve private individuals and businesses. However, in the majority of cases, it affects property and assets owned by the State and local authorities.

In such cases, the direct losses can only be assessed using the owners' internal records, based on the costs of the reconstruction work.

[3] In this document, we will focus exclusively on insurance, since this accounts for the vast majority of natural risk compensation mechanisms.

II.3. Difficulties counting the number of disasters

Is the number of natural disasters rising or falling? Before attempting to answer this question, we must first define what exactly we mean by the term "natural disasters".

On the surface this may appear to be a simple question, but the answer is not quite so obvious or clear-cut. Indeed, the definition of "natural disaster" depends primarily on who is using the term.

In general language, the term "natural disaster" may be considered akin to the concept of "major risks", i.e. a disaster that overwhelms human society: "A major risk may be defined as a threat to humanity and its immediate environment and to its infrastructure. The severity of this threat is such that the society affected will be completely overwhelmed by the immensity of the disaster"[4].

In France, from an administrative perspective, a natural disaster is a condition defined by interministerial decree. Where such an event occurs, the victims are entitled to compensation for their losses under the natural disaster guarantee scheme. Since this "CatNat" scheme does not cover storms, a storm of catastrophic intensity may be considered a "natural disaster" in general language, but not in an administrative sense.

As such, the list of "natural disasters" recognised by the interministerial decree does not cover all "natural disasters" in the general meaning of the term.

Major international insurance firms, such as Munich Re and Swiss Re, regularly publish end-of-year reports on the "natural disasters" that have occurred worldwide during that year. These events are considered "natural disasters" because they meet a specific set of socio-economic criteria.

Swiss Re, for example, treats an event as a "natural disaster" if it meets one of the following conditions[5]:

- total economic losses associated with the event exceed USD 86.5 million (2010), or insured losses exceed USD 43.3 million
- the number of dead or missing stands at 20 or more
- at least 50 people are injured
- the number of people made homeless by the disaster exceeds 2,000.

In 2010, Swiss Re reported a total of 304 natural disasters that met these criteria.

It is report, meanwhile, Munich Re listed 960 "natural catastrophes" in the same year (2010)[6]. Although the German insurance firm explains that it classifies events into six categories depending on their economic and human impacts, its publications do not state the thresholds used to determine inclusion in the report. In 2010, for example, a total of 55 events were classified as "severe catastrophes", each with total losses exceeding USD 250 million (2010) and/or resulting in more than 100 fatalities.

There are therefore two clear observations that can be made. Firstly, the number of natural disasters occurring within a given scope (space and time) depends on how the term "natural disaster" is defined. Secondly, these definitions are generally "*a priori* norms" that may change over time.

If Swiss Re or Munich Re were to make significant changes to their thresholds, the number of annual events that each firm considers "natural disasters" would also change substantially. Furthermore, storms were not excluded from the "CatNat" scheme until 1990. Changes such as these pose major problems when attempting to analyse historical natural disaster trends and data.

Swiss Re adjusts its economic thresholds to take account of GDP trends. Munich Re, meanwhile, adjusts the value of the losses incurred rather than the thresholds, leading to the same result. The aim of these two adjustment methods is to make datasets more comparable from one year to the next.

It is therefore possible to compare the number of natural disasters occurring over time, but with the caveat that these figures use different criteria and cover different scopes.

It is also important to note that, as well as economic trends, other social and economic factors have an impact on the consequences of natural disasters. It is not therefore possible to draw a significant statistical correlation between an increase in the number of natural disasters above a certain loss threshold, and an increase in frequency of these natural events.

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4 Attributed to Haroun Tazieff. See http://www.risquesmajeurs.fr/definition-generale-du-risque-majeur

5 "Natural catastrophes and man-made disasters in 2010: a year of devastating and costly events", Swiss Re, *Sigma no. 1/2011*, Zurich, 2011.

6 "Natural Catastrophes 2010 – Analyses, assessments, positions", Munich Re, *Topics Geo*, Munich, 2011.

II.4. Historical socio-economic data and the reasons for change

Historical datasets covering disaster-related losses are often used as purported evidence of the intensification of natural disasters. It is extremely tempting to attribute responsibility for the rising costs of natural events to climate change.

Here we are not seeking to address the medium-term or long-term effects of climate change[7], but rather to explain the many possible reasons behind the rising cost of insurance payouts, or indeed the increasing number of natural disasters recorded by global insurance firms. If we want to know whether natural disasters are increasing in frequency and/or intensity, we cannot seek the answer to this question by studying the total annual cost of natural disasters. There are many other factors at play.

Any robust analysis must be based on a clear separation between events and losses, since the latter are caused by a combination of the former and human exposed elements. If we wish to conduct a statistical analysis of natural events using insured loss data, we first need to be able to isolate trends in these data related to human exposed elements.

The factors detailed below are given on an "all else being equal" basis. Potential synergy effects are covered later in this document. Throughout this section, natural hazards are considered on the basis of constant intensity.

A) The growth of exposed elements

The first factor behind the increasingly severe impact of natural events concerns the population exposed to such events. According to the United Nations, the global population rose from 2.5 billion people in 1950, to 4.1 billion in 1975, and to 6.7 billion in 2007[8].

These figures show that the world's population doubled over the period concerned. This means that the potential consequences of natural disasters may have increased by the same amount. The corresponding increase in the number of business (assuming constant population distribution) will also lead to an increase in potential losses.

This phenomenon, involving a structural increase in losses as a result of a rise in exposed elements (housing, businesses, public facilities, etc.), echoes Zajdenweber's theory[9] on the relationship between the losses suffered by a conurbation and its size. According to this theory, losses are said to increase disproportionately in relation to city size, due to the concentration of exposed elements. This connection between urban growth and rising losses could be one of the reasons behind the rapid rise in climate-related disasters costing more than USD 1 billion, as observed in the United States since 1988-1991.

Another possible human-related factor behind the rising cost of disaster-related insurance payouts, entirely separate from population growth, is relative wealth accumulation.

Between 1980 and 2010, for example, global Gross Domestic Product (GDP) rose by a factor of 2.6 (on a constant-currency basis)[10]. Over this period alone, annual wealth production (and therefore accumulation) therefore increased almost three-fold.

Economic growth therefore has a double effect: it increases the number of each type of exposed element (buildings, public facilities, businesses, etc.), and it increases the economic value of each element. The result of these two effects is an increase in the potential losses attributable to a natural disaster.

B) The penetration of insurance

Tangible economic losses can be divided into two mutually exclusive categories: insured losses and uninsured losses.

In mainland France, for example, more than 99% of households are covered by a buildings and contents insurance policy (which automatically includes a natural disaster guarantee) on their main home. The coverage rate falls to 52% in France's overseas departments[11].

When calculated on a constant basis, total economic losses increase with the coverage rate, which varies over time, with no *a priori* correlation with the level of risk.

Historical loss payout datasets therefore introduce a bias when used as an indicator of economic losses, due to the impact of the insurance coverage rate. However, provided that sufficient care is taken, it is possible to correct this bias because the coverage rate is generally known.

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7 This topic is addressed elsewhere, in particular in the French interministerial report entitled *Evaluation du coût des impacts du changement climatique et de l'adaptation en France*, Observatoire National des Effets du Réchauffement Climatique, Paris, 2009.

8 *World Population Prospects – The 2006 Revision*, United Nations, Department of Economic and Social Affairs, New York, 2007.

9 *Economie des extrêmes – Krachs, catastrophes et inégalités*, D. Zajdenweber, 2009.

10 *World Economic Outlook Database - April 2010 edition*, International Monetary Fund, Washington, 2010.

11 ***La faible couverture des ménages des DOM contre les catastrophes naturelles. Analyse de la souscription à l'assurance habitation*, L. Calvet and C. Grislain-Letrémy,** General Commission for Sustainable Development, Paris, 2010.

C) Changing vulnerability

Technological or cultural changes within a country can result in an intrinsic increase in the vulnerability of property and persons, entirely independently of the factors outlined above.

Vulnerability

Vulnerability refers to the sensitivity of an exposed element to a given hazard. Vulnerability may vary:

- between exposed elements for the same hazard; for example, crops are much more vulnerable to hailstorms than buildings
- between hazards for the same exposed elements; buildings are not especially sensitive to hailstorms, but are extremely sensitive to flooding.

The gradual replacement of non-vulnerable property and assets with vulnerable property and assets (that fulfil the same functions) can lead to an increase in economic losses greater than the increase in insured value.

The total losses incurred for each insurance policy are calculated as the sum of the insured values, weighted by their vulnerability to a given hazard level. The increase in intrinsic vulnerability in certain property and assets, even at constant value, therefore results in an increase in the total amount of losses incurred.

This point can be illustrated by an example. Product A (considered "not vulnerable to flooding") is priced at 10, and product B (considered "vulnerable to flooding") is priced at 100. If we replace product A with product B, the owner has only increased the total insured value by 90. In the event of a flood, however, the difference between the losses will be 100, not 90. Prime examples of this phenomenon are the replacement of an open fireplace with an oil-fired boiler, manual shutters with electric shutters, or a brush with a vacuum cleaner.

All other things being equal, natural risk prevention policies can help to reduce vulnerability, and therefore losses in the event of a natural disaster. These policies cover geographical areas of varying sizes, from an individual town or group of towns (such as Natural Risk Prevention Plans in France), to an entire country (such as building standards). Where these policies focus on urban planning matters, they can also address questions surrounding the exposure of populations to natural risks.

D) Location choices or restrictions

A more visible factor comes in the form of investment and land use choices which, at constant population and wealth, can lead to increased risk to buildings. This phenomenon can be seen, for example, with a change in farming practices or economic activities. It also applies when individuals decide to move to high-risk areas because they are attracted by the amenities on offer.

This point is best illustrated with an example. Let us consider a given region in which there is intense pressure on land, resulting in a process of urbanisation. The region's urban centres have traditionally been built away from areas subject to frequent flooding, such as at higher altitude. The flood risk in these urban centres is therefore practically zero. The urbanisation of new areas results in increased exposure to flood risk for the population, even if risk mitigation measures are taken. In the event of a flood, each additional house built closer to a waterway results in a higher marginal cost to the local authority than the previous house. Unless specific precautions are taken, the potential losses will therefore rise more quickly, in proportional terms, than the population.

This phenomenon, by which the potential losses caused by a natural event are aggravated by increased population exposure, has been known for at least two centuries. Indeed, this very phenomenon was the origin of a dispute between the philosophers Voltaire and Rousseau. Following the devastating Lisbon earthquake of 1st November 1755, which had tens of thousands of victims, Voltaire wrote "evil stalks the land"[12], to which Rousseau replied that "it was hardly nature who assembled there twenty-thousand houses of six or seven stories; if the residents of this large city had been more evenly dispersed and less densely housed, the losses would have been fewer or perhaps none at all"[13].

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12 *Poem on the Lisbon Disaster*, Voltaire, 1756.

13 *Letter to Voltaire on Providence*, Rousseau, 1756.

E) Changing hazards caused by changes to the environment

Human behaviour can also cause changes to the very mechanisms by which natural events are produced, particularly where such behaviour creates conditions under which more intense events may occur. This is true of climate change. On a more local level, it also applies to certain public policies.

In 1882, for example, France launched a Mountain Terrain Restoration policy in order to combat erosion in mountainous areas, which was causing more frequent landslides, as well as floods in both lowland and upland areas[14]. This rapid erosion was due to the destruction of natural plant cover to clear the way for additional cereal crops and sheep and cattle pastures, in order to produce extra food to meet the needs of the growing French population[15]. Land use decisions therefore have an impact on both exposed elements and hazards.

This phenomenon is not restricted to France, of course. In Vietnam, for example, deforestation in the Mekong Delta has led to an observable increase in the frequency of floods[16].

Another example of human-driven changes to hazard production mechanisms is the phenomenon of "urban run-off", which is defined as "the submersion of normally water-free areas and the channelling of water via non-standard routes following the blockage of the rainwater drainage system after intense precipitation"[17]. As impermeable surfaces cover more and more land, and as low points in urban areas expand, the volume of rainwater that needs to be drained away during heavy rainfall increases. This can lead to the saturation of urban drainage systems, resulting in run-off water in the streets.

This phenomenon is therefore aggravated by the expansion of impermeable surface coverings as a result of urbanisation in France, as well as the reassignment of land that previously played a positive role in regulating these events[18].

III. Aggravation of hazards due to climate change

In its latest report, the IPCC pointed to an increased likelihood of droughts, heatwaves and floods[19]. In this section, we will seek to identify those hazards that are likely to increase in frequency and/or intensity.

All data and results contained in this section of the document are brief summaries of other, original works. For more detailed information about these publications, readers should refer to the full documents as cited in the corresponding footnotes.

It is important to note that French Overseas departments and Territories are rarely covered in the existing literature. Despite this absence, it should be remembered that these territories are also likely to be affected by climate change. However, little information is available about the scale of such impacts at the present time.

III.1. Historical, or "top-down" studies

Some researchers have addressed the issue of hazard aggravation through climate change by adopting an historical approach. Starting from the premise that the influence of climate change increases over time, these researchers make the following assumption: that an unexplained aggravation of natural disasters over time can be attributed to climate change.

The first, and most simple, approach would therefore involve analysing the data of global insurance firms to see if a long-term trend can be identified.

14 *De la politique française de restauration des terrains en montagne à la prévention des risques naturels*, G. Brugnot, Y. Cassayre, XII World Forestry Congress, Québec City, Canada, 2003.

15 *Histoire de la restauration des terrains en montagne au XIXème siècle*, C. Lilin, Cah. ORSTOM, sér. Pédol., vol. XXII, no. 2, 139-145, 1986.

16 *Water Management in the Mekong Delta: Changes, Conflicts and Opportunities*, White I., International Hydrological Programme, Paris, 2002, cited in: *In search of shelter: mapping the effects of climate change on human migration and displacement*, CARE International, 2008.

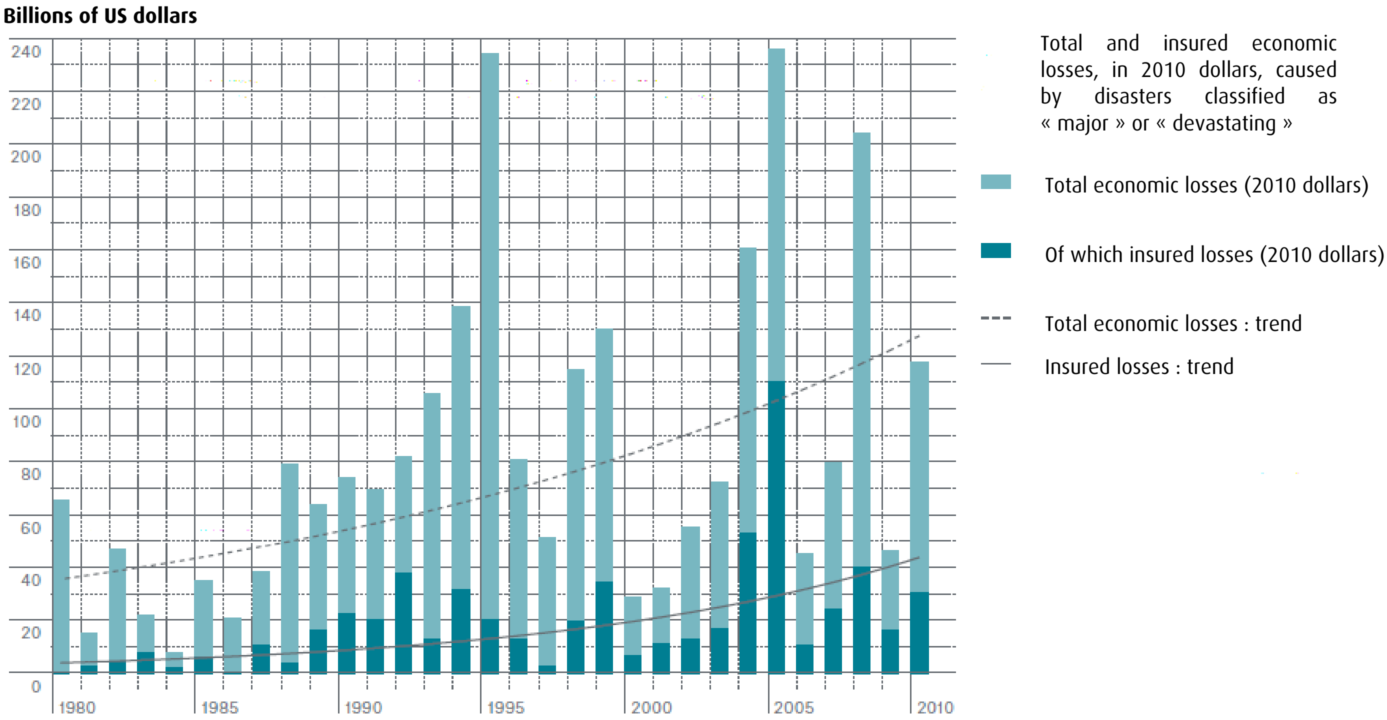
17 *Le ruissellement urbain et les inondations soudaines – Connaissance, prévention, prévision et alerte*, General Council for the Environment and Sustainable Development, MEEDDAT, February 2009, p.16.

18 Ibid, p.18.

19 *Climate Change 2007: synthesis report – Summary for Policymakers*, Intergovernmental Panel on Climate Change, Valencia, 2007.

Figure 1: Total losses and insured losses worldwide

1980 to 2010



Source: Munich Re (translated by the author)

These data are adjusted for inflation, but not for other socio-economic trends such as population growth or wealth accumulation (i.e. changes in GDP)[20]. The rise in the total cost of disasters may therefore be attributed to causes other than the aggravation of natural phenomena due to climate change. The list of "disasters" is, in fact, a list of "disasters that exceed a given loss threshold"[21], and the rising number of recorded disasters is further biased by socio-economic trends.

Several studies have been conducted using econometrics methods to attempt to incorporate factors such as population growth and GDP. In 1998, a study on the cost of hurricanes in the United States[22] demonstrated the major impact of coastal population growth on the value of the losses incurred. By adjusting the loss figures for a given year to take account of inflation, GDP per capita and population, the losses caused by hurricanes in the United States in the 1990s are comparable with the figures from the 1940s to 1960s, following a fall in the 1960s to 1970s. Seven years before Hurricane Katrina (which cost more than USD 60 billion), the authors concluded that the United States was experiencing a generally favourable period, and that "it is only a matter of time before the nation experiences a $50 billion or greater storm".

In 2008, Miller, Muir-Wood and Boissonade[23] conducted a global study. The data they used indicated annual growth of 8% in the cost of losses incurred worldwide as a result of natural events. By compiling these data by country or geographical region (comprising several countries), the authors produced a set of normalised data, adjusted to take account of inflation, GDP per capita and population in each country or region, and set at 2005 levels. However, this study used a broader scale (country or region) than the scale used by Pielke (1995), therefore failing to consider disparities within individual countries.

Over the period 1950-2005, the data did not indicate statistically significant underlying trends, other than at smaller (sub-global) scales, such as in Canada, Europe and South Korea. However, the overall trends varied from region to region. Between 1970 and 2005, losses due to natural disasters increased in certain countries and at global level (by 2% per year, with the threshold for statistical significance set at 1%). However, this trend was no longer statistically significant if the data for US

[20] It is report entitled *Natural Catastrophes 2010 – Analyses, assessments, positions*, Munich Re clearly states that the "influence of population development and real increase in value" were not taken into account when adjusting the loss figures.

[21] Munich Re adjusts its loss data, but does not directly adjust the loss thresholds.

[22] "Normalized hurricane damages in the United States: 1925-1995", R. A. Pielke and C. W. Landsea, in *Weather and Forecasting*, no. 13, 1998.

[23] "An exploration of trends in normalized weather-related catastrophe losses", S. Miller, R. Muir-Wood and A. Boissonade, *Climate Extremes and Society*, Cambridge University Press, Cambridge, 2008.

hurricanes in 2004-2005 and the floods in China were removed from the dataset. In other words the losses suffered in the United States, and particular those caused by hurricanes, tended to produce an "upward bias" in the global data trend.

In the Stern Review[24], published in 2007, the author cited one of the results[25] of Miller, Muir-Wood and Boissonade's study. He took the 2% annual growth figure calculated for the period 1970-2005 and extrapolated[26] this trend into the future, stating that the cost of natural disasters "could reach 0.5 - 1% of world GDP by the middle of the century".

Following publication of the Stern Review, Pielke responded with an article published in the same year[27], in which he criticised Stern for ignoring the conclusions of Miller, Muir-Wood and Boissonade, who had clearly stated that their results were influenced by hurricanes in the United States. He also pointed to the unanimous conclusions of participants at the 2006 workshop, which included a statement to the effect that it was impossible, in 2006, to conclude with scientific certainty that climate change was responsible for the rising costs of natural disasters, even though these costs had increased substantially since the 1980s. In conclusion, Pielke criticised Stern for making future predictions on the basis of a result that, by the admission of its own authors, was somewhat flawed, and for extrapolating and accelerating this trend without evidence-based justification.

In 2009, Barredo, a researcher working at the European Commission's Joint Research Centre, published an analysis of normalised historical loss figures in Europe between 1970 and 2006[28]. In the article, the author focused specifically on flood losses in 31 European countries: the 27 European Union Member States plus Croatia, Norway, Switzerland and the Former Yugoslav Republic of Macedonia. Once again, the datasets were normalised on the basis of inflation, population and GDP per capital, and set at 2006 levels. The author also adjusted the GDP per capita figure to take account of Purchasing Power Parity, to correct price differences between European countries. In his conclusions, Barredo found no evidence of an upward trend in losses once the data had been normalised, although such a trend was observable before normalisation.

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24 *The Economics of Climate Change: The Stern Review*, N. Stern, Cambridge University Press, Cambridge, 2007.

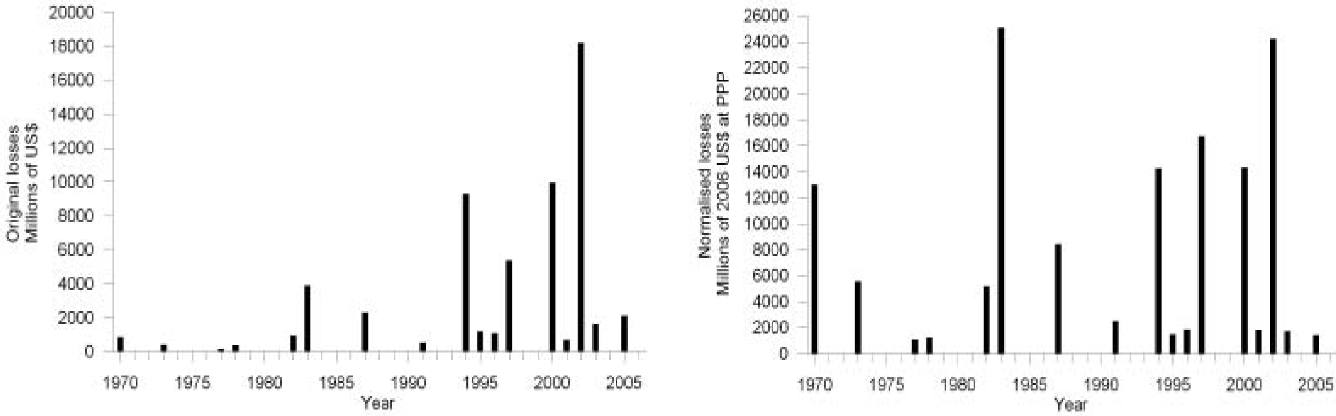
25 Although Miller, Muir-Wood and Boissonade's article was not published until 2008, they presented this finding at a workshop organised by Pielke in Germany in 2006, which explains why the figure was used by Stern in 2007.

26 In fact, he accelerated this trend, adding one percentage point to the increase every 10 years (3% per year in 2010, 4% in 2025, etc.), without justifying the reasons for this methodology.

27 *Mistreatment of the economic impacts of extreme events in the Stern Review Report on the Economics of Climate Change*, R. A. Pielke Jr., *Global Environmental Change,* no. 17, 302–310, 2007.

28 *Normalised flood losses in Europe: 1970–2006*, J.I. Barredo, in *Natural Hazards and Earth System Sciences*, no. 9, 2009.

Figure 2: Flood losses, before and after normalisation, in millions of US dollars



Source: Barredo, 2009

In conclusion, the majority of the normalised historical dataset studies conducted in recent years have revealed either no signal of a link with climate change (no historical trend), or a significant trend, but one that is biased by just a handful of major disasters. It is not therefore possible, at the present time, to confirm that climate change has played a major role in the occurrence and impacts of natural disasters in recent decades.

This conclusion is further supported by the uncertainties inherent in historical datasets, since the constant improvement of observation and communication methods and equipment means that the most recent events are the best documented. It is entirely possible, therefore, that some older events are entirely absent from the available datasets, especially in countries that had limited insurance coverage at the time.

The trends observed in non-normalised datasets would appear, in the main, to be caused by socio-cultural changes within human society over recent decades, and in particular by population growth and rising wealth.

It can therefore be argued that any attempt to assess the impact of climate change on the cost of natural disasters by conducting macro-economic analyses of historical datasets is methodologically flawed. In this context, however, forward-looking micro-economic analyses of the potential consequences of future climate change yield more interesting results.

III.2. Physical phenomenon modelling, or "bottom-up" studies

While top-down methods use macro-level observed historical datasets, bottom-up methods begin with the production of the losses, modelling the economic consequences of the physical phenomenon and then seeking to develop the physical phenomenon to assess the potential impact of climate change.

Unlike the previous models, these studies require multidisciplinary teams involving specialists from various scientific disciplines – natural, human and social sciences alike. The studies generally focus on a single hazard, unlike those studies based on historical datasets.

The following sections summarise the results of several studies[29]. For further information, readers are invited to consult the original articles concerned. Exclusively geological hazards (volcanic and seismic activity) are not covered, even though these are concerned by the changes listed in chapter II.

A) Clay movement

Clay shrink-swell poses a major risk of damage to buildings and structures, although it does not normally pose a threat to human life. This phenomenon is caused by a particular property of clay, namely its ability to store large volumes of water (up to 15 times its dry volume), and for its volume to vary depending on the level of water saturation. As a result, the volume of a block of clay may change substantially between two extended yet unequal wet spells.

29 This work is not intended to be exhaustive.

These ground movements, although slow, can cause extensive damage to buildings because of the sheer forces involved and the undermining phenomenon that this movement produces. This is because the building inhibits the clay from drying out, limiting retraction of the ground in comparison with the surrounding area. This causes the ground to settle in an uneven manner (depending on the coverage), potentially destabilising the building and causing distortions to the structure, which can lead to cracks. Between 1995 and 2003, clay shrink-swell cost a total of €3,533 million (2006 value) in compensation and excesses under the CatNat scheme in mainland France[30].

However, relatively simple measures can be taken to limit damage to buildings constructed in clay areas, including digging foundations that extend below the clay layer, installing substantial wall ties, and avoiding planting large trees and plants nearby (which can aggravate drying-out of the clay during periods of water stress), etc. In most cases, these measures are compulsory under construction codes of practice.

In 2009, a working group conducting a forward-looking study on clay shrink-swell and climate change published a report[31] as part of an interministerial assessment of the impacts of climate change in France. By analysing two distinct summer "types" for any given year (normal or exceptional, such as the summer of 2003) and gradually increasing the probability of a 2003-style heatwave (using an ARPEGE model[32]), average annual costs attributable to clay shrink-swell rose between three- and six-fold (at constant building quantity level)[33]. This same study also details the consequences of an annual increase of 0.925% in total building numbers across France over 20 years, in addition to the effects of climate change. This would lead to an increase in total losses of between 17% and 27% over 20 years. As shown in the previous sections of this report, urbanisation therefore plays a major role in the rising costs of losses associated with natural risks.

A second study (by a team independent from the first) appeared in 2009, covering the whole of France and focusing on a model of past damage caused by clay shrink-swell[34]. The model used in this study seeks to link the meteorological situation with losses at national level, thereby providing an accurate model of losses observed over the period 1989-2002. The study revealed a link between temperature and observed losses, due to the variation in ground moisture levels. It also indicated a potential[35] doubling of average annual losses between two period: 1961-1990, and 1989-2002.

In conclusion, clay shrink-swell is accountable for a significant proportion of compensation payouts for natural risks each year in France. It is also a hazard that needs to be monitored in relation to climate change. Although it is not possible to produce a robust model at present, the causal link between these losses and meteorological conditions suggests that the number of loss events of this type is likely to increase over the coming decades.

B) Coastal risks

Coastal risks is a generic term that covers all hazards that may affect the coast. In general terms, there are two specific risks in coastal areas: coastal flooding and coastal erosion, which refers to coastal erosion caused by the mechanical action of the sea. This risk now receives extensive media coverage and has become symbolic of the threat of global warming, due to the potential impact on sea levels. This, in turn, will eventually lead to the complete submersion of some coastal regions (sea levels are expected to rise by around one metre[36]).

All other things being equal, the rise in sea level caused by global warming (expansion of water, melting of glaciers) is likely to permanently submerge areas of land previously above sea level and aggravate temporary submersions caused by storm surges. A permanent sea level rise of one metre would raise the maximum altitude of storm surges, and therefore temporary submersions, by one metre. In response, the Ministry for Sustainable Development asked its departments to raise the sea level by one metre in current ongoing studies, prior to the completion of the Coastal Risk Prevention Plans[37].

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30 "Le régime d'assurance des catastrophes naturelles en France métropolitaine entre 1995 et 2006", C. Grislain-Letrémy and C. Peinturier, *Etudes et Documents n°22*, CGDD, Paris, 2010.

31 *Estimation des coûts du changement climatique liés à l'aléa retrait-gonflement – Rapport final du Groupe de Travail Risques Naturels, Assurances et Changement Climatique*, E. Plat, M. Vincent, N. Lenôtre, C. Peinturier, B. Poupat, P. Dorelon, P. Chassagneux, J.-B. Kazmierczack, J.-L. Salagnac, S. Gerin, R. Nussbaum and J. Chemitte, BRGM/RP-56771-FR, Paris, 2009.

32 ARPEGE is a forecasting model used by Météo-France.

33 Almost all of the losses concern detached homes.

34 "Simulating past droughts and associated building damages in France", T. Corti, V. Muccione, P. Köllner-Heck, D. Bresch, and S. I. Seneviratne, *Hydrology and Earth System Sciences Discussions*, 2009.

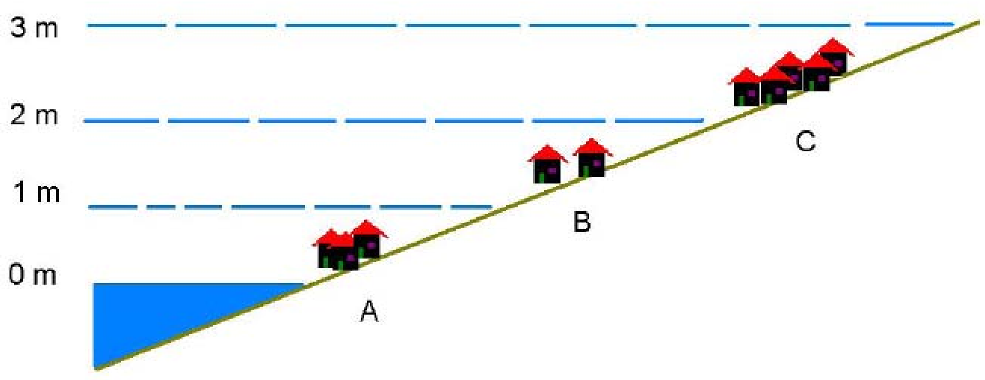
35 There are no quantitative data on clay shrink-swell losses in France prior to 1989. This comparison is therefore based on simulated results, under the assumption that the model used is correctly calibrated.

36 "L'adaptation au changement climatique en France", M. Galliot, Observatoire National des Effets du Réchauffement Climatique, *Synthèse n°6*, Paris, 2011.

37 *Circulaire du 7 avril 2010 relative aux mesures à prendre suite à la tempête Xynthia du 28 février 2010*, Ministry for Ecology, Energy, Sustainable Development and the Sea, Paris, 2010.

The 2009 interministerial working group also looked at this topic and its impact on France[38]. In particular, it conducted a case study of the Languedoc-Roussillon region's coastline, based on one-metre rise in sea level and with all other factors (storms, waves and storm surges) remaining unchanged. This study used statistical methods, with the coastline divided into lines of the same altitude (0-1 metre, 1-2 metres, etc.). By 2100, the study found that the "0-1 metres" section would be permanently submerged, the "1-2 metres" section would be subject to flooding at the same probability as the "0-1 metres" section at present, the "2-3 metres" section would have the same distribution as the current "1-2 metre" section, etc. The figure below illustrates the assumptions made.

Figure 3: Representation of hazard distribution at the coastline



source: Le Cozannet & al., 2009

Note to the reader: According to the study, the temporary submersion hazard currently affects zone A (10-year occurrence) and zone B (100-year occurrence). With climate change, these hazards are expected to "shift" by one metre. As such, zone A would be permanently submerged, and temporary submersions would subsequently affect zone B every 10 years and zone C every 100 years.

The main shortcoming of this method is the fact that it does not consider the mechanisms of submersions, and in particular the role of obstacles (natural or artificial) in the progress of water. This would require additional water flow modelling. However, the scale of the work involved to produce such a model for the entire French coastline means that this is not currently possible.

Based on the assumptions made in this study, the report concludes that, by 2100, a total of around 140,000 homes and 10,000 businesses are under threat of complete destruction, affecting 80,000 people[39] and 26,000 employees respectively. Furthermore, since the most urbanised area of the coastline is closest to the sea (and therefore generally at the lowest altitude), the number of properties exposed to temporary submersions could actually fall. However, if we assume that those residents who lose their homes (due to permanent submersion) resettle close to the coast, then this would nullify this secondary finding. Instead, the number of properties at risk would continue to rise between 2010 and 2100.

The situation is therefore one of a stark contrast. On the one hand, erosion and permanent submersion pose significant financial risks for the local authority. On the other hand, however, these hazards would appear to pose only minimal risk to human life. The expected aggravation of temporary submersions, however, poses a much greater risk to human life, as demonstrated so tragically by Storm Xynthia in February 2010.

However, these two hazards (temporary and permanent submersion) are not entirely separate matters when it comes to modelling their mechanisms. In practice, permanent submersions, or the loss of land due to erosion, generally occur during storms, provided that the right conditions are present.

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38 *Impacts du Changement Climatique, Adaptation et coûts associés en France pour les Risques Côtiers - Rapport du Groupe de Travail Risques Naturels, Assurances et Adaptation au Changement Climatique*, G. Le Cozannet, N. Lenôtre, P. Nacass, S. Colas, C. Perherin, C. Vanroye, C. Peinturier, C. Hajji, B. Poupat, S. de Smedt, C. Azzam, J. Chemitte, F. Pons, BRGM RP 57141, Paris, 2009.

39 The number of homes is significantly higher than the number of occupants due to the presence of a high number of second homes on the coast.

In December 2009, a few months before publication of ONERC's findings, the Centre for Maritime and River Technical Studies (CETMEF) published a study on the vulnerability of mainland France to coastal risks[40]. This study focused on current 100-year sea level events and the altitude that these events would reach with a permanent sea level rise of one metre. Regardless of the current situation, the working group's conclusions highlighted the vulnerability of the Languedoc-Roussillon and Aquitaine regions to climate change.

This same study also found that the total surface area of France under threat of submersion by a 100-year event at current sea levels is around 590,000 hectares. With a sea level rise of one metre, this would increase to 735,000 hectares. This means that around 250,000 additional hectares of France's national territory would be subject to aggravated threat from this risk (either permanent submersion or an increase in the frequency of temporary submersions).

C) Floods

In all probability, floods are the number one hazard in France in terms of annual economic losses. Between 1995 and 2006, losses under the "CatNat" scheme (compensation and excesses) stood at more than €4,683 million (2006 value)[41]. Furthermore, unlike clay shrink-swell, this hazard also poses a much greater threat to human life. As such, changes to the flood regime in France are an important aspect of the national risk prevention policy.

In order to ascertain whether losses will change in the future, there is one key question that needs to be asked, assuming that all other things are equal: will maximum river flow rate/height levels be exceeded more frequently in future? At present, it is difficult to determine a long-term trend for such events with any degree of confidence, despite the existence of several studies that attempt to address this question.

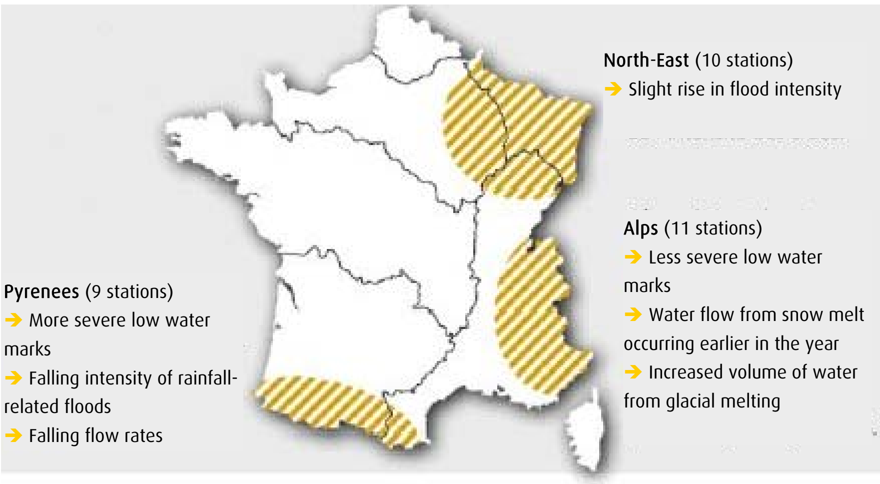
The methods used to tackle this issue can generally be divided into two categories: those based on an analysis of past trends, and those that seek to model potential future effects.

C.1.) Approach 1: analysis of historical trends

A thesis published in 2006[42] addressed the hypothesis that river flow rates had remained stable in France over recent decades. The aim of this study was to collate long-term historical data on river flow rates, then to observe any changes in these collated datasets. Some of the changes observed were associated with other factors unrelated to climate change. The remaining changes were judges statistically insignificant.

In the end, this research failed to demonstrate any trends at national level. However, at local level, three geographical areas appear to have suffered from the impacts of climate change over recent decades: north-eastern France, the Alps and the Pyrenees. These conclusions are summarised in the figure below.

Figure 4: Results of trend detection tests on long-term historical hydrometric datasets for mainland France



Source: Renard, 2006

40 *Vulnérabilité du territoire National aux risques littoraux. France métropolitaine*, CETMEF, CETE Ouest and CETE Méditerranée, Compiègne, 2009.

41 C. Grislain-Letrémy and C. Peinturier, 2010.

42 *Détection et Prise en Compte d'Eventuels Impacts du Changement Climatique sur les Extrêmes Hydrologiques en France*, B. Renard, Grenoble, 2006.

C.2) Approach 2: modelling of future flow rates

In order to make the results less uncertain and more relevant, modelling studies generally involve the cross-referencing of a vast number of climate change scenarios with different hydrological models. This produces a large quantity of results, thereby overcoming the problems associated with specific climate "forcing" phenomena under certain scenarios, or certain hydrological models, instead focusing on general trends.

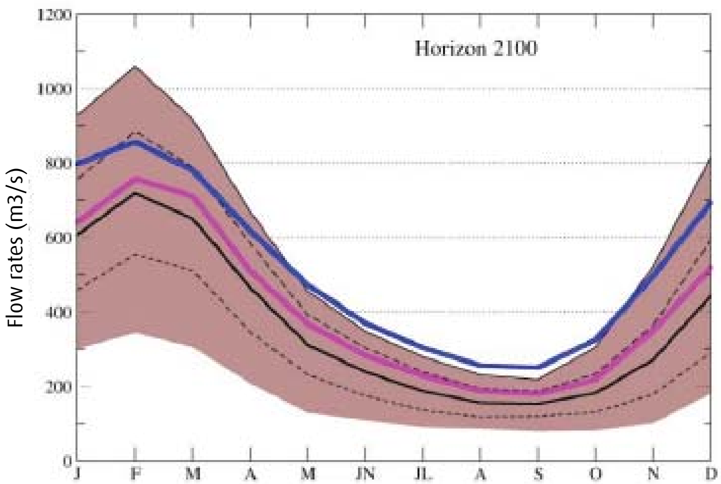
Because each of these climate change impact models requires a series of individual models ranging from climate to hydrological level, this type of work is normally conducted separately for each drainage basin, rather than for France as a whole. The studies presented in this section concern the Rhône, Seine, Loire and Meuse basins.

Work of this type began for the Rhône drainage basin back in 2000, with a study by a consortium of a dozen research teams, as part of the Climate Change Impacts and Management (GICC) project managed by the Ministry for Sustainable Development.

The results[43] of this study, which are based on five hydrological models and six atmospheric scenarios dating from 1999, were somewhat contrasting in nature. They appeared to show, for the Rhône drainage basin (which includes the Saône and the Ardèche), a reduction in average water levels and low water marks. However, they also pointed to an overall increase in high water marks, but with different results for different atmospheric scenarios (one showing an increase, another indicating a fall, but less marked in nature). What these findings showed was that the results were more sensitive to atmospheric models than to hydrological models.

Two similar, more recent studies were also conducted on the Seine drainage basin[44]. The results, based on a combination of 12 climate models and five hydrological models, showed a fall in average annual flow rates, and in groundwater levels (the second result being caused by the first).

Figure 5: Simulated flow rates of the Seine, at Poses



Source: Ducharne, 2011

Note to the reader: Blue: simulated average flow rate at present. Pink: simulated average flow rate in around 2050, and black: simulated average flow rate in 2100. Brown: overall distribution of results obtained in 2100.

The analysis of river floods gives much less clear-cut results. For 10-year floods, the maximum daily flow rate achieved or exceeded every 10 years on average is used as an indicator. Changes in this indicator are highly variable (+10% to -10%) by the end of the century (2081-2100), compared with the current period (1980-2000). The findings for this indicator also present

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43 *Etude des impacts potentiels du changement climatique sur le bassin versant du Rhône en vue de leur gestion - deuxième phase*, E. Leblois, Lyon, 2005.

44 "Evolution potentielle du régime des crues de la Seine sous changement climatique", A. Ducharne, E. Sauquet, F. Habets, M. Déqué, S. Gascoin, A. Hachour, E. Martin, L. Oudin, C. Pagé, L. Terray, D. Thiéry, P. Viennot, in *La Houille Blanche, n°1-2011*, Paris, 2011.

wide distribution and uncertainties, such that they are less certain than current knowledge of the flow rate at the present time. It is therefore difficult to draw even modest conclusions when it comes to future river flooding.

Two separate indicators are used to assess 100-year floods: the maximum daily flow rate achieved or exceeded every 100 years on average, and the maximum flow rate over 24 days achieved or exceeded every 100 years on average. Other than the results produced by combining the hydrological scenarios with one particular climate scenario (which results in a significant rise in these indicators, due to a high increase in rainfall under this model), the results are modest at best and cannot be used to draw any conclusions about marked changes in 100-year flood rates by the end of the century.

Existing conclusions for the Loire drainage basin[45] appear to support the findings of the research conducted for the Seine. A total of 21 climate scenarios were used, with these data fed into two separate hydrological models. The results showed a significant overall fall in average annual flow rates, and an even more substantial reduction in low water marks. In terms of floods (10-year floods, based on the maximum daily flow rate achieved or exceeded every 10 years on average), the results were similar to the findings for the Seine, i.e. a wide variation of +10% to -10%, with significant discrepancies between the results achieved under different models.

Finally, trans-national studies[46] have also been conducted on the Meuse drainage basin as part of the AMICE (Adaptation of the Meuse to the Impacts of Climate Evolutions) project, which involves German, Belgian, French and Dutch partners from water management organisations across the Meuse basin working together on issues related to climate change adaptation.

The Meuse basin is located at the intersection of two climate zones with different behaviours: northern Europe, which is likely to see higher levels of precipitation in the future, and southern Europe, which is likely to see a reduction in precipitation. It is therefore difficult to attribute any changing trends to climate change. In order to overcome this uncertainty, the project team decided to focus on two options: a group of "dry" scenarios, and a group of "wet" scenarios. The partners from each country agreed to define a "dry" and "wet" version of their own, standard climate scenarios. A trans-national climate scenario was also produced (again with a "dry" and "wet" version).

Since each partner used its own hydrological models, the final report indicated the potential changes in each sub-basin by the middle and end of the century (2021-2050, and 2071-2100 respectively). All of the teams used the same indicators: the maximum hourly flow rate achieved or exceeded every 100 years on average (flood indicator), and the minimum average flow rate over seven days between April and September each year (low water mark indicator).

The report found a reduction in the low water mark indicator under all scenarios (dry or wet). However, the flood indicator trend depended on the chosen scenario (dry or wet), with the 100-year hourly flow rate increasing under the wet scenario and decreasing under the dry scenario. In the end, the AMICE project partners agreed on a final result, under which the 100-year hourly flow rate would rise by 15% by 2021-2050, and by 30% by 2071-2100, and the minimum seven-day annual flow rate would fall by 10% by 2021-2050, and by 40% by 2071-2100.

The results of the four case studies presented here (Rhône, Seine, Loire and Meuse) would appear to be relatively consistent with the work conducted on historical datasets by Renard in 2006. While this is not proof in its own right, the correlation is interesting nevertheless. They are also consistent with the multi-model study[47] covering the whole of France, conducted as part of ONERC's work in 2009. This thesis study concluded that there would be a "marked general fall in average flow rates in summer and autumn, more frequent and more severe low water marks, and a rise in flow rates in winter in the Alps and the south-east of the country, with more modest changes in intense flow rates than in average flow rates"[48].

E) Forest fires

Each year, around 4,000 forest fires start across mainland France. A total area of approximately 24,000 hectares is burned each year[49] – a figure that is falling year-on-year. This fall is also observed in Réunion, the only overseas department where population centres are considered to be at risk of this hazard. The total burned surface area on the island fell from 10,000 hectares per year in 1966-1988 to 1,909 hectares in 1990-2006, i.e. a reduction in average surface area of more than 75%[50].

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45 "La Loire à l'épreuve du changement climatique", F. Moatar, A. Ducharne, D. Thiéry, V. Bustillo, E. Sauquet, J.-P. Vidal, in *Géosciences, n°12*, 2010.

46 *Analysis of climate change, high-flows and low-flows scenarios on the Meuse basin*, G. Drogue, M. Fournier, A. Bauwens, H. Buiteveld, F. Commeaux, A. Degré, O. De Keizer, S. Detrembleur, B. Dewals, D. François, E. Guilmin, B. Hausmann, F. Hissel, N. Huber, S. Lebaut, B. Losson, M. Kufeld, H. Nacken, M. Pirotton, D. Pontégnie, C. Sohier, W. Vanneuville, Charleville-Mézières, 2010.

47 *Changement global et cycle hydrologique : une étude de régionalisation sur la France*, J. Boé, Toulouse, 2007.

48 *Ibid*, p.253.

49 "Le risques de feux de forêts en France", C. Magnier, *Observation et Statistiques n°45*, Paris, 2011.

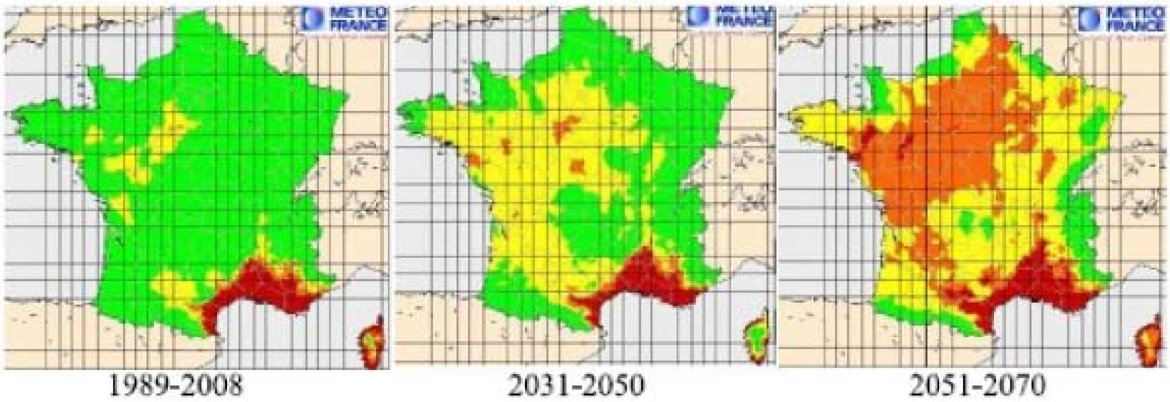
50 *Ibid.*

The main conclusions drawn from the downward trend of this hazard and its relationship with climate change appear in a report[51] produced jointly by the General Inspectorate for the Administration, the General Council for the Environment and Sustainable Development and the General Inspectorate for Food, Agriculture and Rural Areas[52].

The maps showing the zones most at-risk from this hazard appear highly consistent with those zones where the forest fire weather index (FWI) reaches or exceeds a certain level[53]. For the purposes of the study, the mission used the following criterion: "proportion of days between 15 May and 15 October with a FWI greater than or equal to 14", with the threshold set at "three days out of four". As a result of the inspection mission's research, we can postulate that the zones most susceptible to forest fires are those areas of the country where the modelled FWI is, on average, at 14 points or higher for three out of four days between 15 May and 15 October.

The three maps below show the FWI level for the entirety of mainland France, categorised into four bands, and over three time periods, including the reference period (1989-2008).

Figure 6: Maps of France showing the proportion of days with a FWI above 14 points, between 15 May and 15 November



Source: Chatry et al., 2010

The green, yellow, orange and red colours correspond to the following categories respectively: "less than one day in four", "between one and two days in four", "between two and three days in four" and "more than three days in four".

The general inspectors adopted an original approach when it came to assessing the costs of an aggravation of the forest fire hazard. Rather than focusing on the additional losses caused by the hazard (implying constant resources), they looked at the need for additional public resources to maintain the current level of losses.

This was, of course, only possible with access to information about the cost of the forest fire management policy (covered in the Mission's report), and in-depth knowledge of the relationship between aggravation of the hazard and the human resources and equipment necessary to combat this hazard.

Based on current expenditure levels (European Union, State, local authorities and forest owners combined) of around €500 million per year (one third of which were fixed costs) and the extension of the at-risk zones by around 30% in terms of surface area by 2040, the report found that annual forest fire management costs would rise by €100 million (2010 value) – a rise of 20%. This figure is only valid under the assumption that the public authorities maintain safety requirements at their current levels. It is possible that these may change, of course, in response to new regulatory requirements or social demand.

Under this scenario, climate change would therefore cost France an additional €100 million per year by 2040 (under the assumption that prevention expenditure is sufficient to prevent losses greater in value then their cost).

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51 *Rapport de la Mission Interministérielle - Changement Climatique et Extension des Zones Sensibles aux Feux de Forêts*, C. Chatry, M. Le Quentrec, D. Laurens, J.-Y. Le Gallou, J.-J. Lafitte, B. Creuchet and J. Grelu, Paris, 2010.

52 These three government departments conduct inspection activities for three ministries respectively: the Ministry for the Interior, Overseas, Regional Authorities and Immigration; the Ministry for Ecology, Sustainable Development, Transport and Housing; and the Ministry for Food, Agriculture, Fishing, Rural Life and Regional Development.

53 The FWI is an indicator use to measure susceptibility to the ignition and spread of a forest fire on the basis of weather conditions. It is used to estimate the threat of forest fires by the operational departments of several countries. In this report, the FWI data is calculated for individual pixels on the map, each representing a square approximately 8 km by 8 km.

The authors of the report are, however, careful to remind readers that these results are tainted by inherent uncertainties, linked in particular to a lack of knowledge about a particularly complex subject. They also state the need for further analysis of the intricate relationship between meteorological factors (wind, humidity, temperature) and biological factors (distribution of types of vegetation and their relative sensitivity to forest fires).

F) Wind

Storms (and other wind-related phenomena) are often mentioned as examples of hazards susceptible to the impacts of climate change. This a particularly important question, given that the losses associated with this hazard are currently extremely high. According to the French Federation of Insurance Companies (FFSA)[54], storms accounted for a total cost of €16.6 billion between 1988 and 2007 in mainland France.

Several overseas departments are also affected by the risks associated with tropical storms (cyclonic events). Mayotte and Réunion are susceptible to cyclones between December and March (with a peak in January and March)[55], while Guadeloupe and Martinique are affected between June/July and November[56]. Guiana is the only overseas department not affected by cyclones, although it is still susceptible to violent winds, in the same manner as mainland France[57].

At present, there is no convincing evidence to support a potential increase in the intensity or frequency of winter storms in mainland France. The only expected change based on current knowledge is a potential shift in the path of these storms, which is likely to move northwards over time[58].

An analysis of events over the last 35 years has led some researchers[59] to suggest a global change in hurricane production mechanisms. They argue that there has been an increase in the proportion of category 4 and 5 hurricanes (the highest intensity) across all oceans, at constant hurricane production frequency. The data suggests that, at constant hurricane numbers, the likelihood of a category 4 or 5 event increased from 20% to 35% between 1970 and 2004. However, maximum hurricane intensity has remained unchanged over the last 35 years.

Overall hurricane frequency does not appear to have increased significantly over the period concerned, with the exception of the North Atlantic, where the overall number of hurricanes has been on the rise since 1995 (with statistical significance of 1%). Alongside this trend, there has been a significant increase in the surface temperature of this ocean, which could lead to the conclusion that this is a consequence of climate change.

However, other oceans affected by temperature increases have not seen a rise in the frequency of hurricanes. There is no clear consensus on this conclusion. The authors of the article also accept the possibility that other, unknown factors may be involved – factors independent of climate change, such as oceanic oscillations.

G) Gravity-related hazards (ground movements[60], avalanches)

Gravity-related hazards cover a broad range of phenomena, including landslides, collapses, subsidence, rockfalls and avalanches. In France, these events are responsible for relatively minor losses compared with other natural hazards. The impact zone of each event is extremely limited, unlike other risks such as floods and earthquakes[61].

However, these events are so violent and so sudden that they result in costs "per property or asset" that are significantly higher than for other natural hazards. They also pose a substantial threat to human life. For these reasons, and despite their relatively low total cost, gravity-related risks are one of the priorities of the national natural risk prevention policy.

According to the studies summarised by ONERC in 2009[62], there was no discernible change in the mechanisms behind these hazards. However, the research did point to the fact that rainfall can play an aggravating role in triggering catastrophic events

54 *Synthèse de l'étude relative à l'impact du changement climatique et de l'aménagement du territoire sur la survenance d'événements naturels en France*, FFSA, Paris, 2009.

55 See the Departmental Major Risk Studies for these departments.

56 *Ibid.*

57 See the Departmental Major Risk Study for Guiana.

58 *Impact des changements anthropiques sur la fréquence des phénomènes extrêmes de vent, de température et de précipitations – Rapport final*, Michel Déqué et al., 2003.

59 "Changes in tropical cyclone number, duration and intensity in a warming environment", P.J. Webster, G.J. Holland, J.A.Curry and H.-R. Chang, in *Science n°5742*, 2005.

60 Excluding clay shrink-swell, which is covered earlier in this report.

61 C. Grislain-Letrémy and C. Peinturier, 2010.

62 *Evaluation du coût des impacts du changement climatique et de l'adaptation en France, rapport de la deuxième phase*, ONERC, Paris, 2009.

(cavity collapses, landslips, land slides, etc.)[63]. A potential increase in winter rainfall levels could therefore lead to an increase in the frequency of such events.

However, temperature is also an important factor to consider when considering the triggers of a landslip. A recent presentation[64] demonstrated the link between air temperature and the occurrence of rockfalls in mountainous regions. In such cases, deterioration of the permafrost due to heating is said to lead to instability in the rocks, thereby resulting in an increase in the frequency of these events.

IV. How will the cost of disasters change in the future?

In light of the sheer number of factors that influence the costs of natural disasters as discussed in this report, it is difficult to conduct a forward-looking assessment of future natural disaster-related losses in France.

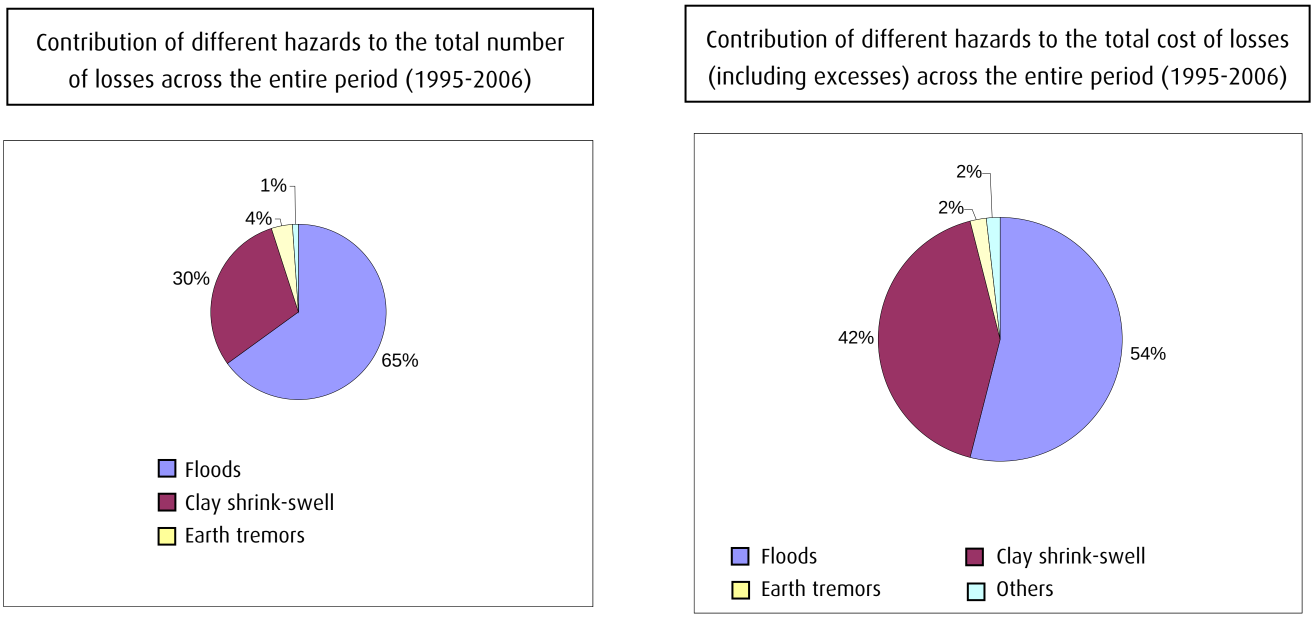
It is, however, possible to draw some conclusions about future trends.

IV.1. What are the potential impacts?

The economic impacts of climate change on a hazard depend on the relative cost of this hazard compared with all natural disaster-related losses. An increase in the frequency or intensity of a relatively inexpensive hazard will only have a limited impact in terms of economic losses. Before considering the potential impact of the aggravation of a particular hazard, it is therefore necessary to look at the current costs of different phenomena affected by climate change.

Figure 7 and Table 1 show the respective costs of different natural hazards under the natural disaster compensation scheme in France (the so-called "CatNat" scheme) between 1995 and 2006[65].

Figure 7: Relative cost of different natural hazards under the CatNat scheme between 1995 and 2006



Source: Grislain-Letrémy and Peinturier (2010)

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63 For more analysis of the role of rainfall, readers may also wish to refer to "Quelques remarques sur l'emploi des probabilités dans le domaine des risques naturels - cas des mouvements de terrain", J.-L. Durville, *Bulletin des Laboratoires des Ponts et Chaussées*, Paris, 2004.

64 "A Study of the Rockfalls Occurred in 2009 in the Mont Blanc Massif", L. Ravanel and P. Deline, *Symposium "Rock Slope Stability 2010"*, Paris, 2010.

65 Except for clay shrink-swell, for which the dataset terminates in 2003.

Table 1: Number of losses and associated cost for different natural hazards under the CatNat scheme between 1995 and 2006

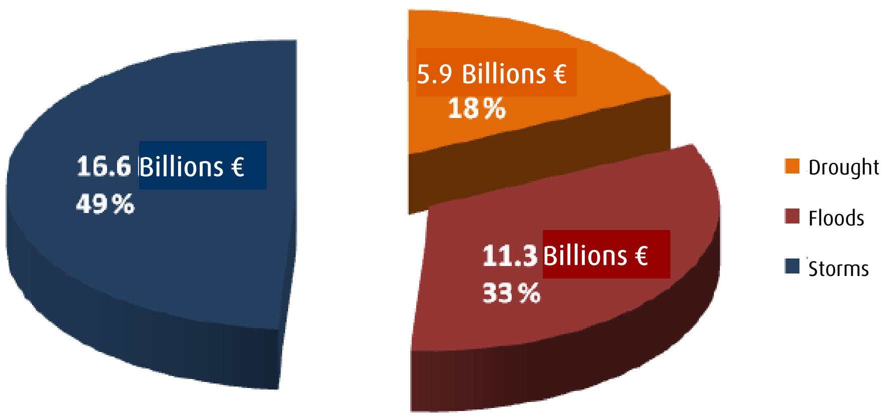
	floods	clay shrink-swell	Earth tremor	Others	Total
Number of losses	501,000	231,000	34,000	11,000	778,000
Total cost in € millions (2006) (including excesses)	4,683	3,533	132	164	8,512

Source: Grislain-Letrémy and Peinturier (2010)

The two natural hazards covered by the CatNat scheme (floods and clay shrink-swell) together account for around 95% of costs and losses. It is important to note, however, that coastal floods are included in the flood figures, which makes it difficult to assess the actual figures for this particular hazard.

However, CatNat does not cover all natural risks, and is just one of several guarantees included in property and asset insurance policies. It does not, therefore, cover all losses caused by natural risks. Storms (other than cyclonic events) are covered by the "Storm, Hail and Snow" guarantees included in these insurance policies. Damage to buildings caused by forest fires, meanwhile, is covered by the "fire" guarantees in insurance policies[66].

Figure 8: Relative cost of insurance payouts for natural risks under comprehensive insurance policies between 1988 and 2007



Source: FFSA (2009)

The data contained in Figure 8 support the conclusions drawn from Figure 7, with clay shrink-swell and floods accounting for a significant proportion of total insured losses. However, they only represent half of total insurance payouts, with the other half concerning storm-related losses. The FFSA has decided not to include insured losses related to forest fires in these figures, suggesting that the associated cost is negligible in relation to the losses caused by the other hazards.

In light of the observations and analysis in chapter III of this report, it is clear that clay shrink-swell is the most concerning hazard in France in terms of climate change. The evidence seems to suggest little potential for aggravation of floods and storms, either in frequency or in intensity. Clay shrink-swell, however, represents a significant proportion of annual costs and there is a general consensus among the scientific community that these events are likely to increase in frequency.

However, there are at least two other hazards that may be of concern in economic terms: forest fires and coastal erosion.

66 "Assurance des risques naturels en France : sous quelles conditions les assureurs peuvent-ils inciter à la prévention des catastrophes naturelles ?", C. Letrémy*, Etudes et Documents n°1*, Paris, 2009.

The costs associated with forest fire prevention and management are similar to the total compensation payouts for floods (around €500 million each year). Although forest fires account for limited insurance payout costs, this can be explained by the fact that public authorities invest heavily in prevention measures. An extension in the distribution of forest fires will naturally lead to an increase in the costs associated with managing this hazard. Due to this balance between compensation costs and management costs, land-owners, public authorities and the State will be on the front line when it comes to shouldering the financial costs of an aggravation of this hazard.

The expected rise in the sea level is a hazard that has never been experienced before. It is therefore impossible, based on known loss-related data, to draw conclusions about the potential impacts of this new threat. The various studies presented in the section on coastal risks in chapter III clearly illustrate the scale of the possible losses associated with this rise in the sea level. These losses would occur across a vast geographical area, and seem to be difficult to prevent.

Historical data therefore enable us, at least partially, to estimate those hazards that may result in rising costs (in terms of both compensation and prevention). However, as explained in chapter II, hazards are not the only factors that determine whether the costs of natural events rise or fall. In order to assess the future cost of natural risks in light of climate change, we must also focus on trends in the relevant socio-economic factors.

IV.2. How can we improve future cost forecasting?

In its coverage of clay shrink-swell, the ONERC report (2009) addressed the question of the comparative influence of climate change and socio-economic factors. As stated in chapter II, the ONERC report estimated that an annual increase of around 1% in the total number of homes, combined with the effects of climate change, would lead to an additional cost, over 20 years, equivalent to the cost attributable to climate change alone.

In other words, climate change and the increase in the number of homes are responsible, in similar proportions, for the expected increase in cost between 2010 and 2030, compared with 2009 levels.

Figure 9: Total estimated losses for 2010-2030, according to climate scenario and growth in the number of homes

Building growth rate	0 %			0.925 % per year	
Scenario	Without CC	A2 min	A2 max	A2 min	A2 max
Total losses 2010-2030 (millions of euros)	4 906.40	5 244.6	7 637.9	6 154.8	9 049.2

Building growth rate	0 %			0.925 % per year	
Scenario	Without CC	B2 min	B2 max	B2 min	B2 max
Total losses 2010-2030 (millions of euros)	4 906.40	5 253.7	6 289.0	6 163.4	7 403.8

Source: Plat et al. (2009)

This example illustrates the need to anticipate both physical changes in the nature of hazards, and socio-economic changes affecting the exposed elements.

The FFSA study on the impact of climate change on France[67] is the only example of a study into natural risks in France[68] that aims to be relatively comprehensive and includes this factor. It is based on a 20-year extrapolation of trends on the exposure of individuals and businesses, drawn from observed historical data between 1988 and 2007, focusing on the location of homes

[67] FFSA (2009).

[68] A similar study, by the name of Explore 2070, is currently being conducted by MEDDTL. However, this particular study focuses on water resources and is designed to help define adaptation strategies for the year 2070. See *Explore 2070 - Eau et changement climatique : quelles stratégies d'adaptation possibles ?*, DGALN, Paris, 2011.

and company premises (and involving estimations of local growth rates). Under these assumptions, the study concludes that costs will rise (over 20 years) by €16 billion due to socio-economic factors alone.

The FFSA's projections in terms of changes to hazards (in this case storms, clay shrink-swell and floods) are not scientifically robust, and while the exercise cannot be considered a sensitivity study, it is nevertheless interesting. With a doubling of the frequency of rare events and a 10% to 15% increase in the occurrence of frequent events, total additional losses under this model would be just €14 billion over the same 20-year period, i.e. an increase comparable with that attributable to socio-economic factors.

However, the FFSA's report also mentions an important factor, namely a rise in potential losses due to an increase in total insured value which, in turn, would also mean higher contributions to cover these losses. Even though wealth accumulation leads to a proportional increase in possible losses, wealth accumulation nevertheless occurs. So if the total insured value rises from 100 to 120 and, over the same period, possible losses rise from 1 to 1.2, then relative losses remain at 1%.

The most important factors are therefore changes to vulnerability or exposure, since these result in a change to losses in relative terms, thereby impacting a society's ability to cover the cost of these natural events. These are the very factors covered in chapter II of this report, which scientists have attempted to "neutralise" in studies (described in chapter III) in an effort to detect the potential effect of climate change on historical losses.

The majority of these factors are therefore already known, and some can even be quantified in fine detail. They include population growth, wealth accumulation, and a rise in the population and wealth exposed to these losses.

The challenge, therefore, is to develop models that take these factors into account, and in which they can be adjusted to test the potential impact of such changes. In particular, there is a need to test these models in the past before they can be extrapolated into the future.

Of all the difficulties that this type of work poses, perhaps the most challenging issue is the ability of researchers to hypothesise about future societal vulnerabilities using projections based on current changes. Some 20 years ago, nobody could have predicted that a flood in Thailand would have caused computer prices in France to soar by 10%[69].

These are questions that researchers will need to address, since the models used will need to be adjusted constantly to reflect new vulnerability factors created by our society in the future.

69 *Disques durs : les prix flambent après les inondations en Thaïlande*, S. Long, 01net.com, 3 November 2011.

V. Conclusion

The economic losses associated with natural disasters (climate-related or otherwise) have risen substantially over recent decades. This observation, reflected in the figures of global insurance and underwriting firms, has given rise to various studies that seek to explain this trend. Climate change has been proposed as one of the possible reasons for these rising costs.

The majority of scientific research in this field has concluded that factors other than climate change are responsible for the increased costs of natural disasters. At present, there is no irrefutable evidence that climate change has influenced the losses associated with natural disasters in recent decades.

However, this same research has highlighted a significant causal link between socio-economic changes in our societies and this upward trend in (economic and human) losses. These trends encompass both quantitative data (demographics, economics) and qualitative data (land use, vulnerability of property and assets). Furthermore, the impacts of the oldest natural disasters in the datasets used may have been underestimated as a result of perceptive bias.

Forward-looking studies conducted in the fields of science and nature suggest that climate change will have an impact on certain natural hazards. Overall, the general trend is likely to lie somewhere between stagnation of the current situation and aggravation of these hazards, either in frequency or in intensity. However, in practice, it remains difficult to anticipate how these changes will play out between now and the end of the 21st century.

As a result of societal changes and the potential aggravation of hazards due to climate change, it is therefore highly likely that the total annual cost of natural events will continue to rise, and possible even accelerate, in the coming years. At the very least, additional investment will need to be made in the national risk prevention policy in order to reflect this deteriorating situation.

It is not easy to estimate the extent to which the cost of natural disasters will rise. It is a complex exercise that requires an understanding of the quantitative impacts of certain factors on this cost, and an ability to predict future trends in these factors (both socio-economic and physical).

However, despite the various sources of uncertainty inherent in this type of work, it is nevertheless necessary to assess the expected consequences for each natural risk. Estimating the potential future losses associated with each hazard will, over time, help to improve existing knowledge and enhance national risk prevention policy. This, in turn, will ensure that the decisions made today will deliver effective strategies in the future.

Appendix - Typology of natural risks

1. Flood

1.1. Due to an overflowing river

- 1.1.1. Slow overflow
- 1.1.2. Fast (torrential) overflow

1.2. Due to run-off and mud flow

- 1.2.1 Rural (often accompanied by mud flows and muddy water)
- 1.2.2 Urban or peri-urban (often accompanied by muddy water)

1.3 Due to debris flow (torrent and thalweg)

1.4 Due to rising natural groundwater levels

1.5 Due to marine submersion

- 1.5.1. Swell, storm surge
- 1.5.2. Tidal wave, tsunami

2. Earth movement

2.1 Subsidence

- 2.1.1. Due to man-made cavities
- 2.1.2. Due to natural cavities

2.2. Collapse

- 2.2.1. Localised (cave-in), due to man-made cavities
- 2.2.2. Localised (cave-in), due to natural cavities
- 2.2.3. Widespread, due to man-made cavities

2.3. Landslip, rockfall

- 2.3.1. Rockfall
- 2.3.2. Landslip
- 2.3.3. Large-scale landslip (or collapse)

2.4. Landslide

- 2.4.1. Landslide
- 2.4.2. Mud flows caused by upstream landslides

2.5. Dune creep

2.6. Coastal and cliff erosion

- 2.6.1. Coast - low-lying coastline
- 2.6.2. Coast - cliff coastline
- 2.6.3. River banks

2.7. Differential settlements

3. Earthquake

4. Avalanche

5. Volcanic eruption

5.1. Lava flows (or intrusions)

5.2. Pyroclastic flows

5.3. Ashfall

5.4. Gas

5.5. Lahars 2

6. Forest fire

7. Atmospheric phenomena

7.1. Cyclone/hurricane (wind)

7.2. Storm and squall (wind)

7.2.1. Storm (wind)

7.2.2. Squall front

7.2.3. Squalls

7.3. Tornado (wind)

7.4. Lightning

7.5. Hail

7.6. Snow and freezing rain

7.6.1. Snow

7.6.2. Freezing rain

Source: Vignal C. Laroche R., *Les événements naturels dommageables en France et dans le Monde en 2002*, La documentation française, January 2003

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The drivers of the cost of natural disasters: the role of climate change in France

In a context of rapidly rising global temperatures (in geological terms), there are recurring questions about the impact of climate change on natural disasters, and about the need to anticipate future developments.

This study provides a brief overview of current economic analysis in relation to natural risks and climate change. It aims to provide a framework for interpreting past events and for understanding critical factors that will arise over the coming decades.

The study is based on the findings of various scientific publications. It constitutes a non-exhaustive summary of recent thought and research in this area, from both economists and technical experts. First of all, this scientific research will be used as a basis to explain the increased cost associated with natural risks in the 21st century, and to discuss the influence of climate change on this cost. Next, the study will seek to determine the potential consequences of climate change on natural hazards in France over the course of the current century. In the final section, the study will examine whether and how these potential future impacts can be quantified in economic terms.

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