The health impacts of climate change in France

What are the issues for the French Institute for Public Health Surveillance (InVS)?
The health impacts of climate change in France — French institute for public health surveillance

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The health impacts of climate change in France — FRENCH INSTITUTE FOR PUBLIC HEALTH SURVEILLANCE
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### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CépiDC</td>
<td>French Centre for Epidemiology on Medical Causes of Death (Centre d’épidémiologie sur les causes médicales de décès)</td>
</tr>
<tr>
<td>Cire</td>
<td>Regional Office of the French Institute for Public Health Surveillance (Cellule de l’Institut de veille sanitaire en région)</td>
</tr>
<tr>
<td>CnamTS</td>
<td>French National Insurance Fund for Salaried Employees (Caisse nationale de l’Assurance maladie des travailleurs salariés)</td>
</tr>
<tr>
<td>Cnev</td>
<td>National Centre for Expertise in Vectors (Centre national d’expertise sur les vecteurs)</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>DGS</td>
<td>French General Department of Health (Direction générale de la santé)</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gas (gaz à effet de serre)</td>
</tr>
<tr>
<td>Insee</td>
<td>French National Institute for Statistics and Economic Studies (Institut national de la statistique et des études économiques)</td>
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<tr>
<td>InVS</td>
<td>French Institute for Public Health Surveillance (Institut de veille sanitaire)</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>MDO</td>
<td>Notifiable disease (Maladie à déclaration obligatoire)</td>
</tr>
<tr>
<td>Meeddm</td>
<td>French Ministry of Ecology, Energy, Sustainable Development and Sea (ministère de l’Écologie, de l’Énergie, du Développement durable et de la Mer)</td>
</tr>
<tr>
<td>N₂O</td>
<td>Nitrous oxide</td>
</tr>
<tr>
<td>Onerc</td>
<td>French National Observatory on the Effects of Global Warming (Observatoire national sur les effets du réchauffement climatique)</td>
</tr>
<tr>
<td>OSCOUR©</td>
<td>Coordinated Health Surveillance of Emergency Departments (Organisation de la surveillance coordonnée des urgences)</td>
</tr>
<tr>
<td>PAHs</td>
<td>Polycyclic aromatic hydrocarbons</td>
</tr>
<tr>
<td>Peraic</td>
<td>Emergency Response to Industrial Accidents and Natural Disasters (préparation en réponse aux accidents industriels et catastrophes naturelles)</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter</td>
</tr>
<tr>
<td>PNC</td>
<td>French national heat wave plan (Plan national canicule)</td>
</tr>
<tr>
<td>Sacs</td>
<td>French system for heat wave and health alerts (Système d’alerte canicule et santé)</td>
</tr>
<tr>
<td>Sniir-AM</td>
<td>French National Information System for Health Insurance Schemes (Système national d’informations interrégimes de l’Assurance maladie)</td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
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<tr>
<td>WHO</td>
<td>World Health Organisation</td>
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It is acknowledged today that climate change will affect human health, via direct and indirect mechanisms. After the first report issued by the Intergovernmental Panel on Climate Change (IPCC), observations and models are bringing about improved understanding of the observed and forecasted changes in climate and of their impacts on the environment and on society. These changes are taking place in a context of environmental, demographic and social disruption and of economic globalisation.

Observations currently show that the average annual temperature is increasing at an unprecedented rate. Eleven out of the twelve years from 1995 to 2006 were among the twelve warmest years since 1850. Global warming has become more pronounced over the last 50 years, with an increase in temperature of 0.13 degrees per decade [0.10 °C to 0.16 °C] between 1956 and 2005. In 2007 the IPCC concluded that it is more than 90% probable that current levels of global warming are due to human activity [4]. The average increase in temperature between now and 2100 simulated by the different climate models could be between 1.1 and 6.4 °C [4].

Several health risks and environmental events that are likely to be exacerbated by climate change are traditionally identified in French [5,6] and European [7-9] reports: the emergence or re-emergence of infectious diseases, the increase in frequency and intensity of extreme climatic events and the profound changes in the environment. Based on the available literature and on its own internal expertise, the French Institute for Public Health Surveillance (InVS) has carried out a study for each identified risk to assess the current level of knowledge available, to identify and describe existing surveillance and alert systems and to identify the new issues raised by climate change in terms of knowledge and surveillance.

The principal conclusions of this study show that the expected impacts of climate change do not justify the development of new surveillance systems. However, the existing systems could be strengthened, for example:

- implementation of systematic and standardised analysis of the health impacts of extreme climatic events in the short, medium and long term. This requires the definition of indicators for health and social impacts that are relevant to public health efforts;
- quantification of interactions between air pollution and temperature;
- integration of the population and housing aspects;
- development of tools that are able to take into consideration the impact of policies aimed at reducing greenhouse gas emissions in the areas of air pollution, housing and town planning;
- encouraging research programmes in the areas of water-related risks, exposure to ultraviolet (UV) rays and chemical products, etc., particularly relating to variations in the methods of exposure that go along with social and environmental changes.

Above and beyond the specific recommendations for each risk, some general recommendations have also been made.

**SURVEILLANCE**

It is important to ensure the durability and sustainability of the existing surveillance and alert systems as well as the quality and accessibility of the data. This should also involve improving the links between the environmental and health surveillance systems as well as their coherency and consistency, in order to enable integrated and relevant surveillance of environmental health. At this point in time, surveillance of exposure is often limited to surveillance of environmental contamination levels. Changes in the climate and in the environment could, however, lead to changes in determinants of exposure. This entails improving the definition of exposure and health impacts as well as taking into account the determinants of exposure, which would enable a better understanding of the possible impacts and therefore more focused preventive action.

In addition, climate change may lead to new and unknown situations, in the face of which the specific surveillance systems may not be effective. Syndromic surveillance could therefore be of value in providing useful information for managing crises and detecting unexpected events. It also routinely generates epidemiological data that can be used in the context of traditional surveillance systems, enabling an increased understanding of the long-term impacts.

**KNOWLEDGE**

The systematic analysis of the impact of extreme climatic events would enable better evaluation of these impacts in the future as well as improved focus and evaluation techniques for preventive measures and measures taken to manage these situations.

Consideration of the current health impacts of policies that aim to reduce aerosol usage and Greenhouse Gas (GHG) emissions is also an important issue for public health. Only when GHG are taken into account can models be produced that explain the increases in temperatures that have been observed over the last 50 years. These gases are emitted by human activity that serves human health but also puts it at risk. Methods must be developed to provide decision makers with information that will enable them to adopt the best policies in terms of striking a balance over the short and the long term.

In terms of taking a more global view that integrates the management of risks, interdisciplinary partnerships are needed to study complex systems and put the health impacts of environmental, social and economic changes into perspective. Within the InVS, this requires the implementation of cross-functional working groups and the development of definitions that are common to all the specialist departments. The requirement for interdisciplinarity is also reflected in interactions with research. In many areas, it is clear that there exists a lack of knowledge about the interactions between climate variability, the environment and health, which means that the reality of the risks and their probable evolutions cannot be effectively assessed.
Finally, the importance of international collaboration should be highlighted, both to encourage the sharing of knowledge and experience, particularly by exploiting the concept of “similar countries” – countries which currently have a similar climate to that which is forecast for the coming years – and also to take into account the health aspects of climate change in international negotiations and decisions.
1. Introduction

It is acknowledged today that climate change will affect human health [1-3], via direct and indirect mechanisms. Climate change may be considered as a factor for change in the state of environments and pathogens, in the exposures to health risks, in the determinants of exposure, in the state of health among populations and in the migration of populations. Climate change could therefore aggravate territorial imbalances and inequalities in healthcare, on a national and a global scale. In parallel, there will be other major changes, such as population growth, for example.

In the face of this level of complexity, the study of the health impacts of climate change is primarily dependent upon expert opinion. A great many national reports are available, listing the potential health risks. They all agree that the impacts will be of three principal types:
- an increase in the frequency and intensity of extreme climatic events;
- the emergence or re-emergence of infectious diseases;
- gradual changes to the environment and to ways of life that will modify existing exposures or even bring about new exposures.

These potential impacts indicate that climate change is indeed a threat to human health. Health and safety and public health have been identified as the priority objectives in the French national strategy for adapting to climate change [10]. Surveillance is also a priority included in the list set out by the French High Council for Public Health in relation to health risks linked to the qualitative effects of climate change (appendix 2).

Surveillance in public health is “the continuous and systematic collection and the analysis and interpretation of data that is essential for the planning, implementation and evaluation of public health practices, closely allied with the diffusion, at the opportune moment, of such data to those that require it” [11]. It enables the detection of epidemics, the description of the epidemiology of diseases, the detection of changes to epidemiology, the evaluation of hypotheses and even the evaluation of control and prevention measures. It is essential in order to monitor the impacts of climate change and to contribute to the development of public health policies, and especially to integrate health-related aspects into the selection of mitigation policies.

In this context, the French Institute for Public Health Surveillance (InVS) has studied the following requirements, from the point of view of its surveillance and alert functions:
- the requirements for development or adaptation of surveillance and alert systems, in order to deal with health-related changes arising from changes in the environment;
- the requirements for updating current knowledge about the health risks and the factors that are likely to bring about changes to these risks.

Drawing from previous reports and literature, this report provides a summary of the principal health risks to which climate change in France is likely to bring about modifications. For each of these risks, it identifies the existing surveillance and alert systems and proposes possible ways in which they could be adapted. The majority of these adaptations may be considered as “no-regret” adaptations insofar as they are useful with or without climate change.

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1 The Canadian, Australian, French and American initiatives, which illustrate the different approaches used to identify health risks linked to climate change, are detailed in appendix 1 – examples of approaches used in reports, publications and other literature to identify the health risks associated with climate change.
2. The climatic and environmental context

2.1 Observed changes in climate

Climate is the statistical description in terms of the mean and the variability of meteorological parameters (temperature, pluviometry, wind, etc.) in a given region, over timescales ranging between a few months to several thousands of years. Traditionally, a timescale of thirty years is used for the calculation of climatic norms [12]. Metropolitan France experiences five major types of climate (oceanic, altered oceanic, continental, Mediterranean and highland).

Changes in the climate indicate a significant statistical variation in the average state of the climate or its persistent variability over long periods (generally over decades or longer). Although temperature is the symbolic variable of these changes, the entire range of climatic parameters (humidity, cloud cover, rainfall, the carbon dioxide (CO2) content of the atmosphere, etc.) all need to be taken into consideration.

In the past, the Earth has already witnessed cycles of warming and cooling, to varying degrees and of varying durations. However, observations currently show that the average annual temperature is increasing at an unprecedented rate. Thus [4]:
- 11 out of the 12 years from 1995 to 2006 were among the 12 warmest years since 1850. Global warming has become more pronounced over the last 50 years, with an increase in temperature of 0.13 degrees per decade between 1956 and 2005. It is also more marked in the northern hemisphere and over continental zones. Figure 1 illustrates the evolution of the average annual temperature over metropolitan France, in the form of the variation from the mean over the period from 1971 to 2007. A similar evolution is observed in the overseas territories (see Guyana, for example (figure 2));
- rainfall levels have increased significantly between 1900 and 2005 in northern Europe and decreased within the Mediterranean boundary;
- observations also show that ice caps and glaciers have diminished in size;
- on average, sea levels have risen at an annual rate of 1.8 mm [1.3-2.3] between 1961 and 2003 and by 3.1 mm [2.4-3.8] between 1993 and 2003;
- the increase in levels of CO2 in the atmosphere has made a significant contribution to the acidification of the oceans. The average pH of the oceans (8.1) has decreased by 0.1 since the beginning of the industrial era.

The mass mixing ratio of CO2 in the atmosphere in 2008 was 38% higher than that of the preindustrial era in 1750. The level of methane was 157% higher than it was in 1750 and that of nitrous oxide (N2O) was higher by 19% than that of 1750 [13]. These increases are principally of anthropogenic origin. The radiative forcing of the atmosphere by all the persistent greenhouse gases increased by 26.2% between 1990 and 2008. Between 2003 and 2008, CO2 was responsible for 85% of this increase. Only when these greenhouse gases are taken into account can models be produced that explain the increases in temperatures that have been observed over the last 50 years. In 2007 the IPCC concluded that it is more than 90% probable that current levels of global warming are due to human activity. [4]

![Figure 1](source: Météo-France)
On the basis of these observations, the IPCC concluded in 2007 that [4]:

- the average temperatures in the northern hemisphere over the second half of the 20th century were very probably (the probability being undoubtedly more than 90%) higher than those of any other 50-year period over the last 500 years, and probably the highest of the last 1,300 years;
- it is very likely that cold days and nights, as well as frosts, have become less frequent in most continents, while warmer days and nights have become more frequent;
- it is probable (with a probability of more than 66%) that heat waves have become more frequent in most continents;
- more than 8 experts out of 10 agree that the natural systems linked to snow, ice and permafrost as well as the water systems have already been impacted by climate change;
- more than 9 experts out of 10 agree that many terrestrial and marine ecosystems have already been impacted by climate change.

A number of environmental indicators (temperatures, sea level, rainfall, flowering seasons, nest-building seasons, etc.) monitored by the French National Observatory on the Effects of Global Warming (Onerc) [14] and by the European Environment Agency [15] show evolutions that are consistent with the overall changes in metropolitan France and in the Overseas Territories.

### 2.2 Climate projections

Climate models enable future climates to be predicted by using scenarios of socio-economic evolution that serve to simulate changes in greenhouse gas emissions (appendix 3). For example, scenario A2 corresponds to an economic development with a high level of regional focus and significant population growth. Although these models are not perfect, the reality of climate change now seems to be well established. The average increase in temperature between now and 2100 simulated by the different climate models could be between 1.1 and 6.4 °C [4] (figure 3). In metropolitan France, the average temperature would be higher by 0.83 °C [0.55-1.24 °C] in 2030 compared to 1990 according to scenario A2 and by 1.37 °C [0.85-1.8 °C] in 2050 (table 1). Figure 4 shows this increase in temperature in terms of geographical displacement to the south, with Paris experiencing a climate similar to that of the south of France at the moment. Rainfall projections (table 2) are more difficult. Forecasts for rainfall in Europe would see two opposing trends, with an increase in rainfall in the north and a decrease in the south. Metropolitan France is located in the models’ area of extreme uncertainty (figure 5).

The islands, in particular those belonging to the Overseas Territories, are identified as territories that are especially vulnerable to climate change, with an increase in temperature during the 21st century of 1.3 to 5.8 °C according to the models (figure 6), an increase in sea levels, changes to patterns in rainfall, a possible increase in the frequency and intensity of tropical cyclones and intensification of the consequences of El Niño [16].
### Table 1
Temperatures (minimum, average and maximum* °C) in 2030, 2050 and 2090 and differences compared to the climate in 1990 for metropolitan France, scenario A2 [17]

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2030 A2</th>
<th>2050 A2</th>
<th>2090 A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>2.95</td>
<td>3.81</td>
<td>4.26</td>
<td>6.15</td>
</tr>
<tr>
<td>Average</td>
<td>11.41</td>
<td>12.24</td>
<td>12.78</td>
<td>14.63</td>
</tr>
<tr>
<td>Maximum</td>
<td>15.7</td>
<td>16.53</td>
<td>17.14</td>
<td>18.87</td>
</tr>
<tr>
<td>Minimum difference</td>
<td>-</td>
<td>0.55</td>
<td>0.85</td>
<td>2.24</td>
</tr>
<tr>
<td>Average difference</td>
<td>-</td>
<td>0.83</td>
<td>1.37</td>
<td>3.23</td>
</tr>
<tr>
<td>Maximum difference</td>
<td>-</td>
<td>1.24</td>
<td>1.8</td>
<td>4.06</td>
</tr>
</tbody>
</table>

* The minimum temperature corresponds to the coldest grid point of the 227 points covering France; the maximum temperature corresponds to the warmest grid point. The average temperature is the average of all the grid points.

### Table 2
Rainfall* (minimum, average and maximum mm/day) in 2030, 2050 and 2090 and differences compared to the climate of 1990 for metropolitan France, scenario A2 [17]

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2030 A2</th>
<th>2050 A2</th>
<th>2090 A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>1.43</td>
<td>1.52</td>
<td>1.54</td>
<td>1.5</td>
</tr>
<tr>
<td>Average</td>
<td>2.47</td>
<td>2.54</td>
<td>2.27</td>
<td>2.17</td>
</tr>
<tr>
<td>Maximum</td>
<td>4.93</td>
<td>5.12</td>
<td>4.75</td>
<td>4.45</td>
</tr>
<tr>
<td>Minimum difference</td>
<td>0</td>
<td>-0.4</td>
<td>-0.78</td>
<td>-1.2</td>
</tr>
<tr>
<td>Average difference</td>
<td>0</td>
<td>0.07</td>
<td>-0.2</td>
<td>-0.3</td>
</tr>
<tr>
<td>Maximum difference</td>
<td>0</td>
<td>0.31</td>
<td>0.18</td>
<td>0.2</td>
</tr>
</tbody>
</table>

* Combination of snow and rain.

### Figure 3
Spread of global warming modelled according to the emissions scenarios* [4]

Source: Solomon et al. [4].

* The numbers correspond to the numbers of the different models used for each simulation.
**Figure 4**

Climate displacement in European cities in 2070-2100 according to scenario A2 [18]

![Map showing climate displacement in European cities in 2070-2100](source)

Source: Hiederer et al. [18].

**Figure 5**

Projections for changes in temperature (high) and rainfall (medium) between 1980-1999 and 2080-2099 in Europe, averaged out over all models – number of models out of 21 predicting an increase in rainfall (low)

![Temperature and rainfall projections map](source)

Source: Solomon et al [4].

**DJF** = December-January-February – **JJA** = June-July-August.
2.3 Sudden Changes

Sudden changes in climate are defined as major changes occurring over a few decades or less and lasting for several decades. The changes that are currently most frequently mentioned are a sudden rise in sea levels, a sudden change in the water cycle, a change in the North Atlantic circulation, the disappearance of the Amazon rainforest, changes in the amplitude and frequency of El Niño events and a change in the methane levels in the atmosphere [20]. Such changes would have social, environmental and health consequences that it is impossible to evaluate today [21].

2.4 Global Changes

Global changes cover climate changes and all other changes of anthropogenic origin having general consequences such as the thinning of the ozone layer, reduction in biodiversity, changes to the water systems and the supply of fresh water, degradation of the soil and pressures exercised on food production systems. All of these environmental, social and economic changes lead to the weakening of human and natural systems and could potentially increase vulnerability to climate change.

From a health point of view, a significant aggravating factor is population growth, which is a clear threat in the long term. In 2050, the population of France could reach 70 million inhabitants (+15% compared to 2005, central scenario). There would be significant regional variations in this population increase; those regions most affected would be the South (+32%), the “Grand Ouest” (+22%) and Île-de-France (+13%). The elderly constitute a group that is especially vulnerable to the risks brought about by climate change, particularly those induced by extreme climatic events. Forecasts from the French National Institute for Statistics and Economic Studies (Insee) for 2030 conclude that the population of France will age, whichever scenarios are chosen. According to the central scenario, the proportion of people aged 60 years or over would increase from 20.6% in 2003 to 31.1% in 2030 (i.e. an increase of more than 7 million people). The number of people aged 75 years or over would increase from 4.2 to 8.3 million between 2000 and 2030 and those aged 85 or over would increase from 1.2 to 2.4 million. When these projections are extended to the year 2050, they demonstrate that the number of people aged 60 years or over would double in comparison to the year 2000; those aged 75 or over would triple and those aged 85 or over would show a fivefold increase [22].

At a global level, estimates of the number of people forced to migrate due in part to climate change give figures that vary between 25 million to one billion between now and 2050, according to sources. These population shifts could be temporary, such as the one occurring after Hurricane Katrina in August 2005 which led to more than a million people migrating. However, these migrations are more often likely to be permanent. There are no projections for the impact of climate change on the number of immigrants into Europe or into France.

This global table gives us an idea of the unprecedented scale of the expected changes, but does not offer a view on the diversity of the situations that will be encountered at different space and time scales.
3. Method for the selection of health risks that are potentially impacted by climate change

3.1 Scope

This report identifies the health risks that are likely to be modified by climate change over a time scale that enables the adaptation of surveillance systems in the medium term. Over this time scale, the adaptation would show immediate benefits, acting on risks that already exist or are almost certain. In the longer term, the effort must be focused primarily on mitigating the impacts, with the objective being to reduce the extent of climate change. The potential short-term impacts of mitigation and adaptation policies have not been systematically researched but are discussed as and when they seem to be particularly important.

In this report, there is no distinction made between metropolitan France and France’s Overseas Territories. The particular geographical situation of the French overseas departments, overseas collectivities and overseas countries and the existence of specific threats (e.g. cyclones, rising sea levels, etc.) to those areas require that a separate study should be carried out on this subject.

3.2 The selection of risks

The estimation of the health impacts of climate change would require three stages (figure 7):
- evaluation of the role played by climate and climatic variability in the different determinants for health;
- projection of the impact of changes to these climatic variables, potentially integrating the concepts of adaptation;
- definition of the impacts of climate change on the other determinants for health, integrating the mitigation and adaptation aspects.

It would be possible to carry out the first two stages to a partial extent for the risks for which there is a known dose-response relationship between a meteorological variable and a health effect, for example extreme temperatures and mortality. However, for the majority of pathologies, the impact of even the current climate, let alone any changes in the climate, is not known. It is therefore very difficult to quantify the impacts linked to climate change. This difficulty results in there being a low number of publications available on the health impacts of climate change. The majority of the publications available are position papers and very few of them go so far as to quantify the impacts (appendix 4).

It was decided that this report should be based on existing documents, limiting the scope to impacts for which:
- a minimum amount of validated information is available;
- the importance is deemed to be high in terms of seriousness and population affected;
- there is an existing public health action.

The validity of information is ensured by using publications from reading committee reviews and reports from recognised institutions. Projections of the changes to the epidemiology of diseases due to climate change and to other changes, as well as the identification of possible actions to reduce the risk, have been made qualitatively, by an internal consultation at the InVS.

For non-infectious pathologies, listings are by risk (extreme climatic events, environments, etc.):
- for extreme events: heat waves, cold waves, cyclones, storms, floods and forest fires;
- for changes to the environment: air quality, respiratory allergens, UV rays, water quality, habitat, soil, potentially dangerous plant and animal species (apart from infectious ones).

For infectious diseases, listing is by pathogenic agent, based on the list of agents and pathogenic entities established in advance by a preliminary study carried out by the General Department of Health (DGS) and the Ministry of Ecology, Energy, Sustainable Development and Sea (Meeddm) [23].

Whatever listing method is used, the existing surveillance systems have been analysed, separating surveillance of the environment, surveillance of exposures and surveillance of the effects. The results are presented in the form of:
- a succinct description of the principal existing environmental and/or health surveillance systems;
- a short summary of the expected impacts and the references enabling more in-depth study of the subject if necessary;
- a study of the potential requirements in terms of developing the surveillance systems;
- a study of the potential requirements in terms of acquiring additional knowledge.

3 An entity being a group of pathogens that have the same consequences; for example the fungus and mildew in the habitat are grouped into a single entity.
3.3 The limitations of the approach

The objective of this report is to identify the requirements for the adaptation of surveillance and alert; these requirements must be based on acknowledged and recognised risks. It is likely that climate change will bring to light other risks than those taken into consideration. Syndromic surveillance could be a key element in the detection of these events. It is also necessary to make the best use of interdisciplinary partnerships (between epidemiologists, meteorologists, biologists, entomologists, sociologists, etc.) in order to interpret any unforeseen signals.

This report is based on current knowledge. In particular, the IPCC’s report 4 on the observations and projections for climate change uses literature published before 2007. More recent observations and studies confirm the conclusions of report 4, demonstrating some underestimations in terms of the extent and rate of changes in temperature, melting of the ice caps and rising sea levels. In addition, the increase in CO₂ emissions is currently towards the top of the range specified in the scenarios used by the IPCC. Projections for temperature could be higher than those forecast in report 4 and the rise in sea levels could also exceed the one-metre mark after the year 2100 (20). The conclusions of this report will need to be updated as and when more knowledge is acquired.

Finally, the prioritisation of risks, initially envisaged as being on the basis of traditional criteria for public health (frequency, seriousness, tendency to evolve, potential for evolution, social or political demand, potential to act on the pathology or the determinant) has not been completed due to difficulties with the methodology. These are as follows:
- the fragmentation introduced by prioritisation, whereas the issues are for the most part complex and involved;
- the uncertainties, particularly surrounding the rate of change, that do not allow a “fixed” future to be defined.
4. **Risks potentially impacted by climate change in metropolitan France and the associated surveillance systems**

4.1 **EXTREME CLIMATIC EVENTS**

Given the random nature of extreme climatic events, one single event cannot be linked to climate change. However, the IPCC concludes that there has been a probable increase in the frequency and intensity of extreme climatic events, linked to meteorological conditions. Other types of extreme climatic events that are not directly attributable to climate change could have more severe consequences than they may otherwise have done, as they may now be occurring in a damaged environment. The ability to anticipate and react to these events will be a key factor in adapting to climate change.

4.1.1 **Heat waves**

The impacts of heat waves on mortality and morbidity rates are well-documented in France today [25, 26]. Nearly 15,000 deaths were recorded during the heat wave in 2003, and nearly 2,000 during the heat wave in 2006.

4.1.1.1 **Current status of surveillance**

Since the heat wave in 2003, France has put in place, each summer, a National heat wave plan (PNC) [27] which is based on a heat wave and health alert system (Sacs) and real-time monitoring of health indicators [28]. The system has been designed to avoid and reduce mortality and morbidity rates during heat waves. Data gathered since 2004 seems to indicate that the plan has contributed to the effective reduction of the vulnerability of populations. Various results point to the 2006 heat wave having less of an impact than expected [26], particularly the disappearance of the spike in mortality rates that was observed in 2003.

4.1.1.2 **The expected impacts**

Climate change is likely to result in an increase in the intensity and frequency of heat waves [29]. Figure 8 shows the evolution of the number of heat wave days predicted in France according to different emissions scenarios through to the year 2050. At the same time as the increase in temperatures, the concentration of populations in urban areas and the aging of the populations will lead to an increase in the number of people that are vulnerable to the heat. Urban areas are particularly sensitive because of the increase in temperatures, particularly at night, per urban heat island [30].

**Figure 8**

*Increase in the number of summer heat wave days in France between 2000 and 2100 according to scenarios A2, A1B and B1*

Source: Météo-France.

A heat wave is defined as a period during which the temperature exceeds normal daily levels = averages for the period 1960 to 1989 of more than 5 °C over at least 6 consecutive days.
4.1.3 Recommendations for surveillance
Currently, there exists no benchmark by which to assess the performance of a heat wave alert system. An international comparison has shown good performances by Sacs compared to other existing heat wave alert systems [31]. Moreover, the system is subject to regular assessments and improvements by the InVS and Météo-France. The issue now is to develop it in a context of increasing temperatures, in order to be able to continue to identify extreme heat waves, which are dangerous to health, while at the same time keeping the number of false alarms at a low level. Temperatures have been increasing in all French departments since the 1960s, and temperatures which were previously rarely exceeded are now being recorded more and more frequently. The gradual evolution of alert thresholds cannot, however, be made unless some fundamental actions are put in place to reduce vulnerability to heat, including at times which are not alert periods, for example by working on the design of towns/cities, of housing and of transport policies [32,33].

At this point in time, Sacs only covers metropolitan departments. However, Météo-France has observed rising temperatures in all of the Overseas Territories over the last 50 years. It is probable that climate change is also bringing about more variability in the distribution of temperatures and therefore more extreme climatic events. No articles on the impact of heat on the Caribbean or Pacific islands are available. Heat episodes in 2008 in New Caledonia and in 2009 on Réunion Island seem to have been accompanied by a low health impact on mortality and morbidity rates (the results are still being analysed). Heat waves remain a minor risk compared to other local problems. However, it is undeniable that a very intense heat wave would have more significant consequences. We must maintain strong links with Météo-France on this subject.

4.1.4 Recommendations for knowledge
The study of risk factors and the identification of populations at risk must be maintained, in order to instigate prevention measures in the medium and long term, for example, the study on urban heat islands.

The study into the epidemiological transition of the relationships between temperatures and morbidity of the population will also need to be developed, as soon as the number of days’ worth of data built up is sufficient [34].

With a view to forecasting, it would be useful to have studies available on the impact of heat waves in spring or autumn, on the assumption that these extreme climatic events could have an effect on health via a change in atmospheric pollution, for example, or even on the transmission of infectious diseases, or physiological adaptation.

4.1.2 Cold waves
The average increase in temperatures is not compatible with the occurrence of extreme climatic events such as cold waves.

4.1.2.1 Current status of surveillance
In the past, France has not experienced any cold waves that have led to a massive spike in the mortality rate, like some heat waves have. This does not mean that such an event will never happen, but the lack of experience of cold waves does not enable a detailed response plan to be defined (other European countries have the same problem). The episode in winter 2009 demonstrated that the syndromic surveillance tools were effective in the rapid detection of an increase in mortality and morbidity rates, but did not enable the different possible causes (cold, infectious diseases, etc.) to be distinguished from each other [35].

4.1.2.2 The expected impacts
A great many articles cite an expected drop in winter mortality rates thanks to climate change. For example, at the European level, the Projection of economic impacts of climate change in sectors of the European Union based on bottom-up analysis project estimates that the reduction in winter mortality rates, defined as the mortality rates linked to a drop in temperatures could compensate for the increase in summer mortality rates. However, the increase in mortality rates observed in winter could be caused by a number of factors other than a drop in temperatures: flu, a change in diet, lower light levels, etc. [36-38]. Huge disparities have thus been observed in Europe; the countries most affected are not the coldest. Between 1988 and 1997, the highest winter mortality rate was observed in Portugal (+28% [25-31%]), in Spain (+21% [19-23%] and in Ireland (+21% [18-24%]) [39]. It is difficult to project the impact of climate change on the evolution of winter mortality rates and a better understanding is needed of the mechanisms underlying winter mortality rates and mortality rates that are specifically linked to cold weather.

Furthermore, the cold wave of 1985 led to an excess mortality rate of 1,039 deaths (+13.5%) during January in the Ile-de-France. During the particularly cold winter of 2008-2009, an excess mortality rate of around 6,000 deaths compared to 2007-2008 was observed in France, associated with flu epidemics and respiratory diseases [35]. Such episodes could continue to occur. The population could acclimatise to higher average temperatures and could prove to be more sensitive than at present to the same temperatures, whether this be by virtue of a reduction in their physiological adaptation to the cold or of a slight change in their behaviour patterns.

4.1.2.3 Recommendations for surveillance
Cold waves are characterised by a much extended impact in terms of time, which can last up to several weeks after the peak of the cold weather. The principal measures to protect the population against the effects of cold weather focus all on prevention over the long term, particularly the effective insulation of buildings (which, moreover, constitutes one of the primary focus points for the plan to reduce greenhouse gases) and access to clean and sufficient energy for all, through various financial aid packages. The lowest winter mortality rates observed in countries with cold climates tend to demonstrate the effectiveness of these types of prevention measures. A cold wave and health alert system, modelled on that used for heat waves, is not suitable. However, meteorological alerts (based on Météo-France’s red and orange alert levels) are necessary in order to warn the population of periods of intense cold and to broadcast advice on ad hoc prevention. During these periods, the InVS will define the health situation based on available data regarding mortality rates and emergency admissions to hospital, in order to alert the public authorities.

4.1.2.4 Recommendations for knowledge
Unlike heat waves, which generally occur in the absence of any other health risk factor, studies carried out in France and abroad have shown that it is difficult to separate cold from other causes (particularly infection) of winter mortality. Furthermore, there have historically been few cold waves in France, and very few indeed with well-documented health data. The data that is available has hardly been used (1985, 2005 and 2009 in particular) and deserves more
4.1.3 Localised phenomena (cyclones, storms, floods, forest fires)

Climate change is likely to bring about an increase in the frequency and intensity of geographically localised extreme climatic events such as floods, cyclones and forest fires. These phenomena are grouped into a single subject area, because even though they require different approaches in terms of forecasting, prevention and management, they use similar tools on the epidemiological front.

These events challenge the vulnerability, resilience and ability to adapt of the emergency services to repeated occurrences of such phenomena very close together, as well as the influence of the actions taken and the way in which the consequences of these events are managed in terms of the recorded effects.

4.1.3.1 Current status of surveillance

Surveillance and the prevention of risks is well-organised in France, with the implementation of prevention plans for foreseeable natural risks [40]. Strong winds, hurricanes and cyclones are monitored by means of meteorological surveillance. Equivalent monitoring for floods has been in place since 2001. Since 2007, Météo-France has also produced a meteorological risk index for forest fires.

Surveillance of the health effects of these events is currently being developed. At the InVS, the programme “Emergency Response to Industrial Accidents and Natural Disasters” (Peraic) aims to integrate the InVS into the issues faced by operational players with regard to managing the consequences of a natural disaster or industrial accident. Its objectives are to assess the health impact of such events in the short, medium and long term and to identify the factors that modify it and the populations that are most at risk. Ultimately, its aim is to provide information on the impact in ways (particularly temporal) that render it useful in terms of management. To do this, the InVS is developing a programme for the analysis of syndromic information provided by the emergency medical services, pre-emergency plans, electronic data on mortality rates and data on medical consumption arising from data on health insurance.

Furthermore, Peraic organises the gathering of data that must be collected in the immediate aftermath of the disaster, as far as this is possible (data on the identification of persons involved and on the known or potential exposures) with a view to future epidemiological monitoring. The programme also works on establishing the means to obtain relevant reference information relating to health, in preparation for such events. The programme must also focus its efforts on the preparation of tools for monitoring the long term expected effects and their determinant factors within populations. These methodological developments constitute the basis for the creation of a true system for surveillance of the impact of disasters.

A surveillance system is only pertinent if it is well-integrated into the management processes. Peraic endeavours, in parallel with the development of methods, to integrate the InVS into the structure of the players’ organisation to achieve better management of the consequences of the accident in its post-accident phase. It also expects to work towards the use and the communication of the results arising from its analysis of this data by local players.

4.1.3.2 The expected impacts

These localised extreme climatic events present similarities in their impacts. In the short term, the deaths and injuries occurring as a direct result of the event and their fundamental prognosis are the principal concern. But very quickly, the consequences of the damage provoked by the event become predominant in the occurrence of the health impact. One can therefore expect to observe:

- injuries due to actions for rehabilitation, clean-up operations or further collapses of buildings that are already weakened;
- hypothermia, carbon monoxide poisoning (due to the improper use of generating sets and improvised heating appliances), water-borne infections, dehydration due to insufficient supply of drinking water;
- an impact on the mental health of the affected population (depression, anxiety, post-traumatic stress, increase in dependence on psychoactive substances, etc.).

If the event completely disrupts society and attempts at management are undermined, one can also expect to observe acts of violence. In the medium and long term the alteration in quality of life, the disruption of the social tissue, situations of psychological stress and the degradation of the environment and the habitat will have an effect on mental health (figure 9) and somatic health.

4.1.3.2.1 Storms, hurricanes and cyclones

Climate change could lead to changes in the intensity of these events. The immediate dangers inherent in cyclones are the deaths directly resulting from accidents and injuries. Indirectly, the damage could lead to the impossibility of gaining access to the emergency services through breaches in lines of communication, their destruction or quite simply because of the high number of injured people requiring the mobilisation of all the emergency services and their medical staff. The destruction of life-supporting infrastructures may also have a significant impact on health. For example, the improper use of generating sets or improvised heating appliances could lead to carbon monoxide poisoning as was the case in the immediate aftermath of the Klaus storm which hit the south-west of France in January 2009. The clean-up operation could lead to a number of injuries (e.g. chainsaw accidents, falls from roofs, etc.). Extreme decoupling of underlying chronic pathologies (treated or not) linked directly to the stress brought about by the cyclones or the impossibility of gaining access to the healthcare system may be observed [41,42]. Finally, the material consequences of the disaster (loss of working tools, loss of housing, significant financial loss) and the difficulties encountered in remediating these can themselves have a significant impact on health, particularly mental health.

4.1.3.2.2 Floods and the effects of rising sea levels

Climate change is identified as a factor that leads to a probable increase in the risk of flooding, both in terms of the seriousness of the flood and the probability of flooding occurring [43]. With regard to rising sea levels, the French Coastal Protection Agency estimates, based on the assumption that sea levels will have risen 22 cm...
by 2050 and 44 cm by 2100, that the effects of erosion and those of submersion are likely to have a limited impact in France, to the order of around 2,000 hectares for erosion and 36,000 hectares for submersion. This involves exposure for few people [44]. The Overseas Territories are undoubtedly more exposed, particularly French Polynesia where many atolls are inhabited (see the example of other Pacific islands [45]). There may also be an increase in the frequency of tidal waves\(^5\), bringing with them an increased risk of flooding. For example, a tidal wave of 1.40 m in the Loire estuary would occur about every ten years if the sea level were to rise by 0.30 m (figure 10) [46].

The health risks identified are essentially as follows:
- infection by contamination of drinking water or contact with dirty water or deterioration of the life-related habitats (mildew, fungus arising from chronic damp, etc.);
- effects on mental and somatic health due to the psychosocial impact of material losses such as housing and working tools and to the resulting deterioration of living conditions;
- effects on the environment, for example due to the spread of toxic products triggered by the flood.

The impact on mental health is important and must not be neglected, particularly in the case of large-scale, sustained or repeated flooding, which involves particularly sensitive populations or requires evacuations and rehousing operations [47,48].

\(5\) Higher-than-normal increase in the sea level compared to tidal forecasts. It can be caused by onshore winds, low atmospheric pressure and the tides.

\(\triangleright\) Forest fires
Climate change will increase the duration of the summer droughts which provide the perfect conditions for forest fires. The health impacts of forest fires in the medium and long term are little known. The smoke is formed of a complex mix of combustion products: carbon monoxide, formaldehyde, acrolein, benzene, carbon dioxide (CO\(_2\)), nitrogen oxides, polycyclic aromatic hydrocarbons (PAHs), ammonia, 2-furaldehyde, inhalable particles and nanoparticles [49,50]. Organic compounds emitted during combustion can also contribute to the formation of ozone. In Asia and North America, a link has been documented between exposure to high concentrations of particles following fires and an increase in hospital admissions for respiratory and cardiovascular problems, principally amongst asthmatics, those suffering from chronic obstructive bronchopneumopathy, children and the elderly [51-54].

The material consequences of the waste resulting from the fire also have a significant psychosocial impact.

\(\triangleright\) Droughts
There are few studies on the impacts of extreme climatic events of long duration such as droughts. In Australia, the social and economic impacts and the impacts on mental health are documented [55].
### 4.1.3.3 Recommendations for surveillance

The issue is to develop surveillance that is useful for better management of the health impacts of localised extreme climatic events and, more generally, disasters. This means surveillance that focuses on the impacts in the short, medium and long term, based around the alert, the analysis of the health impact and its evolution over time based on the actions undertaken or the evolution of French society.

#### The alert

To facilitate the alert and limit the short-term health impact, the InVS, via its central departments, and its regional departments (Cire), is developing tools for assessing the scale of the immediate health consequences of the disaster and the early identification of the emergence of health problems, whether they be directly or indirectly linked to the disaster.

The principle is to analyse the aggregated available data on the various events and their impacts in an iterative, progressively more methodical and standardised manner based on the aggregated available information sources (weather data, power cuts, flood maps, reimbursements per sector, available data on activities in hospitals and by the emergency services, etc.).

Among the actions already carried out and underway are the following examples:

- the development by the Antilles-Guyana Cire of a decisional tool that aims to prioritise the health events to be monitored according to the environmental and social disruptions or damage brought about by the disaster. This tool, created for the Overseas Territories, needs to be adapted for the metropolitan context;
- analysis of the data from the French syndromic surveillance system OSCOUR® following natural disasters: forest fires in Marseille in June 2009, the Klaus storm in January 2009, the volcanic eruption on Montserrat in February 2010, etc.;
- tests relating to the gathering and the relevance of the use of exposure data compared to the analysis of the OSCOUR® data;
- power cuts via the zone’s operational centre, meteorological data via Météo-France, etc.;

In addition:

- a tool for recording the reasons for consultation with hospital emergency departments associated with an event needs to be developed and tested in collaboration with doctors. This tool should enable an alert to be given relating to the scale of an unforeseen health problem;

#### Figure 10

Populations impacted by floods linked to rising sea levels during the period from 1961-1990 (left) and 2080 (right) [15]
finally, the accurate and precise analysis of reasons for the use of the emergency departments in some hospitals located at the heart of the impact zone could enable identification of the specific transitions to a scenario (e.g.: chainsaw accidents in the weeks following the Klaus storm at the hospital in Mont de Marsan).

These actions should enable the development of impact indicators and methods of interpretation of the syndromic data and data on mortality rates and consumption of healthcare resources. The systematic and standardised analysis of this data during and after disasters should ultimately constitute a true surveillance system aimed at rapidly identifying health problems according to disaster scenarios and assessing their extent and scale. The information gathered will be useful in adapting the ways in which the disaster and its impacts are managed. Thus, the alerts and prevention messages for specific meteorological events should be prepared in advance and disseminated according to the event in question, its expected impacts and its impacts as measured by the surveillance systems already in place (e.g. cases of carbon monoxide poisoning due to improper use of generating sets and improvised heating appliances following the Klaus storm and the resulting power cuts).

Analysis of the health impact
To improve the analysis of the health impact in the short, medium and long term, the work begun by the Peraic programme on the analysis of the data mentioned previously for the alerts must continue. It should be enhanced by a more precise and systematic analysis of the data relating to healthcare consumption (medications, consultations) gathered by the French National Insurance Fund for Salaried Employees (CnamTS) and compiled in the French National Information System for Health Insurance Schemes (Snir-AM). An initial stage consists in the analysis of the échantillon généraliste de bénéfi- ciaires (a permanent representative sample of the population protected by French health insurance). This analysis should enable us to go further in identifying the relevant information to be extracted from the Snir-AM in order to assess the health impact of an event more accurately. Currently, Peraic is testing the relevance of the use of the data relating to reimbursement for psycho pharmaceutical medications in the aftermath of the Klaus storm. This will constitute an indicator of the impact of the event on the mental health of those involved.

To improve the analysis of the health impact of a significant event, Peraic is currently working with partners operating in the management of emergency situations as well as in the management of the post-accident phase on the feasibility of implementing, straight after the event, a census of the identities of those involved in order to enable epidemiological surveillance in the medium and long term of the state of health of these people. The programme must also focus its efforts on the preparation of tools for monitoring the long term expected effects and their determinant factors within populations. In particular, it will work on the implementation of protocols for monitoring the cohort. Likewise, the relevance and feasibility of joining this data with that of the Snir-AM must be investigated. The analysis of catastrophic events and their impacts should enable a better understanding of the plans for management and the preventive actions implemented before, during and after the event.

Analysis of the evolution over time of the health impact of disasters based on the actions undertaken or the evolution of French society.

Once the health impacts and specific scenarios have been defined, real-time surveillance of the impacts corresponding to the events will enable information on the adaptability of the population to the management of these events or the weakening of the population to be gathered, depending on the time and the management policies implemented.

4.1.3.4 Recommendations for knowledge
The research must focus on the factors influencing the health impact in the short, medium and long term and on the means of assessing them in a reliable and cost-efficient fashion. Note:
- the social and economic characteristics of the population;
- the ways in which the population is exposed to the consequences of the disaster and the management actions undertaken;
- the evaluation of the effects of the methods of uptake of emergency medical and psychological care and the methods used for long-term psychological monitoring of patients and populations.

The InVS plans to facilitate the development of the research on two issues in particular:
- the analysis of the impact on mental health of such events according to the social and economic characteristics of the population, the ways in which the population is exposed to the consequences of the disaster and the management actions undertaken;
- the evaluation of the effects of the methods of uptake of emergency medical and psychological care and the methods used for long-term psychological monitoring of patients and populations.

The aforementioned census of the populations involved will facilitate the establishment of specific cohorts that should enable this research to be carried out.

4.2 Changes to the environment

4.2.1 Air quality

The short-term effects of atmospheric pollution on health have been quantified in a number of international studies carried out since the beginning of the 1990s. They have shown an increase in mortality rates, hospitalisations and admissions to casualty departments for respiratory and cardiovascular problems in line with an increase in atmospheric pollution. Studies into the chronic effects linked to long-term exposure to atmospheric pollution tend to show an increase in the risk of developing lung cancer or a cardio-pulmonary disease (myocardial infarction, chronic obstructive bronchopneumopathy, asthma, etc.). These effects are more significant than the short-term effects.

The interactions between climate change and air quality are complex. On the one hand, climate change will have an effect on the concentrations of pollutants. On the other hand, atmospheric pollution contributes to climate change. It is also directly impacted by policies that aim to reduce greenhouse gas emissions.

4.2.1.1 Current status of surveillance

Surveillance of air quality is routinely carried out by the French Official Air Quality Monitoring Associations.
The "Programme for surveillance of air and health" has the objective of maintaining and coordinating, at a national level, the activities relating to the epidemiological surveillance of the health impact of urban atmospheric pollution in the short term [57,58] and the long term, and aligning these activities with plans in place at a European level. The development of this programme over the coming years will include the study of new pollution indicators and health indicators such as the consumption of medications or interventions by the emergency services (surveillance of the short-term effects of atmospheric pollution) and the use of data from the Elfe and Gazel cohorts (surveillance of the long-term effects).

4.2.1.2 The expected impacts

- **Impacts of climate change on atmospheric pollution**
  High temperatures encourage the production of ozone. Increasing temperatures are likely in particular to provoke an increase in emissions of the precursors of ozone (biogenic organic compounds of plant origin such as isoprene) and stimulate the photochemical reactions that lead to the production of ozone. The very high levels of ozone observed during the summer 2003 heat wave in Europe [59] and their associated effects on health [60,61], even though they were relatively marginal in comparison to those linked with high temperatures, can certainly be considered as the model for what could be produced in future [59,62] (figure 11). The effect on the base levels of ozone has been the subject of more discussion because the results of the models are somewhat contradictory, due to the opposing effects of the increase in temperature on the increase in ozone production on the one hand and, on the other, the increase in rainfall and the water content of the atmosphere on the increase in the elimination of ozone [63].

  The effects of climate change on the concentrations of particles are less well-established: the impact of more frequent forest fires, higher demand for electricity and increasing recourse to thermal power stations suggest, however, a tendency for the concentration of fine particles to increase.

- **Impacts of atmospheric pollution on climate change**
  Air pollutants, particularly ozone and particles, have an overall impact on climate change. Ozone is classified in the third category of greenhouse gases [4]. Methane is one of the principal greenhouse gases and is also a precursor of ozone. The effect of particles is more complex: although carbon soot aerosols produced by the combustion of fossil fuels have a direct positive radiative forcing effect on the atmosphere, sulphates produced by the oxidation of sulfur dioxide (SO2) have a direct negative effect (reflection effect). Likewise, aerosols contribute to cloud formation, having a reflective power and therefore, a negative forcing effect.

- **Impacts of policies aimed at reducing greenhouse gases on atmospheric pollution**
  The combustion of fossil fuels is a major source of greenhouse gases and pollutants. If their usage were reduced, this would produce a twofold benefit and the net impact on health could be very significant. Given the part that transport plays in greenhouse gas emissions, this is also the case for policies that aim to reduce the usage of road, air and sea transport (for example, a modal shift away from air transport to the train). Dealing with the two issues of climate change and air pollution together also enables us to take advantage of the fact that the formation processes of pollutants in the troposphere will respond very quickly, while the effects of measures to reduce greenhouse gas emissions will only be discernable after several decades. An economic analysis carried out in 2009 shows that the benefits of policies that aim to reduce CO2 and PM10 were higher than their costs, that the policies that aim to reduce GHGs would lead to a significant reduction in CO2 emissions and in PM10 emissions to a lesser extent, while local policies that aim to fight against air pollution would reduce PM10 emissions but not CO2 emissions. Introducing synergy between these two policies could lead to additional reductions in CO2 estimated at 15% for Western Europe [64]. The Organisation for Economic Co-operation and Development suggests that the policies that aim to reduce greenhouse gas emissions could lead to significant benefits for policies that aim to improve air quality in terms of health, the environment and reduction in costs. The European Environment Agency estimates that the contribution by the European Union to the mitigation of global warming should lead to a reduction in emissions of pollutants and a reduction in health impacts as well as in their associated costs. In the United Kingdom, the group of experts on air quality concluded that a change in the quality of the air is expected in line with the changes in the summer and winter climates. Conversely, an improvement in air quality leading to a reduction in the overall concentration of aerosols could contribute to a reduction in global warming, particularly if the concentrations of elementary carbon particles were to be reduced [65].

  Certain strategies could also have beneficial effects on one issue and damaging effects on the other: thus, the use of wood as a fuel could be encouraged due to its attractive carbon balance, but under non-optimal conditions of combustion and processing of waste, it would lead to an increase in emissions of pollutants (fine particles, NOx, PAHs). AirParif, the French organisation responsible for monitoring air quality in the Ile-de-France, estimated that a 150% increase in the consumption of wood for heating compared to 2005, under the same conditions of use, would lead to a 40% increase in emissions of particles (PM10 and PM2.5), a 45% increase in emissions of carbon monoxide (CO) and a 50% increase in emissions of volatile organic compounds. GHG would be reduced by 2% [66].

  The assessment of measures for dealing with automobile emissions is also often very complex. For example, catalytic converters and particle filters enable the emission of pollutants to be reduced (particulate matter (PM), NOx) but tend to reduce the energy efficiency of the vehicles and therefore increase greenhouse gas emissions per kilometre driven. Furthermore, the use of diesel has been encouraged for reasons of improved energy efficiency but its use leads to an increase in emissions of PM, especially carbon soot, and NOx, while the use of technologies to limit these emissions of PM and NOx reduces the benefit in terms of CO2 emissions.

  These few examples demonstrate the value of integrating the health element into the development of public policies, aiming both to improve local air quality and to mitigate climate change [67-71]. Several other examples of synergies and conflicts between the fight against climate change and the fight against atmospheric pollution have already been listed by the French National Institute for Industrial Environment and Risks [72].
4.2.2 Respiratory allergens

The principal pathologies associated with respiratory allergens are asthma and allergic rhinoconjunctivitis. Pollen allergies affect 10-20% of the population in Europe. In France, the prevalence is 18.5% among adults and 11-27% among adolescents of 13-14 years; this has tripled in the space of 25 years among the French population [74]. The allergic risk depends on meteorological conditions that impact the vernalisation (winter cold requirements) of perennial plants and the heat requirements that influence the development of annuals and flowering.

4.2.2.1 Current status of surveillance

Surveillance of pollen counts is carried out by the French National Aerobiological Surveillance Network. The data is joined with meteorological data and surveillance data from the sentinel network of doctors (rhinitis, conjunctivitis, asthma attacks) to produce allergo-pollen bulletins offering weekly forecasts. Around twenty allergenic plants are being monitored. Ragweed is the subject of a specific strategy for surveillance, prevention and early eradication in the areas where it still has a small presence or is no longer present, as well as monitoring of its growth.

Epidemiological surveillance of asthma is carried out at the InVS (prevalence, mortality rates, hospitalisation rates and emergency admissions for asthma). Data from the French Programme for Medicalisation of Information Systems and the French Centre for Epidemiology on Medical Causes of Death (CépiDc) are routinely analysed at a national level according to a schedule that is linked to the availability of the databases. SurSaUD data (Health surveillance of emergency departments and deaths) is also used at a national and regional level to monitor emergency admissions for asthma [75]. Within this framework, a working group (InVS and Cire) has enabled the standardisation of the methodology for analysis of the data relating to emergency admissions for asthma.

4.2.2.2 The expected impacts

Some authors hypothesise about the role played by climate change in the increase in cases of asthma observed since the 1950s [76]. However, it is worth remembering that respiratory allergens are not the only risk factors in the occurrence of asthma, or in the aggravation of an existing case of asthma.

Meteorological conditions encourage the production and dispersal of pollen, and the climate influences the existing species in a given geographical zone. Climate change is likely to bring about changes to the vegetation zones (movement further north of some Mediterranean species, for example [77]), prolonged periods of pollination, which has already been observed for certain species (figure 12), and even an increase in the quantities of pollen produced [78]. The end of the pollination period is often very late, with an average delay of 5 days over the whole continent of Europe and for all species [79], the pollination period is often very late, with an average delay of 5 days. The allergic risk depends on meteorological conditions that impact the vernalisation (winter cold requirements) of perennial plants and the heat requirements that influence the development of annuals and flowering.

Meteorological conditions encourage the production and dispersal of pollen, and the climate influences the existing species in a given geographical zone. Climate change is likely to bring about changes to the vegetation zones (movement further north of some Mediterranean species, for example [77]), prolonged periods of pollination, which has already been observed for certain species (figure 12), and even an increase in the quantities of pollen produced [78]. The end of the pollination period is often very late, with an average delay of 5 days over the whole continent of Europe and for all species [79], even though there are exceptions for some plants and some localities. This is already leading to more prolonged periods of exposure to allergenic pollens for sufferers, and these could extend even further in the years to come. In addition, even though few studies have been carried out so far, the increase in temperatures is likely to render the pollen even more allergenic. This has been demonstrated in the case of the birch; the higher the temperature, the more of the allergen Bet v1 is contained in the pollen [80,81] and for the common ragweed
Ambrosia artemisiifolia, for which an increase in temperature of 3.5 °C would lead to an increase of 30-50% in the allergen Amb a1 in its pollen grains [82,83]. The increase in levels of CO₂, which goes hand-in-hand with global warming, is likely to increase the quantities of pollen produced [84] and their allergenicity [83,85]. Models produced for the ragweed pollen have demonstrated that the production of this pollen is likely to increase by 32-55% between 2070 and 2100, due to the increase in the CO₂ content of the atmosphere [86].

Common ragweed (Ambrosia artemisiifolia) is currently present in many regions of France and is capable of growing in a large range of temperatures (its optimum temperature is around 30 °C). With climate change, the common ragweed will benefit from a delay in the first frosts at the end of the season to produce more seeds or to terminate its development cycle in new geographical zones, further north. These geographical changes currently being recorded are not exclusively due to climate change. They are part of the overall changes in land use, for example the increase in fallow land, the increasing number of allotments in city suburbs, developments made in some cultivations (corn, sunflowers, soya) and in uncultivated land areas (since 1992, the Common Agricultural Policy, which imposed a freeze of cultivations (corn, sunflowers, soya) and in uncultivated land areas which 84% of symptoms involve rhinitis or conjunctivitis). Bearing in mind the current surveillance system that exists for asthma, it does not seem to be a priority to develop a specific surveillance system for allergic rhinoconjunctivitis. On the other hand, to enhance the current surveillance mechanisms, regular measurement of the prevalence of atopic syndrome (sensitisation to allergens by production of Immunoglobulines E) within the general population could be envisaged.

4.2.2.3 Recommendations for surveillance
At the present time, the InVS has no specific surveillance system for monitoring allergic rhinoconjunctivitis. Allergic rhinoconjunctivitis represents a public health problem due to its high prevalence, but this is a benign pathology, although it is incapacitating and can involve a cost to society that is far from negligible in terms of absence from school and work and consumption of healthcare (this cost has, for example, been estimated at 156.6 million dollars for allergies to ragweed pollen in Quebec, where the prevalence is 17.5% and for which 84% of symptoms involve rhinitis or conjunctivitis). Bearing in mind the current surveillance system that exists for asthma, it does not seem to be a priority to develop a specific surveillance system for allergic rhinoconjunctivitis. On the other hand, to enhance the current surveillance mechanisms, regular measurement of the prevalence of atopic syndrome (sensitisation to allergens by production of Immunoglobulines E) within the general population could be envisaged.

4.2.2.4 Recommendations for knowledge
More in-depth study is necessary of the interactions between atmospheric pollutants and allergens on the risk of allergies. The impact of changes in temperature, atmospheric CO₂ and water resources on the development of plants and changes to their allergenic potential is still not well understood and further research should be encouraged.
More development is also needed in terms of taking into account allergenic pollens in the selection of plants for land use [94].

4.2.3 Habitat

Habitat is a central element in the issues surrounding public health, both in terms of meteorological events and for climate change. The French pass more than 80% of their time inside buildings and 70% inside their own homes.

4.2.3.1 Current status of surveillance

The National Housing Survey (ENL7), the most recent iteration of which was carried out in 2006, includes detailed information on the characteristics of residential dwellings (quality of the habitat: state of the dwelling and the building, noise levels, exposure, location, environment, neighbours, security, construction works in progress, etc.) and the social and economic characteristics of the occupants.

In order to strengthen the fight against carbon monoxide poisoning, a surveillance system, driven by InVS, was implemented across the entire territory of metropolitan France in 2005. The objectives of this system are to alert the public authorities so that they can take preventive action or take steps to prevent recurrences, evaluate the scale of the problem, describe the circumstances under which it arose, characterise the victims of poisoning and evaluate the public health measures put in place. The surveillance system depends on information being provided in the event of any suspected case of CO poisoning [95].

4.2.3.2 The expected impacts

Habitat is a central element in extreme climatic events, heat waves [96,97] and cold waves [98]. The increase in the number of extreme climatic events could be associated with an increase in cases of carbon monoxide poisoning, as was seen at the time of the Klaus storm.

An increase in mould or mildew contamination in the air inside buildings could also be envisaged; this is likely to develop more easily in warmer climate, or to arise more frequently following extreme climatic events such as floods. These moulds and mildews can lead to significant health problems, including respiratory symptoms, allergies and asthma [99]. The LARES study, carried out in eight cities by the WHO’s regional office in Europe, found that a bad state of health was significantly associated with high levels of discomfort caused by heat, with problems linked to waterproofing and with the presence of humidity and/or mildews and mould [100].

The improvement of energy efficiency in residential properties is a key element in policies aimed at reducing greenhouse gases implemented in France. It enables mortality and morbidity rates to be reduced in summer and in winter, and is reflected in a general improvement in the quality of life [101]. An English evaluation of the impact of improvements in energy efficiency by different methods (improvement in materials, better ventilation, changes in heating systems and behaviour patterns) demonstrated an overall positive impact on health [102]. The consequences for quality of air inside buildings of these measures that aim to improve energy efficiency must of course be subject to precautions (e.g. insulation and the inherent consequences of confinement of air) [103], but they will be limited and will favour the implementation of adapted technologies.

4.2.3.3 Recommendations for surveillance

The French national housing survey should be continued and enhanced by the addition of a health-related section. Data from the general census of the population could include elements relating to the minimum comfort levels for housing and could be enhanced by the addition of information contained in the Communal housing file (FILOCOM)8/Potentially unfit private housing (PPPI)9/administrative database or with the development of a database listing the various compulsory diagnostics carried out during changes of occupancy (energy efficiency in particular).

Monitoring of surveillance data on the presence of mould and mildew and humidity levels as well as their origin would also be of value. The development of qualitative or semi-quantitative methods of measuring the presence of mould and mildew and humidity levels would enable this monitoring to be carried out.

4.2.3.4 Recommendations for knowledge

More in-depth study is needed of risk factors attributable to housing in mortality and morbidity rates during heat waves and cold waves. A better understanding of the temperatures inside residential buildings, temperatures at which people are effectively exposed, would be useful in orienting preventive measures. Experiments have been carried out, for example, aimed at building models of interior temperatures from exterior temperatures and urban models [104]. Such studies could result in actions for urban development aimed at limiting the size of heat islands, for example.

4.2.4 Ultraviolet (UV) rays

While the risks linked to exposure to UVB rays have been well-known for a long time, the mutagenic activity of UVA rays has been known about for less than ten years [105]. The principal risks relate to the skin (basal cell carcinomas, spinocellular carcinomas, malignant melanomas, sunburn, allergies, and aging of the skin). Around 80,000 new cases of skin cancer are diagnosed each year in France. This number is constantly on the increase, increasing annually by 7%. Melanoma (5-10% of skin cancer cases) is the most serious form and represents the leading cause of death by cancer in young adults (aged 20-40 years) [105]. It is linked to exposure to the sun during infancy [106]. It should be noted that the increase in UV rays observed in Europe does not suffice to explain the increase in cases of skin cancer recorded over recent decades. The major role played by behavioural changes linked in particular to holidays and sun seeking should be highlighted [107].

4.2.4.1 Current status of surveillance

The UV Index is a scale for measuring the intensity of the sun’s UV rays and the risk that this represents to health. Météo-France forecasts the UV Index for metropolitan France throughout the summer period. Thanks to satellite measurements, it is now possible to gain information on the levels of UV light encountered per 25 km² across Europe on a daily basis.
Certain cancers occurring in adults, including skin melanomas, are subject to epidemiological surveillance based on known mortality rates across the whole territory (death certificates, CépiDc) and on the number of cases recorded in departmental cancer registers. As these departmental registers cover around 18% of national territory, methods for estimating the number of cases nationally have been developed in the framework of a scientific partnership between the French network of cancer registries, Francim (the association of French cancer registries), the French Institute for Public Health Surveillance, the Biostatistics Department at the Lyon Civil Hospices and the French National Cancer Institute. The other types of skin cancer are not subject to systematic surveillance by the cancer registries. The Haut-Rhin and Doubs registries record basal cell carcinomas. Spino cellular carcinomas are also recorded by some registries but the data is not presented at a national level.

UV rays can also be responsible for lesions and serious eye problems: cataracts – the most common cause of blindness in the world and responsible for 450,000 surgical procedures per annum in France (cataract operations are the leading procedures in France in terms of frequency), age-related macular degeneration and, more benignly, ophthalmia.

4.2.4.2 The expected impacts
The evolution of UV rays as related to climate change is at the present time still uncertain. Some models predict a marked decrease in rainfall and cloud cover across parts of Europe during the summer, which would lead to an increase in ultraviolet rays. Initial measurements of the quantity of UV light per 25 km² showed an increase in UV rays in June during the last decade compared to the previous decade. In addition, longer summers and an increasing number of sunny days could lead to behavioural changes that would increase the exposure of the population to ultraviolet light.

4.2.4.3 Recommendations for surveillance
In order to monitor the temporal and spatial evolution of cancers that are attributable to UV rays, it would be necessary to improve the epidemiological surveillance of spinocellular and basal cell cancers. At the current time, local initiatives are recorded by the Haut-Rhin and Doubs registries. These initiatives need to be strengthened, and extension to other registries could be envisaged. Other surveillance methodologies would need to be discussed with the clinicians concerned.

With regard to melanomas, the current surveillance seems to be sufficient to meet requirements. For cataracts, only the data on surgical procedures is routinely available at the moment. This type of data does not seem to be optimal in terms of monitoring the health impact of UV rays. It would therefore be necessary to obtain an estimate of the incidences of cataracts by carrying out transversal repeated surveys across the general population or with ophthalmologists.

Definition and surveillance of individual behaviour patterns are essential in understanding the evolution of risks and in providing levers for action in the areas of risk prevention and public health. In France, sun prevention campaigns are carried out on an annual basis. They were led in 2009 by the French National Institute for Prevention and Health Education (Inpes) 10. These campaigns are the subject of impact assessments, which evaluate in particular changes in individual behaviour patterns subsequent to the campaigns. The implementation of temporal and spatial surveillance of individual behaviour patterns could depend on this evaluation tool. Thus, this type of surveillance would enable the study of interactions between the behaviour of populations and UV levels.

4.2.4.4 Recommendations for knowledge
The development of models and studies enabling the definition of exposures to UVA and UVB needs to be encouraged. Combining estimates of average levels of UV rays with distribution indicators for behaviour as it relates to UV light among the population could enable surveillance of exposure to UV light and, consequently, of the future evolution of the risk of skin cancers which are attributable to the sun.

Epidemiological and mechanistic studies are also essential, to enable the fine tuning of knowledge about the relationships between exposure to UV light and health risks.

4.2.5 Water-related risks
Waterborne health risks include risks linked to the water supply and risks linked to water used for leisure purposes, as well as industrial water (Legionnaires’ disease). This type of risk is associated with all three methods of exposure (ingestion, inhalation and contact). The dangers associated with these exposures are many and varied. The risk of infection includes around a hundred micro-organisms carried in faeces (Salmonella typhi, pliovirus, Helicobacter pylori, Cryptosporidium sp. and the other agents of gastroenteritis) and opportunistic agents (Legionella pneumophila, Naegleria fowleri, Pseudomonas aeruginosa…). The World Health Organisation (WHO) considers that the risk of infection is the most widespread and the most worrying for all countries, including developed countries [108], and advocates epidemiological surveillance of the risk in addition to assessment of the water quality and evaluation of the risk. The toxic risk is primarily a long-term one and often very localised [109]. The risks that present the most concern in France are those linked to the by-products of disinfection [110] and to a lesser extent to arsenic, vinyl chloride, lead and cyanobacteria. Some very well-known toxins do not currently fall within the scope of health surveillance, either because they do not present a risk at the present time (nitrates) or because exposure to them through water is negligible (pesticides), or because the risk to human health has not yet been established and requires more research (medicines in water).

4.2.5.1 Current status of surveillance
The InVS has focused its surveillance efforts on the risks of infection from faecal matter carried by water in the water supply. Other risks have been the subject of specific epidemiological studies (Legionnaires’ disease, arsenic) and studies that aim to take the approach of exposure (by-products of disinfection).

Severe cases of gastroenteritis are a traditional indicator of pathologies that can be attributable to pathogens of faecal origin. The InVS has indentified the data from reimbursements for medications, collected by the various health insurance bodies and brought together in the French national information system for health insurance schemes (SniiR-AM), as a source of data that enables daily monitoring at a community level of the incidences of severe gastroenteritis. The sensitivity and the level of spatial and temporal resolution of this indicator have proved to be adequate for the study of the risk of infection carried in the water supply originating from faecal matter.

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10 Institut national de prevention et d’éducation pour la santé.
Other sources of health data are used to study waterborne risks. These are principally cancer registries, necessary for the study of toxic risks in the long-term. The cancers of interest are those relating to the urinary system, the lungs, the liver and the stomach as well as colorectal cancer, etc. Furthermore, gathering data from the compulsory notification of certain infectious diseases (typhoid, Legionnaires’ disease, etc.) or non-infectious diseases (lead poisoning) enables the monitoring of incidences of serious pathologies that are potentially linked to water.

Finally, syndromic surveillance and toxicant monitoring based on calls to anti-poison centres provide alerts relating to rare and unforeseeable risks, such as those brought about by malicious acts or the appearance of a tropical toxic alga.

As diseases originating in the water are multifactorial (i.e. there are several causal agents and several methods of exposure), the health data alone cannot indicate to what extent they are attributable to water. In this regard, data on exposure to water is indispensable. The "Sise-eaux" database (Health and environment information system – water supply)\(^{11}\) which brings together the results of the statutory inspections of the quality of the water in the water supply, is the only national resource, continuously supplied with data since the year 2000, that enables the exposure to contaminants in drinking water throughout France to be estimated. The InVS also evaluates the usefulness of the records relating to usage data (cloudiness, residual chlorine, outflows, etc.) to estimate the exposure to the risk of infection originating from faecal matter.

### 4.2.5.2 The expected impacts

> **Water for consumption**

Rather than causing new risks to emerge, climate change is likely to bring about an increase in the frequency and intensity of well-known adverse phenomena such as severe low water levels and surface runoffs immediately following episodes of heavy rain. It will have a direct affect on ecosystems via a rise in temperatures. The exposure of the populations will therefore be modified both by changes arising from the contamination of environments and by the modification of "determinants of exposure".

Ecology and the pathogenicity of toxic or “opportunistic” micro-organisms could be modified by changes in certain climatic parameters \(^{111}\). Experts agree, for example, that the frequency of the blooming of cyanobacteria is estimated to increase with climate change. The increase in water temperatures in summer will on the one hand encourage the growth of cyanobacteria (the optimum temperature is around 25 °C) and on the other hand favour the stratification of water in the reservoirs which is a precondition for blooming. The production of toxins, which is inconstant, also seems to be determined by climatic factors but the link is insufficiently understood to be able to support any forecasts. This blooming principally affects water in reservoirs, which represents 1/3 of the surface water used for the production of drinking water, and particularly dystrophic water, through the excessive inflow of fertiliser into bodies of water. The impact of the blooming of cyanobacteria on the quality of water in the water supply may be reduced by adequate treatment of the water (for example, filtration on the banks, ultrafiltration). Assuming that neither agricultural fertilisation practices nor methods of treatment of water to make it drinkable change, the exposure to cyanobacteria of the population supplied by reservoir water will increase in the context of climate change.

Data from countries with hotter climates than France does not suggest that for pathogens originating in faecal matter there will be a significant rise in risk levels in line with an increase in temperature, but rather that there will be a reduction, linked to the direct stimulation of their disappearance by predation. *Non-cholera Vibrio* is the exception, due to the presence of intermediate hosts (copepods), the populations of which would increase in line with a rise in temperature, but this concerns the food-related risk via the consumption of shellfish.

The essential drivers that will increase the risk of contamination of water by faecal matter are surface runoffs and severe low water levels rather than variations in temperature. These two extreme water-related situations are likely to bring about severe water pollution, either by concentration of pollutants (in the case of low water levels) or by the introduction into the water of faecal matter from the ground or from overflows from sewerage systems (in the case of surface runoffs). The pollution by faecal matter of raw water concerns vulnerable surface water and groundwater (alluvial deposits, karsts) but the risk of infection principally affects rural populations that are supplied by karst water systems, because treatments used in small water treatment installations are often insufficient for inactivating or eliminating micro-organisms.

Surface runoffs and low water levels also lead to an increased concentration of soluble organic matter or particles in the surface water. The organic matter reacts with disinfecting products (chlorine, ozone) to create by-products of disinfection such as trihalomethanes. Water in the water supply produced from surface water (1/3 of the total water in France) is particularly sensitive to the risk of appearance of by-products of disinfection.

Changes in the determinants of exposure may also be envisaged. A trend towards water-saving is already appearing via the use of private wells or rainwater harvesting, which is in theory reserved for uses other than consumption. It is difficult to forecast quantitatively the effect of this trend on exposures to toxins and pathogens. The drop in consumption leads to the water being held in the distribution network for longer, which is likely to affect the water quality: production of certain by-products of chlorination, the development of bio film sheltering opportunistic pathogens. Also of concern is a possible increase in the number of accidents due to the inflow of water into the urban network attributable to the installation of unprotected connections between the urban network and the domestic network, dedicated to water produced on the spot.

> **Water used for bathing or swimming**

Water used for bathing or swimming is also likely to see an intensification of the risks linked to the presence of cyanobacteria. The free-living amoeba *Naegleria fowleri*, which is periodically found in low concentrations in fresh water, but which has not been the cause of any reported cases of meningitis in France, could become a cause of this disease with the warming of fresh water bodies. The emergence of tropical algae could also be a concern, as in the growth of Mediterranean *Ostreopsis ovata*. This dinoflagellata is the

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\(^{11}\) Système d’information santé environnement – eaux de distribution.
cause of skin irritations in swimmers and can provoke epidemics of asthma attacks among riverside dwellers by aerosolisation of cellular debris. Exposure is therefore dependent on particular meteorological conditions which could occur more frequently in the future. Exposure could also increase along with an increase in the practice of swimming in natural water. The food-related risk linked to the bioaccumulation of dinoflagellate toxins in the food chain, present in the tropics but limited in France to diarrhoea syndrome (Dinophysis ovata), could also increase and bring about more serious effects, such as neurological ones, for example.

**4.2.5.3 Recommendations for surveillance**

The expected impact of climate change does not justify the development of new health surveillance mechanisms. It requires however the improvement.

The system for compulsory notification covers infectious pathologies originating in faecal matter that are likely to re-emerge in metropolitan France or to increase in the Overseas Departments, as well as Legionnaires’ disease. The cancer registries, or in the future, the “multi-source” system, which will join together various databases of medical and medico-administrative activity (hospitalisations, medical insurance and anatomical pathology) will constitute convenient sources for supporting studies on long-term toxic risks. Cancers to be monitored as a priority are identified with regard to (i) current risk levels, (ii) how attributable they are to water and (iii) possible increase with climate change (table 3). An increase of exposure is unlikely regarding arsenic. On the opposite, exposure to chlorination by-products may increase, due to a lower water quality and an increase residency time in the network. Cancers to be monitored as a priority are then bladder cancer, colorectal cancer and liver cancer.

From the climate change point of view, databases that are not dedicated to epidemiology may, however, pose a problem in terms of homogeneity over time.

With regard to exposure, the content of the Sise-eaux database of the Sniir-AM needs upgrading, which poses the problem of its capacity to bring to light epidemiological trends. Data from statutory water inspections are, for example, subject to changes in sampling and analytical techniques imposed by European regulations which are revised approximately every 10 years. The biases introduced by these changes must be subject to careful assessment so that the data can be properly and appropriately used.

Use of data relating to reimbursements for medication collected by the CnamTS poses a similar problem. The medications used in the treatment of gastroenteritis are of limited effectiveness. They have been partly disallowed and this may continue, thus removing disallowed specialities from the database and altering over time the homogeneity of the epidemiological indicators based on this data. In order for this resource to enable agreement on the epidemiological trends moderated over the timescale of one decade, it would involve developing a system for referencing the definition of cases that is independent of medical activity. This bias does not, however, affect the monitoring of risk factors over time, i.e. it is still effective in supporting actions for public health.

Given the indispensable nature of these resources for the surveillance of water-related risks, the epidemiological valuation of Sniir-AM and Sise-eaux must be continued as must the amendment of the content of the database in order for it to be more useful in epidemiology. A description of the treatments and the safety mechanisms in the Sise-eaux database would, for example, increase significantly the potential of the database in terms of estimating the exposure levels of the French people but also of defining those installations that are most vulnerable to climate change. With regard to Sniir-AM, the recovery of prescribed but not reimbursed medicines would write off the effect of disallowing them.

Finally, the surveillance of determinants of behaviour would be necessary in order to achieve a greater understanding of the risks. It is a question of moving away from the model that has prevailed in many studies, which consists in confusing exposure with water contamination, assuming a standard level of consumption in the population and over time.

In the case of dinoflagellata and other algae and toxic bacteria, it is necessary to adapt the existing environmental surveillance systems to the detection of new species and the evolution of the phenomena. It is important that the InVS maintains its relationships with agencies and expert universities in order to monitor and ensure that these systems meet the requirements in terms of alerts for public health.

**4.2.5.4 Recommendations for knowledge**

The definition of the organic matter in water in order to treat it requires more research as a priority, given the influence of this parameter on the toxic and microbiological risk and the probable adverse evolution of the problem. Furthermore, it would appear necessary that French research also returns to some subject areas which have been neglected, such as the risk of infection in the water supply originating from faecal matter or the risk of cancer attributable to the by-products of disinfection. Here also the priority must be to define the nature of the exposure, as the nature of the carcinogenic molecules remains controversial.
Many terrestrial and marine ecosystems have already been impacted by climate change, with displacement of species or changes to species having already been observed. For example, the expansion of the pine processionary caterpillar (Thaumetopoea pityocampa) is considered as a marker for climate change by the Onerc (figure 13).

The health effects are stinging or itching; the caterpillar’s hairs release a substance that brings about a localised inflammatory response: urticaria, conjunctivitis, irritating cough. In some cases, the effects can be similar to those of an allergy: triggering of an allergic reaction, provoking IgE synthesis against the allergen, with the possibility of serious systemic effects (laryngeal oedema, anaphylactic shock) [112].

The oak processionary caterpillar (Thaumetopoea processionea) and the brown tail moth caterpillar (Euproctis chrysorrhoea) have also already been the subject of health alerts.

4.2.6.1 Current status of surveillance

There are no specific surveillance systems in place. However, the national toxicant monitoring network, which is particularly dependent on the anti-poison centres, could enable monitoring of cases. Syndromic surveillance enables monitoring of emergency admissions for stings and contacts with venomous animals. The French Museum of Natural History has launched a network of amateur naturalists that will constitute a system for surveillance, monitoring and alert regarding the distribution of animal and plant species.
4.2.6.2 The expected impacts

The geographical distribution of a species depends on the physicochemical conditions of its environment, interactions with other species, restrictions on its spread or factors that encourage it. The interaction between these factors is complex, such that it is difficult to forecast the geographical evolution of a species. By default, it is primarily the physicochemical conditions that are used to determine a "climatic envelope" in order to predict the response of a species to global warming. For the moment, apart from some specific cases, this indicator on its own is not sufficient to be able to predict the evolution of a species, since there are many other factors, such as land use [113], which come into play. By default, the implementation of monitoring and surveillance systems for watching the evolution of species in space and time would be potentially very useful. Studies carried out by naturalists' associations have warned, for example, of the migration of some species from the south of France towards the north (insects, birds). Likewise, the observation carried out in collaboration with the French Museum of Natural History demonstrates that northern species in France are witnessing a negative evolution.

4.2.6.3 Recommendations for surveillance

Existing environmental surveillance should enable the identification of unusual episodes, in terms of species, numbers, time periods, geographical extent and trends. Previous experience shows that it is, however, necessary to maintain expertise in France in terms of amateur and professional naturalists' ability to identify species.

The identification of health episodes is possible via syndromic surveillance and the network of French and European anti-poison and toxicant monitoring centres.

4.2.7 Soils

4.2.7.1 Current status of surveillance

There are several environmental databases that document the chemical quality of the soils in France [114]. The network for measuring the quality of the soils will enable ten-yearly monitoring, allowing the evolution of the soil quality to be monitored [115].

There is no specific surveillance programme in place that measures the impact of soils on health. However, the InVS is regularly approached with regard to issues relating to soil pollution and public health. Its work focuses on estimating the exposure to soil pollutants and on understanding the role of the populations concerned.

4.2.7.2 The expected impacts

The evolution of the soils under the influence of climatic, environmental and anthropogenic factors is a long process that is difficult to observe. Climate change could cause changes to the quality of the soils and particularly their agricultural properties, with consequences for food production that are not discussed within the scope of this report [116]. Changes to stock water may also be expected, along with changes to the physical stability of the soils and erosion [46].

At the present time, there are only a very few articles which mention possible changes to the transfer of chemical pollutants in the different environmental compartments [117], or changes to the determinants of exposure (for example, time passed outside, agricultural practices, vector control, etc.) [118,119].

Changes in land use could also generate new exposures, for example by building on contaminated land. They also pose increasing problems linked to erosion, causing dust to play a more influential role in exposure, and risk mobilising contaminants contained in sediments, during floods, for example.

Finally, soils represent a reservoir of organic carbon that could be disturbed by climate change and by changes in the usage of the soils. [116].

4.2.7.3 Recommendations for knowledge

The current level of knowledge on the interactions between soils, climate change and health does not allow us to focus our surveillance effectively. Our knowledge in this area can only be developed by monitoring the evolution of the soils over time and by multidisciplinary research.

4.3 Infectious Diseases

From the results of a previous census carried out in the French report on the impacts of climate change [23], 21 pathogens or groups of pathogens were identified as those which might potentially be impacted by climate change. These 21 pathogens or entities can be grouped into four categories:

- **Group A** covers infections carried by arthropods:
  - seven viruses or parasites transmitted by mosquitoes or sandflies: chikungunya, dengue, yellow fever, malaria, West Nile virus, Rift Valley fever, visceral leishmaniasis *L. infantum* (cutaneous leishmaniasis, which is extremely rare in France, does not appear in this list),
  - four infections transmitted by ticks: Crimean Congo haemorrhagic fever, Lyme disease, tick-borne encephalitis and Q fever;
- **Group B** covers infections transmitted through contact with rodents: haemorrhagic fever with renal syndrome (hantavirus) and leptospirosis;
- **Group C** concerns infections transmitted by the faecal-oral route: hepatitis A and E, norovirus, salmonella typhi and non-typhi, pathogenic vibrio infections and finally various parasitic infections, particularly cryptosporidium and giardia;
- **Group D** covers very different pathogens: legionellosis on the one hand, fungus/mould on the other.

4.3.1 Current status of surveillance

Among the 21 pathogens or entities listed, 20 are already the subjects of exhaustive or partial surveillance by the InVS, by means of compulsory notification or other systems of surveillance (appendix 5).

Some of this surveillance has been in place for more than ten years. It was considered necessary due to the frequency and the seriousness of the diseases in question, their potential to spread and the possibilities for actions for public health that aim to reduce the risk. Moreover, the 13 infections in groups A and B have already been subject to a re-evaluation concerning the relevance and suitability of the surveillance carried out on them, in the framework of the "prioritisation of the surveillance of non-food-related zoonoses". This approach, which aims to establish a hierarchy of priorities in terms of surveillance, was initiated in 2000 [120]; it was updated between 2005 and 2008.

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12 An entity being a group of pathogens that have the same consequences; for example, the fungus and mildew in the habitat are grouped into a single entity.
(the report is in progress). It is based on multidisciplinary expertise including that of clinicians, epidemiologists, biologists, veterinarians, public health officials, researchers and managers. The group of experts defined the priorities for the zoonoses to be monitored according to the following criteria:

- seriousness of the disease in humans (frequency or prevalence, severity, mortality rates, potential to become an epidemic, modes of transmission, existence of prevention and control measures);
- seriousness of the disease in animals or the fact that it is carried by the animal (mammal or insect);
- determinants linked to the environmental context, which could develop over time. Recently, climate change has been added to the criteria that were previously defined.

By extension, the same table of criteria has been used for the pathogens covered by groups C and D. These criteria are detailed in the tables appearing in appendix 5.

### 4.3.2 The expected impacts

It is important to remember that the epidemiology of infectious diseases is multifactorial and that the role of climate change in the emergence or re-emergence of infections is considered by many authors [121-123] as less important than the other determinants. These last particularly concern the factors linked to the host (susceptibility to infections, weak immune system, infections linked to medical care, risky practices, etc.), to the agent (mutations, reclassifications), and to the environment (sociodemographic changes, migrations, urbanisation, food and drink, circulation of people and goods, globalisation of trade, imbalance in ecosystems, increasing density of inter-species contact, economic decline, etc.).

The incidence of the 13 infections covered by groups A and B (infections transmitted by vectors and rodents) could increase due to climate change, due to the spread of the habitats of the arthropods or the increase in the population of the animal populations (rodents). Infections carried by mosquitoes are rare in metropolitan France whilst tick-borne infections are more frequent (Lyme disease, Q fever). These are for the most part considered as serious diseases.

For 12/13 of these infections, the experts from the “prioritisation of the zoones to be monitored according to the criteria that were previously defined.

The incidence of Legionnaires’ disease could also increase with global warming, by means of two possible phenomena: dissemination of the bacteria via cooling circuits in air-conditioning systems, the use of which would increase with global warming; or an increase in the average water temperature in the black waste water networks that could lead to the multiplication of bacteria.

Pathogenic fungi represent a group of very diverse germs in terms of epidemiology, particularly with regard to populations, modes of transmission and interaction between the agent and the host. Most of these fungi are ubiquitous environmental saprophytes. Their pathogenicity is most often linked to the presence of a temporary or prolonged immunosuppression in the host, which can be of variable etiology: HIV infection (candida, cryptococcosis), haematopoietic pathologies and/or bone marrow transplants (pulmonary aspergillosis, zygomycosis), etc. The elderly also seem to represent a population group at risk due to specific immune deficiencies.

Among these at-risk populations, some could be exposed more than others (dose-response effect) due to climate change; increasing periods of warm and humid weather could contribute to an increase in moulds in these people’s homes. Floods also contribute to an increase in risk, via changes in the ecology of the moulds [124-126].

### 4.3.3 Recommendations for surveillance

For the majority of the pathogens studied in this report, the existing surveillance systems could certainly be improved, but they do exist and appear to be sufficient to identify increases in the numbers of cases and to research the causes of such increases, by exploring the hypothesis of climate change among other hypotheses that could offer an explanation. According to the requirements and the conclusions of these investigations, the relevance and suitability of the current systems will be reviewed.

Global warming could provoke further emergence of these diseases, hence the importance of being able to detect them and define them from a climatic, epidemiological, environmental and microbiological point of view. On this last point, the capabilities of specialist laboratories are crucial and must be integrated into the planning for the requirements of the National Reference Centres (NRCS).

For example, in the case of Legionnaires’ disease, an increase in notified cases could raise new hypotheses with regard to the role of climate change and could lead to a re-evaluation of the current methods of surveillance. Under these circumstances, whatever the cause of the observed increase (climate change or another cause), the surveillance will need to be strengthened or adapted in due course.

From the perspective of prevention and reduction of risks, the issue of upstream surveillance and prevention also arises. Surveillance of the rates of Legionnaires’ disease in cooling towers could enable infections in humans to be anticipated in the event that thresholds are exceeded. Surveillance of dengue and chikungunya fever is strengthened each year in the south-eastern departments of France where the vector Aedes albopictus is implanted. Furthermore, a progressive extension of the habituation zone of this vector has been observed in the south of the country. The role played by climate change in this extension remains to be determined, given that there are other potential explanatory factors; whatever the explanation might be, the observation of this extension of habituation zones requires that surveillance be adapted. Surveillance must also be carried out on vectors with implantation zones that extend beyond those habituation areas.
zones that are commonly known as territories where certain vectors are implanted. The surveillance of vectors requires strengthening by means of standardisation of indicators. The strengthening of the surveillance of vectors must be looked at on a pan-European scale to be able to evaluate their extension beyond borders, particularly for the species *Aedes albopictus*. In France, the joint assessment of vector control by the Institute of Research for Development recommended to the authorities in 2009 that a National Centre for Expertise in Vectors (Cnev) be established; one of the priorities for this Centre will be to provide expertise in the development and standardisation of indicators for surveillance of vectors. The Cnev should be established in 2010-2011.

For enteric diseases, increased and strengthened monitoring of the food chain in the event of an increase in the global temperature could be envisaged. Surveillance of non-cholera vibrio infections could still be based on the effects (occurrence of the disease) or be anticipated through strengthening of environmental surveillance. *V. parahaemolyticus* infections are currently rare in France. They are transmitted in food (shellfish) and can affect the general population. Their detection is already ensured due to compulsory notification of foodborne illness outbreaks. A plan for surveillance of contamination of shellfish could be envisaged if outbreaks of the disease were to become more frequent in France. Other non-cholera vibrio (*V. vulnificus*, *V. alginolyticus*) or cholera vibrio (*V. cholera non O1, non O-139*) were reported as being the cause of various cutaneous or ENT infections in countries bordering on the North Sea and the Baltic Sea, following the heat waves of 2003 and 2006 [127-129]. Generally, those presenting underlying pathologies (hepatopathy, diabetes, wounds or sores, etc.) are at risk of contracting the infection during swimming or bathing. In the case of a heat wave followed by an abnormally high presence of vibrio species in water used for bathing or swimming on the coast, warning messages could be disseminated to the at-risk population to reduce the determinants of exposure and to clinicians to help in early diagnosis of these infections. For all these different examples, it will be important to measure the benefit (sensitivity and efficiency) of these upstream interventions that aim to reduce risk.

Finally, with regard to pathogenic fungi, the pathogenicity of these germs is limited to weakened population groups, particularly the elderly, diabetics and those with severely weakened immune systems. Structured surveillance of these fungi is for the moment not open to the public: surveillance of invasive aspergillosis takes place in a hospital environment, observation of fungi is carried out in a defined region, etc. However, the InVS, in collaboration with clinicians, mycologists and hygienists, is seeking to develop a joint assessment covering this area, in order to achieve a better understanding of these infections, their likely hosts and the environmental factors that contribute to the occurrence of these pathologies.

### 4.3.4 Recommendations for knowledge

Some areas for improvement and research are specific to each pathogen (for example: improving disease diagnostic capabilities, improve knowledge of the vectors and the modes of transmission, etc.). These specific improvements are detailed in the tables in appendix 5.

From the perspective of prevention and anticipation, it is important to strengthen the interactions between different disciplines, particularly the more systematic interactions between environmental, animal and human surveillance, as in the example of the surveillance that has been in progress in the departments bordering on the Mediterranean since 2000 (this surveillance is activated every year between June and October for West Nile virus, chikungunya and dengue). Surveillance of *Toscana* virus infections began in 2009, based on this same system. However, the role of climate change in the expansion of the vectors, or the introduction or not of new viruses, has yet to be determined. Virological studies as well as studies on the agent-host-environment interactions could, for example, lead to a greater understanding of the causes of sustained implantation, or not, of the West Nile virus in different geographical territories. Operational research projects that aim to estimate the relative size of the role played by the determinants of occurrence or of increased incidence of these infectious diseases, by putting them into perspective as required against the role played by climate change in relation to the other factors contributing to this emergence, would be useful. Thus, the increased incidence of Lyme disease in Europe is often mentioned as being caused by climate change (as it leads to an increase in the population densities of small rodents, which are the intermediate hosts of the ticks). Various others are, however, raised as contradictory hypotheses: in Belgium, the increasing tendency amongst better-off families to seek houses close to the forests could explain this phenomenon [130]; in the Baltic countries, the elderly could be exposed for longer to forests infested with ticks as they go picking mushrooms in order to sell them, due to the economic decline [131,132]. The concepts of exposure to risks and changes to human behaviour patterns are increasingly cited as being the principal factor in some emergences attributed to climate change [133,134].

Finally, more generic research projects must be planned, for example the role played by climate change in the epidemiology of the different airborne diseases: meningococcal infections, flu, and other respiratory viruses.
Climate change raises a whole range of issues that come under the scope of the InVS:
- the adaptation of tools for surveillance, alert, scientific intelligence and forecasting;
- the interface with research;
- the contribution to the implementation of actions to reduce greenhouse gas emissions by means of recommendations and evaluation of health impacts.

To these ends, the InVS must encourage:
- internal work on the surveillance of the requirements that are not already covered;
- the adaptation of existing surveillance on the areas that are “not sufficiently covered” — for example, mental health, fungi, habitat.

The InVS must also interact with partners in the adaptation or development of systems for surveillance of exposure or the environment that enable the impacts on human health to be anticipated (allergens, ragweed, cyanobacteria, etc.).

The added value of this form of health surveillance is particularly visible when its results, which are available very quickly, are used by decision-makers as a complement to other information to implement a rapid response for the protection of public health. In addition, climate change may lead to new and unknown situations, such as the heat wave of 2003, in the face of which traditional surveillance systems may not be effective. Syndromic surveillance could therefore be of value in providing useful information for managing crises and detecting unexpected events.

The medico-administrative databases could also enable analysis of the data relating to consumption of healthcare (medicines and consultations), which would be useful for monitoring the impacts of natural disasters over the medium and long term. This approach would be of value when assessing the impact on the mental health of those involved in the disaster. The data from these databases is also of value in monitoring environmental risks, water-related risks or risks relating to air pollution, provided that homogeneity in the derived epidemiological data can be maintained over time.

Finally, the cohorts enable individual data to be gathered, which could provide useful information for medium-term and long-term monitoring of the health of those involved in extreme climatic events and exposed to the psychosocial consequences of such events.

Exposure surveillance is the form of surveillance that is the least effectively carried out in the area of climate change. The hypothesis that in the absence of any evolution of the climate, behaviour patterns show little evolution, and the acknowledgement that exposure contrasts amount to the contrasts of environmental contamination, underlies the InVS’s choice of surveillance that thus in practice limits exposure surveillance to surveillance of the contamination of environments. However, the hypothesis of the constancy of behaviour does not hold up in a context of rapid climate change. In addition, surveillance of behaviour patterns could become a high-priority focus in terms of understanding, assessing and monitoring exposure of the population.

5.1 DEVELOPING THE TOOLS FOR SURVEILLANCE, ALERT AND SCIENTIFIC MONITORING

5.1.1 Strengthening the existing systems in the area of health

For the majority of risks that are potentially impacted by climate change, the environmental aspects are often subject to surveillance and, most of the time, they fall within the scope of regulations. The health aspects are also the subject either of continuous surveillance systems or of ad hoc surveys.

It is important to develop and strengthen these surveillance systems by:
- ensuring their sustainability;
- improving the quality of the data as well as its accessibility;
- encouraging better integration of the environmental and health databases.

With regard to the alert systems, they must be designed so that they are flexible and can be adapted easily and quickly to new situations.

In addition to specific surveillance systems, syndromic surveillance undoubtedly has potential in terms of identifying unusual health situations through the emergence of health signals or even by following the temporal and spatial progressions when clinical manifestations are particularly specific (allergic manifestations in particular). The analysis of these signals can then highlight any threat to public health. Continuous monitoring of health activity indicators can contribute to the measurement of the impact of environmental or societal events. In particular, the InVS has developed a system for real time surveillance based on data from the emergency services (the OSCOUR© Network). The objective of this surveillance system is to detect any threat to public health and to evaluate its potential impact on the population as quickly as possible. The routine recording of data also enables the creation of historical reference data. The utilisation of ICD10 codes also enables the evolution of pathologies such as asthma, that are sensitive to meteorological conditions, to be monitored, as well as the effects of heat and cold, vector-borne diseases, dengue, enteric infections (food borne illness outbreaks due to the bad storage of food and the increase in temperatures). Thus, between July 2004 and June 2008, the OSCOUR© network was able to identify two peaks in incidence of asthma in the Paris area in June 2006 (incidence multiplied by 10 explained by the combination of heat, pollution, pollens and storms), the impacts of the heat wave of 2006, several peaks in incidence of CO poisoning during the winter period, insect bites during the summer period (possible surveillance of the importation of a new vector) and food borne illness outbreaks.

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To that end, it would be possible to use, for example, repeated large-scale transversal surveys that look at lifestyles, food-related behaviour patterns, etc.

5.1.3 Strengthening scientific intelligence

Gathering intelligence is an ongoing activity, which aims to monitor actively the scientific, technological and societal environment in the domain of a given activity. This surveillance involves the identification, use and analysis of information sources that enable the support of scientists in their various projects and the anticipation of their requests. This action is carried out within the framework of the task to provide support for decision-making by the authorities.

In the face of climate change, the gathering of scientific intelligence by the InVS could:

- increase its focus on the environment, health and actions carried out both within the domain of research and from the point of view of public health;
- extend to interdisciplinary reviews that bring together social sciences and natural sciences, as do the Global Environmental Change, Global and Planetary Change and Climate Policy reviews.

5.2 Improving links with research

Despite current efforts in terms of research, in many areas it can be seen that there exists a lack of knowledge about the interactions between the climate, the environment, behaviour patterns and health. For many of the presupposed risks, there is not sufficient information to draw conclusions neither for public health nor for health itself in the general sense of the word. For these risks, the priority must be to improve our understanding of the environmental, behavioural and social determinants of the pathologies, and to improve the environmental models (e.g. water-related and ecological forecasts, etc.). A report by the WHO gives specific details of the requirements in terms of research [135], and sets out five broad focus areas:

- assessment of the health impacts of climate change in the short, medium and long term, at a local, national and international level;
- evaluation of the effectiveness of intervention measures and of their adaptation within the health sector;
- evaluation of the health impacts of the adaptation measures taken within other sectors;
- development of tools for health econometrics, enabling the interventions and impacts to be taken into account over prolonged periods of time;
- development of interdisciplinary research networks.

France has many research teams working on the observation and modelling of climate change and its impacts [136,137]. Studies on the health impacts focus primarily on infectious diseases and the impact of heat waves. Other projects are currently being developed in the framework of the programme for the management and impacts of climate change (GICC [138]) and the Paris Research Consortium for Climate-Environment-Society [139].

On an international scale, interactions with the United States research programme for climate change and health may also be envisaged. Heat waves and atmospheric pollution are high on the list of priorities for this programme [140].

Closer collaboration between the InVS and researchers would enable integration into the research activities of the hypotheses arising from the interpretation of the surveillance systems and vice versa. To that end, it is essential that the InVS encourages interdisciplinary research on different subjects, for example via requests for research specific to the InVS or inter-agency research implemented with dedicated InVS funding.

5.3 Monitoring the health effects of actions to reduce GHG emissions and actions for adaptation

5.3.1 Providing useful tools for decision-making and offering recommendations

The response to climate change involves two complementary actions — mitigation and adaptation. Mitigation consists in limiting the scale of climate change by reducing greenhouse gas emissions.

Under the terms of the Kyoto protocol, the objective for France is that it must stabilise its GHG emissions at the same levels as those of 1990. The objective for the European Union is that it must limit the rise in temperature to 2 °C between now and 2050. To reach this objective, global average annual emissions per inhabitant must fall by 80 to 95% compared to emissions per inhabitant of developed countries in 2000 [20].

In France, in 2007, the principal activity sectors that contributed to emissions were transportation (26%), the tertiary residential sector (18%), the manufacturing industry (20%), the energy industry (14%), agriculture and forestry (20%) and waste treatment (2%) [141]. These sectors generate services to human health but also generate risks. The measures necessary to reduce emissions are accompanied by significant changes that could generate positive or negative health impacts. For example, prevention of heat waves, management of transportation [142], reduction in atmospheric pollution [143] and improvements in habitat [102] must be coordinated and should result in long-term actions on urbanism [92,144,145]. Thus, the way forward is to convince policy makers to take into account the impacts on public health over the short, medium and long term when establishing policies that aim to reduce GHG.

As a result of the Climate Plan [146] and the “Grenelle de l’Environnement” round table (French multi-party debate on the environment) [147], several actions in favour of the environment and health, and which contribute to the mitigation of climate change, have already been defined, touching amongst other areas on improvements in the energy efficiency of buildings, the reduction of emissions linked to transportation and town planning. It is important that these actions are coordinated to avoid any counter-productive measures being taken. The InVS could provide data and tools to support several of these plans, for example:

- regional diagrams and maps of the climate, air and energy are a tool for the implementation of integrated policies that aim to fight greenhouse gas emissions and to reduce atmospheric pollution [148];
- the national plan for prevention through physical activity and sports, of which one objective is to develop the urban environment to encourage “active” modes of transportation (walking, bicycling) between home and school, college, university or work,
around relevant movement plans, should enhance the regional climate-energy plans;
- the plan to restore nature to the city environment, which will need to take into account the allergenic risk in its selection of species to be used in towns;
- renovations to existing buildings to make them more energy-efficient, which should take into account the issue of air quality inside the buildings.

5.3.2 Using epidemiological surveillance to evaluate actions

One of the objectives of epidemiological surveillance is to develop the tools that enable evaluation of actions for public health. A number of actions that fall within the scope of climate change are being carried out or need to be carried out (reduction in GHG, public health warnings, etc.). Going forwards, it will be necessary to identify the actions that can be evaluated and to establish protocols relative to these evaluations.

5.4 Developing interdisciplinarity

The complexity and imbrication of the systems involved in the issue of climate change require the InVS to explore new, more integrated resolutions to resolve the problems that arise. Interdisciplinarity assumes a dialogue and an exchange of knowledge, analyses and methods between two or more disciplines. It involves all the specialists concerned working together to share the different aspects and to enrich each others’ knowledge and expertise [149]. It leads to a greater understanding and improved definition of the situation as a whole, by putting into perspective its social, economic, cultural, ethical and political dimensions and by bringing to light the interactions between these dimensions. The issues raised by climate change render this interdisciplinarity, between the sciences of climate and the environment, social sciences and epidemiology, essential; it is indispensable, for example, in order to define the data requirements, understand the role of behaviour patterns and improve the studies relating to the impacts of extreme climatic events. Collaborations between naturalists and veterinarians are also necessary in order to observe the evolution of parasites and vectors of disease, taking into account temperature changes as well as ecological conditions due to changes brought about by human activity.

However, it takes a long time to develop interdisciplinarity to an effective level. The InVS is already committed to achieving this within its organisation, in the areas of climate change and on the subject of emergency admissions. It could be developed further with other agencies and bodies. A valuable example is that of extreme climatic events. When such events occur, it is the long-term impacts on mental health that cause the most concern. However, they are based on a chain of modifications and the extension of the impact into the different sectors of society, which can be described with the support of environmental, human, social and economic sciences. Building interdisciplinarity by integrating into existing networks, following the example of the Paris Research Consortium for Climate-Environment-Society, or by developing new partnerships, requires a great deal of preparation and development working towards shared objectives [150,151] so as not to risk failure and/or demotivation.

5.5 Developing international collaboration

The InVS needs to maintain and strengthen its international collaboration efforts, enabling the sharing of knowledge and experience that are rich in practical information, in particular by exploiting the idea of “analogue countries” – countries that have a similar climate to that forecast for future years. Pan-European projects also enable the sharing of experiences and the development of new methods for approaching complex problems. We can mention two examples to which the InVS has contributed: the EuroHeat project for the development of the alert system and the prevention plan for heat waves in Europe, which provides access to nine prevention plans from different European countries (www.euro.who.int/globalchange/Topics/20040728_1) and the Intarese project that aims to develop a conceptual framework for the analysis of complex systems, the evaluation of risks and communication about doubts and uncertainties (www.intarese.org).

The InVS also contributes via events organised by various partners in the form of conferences (e.g. WHO conference on research priorities) or seminars (e.g. a Franco-American seminar on the impacts of climate change on infectious diseases).

These collaborations are also essential when taking into consideration the health aspects of climate change in international negotiations and decision-making. The WHO and various non-governmental associations play an important role at this level.

Finally, climate change impacts the entire planet at the same time as exacerbating and highlighting inequalities. However, the InVS has a great deal of expertise on many subjects that could be shared with other countries, where the knowledge of the subject in question is less developed, reducing their ability to adapt to climate change.


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Ministère de l’Écologie de l’Énergie du Développement durable et de la Mer. La France face à ses engagements internationaux Climat en 2007 : résultats d’inventaire d’émission de gaz à effet de serre pour le périmètre Kyoto;2009.


Blanchard A, Vanderlinden JP. Selected annotated bibliography on interdisciplinary science/studies;2009.

Blanchard A, Vanderlinden JP. Are the challenges of interdisciplinary structuring and the challenges of science and policy-making integration the two faces of the same coin? A global research case study;2009.


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Intergovernmental Panel on Climate Change. Climate change: a glossary by the Intergovernmental Panel on Climate Change;1995.

The Canadian report [152] relies on consultations and surveys from experts to pick out risks and identify the level of vulnerability of the population (table 4).

In Australia, risks are selected at a workshop, during which experts discuss the health risks associated with the increasing frequency of extreme climatic events, rising temperatures, decreasing rainfall and rising sea levels. The value of their approach is that it separates the short-term (rapid) and long-term (gradual) impacts and that it takes into account the impacts arising from societal changes [153] (table 5).

The French approach consists in listing all the potential impacts of the various changes in the meteorological parameters (impact of temperatures, rainfall, wind, humidity, cloudiness) with which the experts may be concerned. The advantage of this approach is that it results a very detailed table of the possible impacts, with more than forty risks identified [23] (table 6). The disadvantage is that it presents a very fragmented image of climate change, parameter by parameter, whereas the issue of health integrates many different situations.

The work carried out in the United States [154] focuses on the development of indicators that enable the evaluation of the level of vulnerability of the population to climate change and the proposal of actions for prevention in the area of health. It is based on a review of reports and literature to select the associated risks and indicators. The risks selected are air pollution, heat waves, allergens, forest fires, droughts, toxic algal blooms and infectious diseases. The indicators identified arise principally from environmental surveillance systems. In health terms, the proposed indicators are mortality and morbidity rates linked to heat waves, extreme climatic events, air pollution and allergens and the number of cases of infectious diseases (West Nile virus, Lyme disease, dengue fever, coccidiomycosis, hantavirus cardiopulmonary syndrome) and the population of vectors for disease.

These reports are mostly qualitative. Quantitative assessments are limited by the available information, as was illustrated by an Oceanian attempt (table7).

These different approaches, which are principally based on the judgement of experts, are very similar and result in lists of identified risks with some specific regional features; increase in frequency and intensity of extreme climatic events, the emergence or re-emergence of infectious diseases, changes in the environment and ways of life that will bring about new exposures.

### Table 4

**Health risks linked to climate change – adapted from the Canadian report [152]**

<table>
<thead>
<tr>
<th>Possible effects of climate change</th>
<th>Health risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Increase in the frequency and severity of heat waves</td>
<td>- Diseases and deaths linked to the heat</td>
</tr>
<tr>
<td>- General warming but colder conditions possible in some regions</td>
<td>- Respiratory and cardiovascular problems</td>
</tr>
<tr>
<td></td>
<td>- Changes in the distribution of diseases and mortality rates due to the cold</td>
</tr>
<tr>
<td>- Increase in the frequency and violence of storms, increase in the severity of hurricanes, other forms of violent weather</td>
<td>- Deaths, injuries and diseases attributable to violent storms, floods, etc.</td>
</tr>
<tr>
<td>- Heavy rain causing landslides and floods</td>
<td>- Social and emotional damage, mental health</td>
</tr>
<tr>
<td>- Rising sea levels and unstable coastlines</td>
<td>- Scarcity of water and food</td>
</tr>
<tr>
<td>- Increase in droughts in certain regions</td>
<td>- Contamination of drinking water</td>
</tr>
<tr>
<td>- Social and economic disruption</td>
<td>- Accommodation of populations and overflow populations in emergency shelters</td>
</tr>
<tr>
<td>- Increase in atmospheric pollution</td>
<td>- Exacerbation of asthma symptoms and allergies</td>
</tr>
<tr>
<td>- Increase in the production of pollens and spores by plants</td>
<td>- Respiratory and cardiovascular diseases</td>
</tr>
<tr>
<td></td>
<td>- Cancers</td>
</tr>
<tr>
<td></td>
<td>- Premature deaths</td>
</tr>
<tr>
<td>- Contamination of drinking water and water used for recreational purposes</td>
<td>- Hatching of strains of microorganisms, amoebae and other waterborne infectious agents</td>
</tr>
<tr>
<td>- Proliferation of algae and increases in the concentration of toxins in fish and shellfish</td>
<td>- Diseases linked to food</td>
</tr>
<tr>
<td>- Changes in behaviour linked to the warmest temperatures</td>
<td>- Other diseases relating to diarrhoea and the bowels</td>
</tr>
<tr>
<td>- Changes in the biology and ecology of vectors of diseases (including geographical breakdown)</td>
<td>- Increase in the incidence of infectious diseases transmitted by indigenous vectors</td>
</tr>
<tr>
<td>- More rapid maturation of pathogens in insects and ticks that are vectors of disease</td>
<td>- Emergence of infectious diseases</td>
</tr>
<tr>
<td>- Prolongation of the season for transmission of diseases</td>
<td></td>
</tr>
<tr>
<td>- Depletion of the ozone layer</td>
<td>- Skin cancers, cataracts, eye damage</td>
</tr>
<tr>
<td>- Changes in the atmospheric chemistry of the stratospheric ozone layer</td>
<td>- Various issues relating to the immune system</td>
</tr>
<tr>
<td>- Increase in exposure to UV rays</td>
<td></td>
</tr>
</tbody>
</table>

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### Table 5

Classification of health risks – adapted from the Australian report [153]

<table>
<thead>
<tr>
<th>Priority level</th>
<th>Health risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely high</td>
<td>Extreme climatic events</td>
</tr>
<tr>
<td></td>
<td>Heat waves</td>
</tr>
<tr>
<td></td>
<td>UV rays</td>
</tr>
<tr>
<td></td>
<td>Droughts, drinking water resources and food</td>
</tr>
<tr>
<td></td>
<td>Reduced access to healthcare systems, drinking water and food</td>
</tr>
<tr>
<td></td>
<td>Inability to meet energy demand</td>
</tr>
<tr>
<td>Extremely high-High</td>
<td>Fires</td>
</tr>
<tr>
<td></td>
<td>Air quality</td>
</tr>
<tr>
<td>High</td>
<td>Flooding</td>
</tr>
<tr>
<td></td>
<td>Quality of drinking water</td>
</tr>
<tr>
<td></td>
<td>Quality of water used for recreation</td>
</tr>
<tr>
<td></td>
<td>Changes in distribution of vectors for disease</td>
</tr>
<tr>
<td></td>
<td>Allergens</td>
</tr>
<tr>
<td></td>
<td>Food poisoning</td>
</tr>
<tr>
<td></td>
<td>Disruption of social ties</td>
</tr>
<tr>
<td></td>
<td>Mental health</td>
</tr>
<tr>
<td></td>
<td>Changes in biodiversity</td>
</tr>
<tr>
<td></td>
<td>Loss of goods and services</td>
</tr>
<tr>
<td>High-Medium</td>
<td>Pathogens in non-potable water</td>
</tr>
<tr>
<td>Medium</td>
<td>Exposure to volatile organic compounds</td>
</tr>
<tr>
<td></td>
<td>Legionnaires’ disease</td>
</tr>
<tr>
<td></td>
<td>Mycotoxins</td>
</tr>
<tr>
<td></td>
<td>Pathogens in food</td>
</tr>
<tr>
<td></td>
<td>Arthropods and vermin/pests</td>
</tr>
<tr>
<td></td>
<td>Imported food</td>
</tr>
<tr>
<td></td>
<td>Changes in the incidence of crimes, accidents and alcohol consumption</td>
</tr>
<tr>
<td>Medium-Low</td>
<td>Lack of sleep</td>
</tr>
<tr>
<td>Low</td>
<td>Exposure to pesticides</td>
</tr>
<tr>
<td></td>
<td>Exposure to chemical pollutants</td>
</tr>
</tbody>
</table>
### Table 6

**Health risks linked to climate change – adapted from the French report [23]**

<table>
<thead>
<tr>
<th>Events</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased exposure to UV rays (time of exposure and depletion of the ozone layer)</td>
<td>Skin cancers, melanosomes, dermatological and ophthalmological problems</td>
</tr>
<tr>
<td>Extension of the pollen season and changes in species</td>
<td>Increase in allergic reactions to pollen</td>
</tr>
<tr>
<td>Decline in air quality</td>
<td>Deaths, illnesses</td>
</tr>
<tr>
<td>Increase in the use of pesticides to maintain agricultural yield</td>
<td></td>
</tr>
<tr>
<td>Reduction in the water tables</td>
<td>Water restrictions</td>
</tr>
<tr>
<td>Landslides</td>
<td>Destruction of buildings, mental health</td>
</tr>
<tr>
<td>Forest fires</td>
<td>Deaths, mental health, air quality</td>
</tr>
<tr>
<td>Rising sea levels</td>
<td>Mental health</td>
</tr>
<tr>
<td>Changes in the seasons for pathogens and vectors of disease</td>
<td></td>
</tr>
<tr>
<td>Changes in the ecosystems of vectors</td>
<td>Expansion and changes to reproduction</td>
</tr>
<tr>
<td>Increase in winter temperatures</td>
<td>Reduction in winter mortality rates</td>
</tr>
<tr>
<td>Drying-up of ponds, pools and watercourses</td>
<td>Disappearance of reservoirs</td>
</tr>
<tr>
<td>Proliferation of amoebae</td>
<td>Closure of nuclear power stations</td>
</tr>
<tr>
<td>Decline in river levels</td>
<td>Changes to systems for production and treatment of water</td>
</tr>
<tr>
<td>Changes in soil structure</td>
<td>Release of pathogens</td>
</tr>
<tr>
<td>Decline in river levels</td>
<td>Decline in the quality of water resources</td>
</tr>
<tr>
<td>Decline in the water tables</td>
<td>Increase in the vulnerability of water intake</td>
</tr>
<tr>
<td>Proliferation of toxic algae</td>
<td>Food poisoning</td>
</tr>
<tr>
<td>Decline in quality of agricultural production (fungi, etc.)</td>
<td>Food poisoning</td>
</tr>
<tr>
<td>Breaks in the cold chain</td>
<td></td>
</tr>
<tr>
<td>Increase in pathogenicity of bacteria due to rising water temperatures</td>
<td>Increase in the number and seriousness of cases</td>
</tr>
<tr>
<td>Proliferation of amoebae</td>
<td>Decline in the quality of water used for bathing and swimming</td>
</tr>
<tr>
<td>Increased use of air-conditioning systems</td>
<td>Increase in Legionnaires’ disease</td>
</tr>
<tr>
<td>Increase in bacteria and viruses in sea water</td>
<td>Increase in incidence of gastroenteritis and septicemia</td>
</tr>
<tr>
<td>Improvement in water quality due to sunshine</td>
<td>Reduction in incidence of gastroenteritis</td>
</tr>
<tr>
<td>Acidification of the oceans</td>
<td>Changes in bacteria</td>
</tr>
<tr>
<td>Changes in the lifecycles of vectors</td>
<td>Increase or reduction in transmission rates</td>
</tr>
<tr>
<td>Increase in stagnant water from melting snow</td>
<td>Increase in insect populations</td>
</tr>
<tr>
<td>Reduction in snow cover</td>
<td>Increase in the rodent population</td>
</tr>
<tr>
<td>Drought</td>
<td>Changes in vectors’ lifecycles</td>
</tr>
<tr>
<td>All types of extreme climatic events</td>
<td>Destruction of buildings and communications, etc.</td>
</tr>
<tr>
<td>Temperature and ozone</td>
<td>Increase in mortality and morbidity rates</td>
</tr>
<tr>
<td>Increases in humidity and temperature</td>
<td>Increase in mould and mildew</td>
</tr>
<tr>
<td>Heat waves</td>
<td>Increase in mortality and morbidity rates</td>
</tr>
<tr>
<td>Flooding</td>
<td>Deaths, illnesses, mental health</td>
</tr>
<tr>
<td>Storms and cyclones</td>
<td>Deaths, illnesses, mental health</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>Deaths, illnesses, mental health</td>
</tr>
<tr>
<td><strong>Risk</strong></td>
<td><strong>Area studied</strong></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Extreme temperatures</td>
<td>10 Australian towns 2 New Zealand towns</td>
</tr>
<tr>
<td>Flooding</td>
<td>Australia</td>
</tr>
<tr>
<td>Flooding (coastal)</td>
<td>Australia, New Zealand, Pacific Islands</td>
</tr>
<tr>
<td>Malaria</td>
<td>Australia</td>
</tr>
<tr>
<td>Dengue</td>
<td>Australia, New Zealand, Pacific Islands</td>
</tr>
<tr>
<td>Atmospheric pollution and allergens</td>
<td>No quantification</td>
</tr>
<tr>
<td>UV rays</td>
<td>No quantification</td>
</tr>
<tr>
<td>Other infectious diseases</td>
<td>No quantification</td>
</tr>
<tr>
<td>Agricultural production</td>
<td>No quantification</td>
</tr>
</tbody>
</table>
In the short term

- Put in place or strengthen surveillance of health and environmental factors that could be modified by climate change, in order to detect weak signals at a spatial level consistent with the various facets of climate change:
  - surveillance of vector populations and host populations;
  - surveillance of air quality, quality of inland, coastal and estuarine waters and soil quality;
  - surveillance of natural radiation;
  - surveillance of resistance levels and adaptation of pathogens;
  - surveillance of pneumallergens;
  - surveillance of health events potentially arising along with climate change (infectious diseases, skin cancers, allergies, etc.) by integration of environmental data.

- Prioritise, as soon as possible, the relative importance of the various expected consequences of climate change for health, in order to understand the timescales necessary to put in place responses.

- Put in place and standardise plans for responses to extreme meteorological phenomena (based on models of existing plans): heat waves, extreme cold weather, hurricanes, etc.) including the systematic study of the health effects (somatic and psychological) of these phenomena.
  - Evaluate existing plans.
  - Organise responsibility for fragile and vulnerable populations (the elderly, those suffering from chronic conditions, frail and delicate individuals, etc.) when faced with extreme climatic phenomena.

- Integrate health risks of climatic origin with preliminary and ongoing training for the health professions, particularly GPs.

- Integrate health risks of climatic origin into public health warnings and information campaigns aimed at the general public and the media, particularly those targeting adolescents.

- Anticipate phenomena linked to climate change (permanent or intermittent) that have an impact on health, in town planning documents: floods; impact of the design of buildings on the interior air quality, etc.

- Take into account the health risks specific to the regions and Overseas Departments (e.g. ensuring habitats are equipped with anti-vector measures, etc.).

- Participate in the implementation of an adequate prevention policy that does not increase inequalities in terms of access to water and sanitation for the more fragile populations on the social and economic side. With this in mind, it is necessary to encourage adaptations at a local level in order to improve the stability and robustness of resources under extreme climatic conditions and to adapt resources to usage.

- Participate in the promotion of water management (in terms of capacity and quality) in close liaison with soil management.

- Participate at European Commission level to achieve the integration of climate change into the Framework Directive on Water, the strategy against water shortages and the Community Health Programme in particular.

- Anticipate aspects of coastal erosion and inflow of salt water into coastal areas in order to limit consequences for health.

In the medium term

- Monitor the health impact of changes to biological diversity (flora and fauna).

- Implement observation of events relating to mutation of infectious agents and their hosts, particularly in line with natural radiation.
The scenarios relating to emissions are used to analyse possible changes to the climate, their impacts and solutions for mitigation. They portray the primary drivers and demographic, economic, and technological forces for greenhouse gas emissions.

Four different narrative storylines have been developed to describe, in a consistent and coherent manner, the relationships between the drivers for emissions and their evolution and to add a context for the quantification of the scenarios. Each storyline represents a different evolution on the demographic, social, economic, technological and environmental level, which may be seen as positive by some and negative by others (figure 14) [157].

- The storyline and the family in the A1 scenarios describe a future world in which economic growth is very rapid, the global population has reached a maximum level in the middle of the century and then started to decline and new, more efficient technologies are being rapidly introduced. The principal underlying themes are convergence between regions, strengthening of capabilities and increasing cultural and social interactions along with a substantial reduction in regional differences in income per capita. The family in the A1 scenarios is split into three groups, representing the possible directions in terms of technological evolution in the energy system. The three A1 group are distinguished by their different approaches towards technology: heavy use of fossil fuels (A1F1), use of energy sources other than fossil fuels (A1T) and balance between fuel sources (A1B).

- The storyline and the family in the A2 scenarios represent a very heterogeneous world. The underlying theme is self-sufficiency and the preservation of local identities. The regional fertility tables are converging very slowly, resulting in continued global population growth. Economic development has a primarily regional focus and economic growth per capita and technological evolution are more fragmented and slower than in the other storylines.

- The storyline and the family in the B1 scenarios represent a converging world with the same evolution of the global population, peaking mid-century and then declining, as in storyline A1, but with rapid changes in the economic structures towards an economy based on services and information, with reductions in the intensity of materials and the introduction of clean technologies that use resources efficiently. The accent is on global solutions oriented towards economic, social and environmental viability, including improved equality but without additional initiatives to manage the climate.

- The storyline and the family in the B2 scenarios represent a world where the accent is on local solutions in the sense of economic, social and environmental viability. The global population continues to grow but at a slower rate than in the A2 scenarios; there are intermediate levels of economic development and the technological development is less rapid and more diverse than in the storylines and the families of the B1 and A1 scenarios. The scenarios are also focused on the protection of the environment and social equality, but they are centred around local and regional levels.

All the scenarios necessarily include elements that are subjective and open to interpretation. The different preferences among the scenarios presented vary according to the users.
It is necessary to distinguish between the effects on health of the climate, of variability in the climate and of climate change. In current literature, only the health effects of the climate and variability in the climate are the subject of studies, for example the impact of extreme temperatures on mortality rates, or research into climate conditions that are favourable to the occurrence of epidemics of infectious diseases.

Since 2000, we have witnessed an increase in the number of articles and papers on climate change and health. However, most of these are synthesis papers or position papers that call for a greater consideration of the health impact of climate change. The main subject areas dealt with are still air, food, infectious diseases and water (table 8). Very few articles offer forecasts for health impacts; they focus essentially on extreme temperatures, atmospheric pollution and infectious diseases.

| Table 8 |

Number of publications referenced in PubMed associated with climate change

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
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<tr>
<td>Climate change and Health</td>
<td>106</td>
<td>213</td>
<td>149</td>
<td>101</td>
<td>84</td>
<td>76</td>
<td>54</td>
<td>60</td>
<td>73</td>
<td>61</td>
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<td>and Air</td>
<td>23</td>
<td>37</td>
<td>35</td>
<td>18</td>
<td>15</td>
<td>15</td>
<td>3</td>
<td>13</td>
<td>16</td>
<td>9</td>
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<tr>
<td>and Food</td>
<td>21</td>
<td>27</td>
<td>20</td>
<td>9</td>
<td>11</td>
<td>11</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>9</td>
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<tr>
<td>and Infectious Diseases</td>
<td>15</td>
<td>30</td>
<td>11</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>6</td>
<td>9</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>and Water</td>
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<td>25</td>
<td>16</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>and Heat Waves</td>
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<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>and Extreme Climatic Events</td>
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<td>9</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>and Soils</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>and Contaminants</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>and Flooding</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>and Habitat</td>
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<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>and UV</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>756</td>
<td>1,290</td>
<td>1,050</td>
<td>808</td>
<td>632</td>
<td>511</td>
<td>454</td>
<td>410</td>
<td>388</td>
<td>316</td>
</tr>
</tbody>
</table>

* Until 31/07/2009.
### Table 5.1.a

Pathologies carried by mosquitoes or sandflies – Inventory and epidemiology

<table>
<thead>
<tr>
<th>Germ Principal vector in metropolitan France</th>
<th>Incidence Severity (S) Deadliness (D)</th>
<th>Risk of emergence or extension</th>
<th>Impact of climate change</th>
<th>Methods of surveillance among humans in 2008</th>
<th>Methods of surveillance among animals in 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chikungunya Aedes albopictus Rare (imported cases)</td>
<td>S: + D: -</td>
<td>Yes: Vector present around the Mediterranean border</td>
<td>Yes: extension of vector’s habitat</td>
<td>Notifiable disease (MDO): clinicians, labs, NRCs Surveillance strengthened May-November Notification of suspected cases (Mediterranean border)</td>
<td>Surveillance of vector and its extension in south of France: EID&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dengue Aedes albopictus Rare (imported cases)</td>
<td>S: + D: + (to ++)</td>
<td>Yes: Vector present around the Mediterranean border and in expansion</td>
<td>ditto</td>
<td>ditto</td>
<td>ditto</td>
</tr>
<tr>
<td>Yellow fever A. aegypti ++ A. albopictus +</td>
<td>Rare (imported cases) S: ++ D: + to ++</td>
<td>Possible depending on competence of Aedes. (No A. aegypti in met. France)</td>
<td>ditto</td>
<td>MDO: clinicians, NRCs</td>
<td>ditto</td>
</tr>
<tr>
<td>Rift Valley fever Various mosquitoes 0 in 2008 S: + D: + (≤10%)</td>
<td>Yes: Potential vectors present around the Mediterranean border</td>
<td>ditto</td>
<td>No surveillance currently in place</td>
<td>ditto</td>
<td></td>
</tr>
<tr>
<td>Malaria Anopheles Rare native cases (imported cases: many) S: + to ++ D: + to ++</td>
<td>Possible: Vector present although rare</td>
<td>ditto</td>
<td>Native cases = MDO (sentinel surv. for imported cases)</td>
<td>If a native case: entomological investigation + targeted vector control</td>
<td></td>
</tr>
<tr>
<td>West Nile Princially Culex spp, other vectors Rare S: + D:</td>
<td>Yes: Vectors present around the Mediterranean border</td>
<td>ditto</td>
<td>MDO: clinicians, NRCs Notification of suspected cases (Mediterranean border)</td>
<td>Surveillance of vector and extension around extended Mediterranean border: EID&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Visceral leishmaniasis L. infantum Sandfly Rare S: D: ?</td>
<td>Yes: Vector present around the Mediterranean border</td>
<td>ditto</td>
<td>Voluntary notification + NRCs</td>
<td>Surveillance of vector and extension in south of France=EID&lt;sup&gt;d&lt;/sup&gt; Surveillance of dog population (same zone)</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Interdepartmental alliance for vector control; Surveillance of Aedes around Mediterranean border since 1998, intensified in 2006. Demonstrated progressive extension of the implantation zone of Aedes albopictus.

<sup>b</sup> Interdepartmental Alliance for Mosquito Control = Entente interdépartementale de démoustication.

<sup>c</sup> Note that the transmission to humans by vector is marginal. Transmission occurs rather by direct contact with a contaminated animal.

<sup>d</sup> Vectors are more widespread across the territory. But there are many conditions for the introduction and the diffusion of the virus: vector with sufficient capacity, birds.

MDO = Notifiable Diseases

NRC = National Reference Centers
### Table 5.1.B

**Pathologies carried by mosquitoes or sandflies – Capabilities of surveillance systems and improvements envisaged**

<table>
<thead>
<tr>
<th>Germ</th>
<th>Principal vector</th>
<th>Surveillance in animals: Detection and alert capabilities?</th>
<th>Surveillance in humans: Detection and alert capabilities?</th>
<th>Improvements envisaged or recommended, on animal side</th>
<th>Improvements envisaged or recommended, on human side</th>
<th>Decision sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chikungunya</strong></td>
<td>A. albopictus</td>
<td>EID = Seasonal activation of national plan around Mediterranean border</td>
<td>In line with presence of vectors (see National Plan)</td>
<td>Strengthen EID - annual review of implantation zones - early detection and alert - control (vector control)</td>
<td>Surveillance: no modification to the plan</td>
<td>Prioritisation 2008</td>
</tr>
<tr>
<td><strong>Dengue</strong></td>
<td>Aedes albopictus</td>
<td>ditto</td>
<td>ditto</td>
<td>ditto</td>
<td>ditto</td>
<td>ditto</td>
</tr>
<tr>
<td><strong>Yellow fever</strong></td>
<td>A. aegypti (+albop)</td>
<td>Seasonal activation of national plan for Chik/dengue should identify other Aedes vectors</td>
<td>ditto</td>
<td>Risk of importation deemed low</td>
<td>Improve surveillance to detect acquisition of competence by vectors</td>
<td>Surveillance: no modification to the plan</td>
</tr>
<tr>
<td><strong>Rift Valley fever</strong></td>
<td>Various mosquitoes</td>
<td>To be re-evaluated with the AFSSA</td>
<td>Compulsory notification of African haemorrhagic fevers currently satisfactory</td>
<td>Evaluate the implantation risk AFSSA?</td>
<td>Awareness among professionals, clinicians and travellers</td>
<td>ditto</td>
</tr>
<tr>
<td><strong>Malaria</strong></td>
<td>Anopheles</td>
<td>Entomological surveillance</td>
<td>Vector control around imported cases</td>
<td>Detection: labs, clinicians, NRCs</td>
<td>Verify changes in competence of vectors</td>
<td>ditto</td>
</tr>
<tr>
<td><strong>West Nile</strong></td>
<td>Culex</td>
<td>EID = Seasonal activation of national plan around Mediterranean border</td>
<td>In line with &quot;vectors&quot; plan opposite</td>
<td>Strengthen EID - annual review of implantation zones - early detection and alert - control (vector control)</td>
<td>Surveillance: no modification to the plan</td>
<td>Prioritisation 2008 Plan national</td>
</tr>
<tr>
<td><strong>Visceral leishmaniasis</strong></td>
<td>L. infantum</td>
<td>Surveillance carried out (DDSV): focus points for canine populations</td>
<td>Surveillance deemed satisfactory</td>
<td>AFSSA: &quot;despite high risk because vector present, consequences to humans are negligible as canine populations act as alert mechanism&quot;</td>
<td>Raise awareness of clinicians about risk for diagnostic research (disease rare and treatment difficult)</td>
<td>Prioritisation 2000 AFSSA 2005</td>
</tr>
</tbody>
</table>

---

*a French Food Products Safety Agency = Agence française de sécurité sanitaire des aliments.
*b General Food Directorate – Direction générale d’alimentation.
*c French national network for health surveillance of wild fauna.
*d Departmental Directorates for Veterinary Services = Directions départementales des services vétérinaires.
### Pathologies carried by ticks or rodents – Inventory and epidemiology

<table>
<thead>
<tr>
<th>Germ</th>
<th>Principal vector</th>
<th>Incidence</th>
<th>Severity (S)</th>
<th>Risk of emergence or extension</th>
<th>Impact of climate change</th>
<th>Methods of surveillance among humans in 2008</th>
<th>Methods of surveillance among animals in 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CCHF</td>
<td>Rare</td>
<td>S: ++</td>
<td>Yes: Vector rare but present in south of France</td>
<td>Yes: extension of vector’s habitat</td>
<td>Compulsory notification</td>
<td>No specific surveillance</td>
</tr>
<tr>
<td></td>
<td>Tick</td>
<td></td>
<td>D: 10-40%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lyme disease</td>
<td>Frequent</td>
<td>S: + (1/3 are severe cases)</td>
<td>Present in France</td>
<td>Increased incidence possible acc. to incr. vector population</td>
<td>Yes: extension of vector’s habitat and capacity of vector</td>
<td>Sentinel surv. + NRCs + regional studies</td>
</tr>
<tr>
<td></td>
<td>Tick</td>
<td></td>
<td>D: +-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tick-borne</td>
<td>Rare</td>
<td>S: ++</td>
<td>Rare, but increased incidence possible acc. to incr. vector population</td>
<td>Yes</td>
<td>But warming + increase in humidity could lead to decreased incidence</td>
<td>NRCs</td>
</tr>
<tr>
<td></td>
<td>encephalitis</td>
<td></td>
<td>D: 0-1.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q fever</td>
<td>Frequency medium-high*</td>
<td>S: + to ++</td>
<td>Yes</td>
<td>ditto</td>
<td>ditto</td>
<td>ditto</td>
</tr>
<tr>
<td></td>
<td>Tick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leptospirosis</td>
<td>200-300 cases/yr</td>
<td>S: + if risk factors</td>
<td>Present in France</td>
<td>sporadic cases (professionals) or case clusters (summer)</td>
<td>Indirect: Incr. rodents + exposure (bathing)</td>
<td>Raise awareness among clinicians and professionals. Alert via NRCs</td>
</tr>
<tr>
<td></td>
<td>Rodent or direct contact</td>
<td></td>
<td>D: ?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hantavirus</td>
<td>50 cases/yr, some case clusters</td>
<td>S: +</td>
<td>Present in France</td>
<td>sporadic cases (professionals) or case clusters (summer)</td>
<td>Indirect: Incr. rodents + exposure (forest walks)</td>
<td>ditto</td>
</tr>
<tr>
<td></td>
<td>Rodent or direct contact</td>
<td></td>
<td>D: -</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Several thousand cases/year but the proportion of those transmitted by ticks is very low. The mode of transmission is principally aerogenous.
**Pathologies carried by ticks or rodents – Capabilities of surveillance systems and improvements envisaged**

<table>
<thead>
<tr>
<th>Germ</th>
<th>Principal vector</th>
<th>Surveillance in animals: Detection and alert capabilities?</th>
<th>Surveillance in humans: Detection and alert capabilities?</th>
<th>Improvements envisaged or recommended, on animal side</th>
<th>Improvements envisaged or recommended, on human side</th>
<th>Decision sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCHF</td>
<td>Ticks</td>
<td>Professional risks (surv. infection in ruminants) to be confirmed</td>
<td>Comp. notification of African haemorrhagic fevers enough Surveillance deemed satisfactory in 2008</td>
<td>In the case of implantation in met. France = Surv. infection in ruminants, strengthen surveillance of ticks (density, infestation)</td>
<td>Raise awareness among exposed clinicians, travellers and professionals</td>
<td>Prioritisation 2008</td>
</tr>
<tr>
<td>Lyme disease</td>
<td>Ticks</td>
<td>no objective</td>
<td>National sentinel network, regional studies Improve diagnostic tests</td>
<td>Better identification of species of borrelia and their breakdown according to vectors</td>
<td>Inform and raise awareness among population (forest walks, etc.)</td>
<td>ditto</td>
</tr>
<tr>
<td>Tick-borne encephalitis</td>
<td>Ticks</td>
<td>?</td>
<td>Surveillance by NRCs Enhanced by notification via hospitals</td>
<td>Ecology of vectors and reservoirs</td>
<td>Improve capabilities for biological diagnosis Inform about modes of contamination Research into modes of contamination and epidemiology + role of vaccine</td>
<td>ditto</td>
</tr>
<tr>
<td>Q fever</td>
<td>Ticks</td>
<td>Control plan exists but must be evaluated within 2-3 years</td>
<td>Surveillance by NRCs Need to improve biological diagnosis tools</td>
<td>Inform about good animal husbandry practices Research on survival of Coxiella burnetii in the environment</td>
<td>Inform at-risk populations (pregnant women, patients with valvulopathy) and raise awareness amongst their doctors</td>
<td>ditto</td>
</tr>
<tr>
<td>Leptospirosis</td>
<td>Rodent or direct contact</td>
<td>?</td>
<td>Detection of case clusters</td>
<td>Control of the rodent population</td>
<td>Inform and raise awareness: risk to professionals and risk linked to leisure activities</td>
<td>Prioritisation 2000</td>
</tr>
<tr>
<td>Hantavirus</td>
<td>Rodent or direct contact</td>
<td>Elimination of rodents?</td>
<td>Detection of case clusters</td>
<td>ditto</td>
<td>ditto</td>
<td>ditto</td>
</tr>
</tbody>
</table>
### Table 5.3.a

**Enteric infections – Inventory and epidemiology**

<table>
<thead>
<tr>
<th>Germ</th>
<th>Incidence</th>
<th>Severity (S) Deadliness (D)</th>
<th>Risk of emergence or extension</th>
<th>Impact of climate change</th>
<th>Methods of surveillance among humans in 2008</th>
<th>Methods of environmental surveillance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viral hepatitis A, E</td>
<td>Frequent</td>
<td>S: + - D: (≤10%)</td>
<td>Yes</td>
<td>?</td>
<td>MDO and NRCs</td>
<td>no objective? Research? (see P Beaudeau)</td>
</tr>
<tr>
<td>Norovirus</td>
<td>Frequent</td>
<td>S: - D: -</td>
<td>Frequent case clusters; seasonal factor (esp. in winter)?</td>
<td>If warming — decreased incidence</td>
<td>Surv. case clusters (FBI) Detection of winter epidemics: Sentinel/OSCOUR©</td>
<td>ditto</td>
</tr>
<tr>
<td>Salmonellosis</td>
<td>Rare</td>
<td>S: ++ D: + to ++</td>
<td>Rare, but increased incidence possible; imported and native cases</td>
<td>Breaks in the cold chain</td>
<td>NRCs Network of laboratories</td>
<td>ditto</td>
</tr>
<tr>
<td>Parasites (cryptosporidium, giardiasis)</td>
<td>? not monitored</td>
<td>S: + to ++</td>
<td>Breaks in the cold chain Increase in bathing</td>
<td>Surveillance case clusters of GEA Improve diagnostics? (difficult); cost–benefit report to be discussed</td>
<td>ditto</td>
<td></td>
</tr>
<tr>
<td>Vibrios</td>
<td>&lt;10 cases/year</td>
<td>S: + if risk factors</td>
<td>Sporadic cases of non-cholera vibrio in France; imported cases of v. cholerae (rare)</td>
<td>Warming of salt water (estuaries) and risks from bathing</td>
<td>Raise awareness among clinicians and professionals if risk recognised</td>
<td>If required. Plan for surveillance of shellfish</td>
</tr>
</tbody>
</table>

### Table 5.3.b

**Enteric Pathologies – Capacities of surveillance systems and planned improvements**

<table>
<thead>
<tr>
<th>Germ</th>
<th>Environmental surveillance Detection and alert capabilities?</th>
<th>Surveillace in humans: Detection and alert capabilities?</th>
<th>Improvements envisaged or recommended, on environment side</th>
<th>Improvements envisaged or recommended, on human side</th>
<th>Decision sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viral hepatitis A, E</td>
<td>Human or animal population; risk factors for HepE not well known</td>
<td>MDO + NRCs</td>
<td>Strengthening of surveillance by the NRCs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viral hepatitis A, E</td>
<td>No objective for human population</td>
<td>Sentinels/OSCOUR© Network and compulsory notification FBI</td>
<td>Shellfish plan if required</td>
<td></td>
<td>no</td>
</tr>
<tr>
<td>Norovirus</td>
<td>No objective for human population</td>
<td>Sentinels/OSCOUR© Network and compulsory notification FBI</td>
<td>Shellfish plan if required</td>
<td></td>
<td>no</td>
</tr>
<tr>
<td>Salmonellosis</td>
<td>In animal husbandry</td>
<td>NRCs + comp. notification FBI</td>
<td></td>
<td></td>
<td>no</td>
</tr>
<tr>
<td>Parasites (cryptosporidium, giardiasis)</td>
<td>No objective for human population</td>
<td>Notification of case clusters of GEA</td>
<td>Improve diagnostics?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vibrions</td>
<td>Shellfish plan</td>
<td>NRCs + comp. notification FBI</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 6 – Glossary

**Adaptation**: adaptation is the degree of adjustment of natural and human systems to climatic changes, in order to mitigate the potential damage, take advantage of opportunities or face up to the consequences. [158] Adaptation may involve statutory measures or changes to inhabited places and behaviour patterns [159].

**Mitigation**: Mitigation means a human intervention that aims to reduce anthropogenic forcing of the climatic system. It includes strategies that aim to reduce sources and emissions of greenhouse gases and to increase the effectiveness of pits and shafts with greenhouse gases [158].

**Climate**: generally, the word ‘climate’ is used to refer to the "average weather"; more specifically, it is a statistical description of the weather in terms of averages and variables of appropriate size, observed over periods of several decades (three decades in principle, according to the WMO). These are most often surface variables — temperature, rainfall and wind, for example — but in its broadest sense "climate" is a description of the state of the climatic system [158].

**Climatic changes (as per the IPCC)**: Climatic changes indicate a significant statistical variation in the average state of the climate or its persistent variability over long periods (generally over decades or longer). Climatic changes can be due to natural internal processes or to external forcing, or to ongoing anthropogenic changes in the composition of the atmosphere or in land use [158].

**Radiative climate forcing**: this is a simple measure of the significance of a mechanism that can lead to a climatic change. Radiative forcing is the disturbance of the energy balance of the Earth-atmosphere system (in W m²) resulting, for example, from a change in the concentration of carbon dioxide or a variation in solar output. The climatic system reacts to radiative forcing in such a way as to re-establish energy balance. Positive radiative forcing tends to warm the surface of the earth while negative radiative forcing tends to cool it. Radiative forcing is generally expressed with the help of an annual value averaged out on a global scale. [158]

**Greenhouse gases (GHG)**: Gases which, for certain wavelengths of the energy spectrum, absorb the rays (infrared rays) emitted by the surface of Earth and by the clouds. The net effect is the local retention of part of the energy absorbed and a tendency for the surface of the Earth to become warmer. Water vapour (H₂O), carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄) and ozone (O₃) are the principal greenhouse gases that are found in the earth’s atmosphere [158].

**The Intergovernmental Panel on Climate Change (IPCC)** was established jointly by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) to evaluate the scientific, technical and socio-economic information that relates to the understanding of the risk of climatic changes brought about by man. Its purpose is to evaluate, without bias or prejudice and in a methodical, clear and objective manner, the scientific, technical and socio-economic information that is necessary in order for us to gain a greater understanding of the scientific foundations of the risks linked to climate change originated by man, define more precisely the possible consequences of this change and envisage possible strategies for adaptation and mitigation. Its remit does not include the undertaking of research works nor does it include monitoring the evolution of climatological variables or other relevant parameters. Its evaluations are principally founded on scientific and technical publications, the scientific value of which is largely recognised.

The French National Observatory on the Effects of Climate Change (Onerc) was established under the law of 19 February 2001, to collect and disseminate information, studies and research on the risks linked to global warming and to extreme climatic phenomena. The Onerc also makes recommendations on prevention and adaptation measures that are likely to limit the risks linked to climate change.

**Resilience**: Resilience is the ability of a natural or human system to absorb disruption and change while conserving its base structure and its methods of operation as well as its ability to organise and adapt itself to stress and change [158]. Adaptation can be seen as a driver for resilience.

**Environmental health surveillance**: Ongoing and organised process for: the collection of relevant data relating to environmental exposures of which the health effects are suspected or known or suspected health events originating from environmental factors and/or to characteristics of the populations at risk and/or to data about the susceptibility or vulnerability of individuals or communities to environmental agents and/or to interventions (this collection can be supported if necessary by ad hoc surveys or studies); the establishment of indicators from this data then from the relationships between these indicators in the event that such relationships exist and are established; the analysis and interpretation of these indicators; the dissemination of the results of the analyses and their interpretation at the appropriate time to those that require them for information, detection and anticipation of risks and/or an action for public health to control such risks and/or prevention of exposures and/or diseases and the evaluation of these actions.

**Syndromic surveillance**: in the absence of accurate etiological data, syndromic surveillance systems utilise a range of non-consolidated data (symptoms, reasons for emergency admissions, clinical diagnoses, etc.) that enable the real-time monitoring of groups of syndromes. This data can be gathered from numerous sources along with admissions data from healthcare systems such as the following: emergency admissions, hospital admissions, calls to the ambulance service, treatment by private ambulances and even results of biological analyses. Other data sources can be included in order to estimate the number of patients that do not have access to healthcare systems: sales of over-the-counter medications, use of specialist telephone lines, rates of absenteeism, etc. This surveillance requires ongoing recording and analysis (on a daily basis and almost in real time) of data. This is why the data is most often directly extracted from the medico-administrative systems of healthcare management systems.
**Vulnerability**: vulnerability is the degree to which a system is able to face up, or not, to the harmful effects of climate change (including climate variability and extreme climatic events). It depends on the nature, scale and rate of climate evolution, the variations to which the system is exposed, its sensitivity and its ability to adapt [158]. Vulnerability is aggravated by the conjunction of environmental, social and economic factors.
Health impacts of climate change in France
What are the challenges for the French Institute for Public Health Surveillance (InVS)?

Recognizing that climate change will impact human health, an interdisciplinary climate change working group has identified the main needs for adaptation of the Public Health sector, focusing on surveillance and alert. Risks considered included extreme weather events, infectious diseases, and long-term environmental changes. The flexibility and adaptability of existing surveillance and alert programmes covering these risks were assessed by the working group based on a literature review, expert consultations and analysis of past events in France. Both environmental monitoring systems and health end points surveillance systems were included in the review.

For most risks, surveillance of the environment and of the health effects is already available. Strengthening these systems is essential, and data quality, data availability and linkage of environmental and health databases are key steps in this process. A better understanding of the determinants of exposure would improve the understanding of climate risks. Syndromic surveillance could be fruitfully used to complement classical systems. A strong interaction with research is also required through the development of interdisciplinary partnerships relying on existing networks.

Finally, mitigation strategies have the potential to generate major health co-benefits. Decision-makers should have access to health impact assessments of the different available options. Surveillance should be used to monitor and evaluate the efficiency of these strategies.

Impacts sanitaires du changement climatique en France
Quels enjeux pour l’InVS ?


Suggested citation: