Flooding: Prevention as the Best Option

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“The principle of all things is water,
for all comes from it, and all returns to it.”

*Thales of Miletus, Greek philosopher,
(sixth century BC)*

*“Measure what can be measured,
and make measurable what cannot be
measured.”*

Galileo (1564–1642)

«*“These days, everyone wants a dike
that can divert water to his neighbor.
The dike system is nothing more than
a palliative measure, ruinous for the state
and ineffective in protecting the interests
in question.”*

*Napoleon III (1808–1873),
Speech made at Plombières (1860)*

*“Everything that needs to be said
has already been said. But since no one
was listening, it must be said again.”*

*André Gide (1869-1951),
Traité du Narcisse*

*“Misnaming things adds
to the unhappiness of the world.”*

Albert Camus (1913-1960)

*“People only accept change in necessity
and see necessity only in crisis.”*

Jean Monnet (1888-1979)

Inondations,
mieux vaut prévenir

Résumé

Les risques d'inondation restent le risque naturel le plus fréquent et causant le plus de dégâts, toutes géographies confondues. Dans ce rapport technique, on analyse dans un premier temps les éléments explicatifs de cet état de fait : régime hydrologique, existence d'événements extrêmes dans un champ continu des possibles, concepts d'aléa et de vulnérabilité. On décrit dans un second temps les différentes composantes d'une politique de gestion intégrée des risques d'inondation combinant : (i) des mesures de prévention liées à l'aménagement du territoire et l'aménagement hydraulique, qui débouchent nécessairement sur un risque résiduel réputé accepté, (ii) des mesures de gestion de crise incluant une composante prévisionniste, qui permettent de gérer les risques résiduels acceptés, et (iii) des mesures destinées à développer la culture du risque et qui contribuent à rendre compréhensible les messages issus des deux autres champs d'intervention. De cette compréhension des concepts fondamentaux sous-jacents à cette analyse des risques d'inondation, sont tirées quelques recommandations opérationnelles pour définir des projets finançables par l'AFD et dans ses pays d'intervention. Enfin, sont passées en revue quelques situations particulières issues de l'expérience de l'auteur, tant sur le territoire français que dans des pays en développement.

Mots-clés : inondation, crue, risque, prévention, ressources en eau, aléa, vulnérabilité

Pays : France, Cambodge, Thailande, Vietnam, Madagascar, Tchad

Flooding:
Prevention as the Best Option

Abstract

Across the world, flooding remains the most frequent and most damaging natural risk. This technical report begins by exploring the reasons for this state of affairs: hydrological regimes, the existence of extreme events as part of a continuous distribution of possibilities, and the concepts of hazard and vulnerability. It then moves on to describe the components of an integrated flood risk management policy: (i) preventive measures involving land use planning and hydraulic development, leaving a residual, acceptable level of risk; (ii) crisis management measures, including flood forecasting, in order to cope with this accepted level of residual risk; and (iii) measures to encourage a risk culture, communicating the lessons of the other two components. Starting from these fundamentals of flood risk analysis, the author offers operational recommendations for designing projects funded by the AFD in its target countries. In the final section, he reviews some specific situations in both France and developing countries.

Keywords: flood, flooding, risk, prevention, water resources, hazard, vulnerability

Countries: France, Cambodia, Thailand, Vietnam, Madagascar, Chad

Foreword

Despite the amount of work on the subject over the last thirty years—and perhaps even earlier, as illustrated by the epigraph above from Napoleon III—some basic concepts on flood risk management have not yet made their way beyond a small circle of researchers. And even some of these researchers, who specialize in one approach to the problem, are sometimes rather approximate in their use of concepts that relate to other approaches. In addition, from looking at media coverage in particular, and, more generally, the so-called "gray" technical literature on the subject, it becomes clear that certain terms—hazard, vulnerability, exposure, resilience, prevention, prediction—recur frequently, but not always with the same meaning, and should therefore be used wisely. Moreover, to believe the coverage, there has been a recent resurgence in such "disasters," indicating that the prevention policies of the last thirty years have been ineffective. That raises a number of questions. People consistently say that a particular instance of flooding is unprecedented—which is surprising, and very rarely true, given that the wealth of historical data collected within these regions shows that large-scale flooding has occurred there in the past.

Why Ask the Question?

It hardly needs to be explained how serious flooding can often be. Such disasters occur worldwide, always in relation to a particular meteorological event, and have considerable economic consequences. Of all natural disasters, flooding is the most financially costly. It affects countries regardless of their level of development, and so presents a universal concern. Flooding depends on meteorology, which is linked to the climate, and has attracted particular attention over recent years because of global warming and its consequences. But this rapid diagnosis deserves a more careful analysis. Note, first, that, with few exceptions, these disasters are only moderately lethal, and arguably less so than in the past. The number of deaths linked (directly) to flooding is relatively low, given that an estimated 15% of the global population is exposed to such risks. Second, in international rankings like the Global Climate Risk Index 2020, produced by Germanwatch, a German non-profit organization, this is inversely proportional to the cost of climate disasters: in developed countries, the number of deaths is low in comparison with domestic or traffic accidents. Individual tragedies cannot be ignored, of course, and below some ways to respond to them are discussed. Overall, however, flooding is mainly an economic and financial problem.

What causes this situation? There are now many more of us, spread across a finite space whose limits we have reached. We are likely more aware of floods because they now affect areas more heavily subject to anthropization, rather than because they are becoming more frequent. The question should be posed on a case-by-case basis.

The problem of flooding quickly becomes one of land management, and of interaction with water. How do humans and their economic activity occupy and share the space with water—particularly since both vary in time (the latter in a partially random way)?

Other Aspects of the Water Sector

Water is the cause of flood risks. But that is not all it is: first and foremost it is a resource, one that may be sorely lacking. In the typical order of political priority, the drinking water supply comes first, and is privileged when water is limited. Next, it is necessary for economic and industrial activity, in that it is essential for production. Finally, alongside soil and labor, water is a crucial component in agricultural production for food—and the substantial amount of it used for irrigation means that this is usually the first activity to have restrictions imposed on it during periods of water shortage. More generally (although this is not so easy to quantify economically), water, as an environmental factor in the broadest sense, defines the environment that humans interact with. Furthermore, its quality partly determines quality of life.

Any interaction with the water cycle driven by concerns about flood risks may affect other dimensions of the water sector. This must be considered beforehand in order to understand and, if possible, limit any effects. There is no need for lengthy calculations to illustrate this point. If, say, we accelerate flows to evacuate floodwater, we reduce the amount of time that water spends on land, and therefore reduce the time in which it can refill the water table, which is necessary for the drinking water supply. As a result, water resources actually diminish. Conversely, confining water to a dam reduces the exchange surface—particularly since reservoir sites are chosen for being watertight, and the space is "sterilized," reserved full-time for water and no longer available for other human activities (except perhaps leisure).

We must recognize this dual aspect of water—as both risk and resource—in our reasoning. Otherwise, we may end up exchanging one risk for another. We cannot neglect the fact that water is Janus-faced.

Whe Aims of This Report

This report aims to present for a general audience a set of concepts useful for understanding water issues, and for deciding on effective, objective approaches to them.

It is targeted at new and experienced practitioners, at land managers facing risk prevention problems, and at other actors who wish to limit the impact of poor risk prevention policies.

This report makes no claim to be scientific. It is intended for those on the ground, who may benefit from the author's accumulated experience as a researcher and an observer of these issues in different regions over many years. The reader is provided with references, which offer inroads into different aspects of the topic. The bibliography, which has deliberately been kept short, provides a starting point for such research.

This technical report was written as a complement to technical report no. 35, of November 2017, "Flood Risk and Cities in Developing Countries." Its aim is to be both more concise and more precise in its conceptual approach.

1. Fundamentals

1.1. The Natural Phenomenon

The primary cause of floods—that is, overflowing watercourses—is excessive runoff caused in turn by heavy rainfall. We encounter here the familiar elements of the water cycle. The origin of the phenomenon must be understood at the scale of the watershed. This is the task of hydrology.

Water is an incompressible liquid. Once it has fallen to the ground, except for the limited part that can infiltrate the earth, its volume can only be distributed in time and space. Any action will modify this temporal or spatial distribution. At one extreme, the storage dam makes it possible to retain water for weeks or months by concentrating it in a reserved space. Conversely, conventional waterway modification and longitudinal dikes accelerate downstream flow. Downstream, the first of these approaches causes a lamination of the flood wave, which reduces the peak and increases its duration. The second increases the peak and reduces its duration. It is the role of hydraulics to analyze the propagation and deformation of the flood wave, and the effects of such measures, along the entire length of the watercourse. Nevertheless, limiting oneself to only one type of measure will have negative consequences. We should diversify our flood wave management strategies..

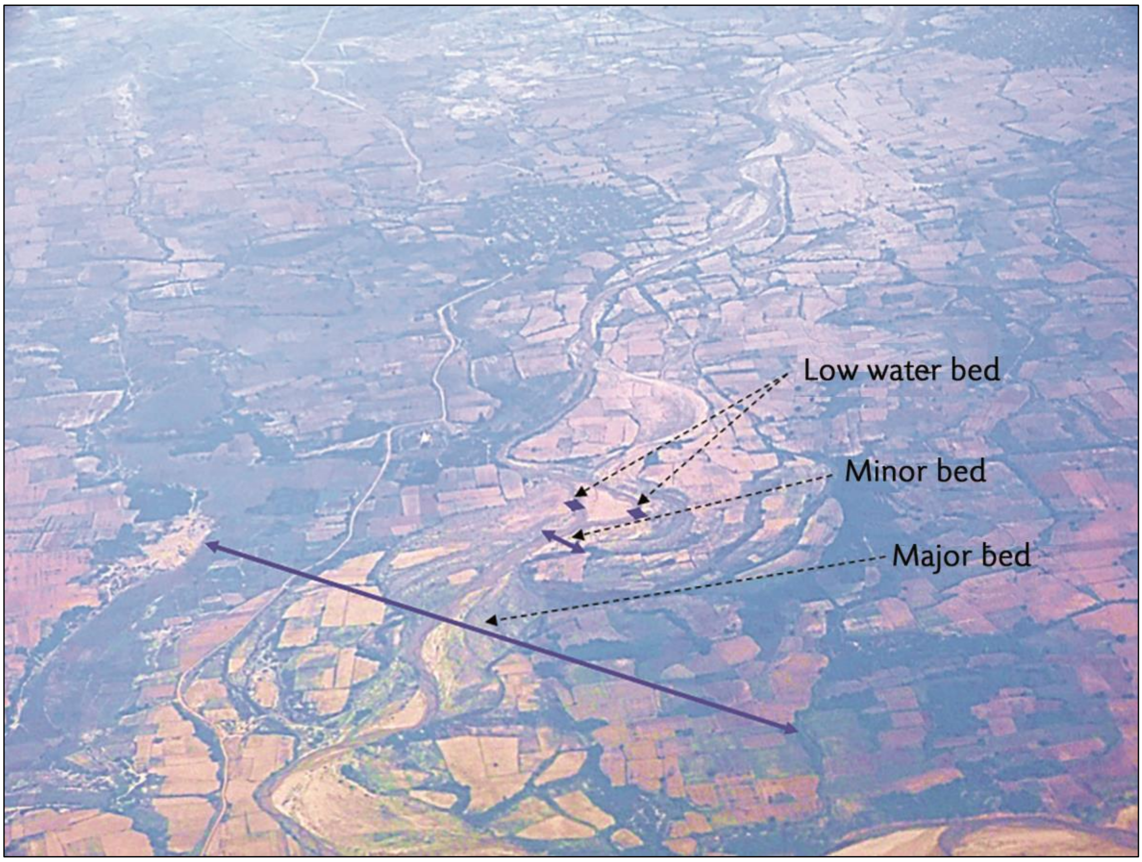
Illustration 1. The diversity of a watershed
Source: http://www.mnivesse.com/portfolio/bassin-versant/
Credit: OFB

In its natural state, a riverbed is composed of different sections. First, there is the minor bed. This is the result of a geomorphological balance between the materials that make it up and the erosive force of the flow patterns circulating within it. In a temperate climate, the capacity of the minor bed allows the maximum annual rising river to pass without overflowing. It is natural for rivers to overflow their minor bed every other year on average. In some specific situations, there may also be a low water bed, which is where the river flows during dry periods of the year.

Next is the major bed. This bears the marks of rainfall and flood regimes, and defines the maximum envelope of possible floods. In areas subject to frequent flooding, an intermediary bed is sometimes also established in order to discriminate the area that prioritizes water from that which prioritizes human activity. One thing is certain: anywhere that has flooded can and most certainly will flood again.

This maximum envelope makes it possible to map the field of possibilities, and should alert those in the region—particularly decision-makers—to the existence of a hazard, even a very unlikely one. Being aware of this hazard is the first step in understanding and preventing it. Further, given the amount of land affected, we cannot simply abandon it to the water. The land must be used alongside the water, with full knowledge of the situation, the existing hazard, and the accepted level of risk. Only then is it possible to plan land use accordingly. This is an essential step in prevention.

Photo 1: The beds of a river
Photo credit: Olivier Gilard, Myanmar, May 2017.



1.2. Risk = Hazard × Vulnerability

There are several approaches to conceptualizing risk. By now, however, it is almost universally accepted that risk is a combination of two factors: hazard and vulnerability. Hazard measures the exposure of an area of land to flooding, while vulnerability relates to the goods and people present. For example, a river overflowing into a forest or a meadow worries no one. Build a house there, however, and a risk now exists. Only the vulnerability has changed!

1.2.1. Land Vulnerability: Estimating the Goods and People Present in the Location

Let us begin with vulnerability, which is typically less documented and less understood. It is also the concept that has changed most in recent decades, across the world, under the influence of population growth, socio-economic development, and increasing urbanization.

To begin with, there is no universal definition of vulnerability: along a watercourse, and even within an urban area, there exist substantially diverse sensitivities to water : a wasteland is not like a farmed field, an urban green space is not like a roadway, a supermarket is not like a school or hospital, a dense patch of housing is not like a sparse group of homes, a two-story house does not pose the same problems as a single-story building, and so on.

Photo 2: The different sorts of vulnerability
Photo credit: Olivier Gilard, Vietnam, suburb of Ho Chi Minh City, January 2007.

Note that vulnerability can be modified by a change in the spatial distribution (urban and regional planning), by construction practices (mezzanine floors, pilings, etc.), and by spatial occupation.

PPhoto 3: Construction methods (pilings) reduce the vulnerability of housing
Photo credit: Olivier Gilard, Cambodia, Phnom Penh, 2009.

For instance, in France, after the flooding caused by Storm Xynthia in 2010, houses in the affected area were modified to provide refuge areas and to enable evacuation through the roof. These homes are now less vulnerable.

Economists have approached vulnerability through damage analyses, sometimes treating it as a function of hydraulic parameters like height, duration, and flow speed. But it is clear that vulnerability affects more than just things with direct economic value, and this makes it more complex to analyze. For example, it would be difficult to give a market value to a photo album that has been destroyed, and yet its loss may have a real psychological impact for its elderly owner. Moreover, this approach very quickly erases the spatial distribution of vulnerability by making it easy to summarize potential damage over an entire region.

Box 1: What's so hard about vulnerability analysis?

Consider a campsite and a nuclear power plant. Which of these two is more vulnerable? The campsite, perhaps, given the deaths a flood might cause. But the consequences of a flood in a nuclear power plant would be far higher. No matter the level of risk of the particular piece of land, a nuclear plant is far more vulnerable than a campsite!

In the case of a supermarket and a fire station, we might think that the latter is less vulnerable, because those inside it are very aware of risks. If the fire station is flooded, however, the entire crisis management system is affected—any intervention by the fire department would be impossible! It is in our interest, then, to view the fire station as more vulnerable than the supermarket, and to better protect it (i.e., reduce the level of risk).

Finally, a distinction should be made between vulnerability from a prevention perspective, and vulnerability from a crisis management perspective. To use the same example: If the right precautions have been taken, those needing immediate assistance will be the people at the campsite and in the supermarket, and not the nuclear plant or the fire station. In a sense, the assessment is reversed—but the same vocabulary is used, which can cause confusion.

Vulnerability analysis must consider social perception across multiple, interlocking levels. Individual perception is not identical to communal perception, which differs in turn from perception in the watershed region, and from the national level. These interlocking levels put individual perceptions into perspective, contrasting them with mechanisms on different territorial and social scales, like insurance systems and community infrastructure projects. Each level has its own role to play in managing risk. I will come back to this.

Note that vulnerability assessments can be carried out independently of hazard: any flooded house (or any other concern) can be described by a damage curve. This is true regardless of whether it lies on a flood plain; what changes is simply the probability of the event. This independence of factors is crucial in maintaining objectivity and differentiating between vulnerability and risk.

Finally, I will use the term "vulnerability," which is broader (spatially, economically, psychologically, etc.), rather than "exposure." Bear in mind, however, that the specialized literature uses the former term in a number of different ways, which may blur its meaning.

1.2.2. Flood Hazards

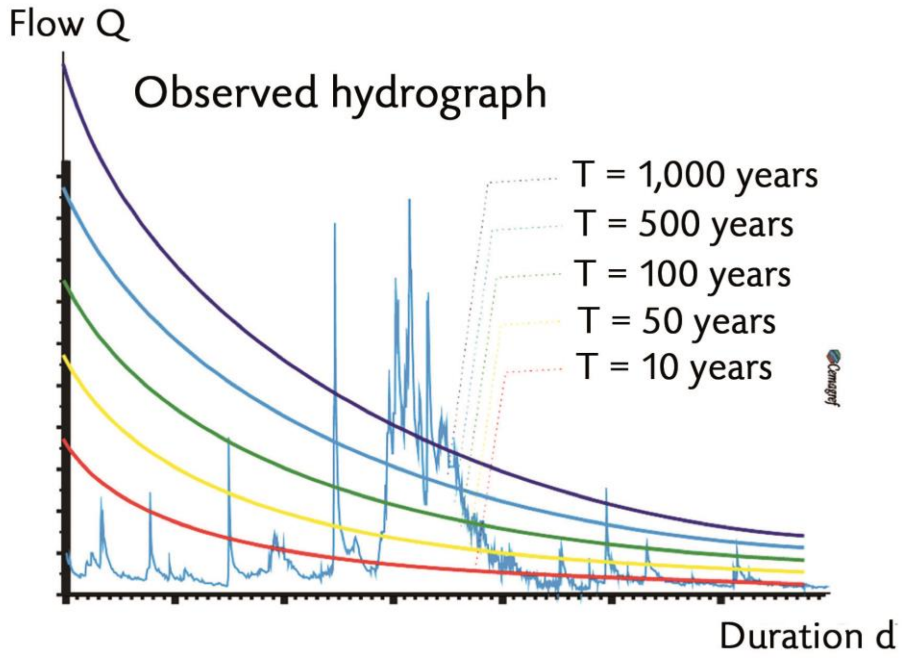
S While vulnerability is essentially a socio-economic issue, hazard is linked directly to hydrological and hydraulic phenomena. Its first characteristic is its extreme intrinsic variability: observing flooding in a river, we find that each event is unique in terms of peak flow (intensity), volume (duration), dynamics, etc. Hydrologists have developed statistical models to summarize and operationalize this variability. The most interesting of such representations involve the flow-duration-frequency (QdF) of a watercourse's flood regime. Because of their overall consistency, these enable robust representation and limit uncertainty. However, their quality depends on the observational data available, and in particular on the length of the time series—since observations over a long period are necessary for a reliable estimate of uncommon events.

Hydrometry, which provides the basic data, is far from an exact science, since we only know how to continuously measure the surface water level. Other variables, like flow, are derived from an initial model, supported by other point measurements (calibration curves). Moreover, maintaining hydrometric measurement networks is a constant, long-term challenge.

Estimating exceptional rising river flows is an art, and such data remains imprecise in spite of efforts to improve it.

It is the consistency of the entire regime that matters, rather than the precise value of a particular flow-duration-frequency estimate. Given the limits of rain-flow models, whose descriptive quality depends heavily on the amount of calibration data available, we should be cautious. It is important that researchers continue to work on them. However, they are rarely useful when data is limited—as is, unfortunately, still too often the case in developing countries.

Graph 1: Flow-duration-frequency (QdF) curves: A synthetic representation of flood risk, reflecting a river's entire flood regime
Source: "Guide pratique de la méthode inondabilité," Olivier Gilard, étude inter-agences no. 60, 1998.



Box 2: Flood events and flood regime.

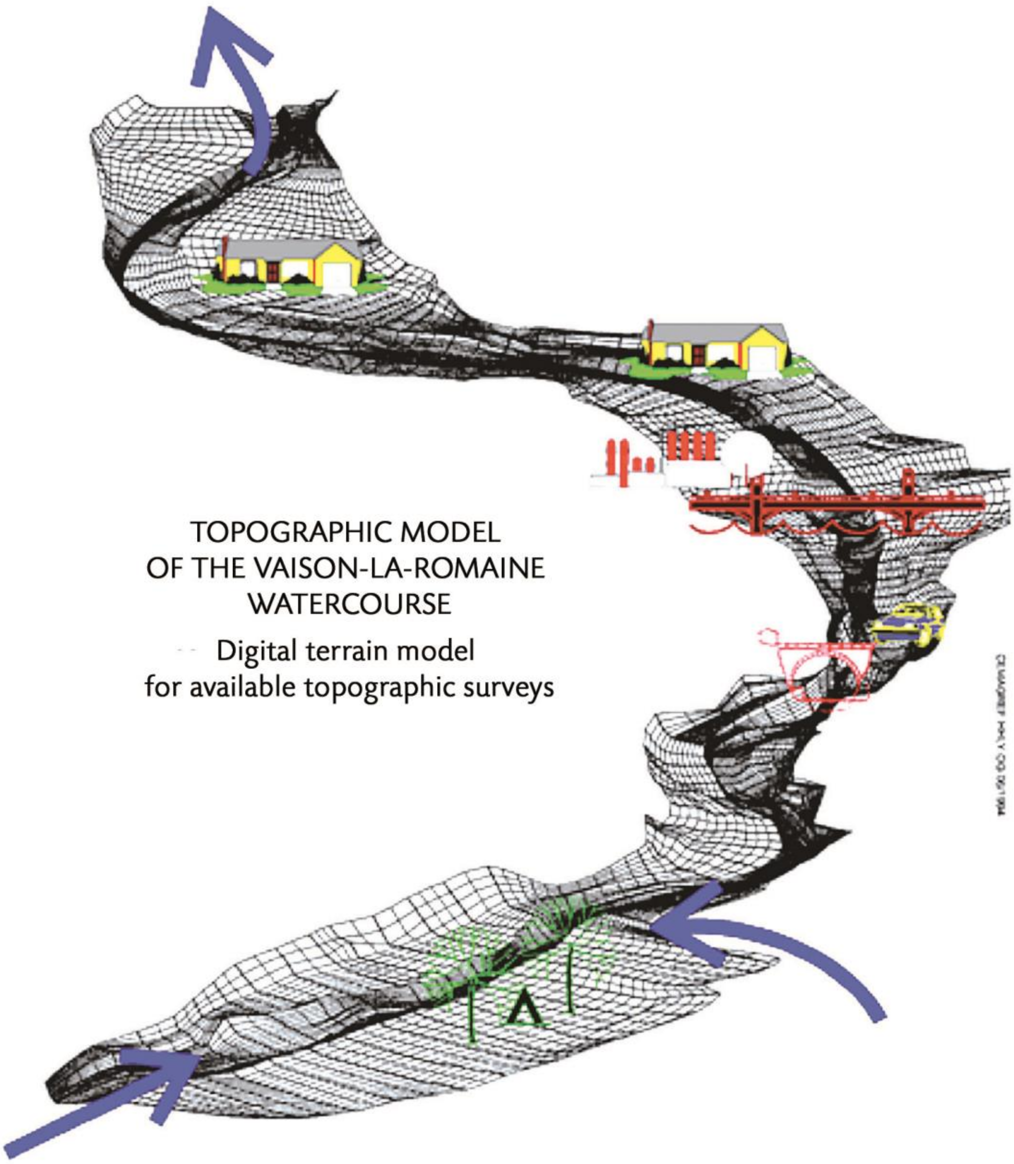
Especially after a disaster- or crisis-provoking event, there is a tendency to see the hazard as being limited to that event alone.
However, the definition of hazard must take into account the whole field of possibilities, rather than being restricted to a particular event—particularly as the chance of exactly the same thing happening again is almost nil, since each particular flood has its own characteristics, involving highly circumstantial factors (an obstruction under some particular bridge, a particular dike breaching, etc.).

Finally, hazard has a spatial aspect that must be considered: the role of hydraulics is to transform hydrological data into water height, and so into a spatial distribution.

Above, I discussed floods related to watercourse overflows, characterized by a partial dissociation between the region generating the flood (the watershed) and the region exposed to the hazard (the major bed of the watercourse).

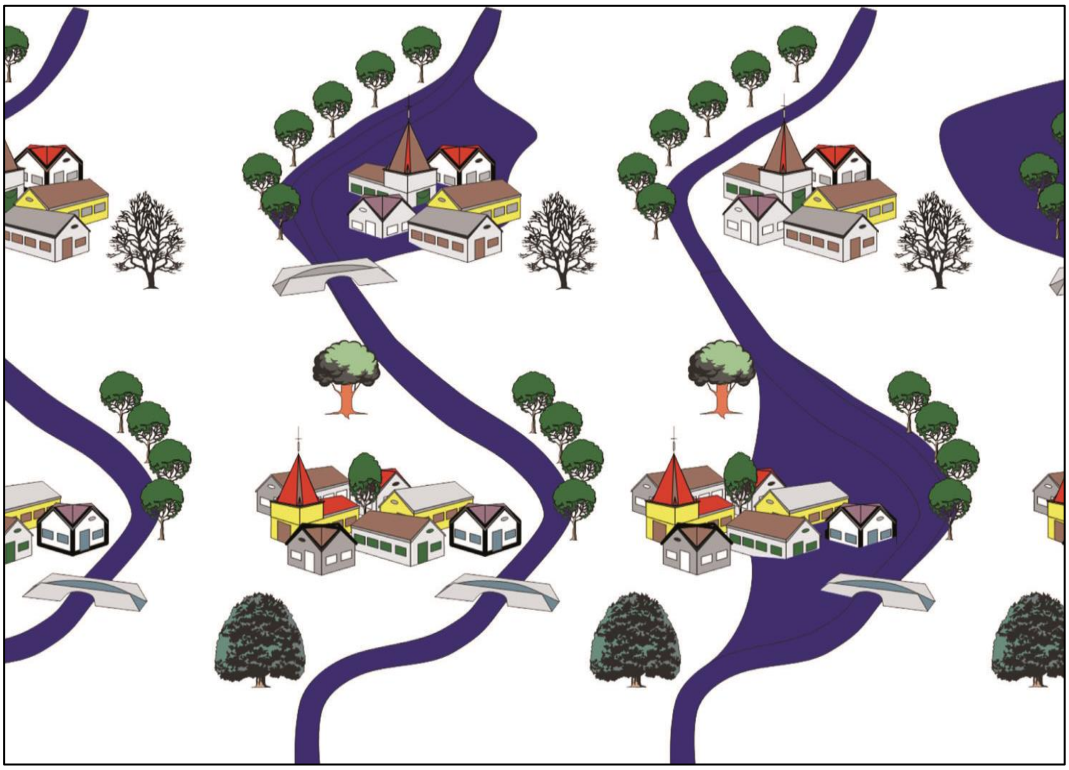
But this reasoning can also be adapted to floods that are the direct result of urban rainfall and runoff. In such cases, the hazard is described by the rainfall regime, itself represented by intensity-duration-frequency (IDF) curves.

Figure 2: A digital terrain model for hydraulic modeling of a river
Source: Created by the author, Cemagref study, 1993.



Finally, whatever land planning measures are proposed, water is an incompressible liquid, and can only be displaced in time or space. Any "hydraulic" measure will modify this space–time distribution, which must be clearly identified to avoid displacing or increasing the risk.

Figure 3: Different land management strategies for relocating floodwaters
Source: "Guide pratique de la méthode inondabilité," Olivier Gilard, étude inter-agences no. 60, 1998.



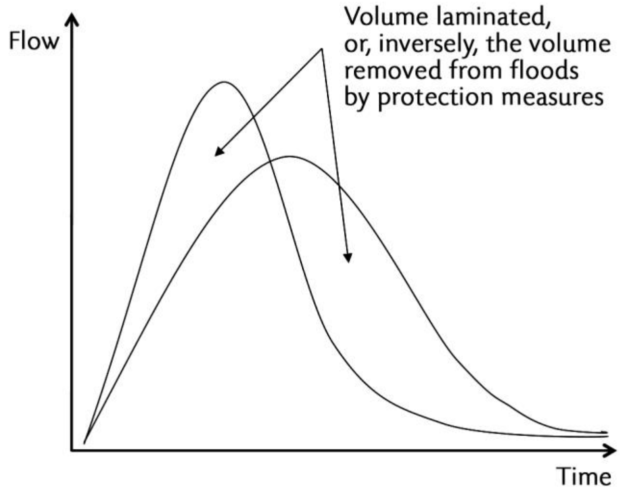
Lamination caused by flood expansion zones and reservoirs involves reducing peaks of flooding (reduction of intensity) by spreading them over time (increased duration). This is illustrated by the graph below, which will be familiar to any hydraulic engineer.

Box 3: Lamination

Lamination is particularly effective when the volumes involved are small, or when duration is short. Conversely, for lengthy phenomena involving large volumes, effective lamination requires substantial storage. A structure may be effective for frequent floods, but of little use for exceptional floods that exceed its capacity. On the other hand, structures intended only for exceptional events may be used in other ways from day to day. The costs incurred in an exceptional event may be compensated by other mechanisms, including insurance.

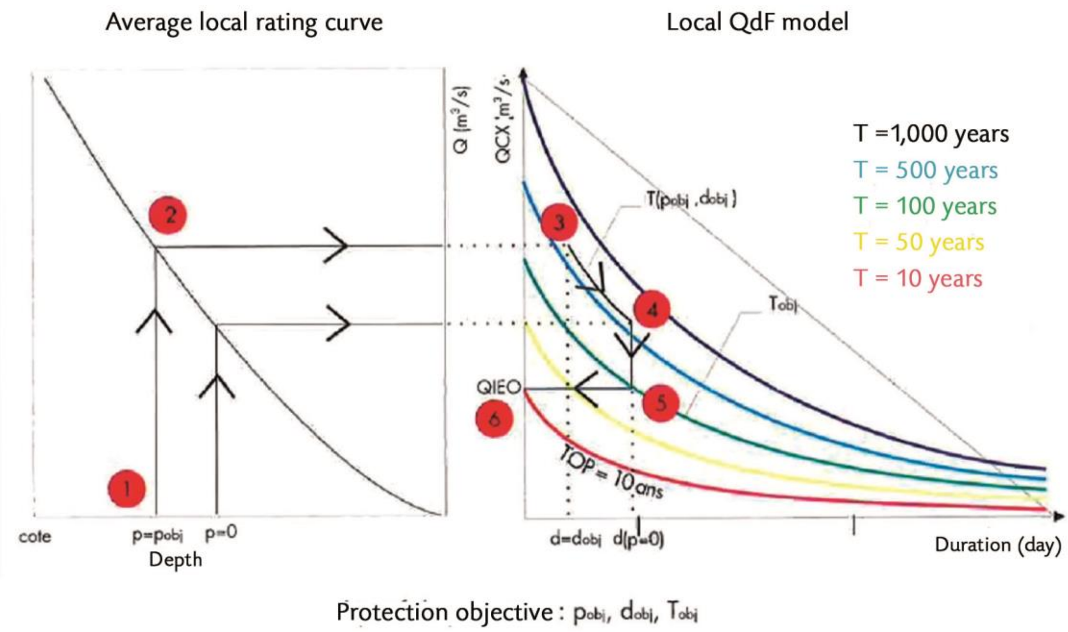
Note also that any solution that accelerates flows and reduces flood zones will have the opposite effect, shortening the duration of the flood and increasing peak flow, with possible negative consequences downstream.

Graph 2: The principle of lamination (and its opposite)
Source: Author



Remember, too, that under natural conditions these phenomena are generally continuous and progressive, except for occasional ice jams, which may break up in certain circumstances. To be flooded by one meter of water during exceptional flooding, a piece of land must already receive at least a centimeter of water during more normal flooding. Conversely, if we know that one plot of land is barely reached by water during a return period T, we have all the information we need about what happens during other return periods, in terms of height and duration of flooding.

Graph 3: The equivalence of various flooding characteristics
Source: "Guide pratique de la méthode inondabilité," Olivier Gilard, étude inter-agences no. 60, 1998..



From this, we may infer that floods cannot simultaneously become more frequent and more intense: either they become more frequent at a given intensity, or they become more intense at a given frequency. (This amounts to a translation of the QdF curves representing the hydrological regime.) Unfortunately, this misconception is common, particularly in the press, and especially when discussing the effects of climate change.

This progressiveness and continuity can be modified by hydraulic means. In particular, they can be affected by dikes. If these burst or overflow, they create discontinuities, and we pass from a situation without flooding to one with very high, long-lasting, fast floods as soon as an event exceeds the reference conditions used for the anti-flood measures. These threshold effects are much more difficult to manage, and ultimately cause the greatest disasters. By resolving the problem of minor floods with a dike, one can seriously worsen the impact of an exceptional flood—particularly as people may have "forgotten" the existence of this residual risk, and believe themselves to be safe.

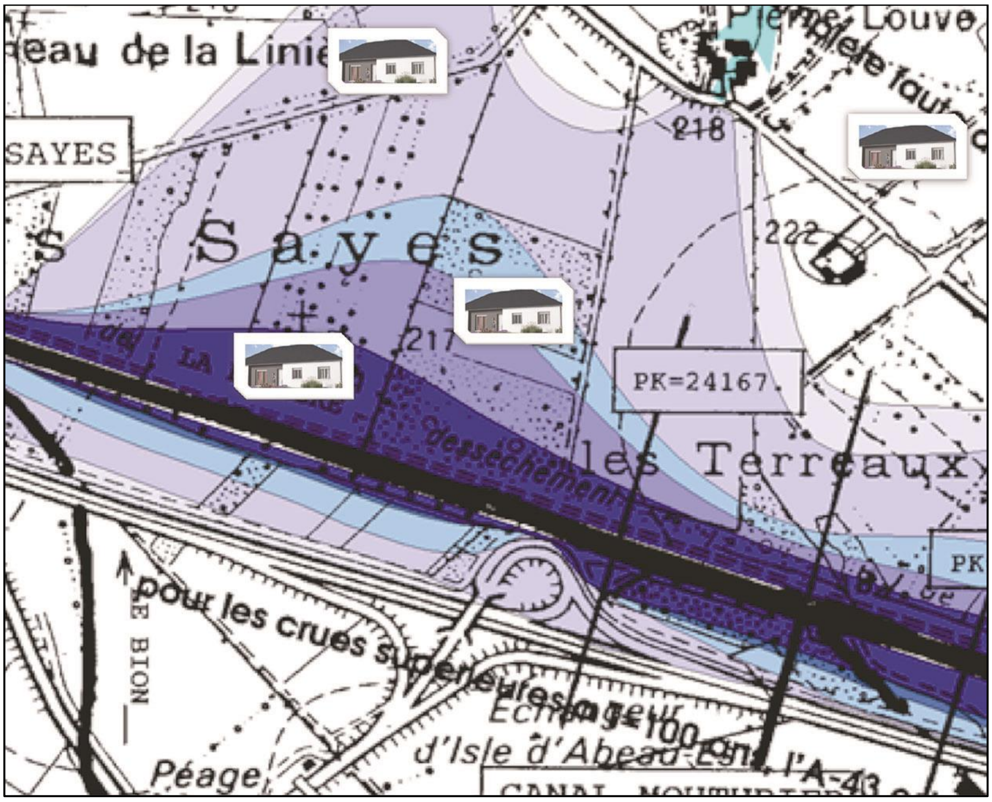
Photo 4: The Vltava in Prague, 2002: The danger of a catastrophe when a dike bursts
Photo credit: Pierrick Givone (personal communication, all rights reserved).

1.2.3. Combining the Concepts of Vulnerability and Hazard

To describe risk, we must combine the concepts of vulnerability and hazard.

On Map 1, we see that the same, equally vulnerable house, located at different points on a partially floodable plain, gives rise to different risk situations.

Map 1: Identical vulnerabilities but different hazards as a result of position
Source: Author. Cemagref study, 1992.



Conversely, two architecturally different houses on the same flood-prone plot of land—one of them a story higher than the other, for instance—face different levels of risk, even though the level of hazard is the same.

Figure 4: Identical hazards but different vulnerabilities as a result of habitat
Source: Original design by the author, all rights reserved.

The traditional approach involves multiplying the cost of damage (vulnerability) by the probability of occurrence (hazard), and possibly integrating this function over the entire field of possibilities. But this approach has two weaknesses. First, the function is always positive, and the search for risk minimization leads de facto to the endless pursuit of zero risk, the only minimum of a positive function. Second, it does not allow for fine-grained, spatialized analysis.

Figure 5: The classic combination of hazard (the dice) and vulnerability (an estimation of the cost of damages)
Source: Author.

The result is the same when comparing the cost of damage to the cost of investment in substantial protective infrastructure. Without an explanation of the accepted risk, there will always come a time when the cost of the infrastructure is exceeded by the cost of damage from a flood that exceeds the one used as a reference for the design, therefore justifying additional investment. This explains the spiral of land planning, in which a decrease in hazard leads to an increase in vulnerability, and, ultimately, an increase in risk—going against the argument initially used to justify the money spent on reducing hazard.

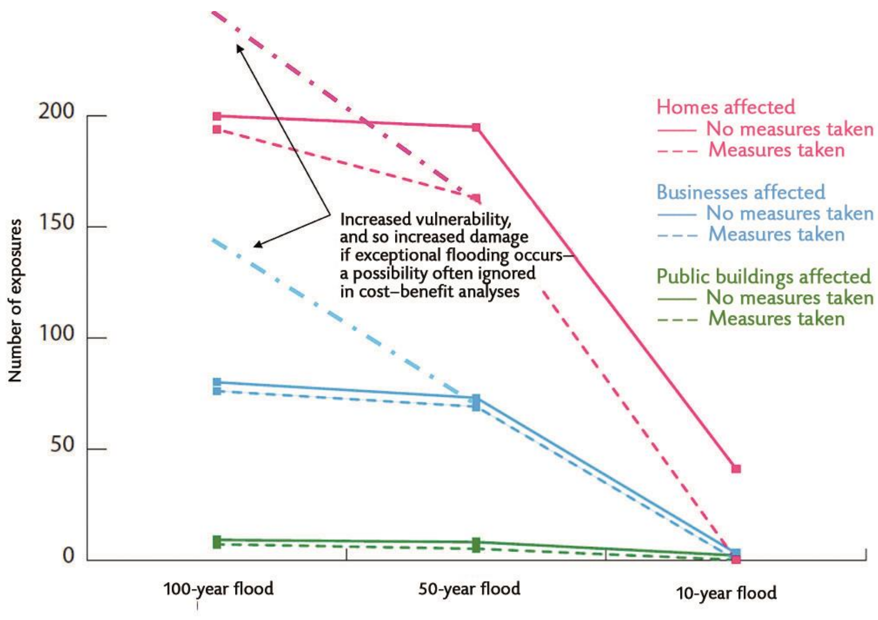
Box 4: Illustrating the land planning spiral

In most cases, this approach does not properly take into account the fact that there is a residual risk of events that surpass those used to design the protective infrastructure, or the increased vulnerability that the protective measures may cause.

Graph 4, taken from the cost–benefit analysis guide of the European Center for Flood Risk Prevention (CEPRI) and modified by the author, illustrates this by adding a like rise in vulnerability as a result of a protection plan.

(See http://www.cepri.net/tl_files/pdf/guideacb.pdf).

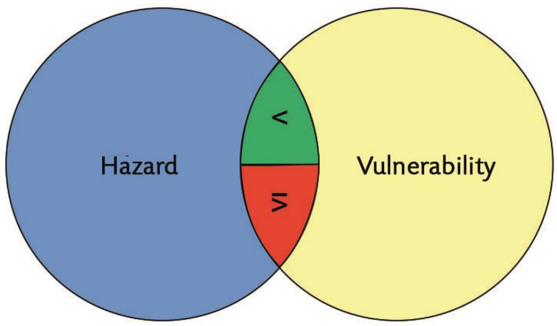
Graph 4: Potential effect of a protection measure on vulnerability



If we agree that zero risk is impossible, we agree to the notion of acceptable risk—and, consequently, to the existence of positive (unacceptable) and negative (acceptable) risk situations. This implies that hazard and vulnerability should be added, rather than multiplied. Finally, the diversity of situations must be represented at the level of each plot of land if we are to have a spatial representation of risk that allows us to identify possible solutions. Just as the hazard (water) is moved spatially by land planning, risk is distributed differently when the vulnerability factor (the occupation of space) is also modified—something that makes risk acceptable everywhere.

In the 1990s, the National Centre for Agricultural Mechanization, Rural Engineering, Water, and Forestry Management (Centre national du machinisme agricole, du génie rural, des eaux et des forêts, Cemagref)—later known as the National Research Institute of Science and Technology for Environment and Agriculture (Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture, IRSTEA) and then the National Research Institute for Agriculture, Food and Environment (Institut national de recherche pour l'agriculture, l'alimentation et l'environnement, INRAE)—led a reasonably successful project to model risk, known as the Inondabilité program. However, this method has remained confined to academia.

Figure 6: Combination of hazard (return period equivalent to hazard, TAL) and vulnerability (return period equivalent to protection objective, TOP) in the Inondabilité method
Source: Cemagref, 1992.



The work of the Intergovernmental Panel on Climate Change (IPCC), following that of the United Nations International Strategy for Disaster Reduction (UNISDR), has introduced a third element to conceptualize risk, in addition to hazard and vulnerability: exposure. This is likely a result of the UNISDR attempting to take all types of risk into consideration. Restricting ourselves to flood risk alone (the spatial distribution of which can be defined when describing the hazard), we can conclude that exposure is not independent of either hazard or vulnerability, and is redundant with the concept of risk as defined above.

As with the definition of vulnerability, what holds in analyzing a crisis situation may not necessarily hold from a prevention or management perspective.

1.3. Three Components of Risk Management

In terms of policy responses to natural disasters, and floods in particular, possible actions can be classified into three complementary components:

- prevention
- crisis management
- a risk culture

Figure 7: The three components of a policy for recognizing flood risks and reducing the risk of flood-related disastersx
Source: Created by the author.

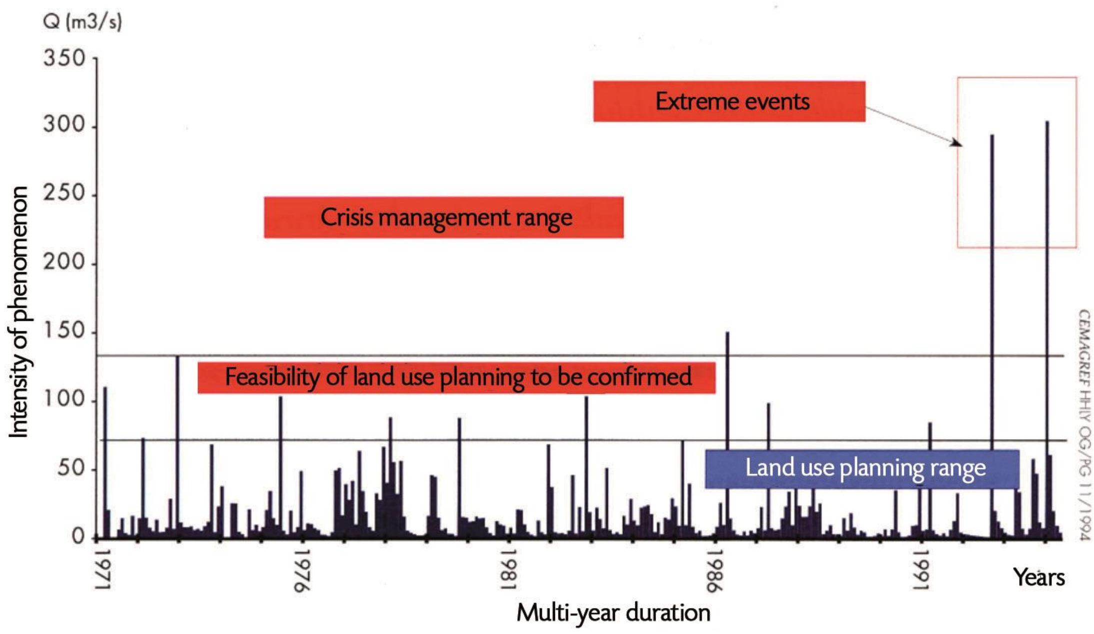
Prevention takes measures to ensure that the level of risk is acceptable and well-understood. This is a feature of regional management, and cannot be restricted to an event-driven approach.

Crisis management and insurance mechanisms, recognizing the level of (residual) risk accepted, enable ad hoc measures to reduce the impact of inevitable disasters, and to increase individual and regional resilience. Unlike prevention, an event-driven approach predominates here.

A risk culture enables knowledge to be shared between the people and institutions concerned, in order to maintain awareness of the accepted risk and the possibility of crises. This promotes individual and collective reactions that are well adapted to crisis situations in terms of both prevention and behavior.

The way these three approaches are combined should reflect the natural variability of the phenomenon. It is hopeless to try to protect oneself against the very rarest events through structural means, although good crisis management will enable one to limit their consequences. Conversely, the most frequent events must be dealt with through good prevention, based on hazard and vulnerability. This will mean that regular economic activity is compatible with the risk situation, once controlled. Where does the boundary between these lie? The whole question of acceptable risk must be negotiated locally with stakeholders in the region, and adapted spatially to local vulnerability. For instance, an agricultural area and an urban area will not be protected in the same way.

Graph 5: Illustration of the proportion of hazard that can be controlled by prevention or prediction/crisis management strategiese
Source: "Guide pratique de la méthode inondabilité," Olivier Gilard, étude inter-agences no. 60, 1998.

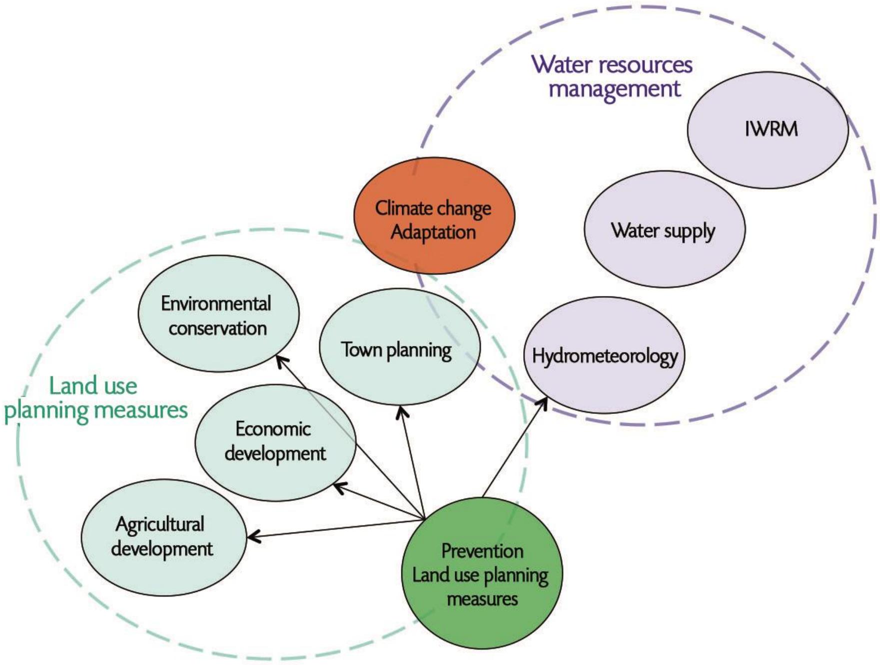


1.3.1. Limiting Damage through Flood Risk Prevention

Prevention is understood as the set of measures to control the level of hazard (hydraulic measures) and vulnerability (land use, construction standards, etc.). It must be pursued through land use planning, using structural and non-structural measures, following a process negotiated between all individuals and institutions involved. All this must take place on a spatial scale that is adapted to take advantage of the diversity of situations, using these to create room for maneuver.

Prevention involves all institutions in charge of land use planning. It must seek negotiated compromises between these stakeholders' concerns: economic, environmental, urban planning, landscaping, etc. Priorities can change over time, and risk prevention often comes back to the fore after a catastrophe or near-catastrophe. But other objectives, like urban growth and economic development, are just as legitimate and necessary.

Diagram 1: The components of a prevention policy
Source: Created by the author.



A well conducted prevention process does not prevent economic growth in flood-prone areas, as long as the frequency of the hazard is sufficiently low. However, the underlying constraint must be taken into account. In agricultural areas, this might mean more flood-tolerant crop strategies (choosing between plowed and unplowed fields, for instance). In urban areas, it might be reflected in construction practices (mezzanines and pilings, the design of the electrical network, etc.), and in related projects like hydraulic routing for water evacuation, which allows faster draining and a quicker return to normality. This could also result in easements on the land, as used in other collective problems (e.g., rights of way). In an emergency, all such measures would limit damage and preserve economic functionality as much as possible.

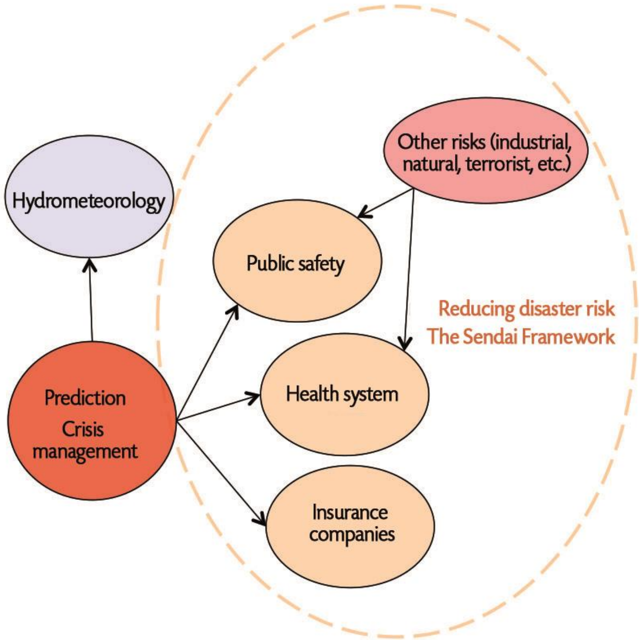
But effective prevention, by reducing the frequency of crises, can also be partly counterproductive, lowering awareness of residual risk and so reducing the risk culture and resilience of the populations concerned. For example, the management and diking of the lower plain of the Aude reduced the frequency of floods during the twentieth century. Traditionally, houses were built with two stories, with the ground floor serving as a storage area, and had low vulnerability to flooding. Gradually, as the memory of the risk faded, these ground floors were made part of the home—meaning that the damage caused by flooding, while exceptional, was more serious.

1.3.2. Crisis Management as a Means of Resilience

As long as prevention is not absolute, crises will occur from time to time, as a result of the compromises mentioned in the previous section. Mechanisms are needed to manage these crises effectively.

There is a wealth of literature describing crisis management methods: contingency plans, warning systems, crises, post-crisis, clean-ups, reconstruction, lessons learned, and so on. Crisis management calls on institutions reserved for exceptional circumstances: emergency services, public safety services, law enforcement, etc.

Diagram 2: The components of a crisis prediction and disaster management policy
Source: Created by the author.



Through evacuations, effective crisis management can greatly reduce the risk of loss of life. Note, however, that poorly thought-out prevention strategies can increase the difficulty of alerting people. They may thereby increase risk during a crisis through threshold effects that do not ordinarily exist—for instance, when a dike bursts or overflows.

On the other hand, even the most effective crisis management has little impact on economic damage, since only easily movable assets can be protected. The faster the dynamics of the flood (particularly in Mediterranean and tropical climate regimes), the less effective warnings are in reducing financial damage. This is because of the short time for decision-making between the forecast and the onset of the flood..

In slower cases (for instance, floods lasting several days or weeks, on the banks of large rivers), a warning may allow the deployment of temporary local protection systems, enabling some sections with particular goods to be protected. Remember, however, that a disaster, at its height, leads to many services being temporarily disorganized. Crisis systems do not always have the substantial workforce they require, and supposedly automatic systems sometimes fail because of power or communications failures. When the exposure is very high—a nuclear plant, for instance, is extremely vulnerable, and therefore an additional risk factor—it is crucial to have redundancy systems in place, and to ensure limited operation in order to get through crises without adding to the disaster.

These systems improve resilience in crisis management, and make it faster to return to normal.

Note that the hydrometeorological skills required to manage crises, in real time and in the face of uncertainty, are not the same as those required to determine hazard and risk. Crises are defined by the unique nature of the event that caused them, which will certainly never happen again in precisely the same way, making them to some extent impossible to predict.

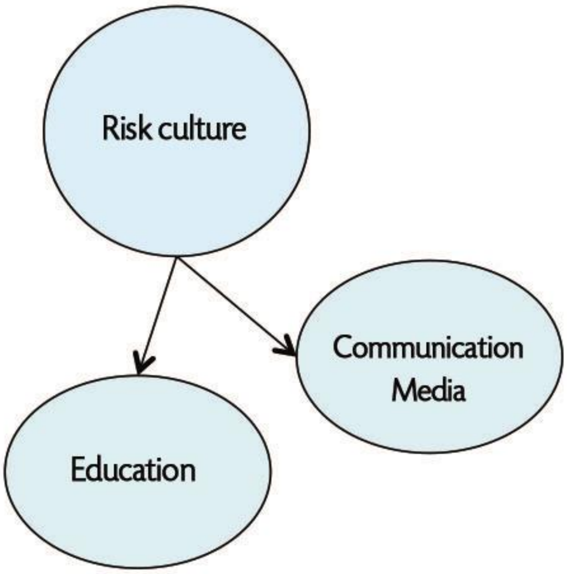
Predicting exceptional events is an art, one made even more difficult by the fact that, by their nature, they diverge from models that describe “normal” situations, and are very difficult to measure. (It is almost impossible to gauge a river during an exceptional flood!) To be precise, hydrological and hydraulic models must be based on observational data, but this is often marred by errors—which become particularly pronounced when the observed event is rare and difficult to measure. Trying to predict the exceptional is something of a contradiction in terms!

1.3.3. A Risk Culture: An Essential Prerequisite

A risk culture is the third and final component of an effective risk management policy, without which the other two are less effective. A population not used to the concept of risk will not correctly interpret the messages coming from the institutions in charge of prevention and crisis management. While the problem depends heavily on collective processes, it also depends on appropriate individual behavior.

This is true in prevention. Without a risk culture, the denial of a building permit because the hazard level is too high, or strict building standards that increase construction costs, may be misunderstood and ignored—until the next crisis, at which point individuals will turn on the community, even demanding prosecution if a tragedy occurs.

Diagram 3: The components of a policy for developing a risk culture
Source: Created by the author.



This is also true in crisis management because its effectiveness depends on "reflex" behaviors that do not allow for reflection in the moment. This is particularly true for evacuation orders, which are only followed immediately if the psycho-sociological groundwork has been properly laid.

Without regular communication and risk education, the memory and risk culture disappears, reinforcing a sense of security that is valid only below a certain threshold.

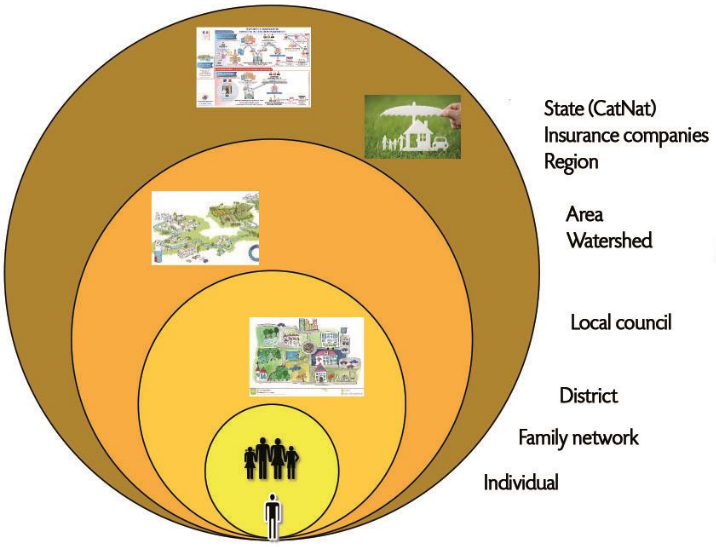
Moreover, this risk culture is essential for enabling the political decisions and financial measures needed to fund investments aimed at better documenting, preventing, and predicting natural risks, by giving them sufficient priority.

The mapping of hazards, vulnerabilities, and risks is an essential element of this risk culture, regardless of how precise it may be. These maps are the basis of valuable discussions for all stakeholders involved.

1.4. The Interlocking of Geographic and Social Levels

I should end this chapter on the fundamental concepts of flood prevention by noting the different spatial and social scales that must interlock in responding effectively to such risks.

Figure 8: Vulnerability and risk are affected by the interlocking of different geographic and social levels
Source: Created by the author.



The operational scale is that of the watercourse, including its catchment area. This is the right scale to identify the transfer effects caused by hydraulic developments. It also offers a range of land use, and so a range of vulnerability, allowing room for maneuver and negotiation—particularly regarding the acceptability of specific levels of risk in different zones. While the consequences of flooding are often seen mainly in urban areas, the search for solutions may involve negotiations with nearby rural areas, which are more able to tolerate a hydraulic constraint, provided that it comes with appropriate compensation. Urban areas present some diversity, but do not offer so much room for maneuver. The exception is when it comes to the risk of rain flooding and urban runoff, which has to be dealt with in the city proper.

This collective dimension should not obscure the role of individual responsibility: while the exposure of an area of land to a hazard depends on external factors, its vulnerability is partly dependent on each individual owner. The individual plays a role in reducing overall risk. This can and must be encouraged by higher levels like local authorities.

Finally, these higher levels must intervene during exceptional crises. In general, the whole of the operational region is affected by a single such event, and must find external resources. The role of the national level, and of insurers, is to provide mutual, large-scale support for local risks. This builds resilience, allowing those affected to recover from a crisis. Collectively, however, care must be taken that increased vulnerability does not lead to the collapse of the larger system when an extreme crisis occurs. When risk becomes generalized and crises spread, these mechanisms may be endangered.

This may explain the difference between the situation of developed countries when faced with a crisis, and that of less developed ones, where progress in governance and financial resources do not yet allow for a high degree of effectiveness in these interlocking levels. Such weaknesses in governance have consequences both on the implementation of prevention policies (including difficulties in enforcing urban planning regulations and insufficient financial capacity to invest in prevention) and on crisis management policies (for instance, coordination between actors and emergency aid measures). These are sometimes partly offset by a better individual risk culture, as individuals rely little on the higher levels in the event of a crisis.

2. From Theory to Practice

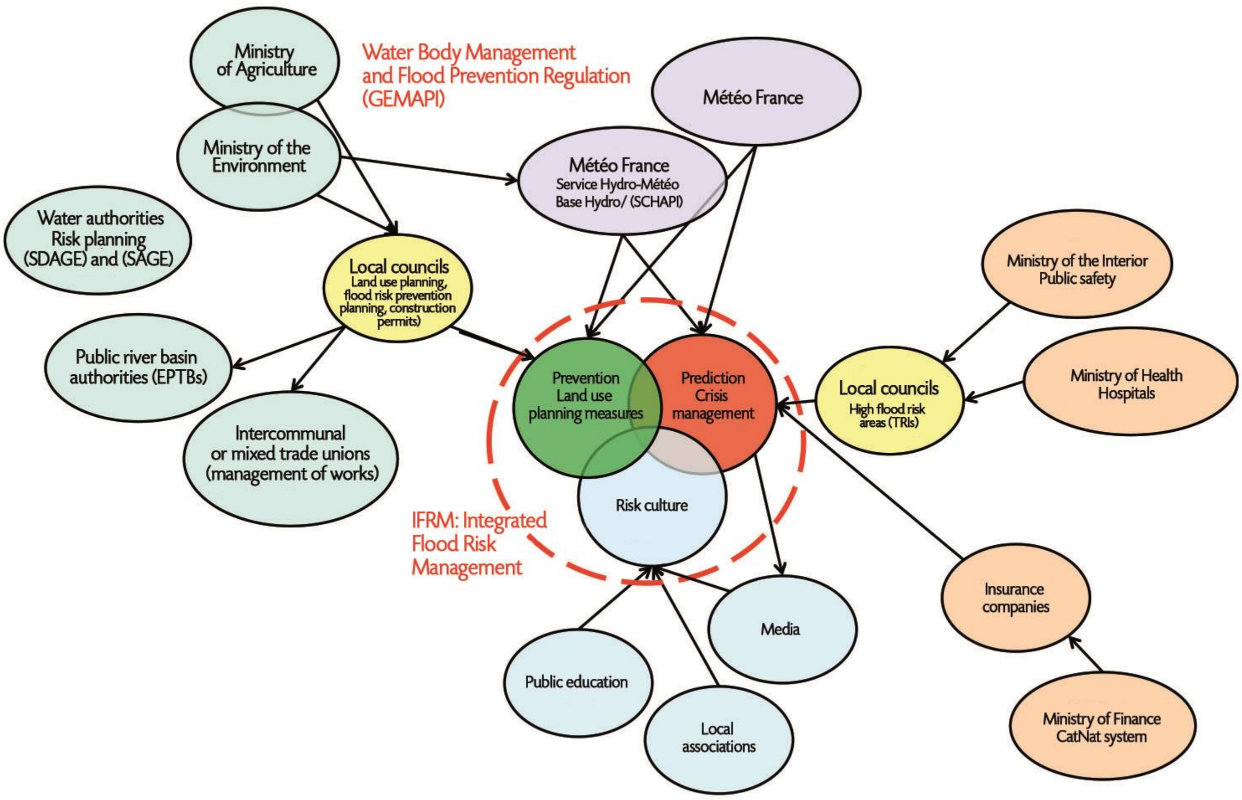
2.1. What Is a Flood Risk Reduction Project?

2.1.1. Integrated Flood Risk Management

The definition of integrated flood risk management (IFRM) takes three components into account—prevention, prediction, and culture—and emphasizes that they complement each other.

This concept is very useful for analyzing problems, but it does not seem to be particularly practicable: each component requires different expertise, and must be managed by different types of institutions. Two examples illustrate this point. Statistical hydrological models, necessary for preventing flood risks, have little in common with deterministic hydrological models, necessary for flood forecasting. Both cases involve hydrology, but experts in one field are not necessarily experts in the other. The second example concerns institutions: public safety services, which are essential for effective crisis management, are not responsible for land use planning, which is essential for risk prevention.

Diagram 4: The many institutional actors involved in an IFRM policy in France
Source: Created by the author.



This diagram presents the different components of flood risk management reviewed in the previous chapter, identifying the different institutions involved in a region. It highlights the complexity of the system, and the intersectoral dialogues required when evaluating such a project.

2.1.2. Defining the Project

For a project to be manageable and effective, it must be defined spatially, and divided across a number of participating institutions. The choice of these boundaries is affected by constraints. Some of these are fairly objective: the boundaries of a watershed are not up for discussion; nor are the geographical limits of the flood zone in the case of the least likely, most extreme hazard. Others can be negotiated, like the funding available for the project, and the number of institutions involved in steering it. The effectiveness of projects depends primarily on the choice of a limited number of stakeholders with well-defined roles.

In terms of prevention, local authorities—which will always be numerous in a watershed that covers dozens of square kilometers—must be involved, and their concerns must be voiced by a range of representatives: city planners, environmentalists, spokespeople for economic interests, water managers, and so on. In addition, national authorities are responsible for risk prevention policies and other water-related interests like irrigation, energy, and the environment.

In terms of crisis prediction and management, it is best to also include public safety services, the meteorological and hydrological services that measure these phenomena in real time, health and victim support services, and so on.

In terms of the risk culture, it is advisable to involve educational services, which can promote a risk culture; the media, which can spread information; and insurance companies, which can compensate victims.

2.2. Preventing or Predicting: A Choice to Be Made

Each situation requires a decision about priorities. In particular, there is a choice to be made between prevention (taking into account the entire field of possibilities) and prediction, aimed at the management of potential crises (targeting a specific, unique event).

The actors and methods involved will differ according to the chosen goal. In hydrology in particular, statistically describing a hydrological flood regime has little to do with modeling a rain-flow relationship during a particular hydrometeorological episode that predicts a coming flood. By contrast, working on prevention and prediction simultaneously does not increase the effectiveness of either. Indeed, it may have the opposite effect: once warning systems are put in place, there is no need to control vulnerability; conversely, with a protective dike, there is no need to develop an effective warning system.

The main challenge in establishing effective crisis management lies in securing basic funding for an institution that only acts during crises—that is, hopefully, only rarely. The initial investment phase is onerous, but not disproportionate. When the states involved have small operating budgets, such "dormant" institutions are difficult to maintain, particularly when their activity is sporadic. This is a reason for these institutions not to specialize in flood risks alone, but to respond to all risks in the region.

In contrast, establishing effective prevention requires potentially heavy investment, particularly in infrastructure. However, if these projects are well designed, their operating costs should be relatively low. They should allow development in the region, as long as it is careful, which will generate economic activity and increase financial resources. These will, in turn, help maintain the infrastructure projects in question.

Reasonably, because of the nature of the funding methods available, donors like the AFD prefer to focus on prevention. But this does not mean that crisis management is useless, or that it should not be funded by other means.

2.3. Adapting to Each Project's Specific Context

This general framework makes it possible to analyze a situation in a structured way. This is particularly true as requests to donors often follow a recent crisis, specific to the hydrological event that caused it. The first trap to avoid is to treat this event as the "standard" flood to guard against. If that event was exceptional, such a plan would be neither reasonable nor feasible. On the other hand, if the event were a frequent one, it would only demonstrate that using the space involves an unacceptable risk—as may be the case for informal settlements and insecure neighborhoods, in areas that are unsuitable for building and should remain off limits. The solution in such cases is relocate these neighborhoods, or to reduce their vulnerability through changes in construction practices, like pilings.

Such an analysis will also make it possible to determine the best strategy in terms of prevention or prediction, to identify the stakeholders, and to contextualize the problem of risk management within the larger one of water management, in order to identify possible impacts and take these into account.

When conducted using the concepts discussed above, such analysis makes it possible to roughly describe the specific problem, and to adapt the reference standards used in a feasibility study to take account of specific local constraints. The following section offers a more detailed guide to the process of discussion that should precede the definition of reference terms for a project feasibility study.

2.3.1. Sketching Out the Hazard

This part of the analysis asks the following questions:

- Is it a rain or river flood?

  - This makes it possible to determine the boundaries of the area to be studied. For rain floods, this will be restricted to urban areas. For river floods, it will consist of the entire watershed.

- This makes it possible to determine the boundaries of the area to be studied. For rain floods, this will be restricted to urban areas. For river floods, it will consist of the entire watershed.

  - This makes it possible to decide between flood prevention and prediction, and to determine whether to focus on hazard or vulnerability.

- What hydrometeorological data sources are available?

  - These help define the degree of precision that can be expected from the hazard analysis.

Note that hazard is affected by the impact of climate change. The ability to predict this depends on the existence of data that makes it possible to calibrate predictive models. The absence of such data (long-term rainfall or hydrometric data) makes it far harder to analyze the impact of climate change, which leads to imprecision in the reference standards used to calibrate hydraulic projects.

2.3.2. Analyzing Vulnerability

Due to its socio-economic nature, vulnerability is the most complex of our components to address. It is very often left out of initial analyses. By describing it more effectively, we can offer a firmer understanding and a more balanced solution.

The aim of this initial analysis is to reveal the range of vulnerability within the region, and to expand this region to adjacent areas. This leads to greater diversity, and so offers greater resources for finding solutions. If this expansion is required to find an appropriate solution, it may also make it possible to get past administrative barriers. Finally, it provides an opportunity to better understand the institutional complexity involved, and so make the project more effective.

Photo 5: Initial analysis of range of vulnerability based on zones
Photo credit: Olivier Gilard, Thailand, near Bangkok, May 2013.

The terms of reference of the feasibility study must then define the scale at which the spatial distribution of vulnerability is to be examined. This must be consistent with the level of precision of the hazard description, which itself depends on the quality of the available hydrometeorological data. Conversely, it is inefficient to make too detailed a study of the hazard if we do not describe the spatial distribution of vulnerability with the same detail.

Finally, as for the historical analysis of hazard, the way in which vulnerability changes should be understood. This allows us to better explain the reasoning about hazard and vulnerability in the risk situation when asked, and to follow and perhaps influence any foreseeable changes to it.

2.3.3. Summarizing Risk and Outlining Solutions

This is an essential step for engaging in a dialogue with project stakeholders while taking hazard and vulnerability into account. Such a summary has several objectives:

- to describe the protection possible across the full range of land types in the region;
- to illustrate instances of cooperation between different sections of the same watercourse;
- to reiterate the level of residual risk that still exists;
- to enable a comparison between different anti-flood plans, both from the point of view of hazard (hydraulic infrastructure) and vulnerability (negotiated level of protection, changes in land use, construction standards).

This last point should make it possible to highlight the impact of different proposed plans, and to serve as a basis for negotiation between the different parties involved.

Such a summary allows us to go beyond the idea of a "standard" flood, and take into account the watercourse's entire hydrological regime, introducing other measurement categories like flood warnings and crisis management, in order to take into account the accepted residual risk.

Finally, the search for solutions must focus equally on hazard (via hydraulic installations) and vulnerability, in both urban and rural areas. In urban areas, action happens through urban planning and regulation; in rural areas, through land use and less vulnerable cropping systems, alongside sustained hydraulic constraint.

In agriculture, agro-ecological systems—like conservation agriculture, which maintains ground cover throughout the year—make land more resilient to flooding. These systems reduce erosion significantly in comparison with plowed land. In addition, by promoting infiltration, allowing this land to remain partially floodable can help refill the water tables, and therefore restore water resources.

2.3.4. Costs and Savings

Finally, it is a good idea at this stage to introduce the costs for the scenarios under consideration. How realistic a project is depends on the financial cost of carrying it out. Conceiving a large-scale protection strategy that is prohibitively costly is useless. Ultimately, cost is often what makes it possible to decide between different possible strategies. Such cost analysis should also take into consideration initial investment costs, and recurrent costs associated with the chosen solution, and should include possible compensation negotiated by different parties (compensation or insurance mechanisms, for example). Such analysis is also crucial for identifying the various financial resources to be mobilized and the institutions responsible for them, making it possible to properly assess the mechanisms to be implemented.

Economic analysis usually goes hand in hand with cost estimates of development, and this is particularly complex in the case of flood risks. Existing methods are not yet very effective at taking into account the random, probabilistic nature of flood hazards. The economic efficiency of an anti-flood measure will be understood differently depending on whether a very rare flood occurs a year after it is put in place, or whether it takes ten or twenty years to do so.

In the first case, people will view the measure as ill-conceived and ineffective. In the second, people may go on to forget the residual problem, and allow vulnerability to develop, sheltered by a protective system that is viewed as effective—leading eventually to far higher losses than initially estimated. This leads to a spiral of anti-flood planning: lower hazard increases vulnerability, until the next crisis, which justifies investing more in hazard reduction, leading to further vulnerability, and so on. Breaking this cycle is very difficult, and requires political willpower supported by far-sighted technical expertise with a balanced, integrated understanding of hazard and vulnerability.

2.4. River Flooding and Rain Flooding

The foregoing discussion is based on the assumption that we are trying to prevent flooding caused by rivers overflowing across areas used in various ways, natural and agricultural areas alternating with urban or industrial areas. This diversity offers room for maneuver and intra-regional negotiation, potentially leading to flood systems that are differentiated by area.

Rain floods in urban areas should be treated differently. This comes from the fact that a vulnerable piece of land may generate runoff that can cause flooding. The deconvolution of hazard and vulnerability to qualify a risk becomes more complex. Nevertheless, the concepts presented are still applicable to the urban environment, which also contains a wide range of vulnerabilities. A grid of streets does not have the same vulnerability as adjacent buildings, green spaces, or sports areas. Buildings vary in their susceptibility to hydraulic risks, depending on whether they are two-story or single-story. Offices are not as vulnerable as residences. Finally, the sociology of neighborhoods involves a differentiated perception of flood risk, provided that human risk has been properly managed through appropriate crisis management measures. Within urban areas, we can analyze runoff flood risk using the same concepts, and continuing to think in terms of hazard and vulnerability. Just as it is impossible to avoid exceptional watercourse flooding, drainage networks cannot absorb exceptional rainfall, especially in climates with high rainfall, like the inter-tropical zones or the Mediterranean. It is therefore advisable to identify the major bed of drainage networks—particularly as these are underground, and so forgotten by the population. This has led some urban planners and architects to develop the concept of cities without drainage networks, aimed at managing urban runoff exclusively using surface flows.

It should be noted that protecting an urban area from river flooding always leads to the hydraulic isolation of the city from its natural drainage pathway and, consequently, to more difficult rainwater flood management. If you build a dike that isolates you from the river, the rains that fall on the urbanized side of the dike no longer find their way to the river as easily, which is typically how they are evacuated. This negative impact of hydraulic works should be taken into consideration—even if, generally, as a result of the difference in the scale at which these problems must be dealt with, it is commonly recommended that the two "risks" be handled through independent projects, one focused on river risks (on the watershed scale) and the other on rainfall risks (on the urban scale).

Finally, to put the problem in perspective, recall that, if we could store 100mm of water for a few hours over the whole urban area (roofs, roads, etc.), we would solve the problem of rainwater flooding in temperate regions—and that, with 300mm of storage, we would also solve the problem for the Mediterranean and the tropics.

3. Interacting with Other Policies and Dealing with Impact

Water is Janus-faced: on the one hand, it is an essential resource; on the other, there is a risk factor associated with it. It has many uses as a resource: drinking water, industry, agriculture, the environment, and so on. The concept of Integrated Water Resources Management (IWRM) was designed to take these manifold interactions into account. Flood risk management must be included in this. This is particularly true of flood risk prevention.

Water is connected with meteorological phenomena, and, consequently, with the climate. Interactions between flood risk prevention and climate change must also be analyzed through the lens of climate policy, particularly when it comes to aspects involving adaptation to climate change.

Water is an essential component of the environment, and a constraining factor for biodiversity within it. This interrelationship must be taken into account—particularly now, when threats to biodiversity have taken center stage.

3.1. Risk and Resources

Typically, when flooding occurs, the usual reflex is to get rid of the water as quickly as possible, by accelerating flow. Unfortunately, systems that make this possible—waterway modification, linear dikes, strengthening banks—are generally not specific only to flood periods, and have repercussions on the entire hydrological system. As a first approximation, however, because of the dynamics of exchanges between the water system and the water tables (which are a major source for the water supply system), the volume of water available is proportional to the duration of exchanges. If there is a widespread acceleration in outflows, there will be a fall in the amount of water available. Moreover, the self-purifying processes that occur in the natural environment need to take place slowly, and as such are less efficient when water spends a shorter time in the environment. These accelerating systems will also have a negative effect on water quality.

The concept of dynamic slowdown was developed as a result of these considerations. Its objective is to reverse the instinct to accelerate flows. The term “dynamic” indicates that the duration involved is limited, as opposed to storage in dam reservoirs, where the water is static. By taking advantage of the lamination effects of flood peaks caused by storage on less vulnerable land, flood prevention can be improved, even as water resources and their quality are improved because of increased exchange time. This strategy is particularly effective with floods that are intense but limited in volume.

Photo 6: Example of "spontaneous" dynamic slowdown in an agricultural region of Xiangkhouang province, Laos
Photo credit: Olivier Gilard, Laos, May 2013.

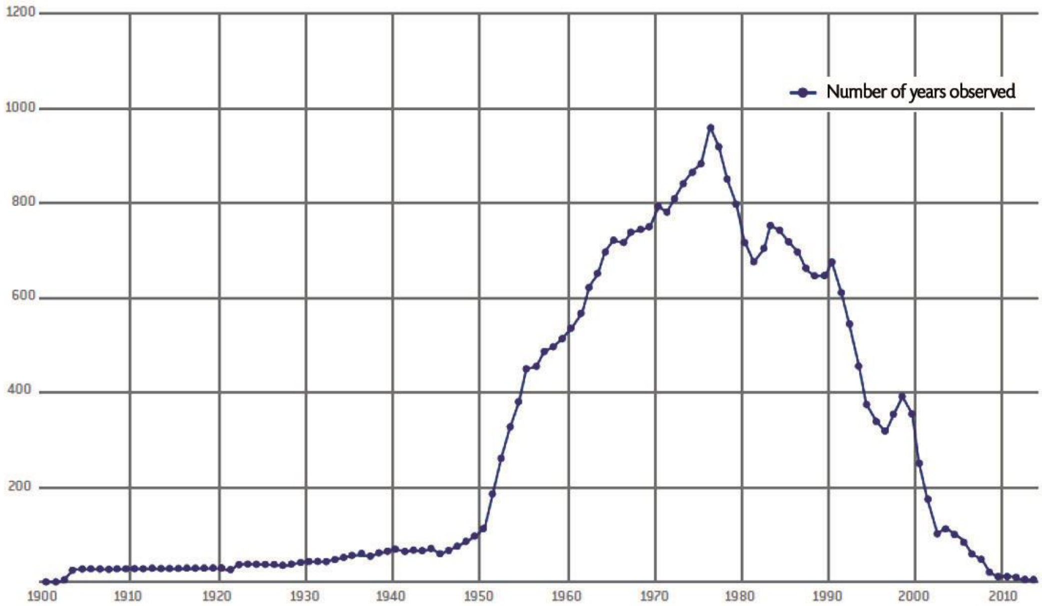
Agricultural land is particularly useful for implementing this strategy, especially with adapted crop systems (like conservation agriculture) that make it more tolerant to flooding. Permanent plant cover reduces the negative effects of flooding by limiting erosion and increasing soil permeability, so refilling the water table.

3.2. Risk and Climate

The hydrometeorological variables that cause floods are intrinsically linked to climatic variables, and are therefore potentially influenced by climate change. However, current models do not allow us to precisely quantify the local impacts of these global changes. We often lack the hydrological data to properly calibrate the models used. This is particularly true for exceptional floods, which are in any case difficult to measure precisely. Studies on the subject often give contradictory results, and reveal no unambiguous trends.

This should encourage those involved to redouble their efforts at hydrometeorological observation and measurement, which will enable us to better predict the impact of these changes. Unfortunately, such work is insufficient in most parts of the world, even though it is only the collection of long-term data that will allow us to identify reliable statistical trends.

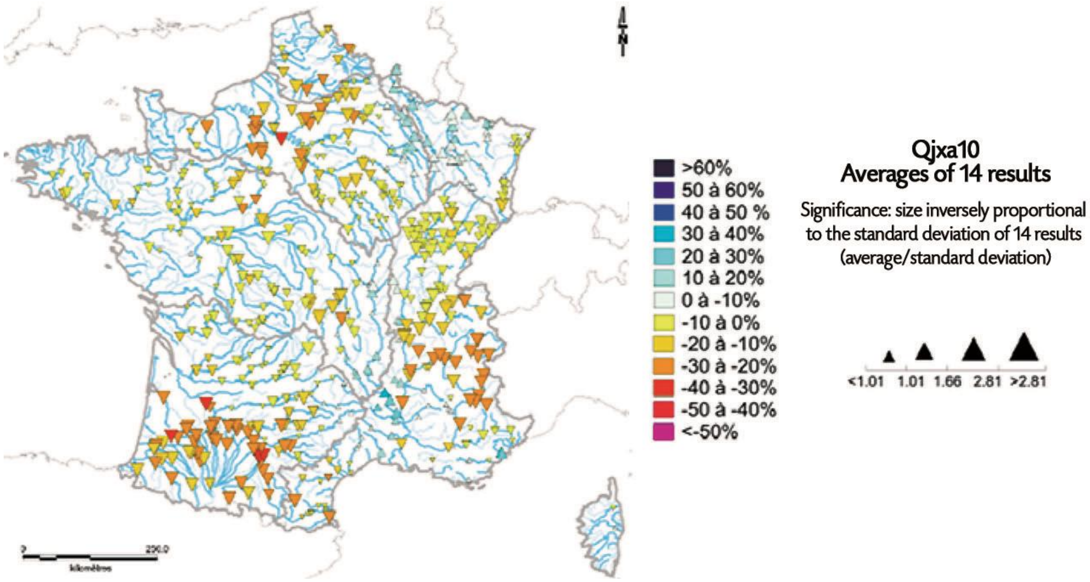
Graph 6: Number of functioning hydromet stations in Africa over time (1900–2010)
Source: Data extracted from the French Water Partnership (FWP) report Water, Climate, and Development: Better Knowledge for Better Management, 2016, http://www.partenariat-francais-eau.fr/en/production/water-climate-and-development-better-knowledge-for-better-management-october-2016/.



Every current effort to prevent floods and to control vulnerability will help adapt these regions to the effects of climate change. Even if the level of protection achieved decreases due to these changes—if 100-year floods become 50-year floods, for instance—an effective hazard reduction strategy, coupled with vulnerability control, will still be valuable for future hydrological approaches. With a few local exceptions, where settled populations may be displaced, demographic pressure and the trend toward increasing urbanization make it unlikely that regions will be abandoned because of flooding (which has other advantages in terms of urbanization, as evidenced by the number of cities built along rivers). The sooner construction practices and land use regulations are integrated in order to control vulnerability, and combined with an understanding of the different levels of possible risk, the less dramatic and the more economically bearable the future impacts of climate change will be.

Such measures contribute effectively to a general policy of climate change adaptation.

Map 2: Influence of climate change on flooding in French watersheds
Source: Summary of the Ministry of Ecology and Sustainable Development's Explore 2070 project,
http://www.gesteau.fr/sites/default/files/gesteau/content_files/document/explore2070-hydrologie-surface.pdf



3.3. Risk and Biodiversity

Flood protection infrastructures generally make the natural environment, especially minor river beds, more artificial. This is particularly true in cases of watercourse modification, and for dikes that hydraulically disconnect the river from its major bed. These developments considerably modify the habitat of aquatic plant and animal species, decreasing biodiversity.

The concept of nature-based solutions (NBS), supported by the International Union for Conservation of Nature (IUCN), was developed to combat these effects, and to give biodiversity a place in the debate. When applied to flood risks, this essentially involves maintaining or restoring wetland zones, which help to cap the high point of the rising river through lamination and the temporary storage of floodwaters. But an NBS approach can also be used to modify a watercourse while maintaining a minor bed in the modified section. If the minor bed is geomorphologically stable, it reduces the need for maintenance operations, which destroy the substrate and the area's biological equilibrium each time they are carried out. This would preserve the natural ecosystems that develop there.

The NBS approach can be complemented by ecological engineering techniques that use plants to stabilize the proposed measures. Roots are useful for this purpose, and are to be preferred to riprap or concretization techniques, as for natural watercourses. While they do not preserve natural biodiversity, these techniques make it possible to recover a modified biodiversity that is richer than an artificial environment would be. This presents a compromise between the planning required to improve flood risk prevention and the preservation of aquatic biodiversity.

Box 5: From “hard” management to “soft” management

There are many examples where, after years of “hard” engineering, rendering the environment increasingly artificial through the use of dikes and concrete, people have returned to a “softer” approach that is more respectful of natural geomorphological processes. This choice may be made both to reduce maintenance costs and to improve the effectiveness of developments on the various functions of the watercourses.

A series of films for the Rhône Alpes Auvergne River Association (Association Rivière Rhône Alpes Auvergne, ARRA) by the Grenoble Major Risks Institute (Institut des Risques Majeurs de Grenoble, IRMA Grenoble) provides an excellent illustration of such a change in policy to better respect the green and blue infrastructure necessary for better environmental functionality.

4. Some Concrete Examples

4.1. French Examples

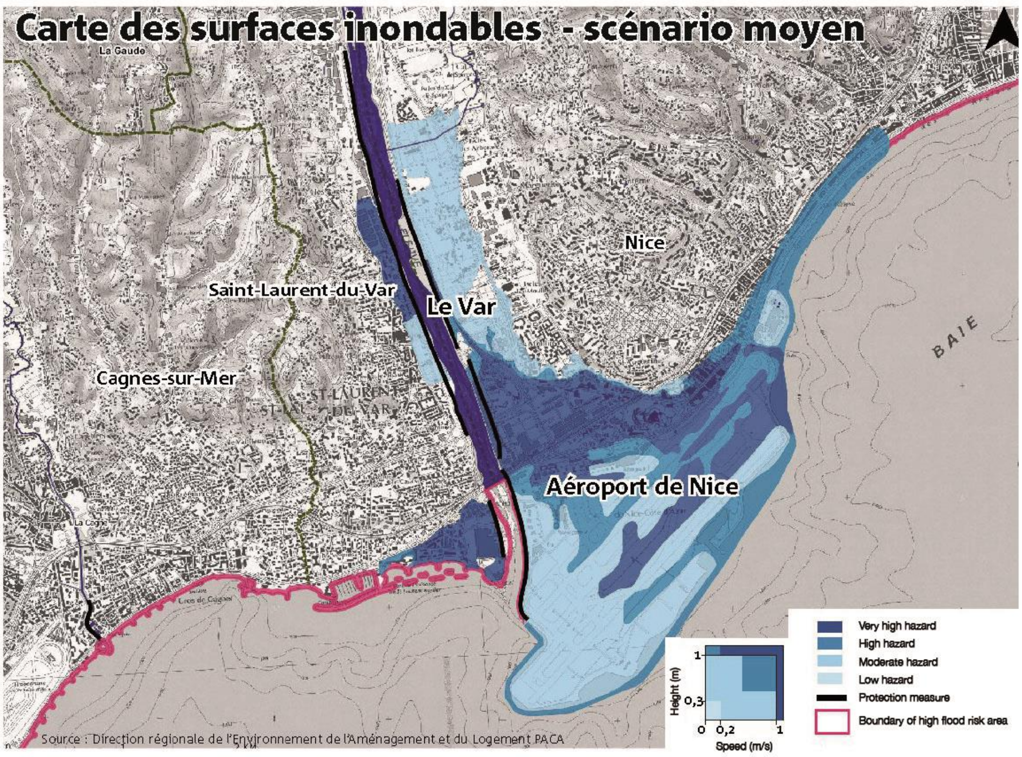
4.1.1. Nice Côte D'Azur Airport: Neglecting Accepted Risk

Those who know the Alpes-Côte d'Azur region will appreciate that its topography is hardly conducive to building airports. The only flat land available lies beside the sea and the alluvial fan of the Var, a small coastal river with a tendency to flood. That is where the airport was built in 1910, and expanded between the 1970s and 1983.
(https://societe.nice.aeroport.fr/Le-groupe/LA-SOCIETE/Historique).

The airport is therefore quite naturally vulnerable when the Var floods exceptionally. It is protected by dikes for events below the "standard" flood level. The area is classed as a flood risk, and the hazard maps are well-known and publicized. This was forgotten when the airport was extended, however, and all its IT equipment was installed in a basement. During the exceptional flood of 1994, the airport was flooded, and its return to operation was delayed even further.
(See the archival images available at : https://www.ina.fr/video/CAB94101660.)

By recognizing the residual risk, planners could have protected the airport's nerve center by placing the IT equipment on an upper floor, rather than in the basement.

Map 3: Extract from a high flood risk area hazard map
Source: Risk map for the Cannes–Nice–Mandelieu high flood risk area, downstream section of the Val, https://rhone-mediterranee.eaufrance.fr/cartographie-des-risques-dinondations-du-tri-de-nicecannesmandelieu.

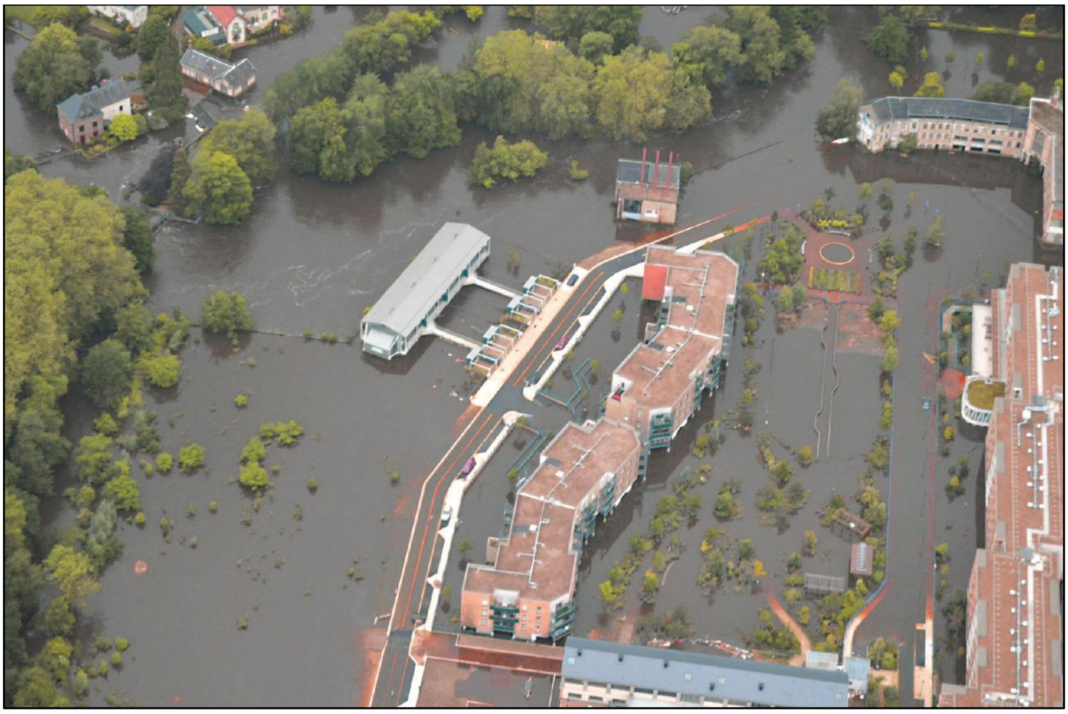


4.1.2. The Seine Flood of 2018: Managing Vulnerability Locally

Much of Paris has been built within a well-known flood zone. The last major flood, well documented by historians, occurred in 1911. Throughout the twentieth century, major developments were made to alleviate this risk—particularly reservoir dams, which can be used for rising river capping, water storage, and managing flood-prone areas along the river upstream of the urban area, like La Bassée (see http://www.seinegrandslacs.fr/la-vallee-de-la-bassee, the flood meadows of the Oise River). In addition to their hydraulic role, these developments preserve protected natural areas and offer other useful services to the region, helping water purification and providing recreational areas for an urban population in need of green spaces.

In 2018, heavy rainfall led to a major flood in the Seine basin. It highlighted the importance of the urban development of Romorantin, a town upstream from Paris with a flood-tolerant district (see photo 7). Although the district was flooded, the hazard had been taken into account by architects and town planners, and the damage was very limited. The period of upheaval was kept to only a few days. The flooded areas are used as green spaces in normal times, providing urban utility and preserving them from development pressures.

Photo 7: Lavoir, an area of Romorantin, designed to reduce vulnerability to flooding
Photo credit: Les Cols Verts flying club.



Another example of vulnerability control, at an even more local level, is the removable barrier used to protect the AFD's headquarters in Paris. But such "active" solutions require good forecasting and sufficient time to deploy, as opposed to "passive" solutions of the sort used in Romorantin.

Photo 8: Movable barrier around AFD headquarters, 2018
Photo credit: Olivier Gilard.

4.1.3. The Vaison-la-Romaine Flood of 1992: A Range of Vulnerabilities

This very intense flood, in a small catchment area of a few hundred square kilometers, took place on September 22, 1992, and led to around forty deaths. It provoked substantial debate. Retrospective analysis showed that, while not a one-off (records showed a similar event in 1616), both the peak and volume were exceptional: a return period of 4 to 600 years in peak, and on the order of 100 years in volume.
(See https://fr.wikipedia.org/wiki/Inondation_de_Vaison-la-Romaine_en_septembre_1992.)

Note that, despite an intense mobilization of expertise, the estimate of the peak flow of this event remained between 800 and 1200m3/s, with no possibility of reducing its amplitude. This illustrates the difficulty of measuring these exceptional events.

The deaths occurred primarily at two sites: a campsite located upstream of the Roman bridge, and a housing estate located downstream. The campsite had been set up in the major bed of the Ouvèze, because of the pleasant atmosphere this location provided and the fact that it was only being used temporarily. On September 22, 1992, the seriousness of the situation became clear: the campsite quickly became an island, with no evacuation possible, and those trapped were swept away with their caravans.

The housing estate was also located in major bed of the Ouvèze. The houses had already been affected during smaller floods, and their construction was of low quality. When the water rose several dozen centimeters—more than a meter, at high speed, made worse by the houses, which acted as obstacles to the flow—the buildings offered no resistance. Construction was subsequently forbidden on the land.

Applying our method of analysis, we can see that the two sites were vulnerable in different ways: a campsite can be quickly evacuated, with only limited, purely material damage. By contrast, a housing estate is occupied permanently, including by people with limited mobility, and therefore represents far more non-movable capital, which should be built to withstand such events. The campsite might return to the site, with an ad hoc evacuation plan and a flood warning system. By contrast, it was right to forbid further construction on the estate site, which was impossible to protect effectively.

Today, both sites have become parking lots, as shown in satellite images of the city.

4.2. Examples from Elsewhere around the World

4.2.1. The Antananarivo Plain in Madagascar, and Similarities With Grenoble

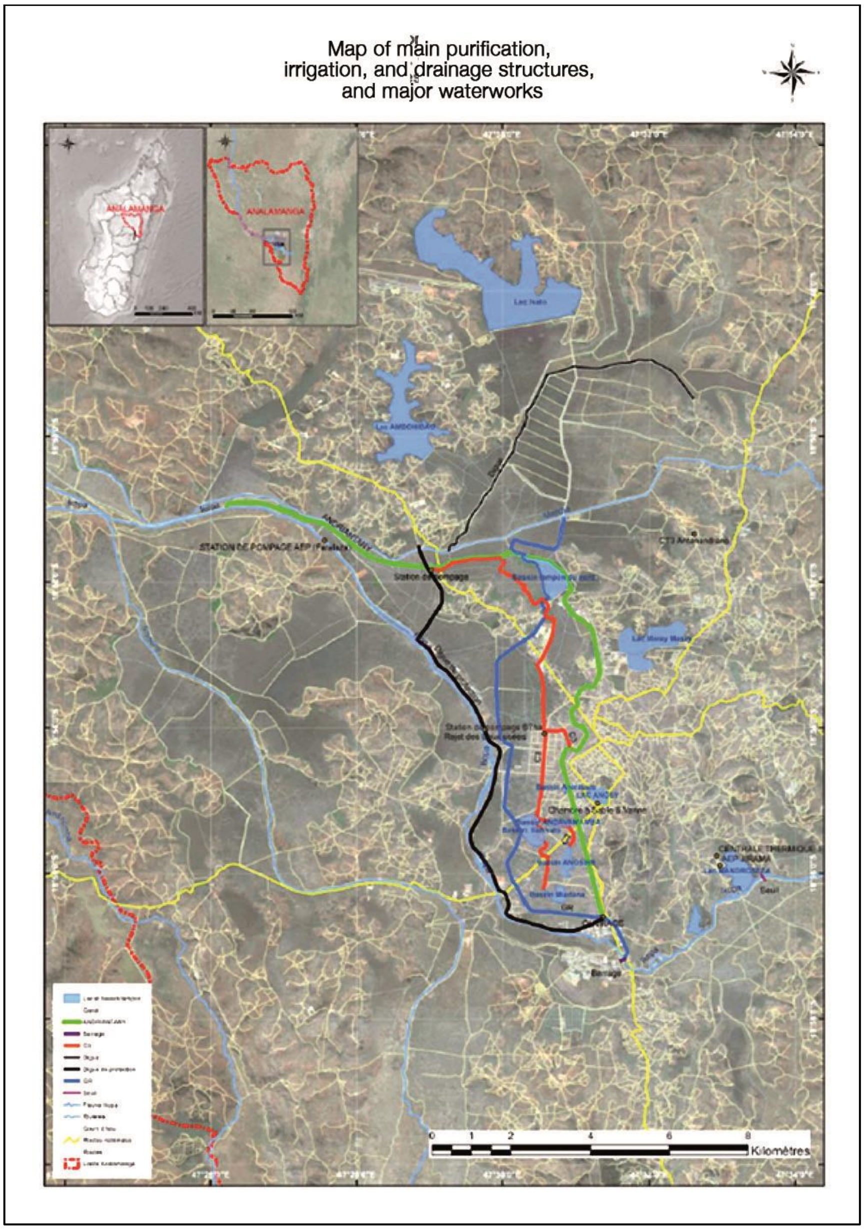
Antananarivo, the capital of Madagascar, has traditionally been built on the hills that lie on the edge of the flood plain of the Ikopa River. This plain, historically given over to agriculture, and especially rice farming, has been protected from flooding over the years by a network of dikes. The hazard having thus diminished, and with the city needing to develop, the plain has been gradually urbanized, at the cost of substantial infilling. With a tropical climate, regularly affected by cyclones from the Indian Ocean that bring heavy rainfall, urban runoff now produces major flooding in neighborhoods built on the plain, a result of the difficulty of removing the water to the Ikopa, its natural outflow. Sanitation channels have been dug (the Andriantany Canal and the C3 Canal), but maintenance problems and difficult-to-cover pumping costs lead to frequent heavy flooding. This particularly affects poor areas, whose migrant population lacks the means to construct an environment that can withstand such hydraulic constraints. Controlling flood risks requires leaving the water in place on the plain, so that the pumping stations (and their operating costs) are not overstressed, and so that an efficient hydraulic pathway is maintained to enable the floodwater to be moved, while limiting damage and allowing timely evacuations. The movement of rainwater runoff is also necessary for exceptional floods of the Ikopa River, which sometimes cause dikes to burst or overflow. A clear hydraulic pathway makes it possible to reduce the damage and the catastrophic consequences of a rare event.

Photo 9: Antananarivo plain after Cyclone Enawo in March 2017
Photo credit: Olivier Gilard.

A useful comparison can be drawn with Grenoble's development in the Isère flood plain, classed as a high flood risk area (territoire à risque important d'inondation, TRI) by the current French system. (For a description, see http://www.isere-drac-romanche.fr/?Histoire-de-l-endiguement-de-l.)

Floods are prevented by a range of systems that have been built over the centuries, and particularly over the last two hundred years, meaning that they occur around once every hundred years. Nonetheless, as the TRI classification makes clear, crisis management measures must always be in place to prevent an exceptional flood from having a catastrophic impact. Currently, the city is investing in creating upstream water storage areas delimited with levees on agricultural land that can be used in the event of major flooding (and only then). This project is being led by the Joint Council of the Watersheds of the Isère River (Syndicat Mixte des Bassins Hydrauliques de l'Isère, SYMBHI—see https://www.isere.fr/symbhi/projet-isere-amont/projet-global/.)

Map 4: Main water infrastructure on the Antananarivo plain
Source: Agetipa document, used in "Évaluation institutionnelle rapide des acteurs clés impliqués dans la gestion des eaux urbaines du grand Antananarive," Nodalis-OIEau, 2016.



In the case of Antananarivo, the situation is worsened by the failure of waste collection services. Refuse often ends up in the canals, reducing their hydraulic efficiency. Another aggravating factor is the lack of efficient wastewater collection, and restricted on-site sanitation, which has reached its limits following an increase in urban density.

The situation also shows the need for strong institutions to manage infrastructure. The Antananarivo Plain Flood Protection Authority (Autorité pour la protection contre les inondations de la plaine d'Antananarivo, APIPA) was founded during an earlier phase of development on the plain, and still plays its role as the main infrastructure operator. The Independent Maintenance Service for the City of Antananarivo (Service Autonome de Maintenance de la Ville d'Antananarivo, SAMVA), which was born out of the same initiative, has not yet reached a point of financial and technical equilibrium—a result, among other things, of the meager funding it receives, and likely from a lack of political support, arising in part from the tensions between the state and the province of Antananarivo.

4.2.2. Phnom Penh: A Necessary Reclamation Strategy

The city of Phnom Penh, the capital of Cambodia, is located on the flood plain of the Mekong River. The hydraulic configuration of the region is very distinctive. This is due to the presence of a hydraulic node between the Mekong River upstream; the Tonlé Sap hydrological system that connects it to the lake of the same name, which plays a flood expansion role that is essential to reducing the hydraulic pressure on the delta downstream; and, finally, the two main distributary arms that mark the beginning of the Mekong Delta, the Mekong and the Bassac. To allow the city to grow, a dike belt was built to isolate it from the flood plain. This surrounds it entirely when the waters are high, giving the appearance of a polder entirely surrounded by water. As a result, it has been necessary to develop a substantial drainage network, with pumping stations to remove urban runoff, which is particularly heavy in this monsoon region. The disappearance of several urban lakes as a result of urbanization pressure poses an even larger problem for these drainage and pumping networks, which are meant to limit the risk of flooding and keep it to an acceptable level. But the absence of a clear strategy to maintain a major bed in the urban fabric makes it likely that the inevitable crises to come will cause heavy damage.

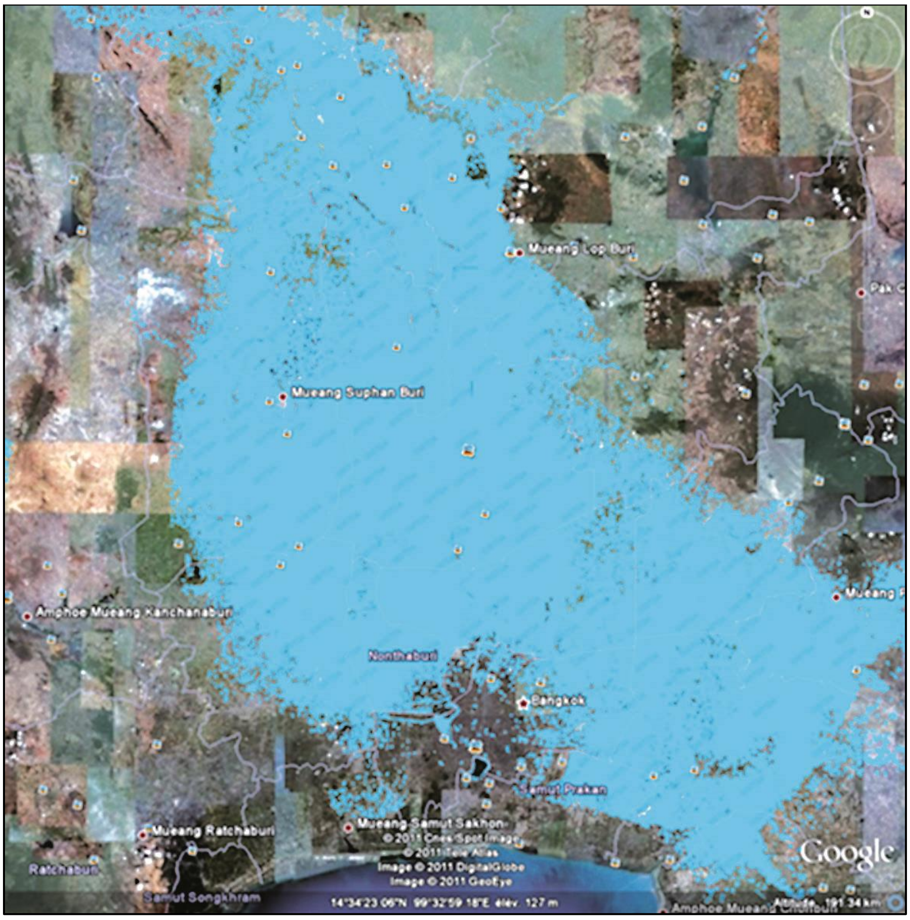
Photo 10: Tonlé Sap, a tributary-distributary of the Mekong, near Phnom Penh, during the September 2009 flood
Photo credit: Olivier Gilard.

The existence of a flood warning system on the Mekong, managed by the Mekong River Commission (MRC), and shared between the hydrometeorological services of the member countries, makes it possible to effectively predict, several days in advance, the propagation of flood waves from Laos, where the river receives most of its inflows.

Photo 11: The area around Phnom Penh in May 2010
Photo credit: Olivier Gilard
(see https://journals.openedition.org/espacepolitique/3886).

4.2.3. Bangkok and the 2011 Flood: "Sacrificing" Rural Areas and Suburbs to Protect the Inner City

Map 5: Flood zone on the plain of the Chao Phraya at the height of the 2011 flood
Source: Geo-Informatics and Space Technology Development Agency (GISTDA), https://gistda.or.th/main/en/node/4053. © GISTDA



Bangkok, Thailand's capital, is situated on the flood plain of the Chao Phraya, which runs through it. In 2011, a major flood led to a crisis for local populations, although the center of the city was not heavily affected. Bangkok's strategy is similar to that of Phnom Penh, aiming to limit the floodplain to the area around the city center.

The problem with this strategy is that, without a hydraulic channel enabling the water to move to the sea, a substantial length of time is required to clear out the flooded zones. In 2010, this took several weeks, increasing the burden on the affected regions and those living in them. The region is home to many industrial areas, which remained closed for long stretches of 2010. The large number of mainly Japanese-owned out-of-action assembly plants led to a global crisis in the digital supply chain.

Photo 12: Sandbags in front of buildings in Bangkok city center during the 2011 flood
Photo credit: Olivier Gilard.

An effective flood warning system meant that the authorities could anticipate the crisis, closing the gates that normally allow some of the Chao Phraya's water to flow through the city via a network of canals called khlongs, and building sandbag barriers across roads that would have carried water to the city center. It also gave the city's residents time to install sandbags along the edges of houses and stores to limit water intrusion in case the flood reached the city center—giving the impression, for a few weeks, of a city under siege.

Note that political tensions prevented effective coordination between the state services and Bangkok city services, and the hydraulic capacity of the khlongs was under-utilized during this crisis, increasing the duration of the flooding in the periphery in order to save the city center.

Following this crisis, there was much discussion of reducing risk by making it easy for water to move toward the sea, and by adapting housing to make it more tolerant to the constraints imposed by flooding, so reducing its vulnerability. The problem of financing these investments remains unresolved, however: the sums involved for such collective infrastructure are very large, and funding opportunities for housing improvement are non-existent.

Photo 13: The outskirts of Bangkok, where land and water meet, June 2018
Photo credit: Olivier Gilard.

Photo 14: The Chao Phraya flowing through Bangkok, May 2013
Photo credit: Olivier Gilard.

4.2.4. Ho Chi Minh City: Living with Flooding

Ho Chi Minh City, Vietnam's economic capital, also faces major flooding problems, due to its location in the flood plain of the Saigon River, near its outlet to the sea, in an area with very little relief and heavily affected by the tide. The city is located on a former swamp, as shown by the multiple secondary waterways (rach) that criss-cross it.

To prevent flooding during the rapid urban development of recent decades, Vietnamese authorities have revised their flood prevention plan, using zoning strategies and dike belts, and improving the drainage network. In recent years, this plan has been implemented through numerous infrastructure projects.

Photo 15: The Saigon River flowing through Ho Chi Minh City, December 2014
Photo credit: Olivier Gilard.

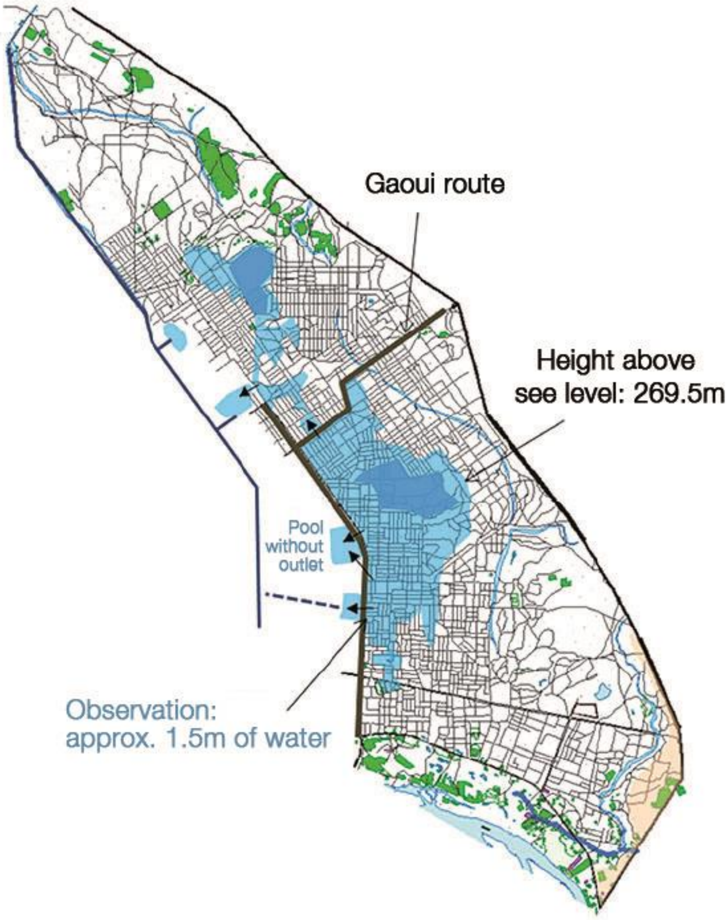
In peri-urban areas, which are partly agricultural, these projects typically maintain farming production while keeping the land available for flood spreading in periods of severe hydraulic constraints, following the example of the AFD-funded Saigon River project.

4.2.5. N'Djamena: Rain Flooding

N'Djamena, in Chad, is another capital city at risk of flooding, mainly because of heavy rainfall during the rainy season, and a very flat topography that makes it difficult to remove urban runoff. The flood regime of the Chari and Logone Rivers, which border the city, can also be significant. These rivers are little developed upstream, however, allowing for substantial overflowing upstream of the city. This tends to naturally regulate flooding, limiting the risk of overflows in the city, with the exception of some more exposed neighborhoods—Walia, in particular, which lies on the other bank of the river from the city center.

For sanitation, a series of drainage routes collect and evacuate the water to the Chari River using natural depressions in the topography, even when these are fairly shallow. Some of these routes are old, and have been developed for some time, like the Canal des Jardiniers. However, urban sprawl in new areas of the city requires the creation of the same sort of infrastructure to reduce the risk of flooding during the rainy season. The flow of water is slow, due to the low slope of the natural terrain, and this requires intermediate storage spaces. The challenge is to protect these spaces from urbanization, so that their vulnerability does not change in ways unrelated to hydraulic constraints. The best strategy is to find them an alternative socio-economic function for the period when flooding is not a concern—as sports fields, green spaces, market gardens, and so on. Urban regulation alone will not necessarily prevent any changes in vulnerability, as administrative services still have a limited presence on the ground, and have difficulty enforcing urban planning restrictions.

Map 6: Floods and drainage routes in the east of N'Djamena
Source: Preliminary feasibility study for rainwater drainage measures in the new northern and eastern areas of N'Djamena, Sogreah, January 2012.



Another issue, equally important, is to define which institution will handle the operation and maintenance of these projects, and to provide it with funding and properly trained staff, particularly for the pumping stations.

Photo 16: Works on the north basin in February 2019, part of the N'Djamena water and sanitation project
Photo credit: Olivier Gilard.

Photo 17: Works on the north basin in February 2019, part of the N'Djamena water and sanitation project
Photo credit: Olivier Gilard.

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Glossary of Technical Terms

Adaptation measures
Measures taken by natural or human systems to adapt to conditions in a changing environment.

Catchment area/watershed
The hydrological unit that drains runoff to its surface, evacuating it toward the furthest point downstream through the water system. In terms of flooding, this is the zone that contributes the inputs that affect the point of analysis.

Climate
The statistical distribution of conditions in the terrestrial atmosphere of a given region during a given period. It is distinct from meteorology, the study of the weather in the short term and in smaller areas (definition adapted from Wikipedia).

Disaster
A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources. [...] Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences (UNISDR, 2009).

Disaster risk
The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period (UNISDR, 2009).

Exposure
People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses (UNISDR, 2009).

Flood
The temporary submersion by water of areas that are not normally submerged. This concept includes floods due to rising rivers, flows from mountains and intermittent Mediterranean watercourses, and those in coastal areas due to the sea (https://www.gouvernement.fr/risques/risques-naturels).

Flood hydrograph
A curve representing the development of the flow at the mouth of the watershed as a function of time (Musy, 2005).

Flow-duration-frequency curves (QdF)
Curves that present a visual overview of the flow regime of a river, and the statistical distribution of the field of possibilities. Rising rivers are to be contrasted with low water.

Hazard
A natural or human phenomenon, the damage it inflicts varying with its intensity (https://www.gouvernement.fr/risques/risques-naturels). At an international level, the UNISDR (2009) has proposed a similar definition. Applied to floods, the term denotes hydrometeorological and hydraulic phenomena.

Hydraulics
The branch of fluid mechanics dealing with gradually varied free surface flows that occur in natural and artificial watercourses.

Hydrology
The science that studies the processes controlling fluctuations of water resources on the surface of the earth, and the different phases of the hydrological cycle (see, for example, the WMO's various HYCOS projects and UNESCO's International Hydrological Program [IHP]). Note that methods used for prevention (statistical methods, regime characterization) are different from those used for prediction (rain-flow models, representations of individual events).

Infiltration
The vertical transfer of water from the surface of the earth to its upper layers, as a result of gravity or pressure. This occurs as long as the earth is not saturated.

Intensity-duration-frequency curves
Curves that present a visual overview of rainfall data for a given location, establishing relationships between rain intensity, duration, and frequency. They represent the statistical distribution of rainfall at a given point.

Low water flow
Minimum flow of a watercourse, calculated over a given time during a period of low water. For a given year, daily low water flow is used (MEDDE, 2015).

Major bed
An area including the lower zones on both sides of the minor bed, spanning from a few meters to several kilometers, depending on the level of flooding. The major bed marks the limit of exceptional floods (MEDDE, 2004).

Meteorology
The science of meteorological phenomena in the atmosphere. In the context of flooding, these are primarily rainfall phenomena.

Minor bed
The typical bed of a watercourse (MEDDE, 2004).

Precipitation
The water (both liquid and solid, as in the form of snow or hail) falling on the ground as a result of changes in temperature or pressure.

Reduction measures (for greenhouse gases)
Measures resulting from human efforts to reduce sources of greenhouse gases, or to increase their absorption (see climate change-related literature). Such measures are not directly related to flood risks.

Resilience
The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner (UNISDR, 2009).

[Note that such a definition has little application to resilience toward the impact of climate change, which requires adaptation to new conditions without any return to the initial state.]

Return period of a flood
The inverse of the annual probability of flooding (Ledoux, 2006), describing the frequency of such an event.

Rising river
A rise in the flow of a river (MEDDE, 2004). A rising river does not always lead to flooding.

Rising river flow for a given year
Over the course of a year, rising rivers can be characterized either using the largest flow at a particular moment, or the largest daily flow. Over several years, using the largest possible sample of rising river flows, the value of the flow associated with different theoretical return periods (2, 5, 10 etc.) can be determined (MEDDE, 2015).

Vulnerability
The propensity of goods, persons, activities, functions, systems, and other exposures that make up an area and a society to be damaged or to cease functioning (http://geoconfluences.ens-lyon.fr/glossaire/vulnerabilite)

Waterway/water system
The canals, watercourses, and rivers, both natural and artificial, both permanent and temporary, by which water flows into a given watershed (Musy, 2005).

List of Abbreviations

AFD	Agence française de développement (French Development Agency)
APIPA	Autorité pour la protection contre les inondations de la plaine d'Antananarivo (Antananarivo Plain Flood Protection Authority)
ARRA	Association Rivière Rhône Alpes Auvergne (Rhône Alpes Auvergne River Association)
Cemagref	Centre national du machinisme agricole, du génie rural, des eaux et des forêts (National Centre for Agricultural Mechanization, Rural Engineering, Water, and Forestry Management)
CEPRI	Centre européen de prévention du risque d'inondation (European Center for Flood Risk Prevention)
EPTB	Établissements Publics Territoriaux de Bassin (public river basin authorities)
FWP	French Water Partnership
GEMAPI	Gestion des milieux aquatiques et prévention des inondations (Water Body Management and Flood Prevention Regulation)
GISTDA	Geo-Informatics and Space Technology Development Agency
IFRM	Integrated Flood Risk Management
INRAE	Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (National Research Institute for Agriculture, Food and Environment)
IRMA Grenoble	Institut des Risques Majeurs de Grenoble (Grenoble Major Risks Institute)
IRSTEA	Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture (National Research Institute of Science and Technology for Environment and Agriculture)
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
MRC	Mekong River Commission
NBS	Nature-based solutions
QdF	Flow-duration-frequency curves

SAMVA	Service Autonome de Maintenance de la Ville d'Antananarivo (Independent Maintenance Service for the City of Antananarivo)
SAGE	Schéma d'aménagement et de gestion de l'eau (water development and management local plan)
SCHAPI	Service central d'hydrométéorologie et d'appui à la prévision des inondations (French National Hydrometeorological and Flood Forecasting Centre)
SDAGE	Schéma directeur d'aménagement et de gestion des eaux (water development and management master plan)
SYMBHI	Syndicat Mixte des Bassins Hydrauliques de l'Isère (Joint Council of the Watersheds of the Isère River)
TAL	Période de retour équivalent à l'aléa (return period equivalent to hazard)
TOP	Période de retour équivalente à l'objectif de protection (return period equivalent to protection objective)
TRI	Territoire à risque important d'inondation (high flood risk area)
UNISDR	United Nations International Strategy for Disaster Reduction

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Qu'est-ce que le groupe AFD ?

Agence Française de Développement (AFD) Group implements France's policy on development and international solidarity.

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