TECHNICAL REPORTS
TECHNICAL REPORTS

NOVEMBER 2017
No. 35

Flood risk and cities in developing countries

Authors Yves KOVACS, Nicolas DOUSSIN, Marion GAUSSENS (SEPIA Conseils)

Coordination Laurent PACOUD, Olivier GILARD (AFD)

AFD

Country **Multi-country**

Key words **Flood risk, vulnerability, natural hazard, integrated management, hazard, water, climate, forecast, rain, rising river**

AFD, 5 rue Roland Barthes, 75598 Paris cedex 12, France – ☎ +33 1 53 44 31 31 – +33 1 53 44 39 57
✉ _AFDlib@afd.fr – http://librairie.afd.fr

AUTHORS

SEPIA Conseils is a consulting firm founded in 1991 providing engineering, consulting and project management assistance services in the field of water for project owners in the public sector and private developers in France and abroad.

Contact: sepia@sepia-uw.fr

SUMMARY

The risk of flooding is a natural hazard affecting the most people worldwide. However, it is more of a risk in terms of material damage than a lethal risk for the affected population. Integrated flood risk management (IFRM) constitutes a global response to flood risk that is structurally systemic and prone to evolve over time. An operational approach to IFRM is to consider three complementary and interconnected components of flood risk management: prevention, preparedness and risk culture. This technical report explains the issues of each of these components and draws up a non-exhaustive list of the different existing tools, also presenting their limits of application. A presentation of examples of at-risk territories supports, by specific examples, the elements explained in the report.

ORIGINAL LANGUAGE

French

ISSN

2492-2838

LEGAL DEPOSIT

4th quarter 2017.

The *Technical Reports* are available for download
on the AFD website: **http://editions.afd.fr**

CONTENTS

Introduction

I. Flooding: the natural disaster affecting the most people in the world

With more than 2.8 billion people affected since 1990 around the world (EM-DAT, 2016), **flooding is the phenomenon with the most impact on human population worldwide** (UNISDR, 2015). However, it is more of an **economic risk because of the material damage caused** rather than a lethal risk for the affected population. A comparison with other types of natural disasters shows, for example, that floods produce significantly fewer deaths than earthquakes (Figure 1).

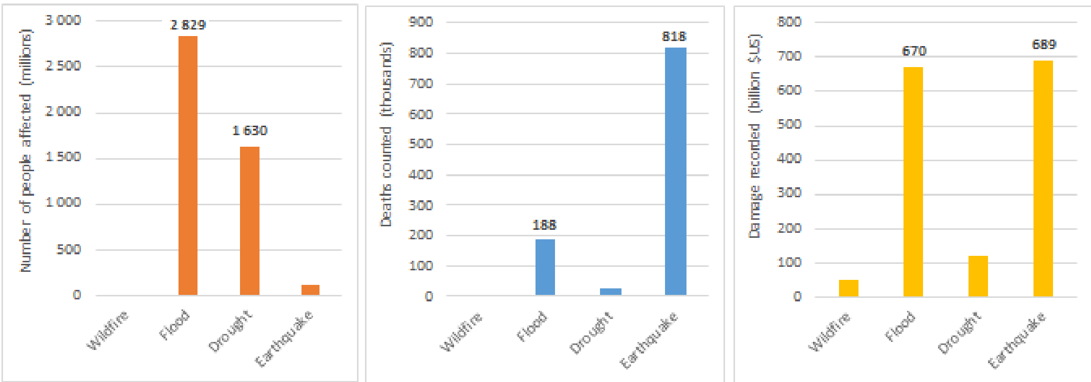

Figure 1: Comparison of the damage caused by different natural disasters since 1990 on a global scale (Data source: EMDAT - 2016)

The material damage has a significant impact on the living conditions of the people affected by the floods, in particular by the degradation of buildings (housing and strategic infrastructure such as hospitals and schools), disruption or breakdown of networks (drinking water, sanitation, waste, energy, transport), disruption or cessation of economic activities, and displacement of populations.

Globally, some countries are more affected by floods than others (Figure 2). Asia is particularly exposed: 9 of the top 10 countries in terms of flood-affected populations are in Asia (including China in first place) [1]. The detailed human and material impact due to floods for each country of AFD intervention are presented in annex.

[1] Which we can attribute in the first place to the average density of population in that region.

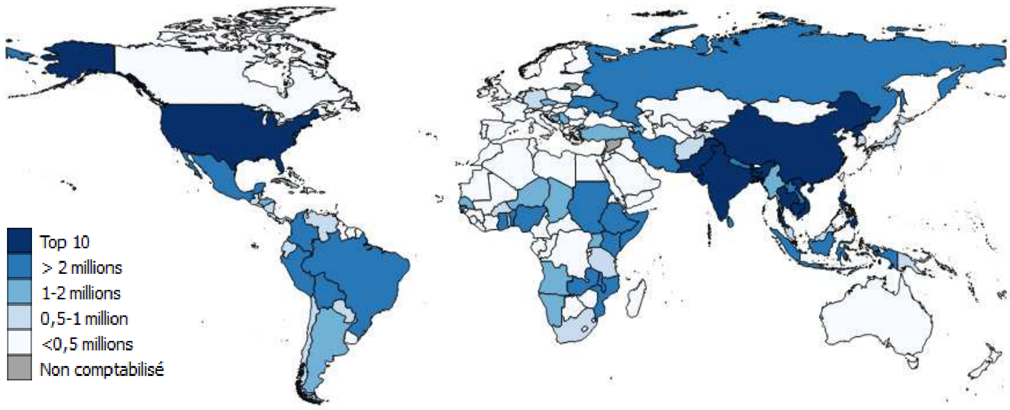

Figure 2: Global distribution of people affected by floods since 1990 (EM-DAT, 2015)

II. The central role of cities for developing countries

Rapid urbanization in developing countries, and particularly in Africa and Asia (Figure 3**), is a real challenge for flood risk management.**

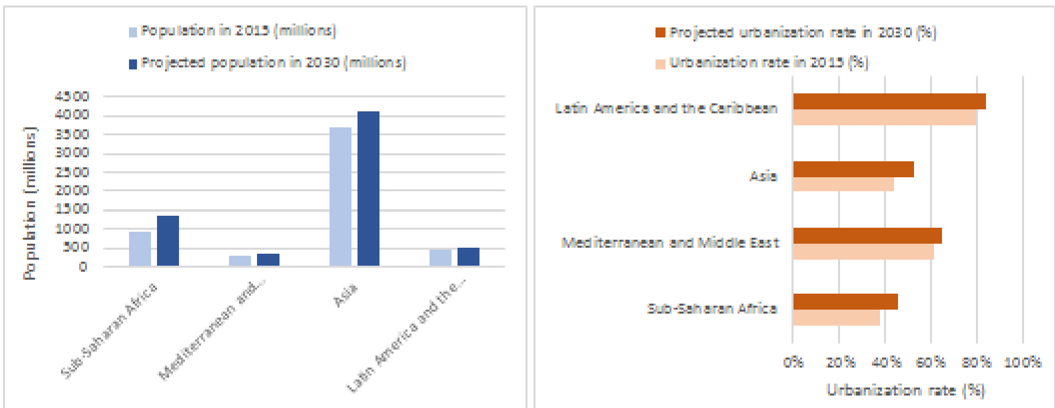

Figure 3: Summary of demographic and urban development by 2030 in regions of AFD intervention (ONU, 2014) (ONU, 2015)[2]

Urban development catalyses the increase of vulnerabilities by concentrating human and material issues in areas previously dedicated to other land uses but often subject to a flood hazard. The poor populations, resulting from the rural exodus and attracted by the economic prospects, are indeed brought, for lack of means, to available spaces and effective territorial

[2] The UN projections presented in this report refer to the "medium variant" scenario, a scenario commonly used internationally. But changes in certain assumptions can lead to significant variations of these projections. Among these assumptions, we find first of all the evolution of fertility, a central factor of demographic evolution, but also the evolution of migratory flows which is difficult to predict.

planning, to settle there. It should be noted that these populations often prefer to settle (or resettle after a flood) in these exposed areas because the economic outlook outweighs the risk they incur.

In addition, the dynamics of urbanization move towards an insufficiency of the drainage infrastructures, in spite of the new investments, targeted mainly on the flood hazard instead of tackling the reduction of vulnerabilities. We are witnessing a "race ahead" to build infrastructures that meet the growing needs of cities (which results in a constant delay in the requirements of under-sizing), while having limited financial resources. The development of urbanization also leads to an increase in runoff due to the waterproofing of surfaces and can lead to obstruction of natural drainage channels.

III. Risk prevention for sustainable development of urban territories

In developing countries, flood risk management occupies a position relative to other natural and social elements perceived as a risk to the population. **The socially acceptable level of flood risk is, therefore, often higher than that of developed countries.**

In view of the adaptation dimension of territories in the face of climate change and the reduction of natural hazards, sustainable development can be considered as a lever to increase **urban resilience**, i.e., the city's capacity to adapt to changes or context developments, and rebuild after a crisis.

The link between risk prevention and sustainable development in a territory thus contributes to **allowing the various stakeholders, to participate in an approach, at an acceptable level of risk** according to the areas of the territory, **and subsequently, to appropriately adapt the land use.**

Characterization of flood risk and its management

I. The risk of flooding resulting from multiple factors

According to a simplifying approach commonly used, the risk of flooding, like any risk of disaster, can be characterized by the **exposure of vulnerable stakes to a hazard**, in this case a temporary presence of water. These two main factors (issues and hazards) are themselves **influenced by multiple interconnected factors**, such as land use, urbanization and meteorology (Figure 4).

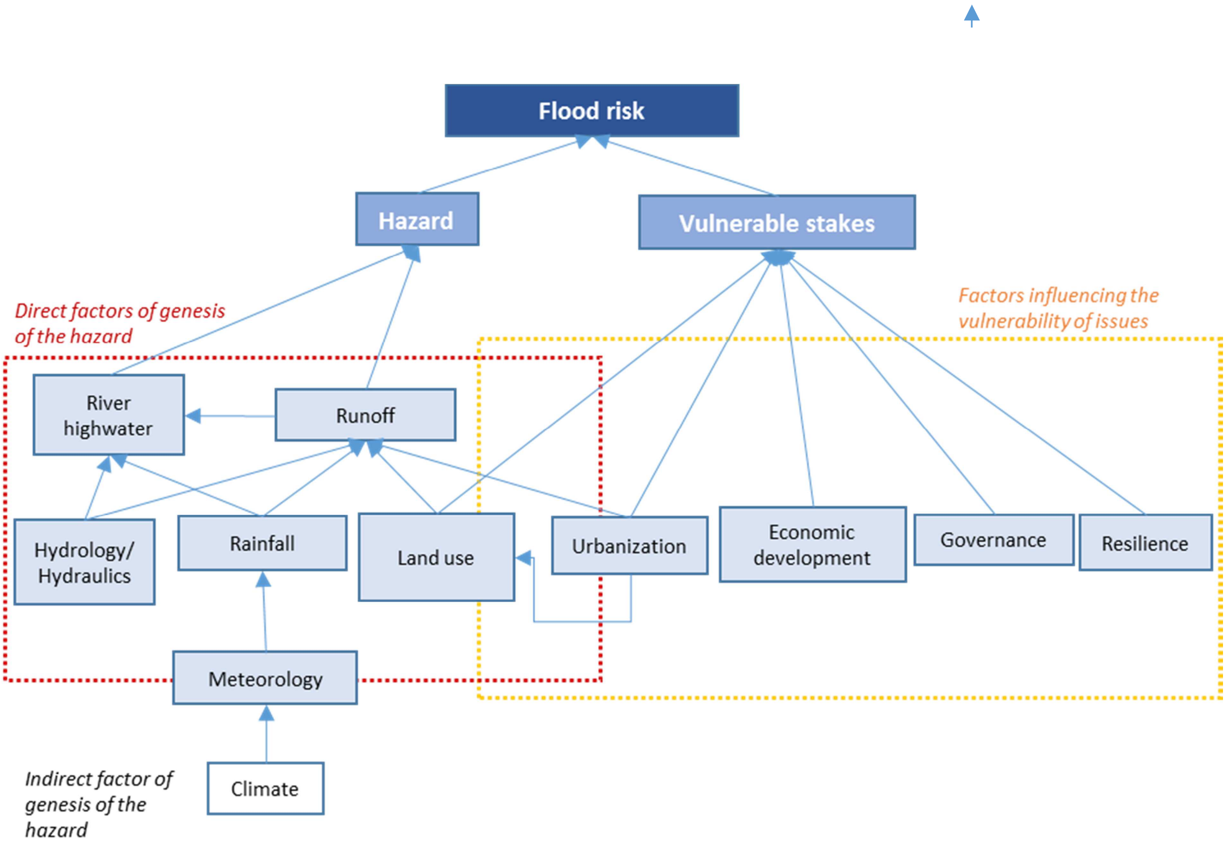

Figure 4: Simplified representation of the links between flood risk and its components

1. The vulnerability of the territory (or the measurement of the issues)

Towards a multidimensional concept of vulnerability

Vulnerability is an essential component of risk, now recognized as such in most developed countries, such as France, even though it has long been overlooked in favour of the mere consideration of hazard into the understanding of natural hazards. **Vulnerability on a territorial basis varies not only in space** (the analysis of vulnerability or issues must be carried out at the plot level) **but also over time** (urbanization tends to concentrate wealth in a limited territory).

The vulnerability of a territory can be seen as systemic in the sense that **it cannot be summed up in the issues that lie on that territory.** The advantage of such an approach is **to consider the indirect impact in issues where the problem is not flooding but the disruption of operations by the occurrence of a hazard that then turns into a disaster.** The classic example of that is a company vulnerable to rising river due to the fact of the water level reaching its access roads, while the premises of the company itself are not flooded: the rising river no longer allows the transport of raw materials necessary for its operation, nor of its employees, consequently we can consider this factory as vulnerable to floods. This situation illustrates the fact that vulnerability must be understood on a territorial level that is not stricly speaking defined by the geographic influence of the rising river (the hazard). There is also interest to highlight possible organized solidarities on a territorial scale adapted to make the risk collectively more acceptable.

Vulnerability in terms of natural hazard has been the subject of many definitions in recent years. As the reflections and analyses progress, the concept tends to become more complex and to gradually widen moving towards a **"global" and multidimensional vulnerability** integrating not only physical but also social, economic, environmental and institutional properties. Vulnerability also includes adaptive capacities, responses and interactions with disturbances and stresses. This multidimensional nature can be symbolized by the image of the diamond (figure opposite), although this is still debated in world literature. (Quenault

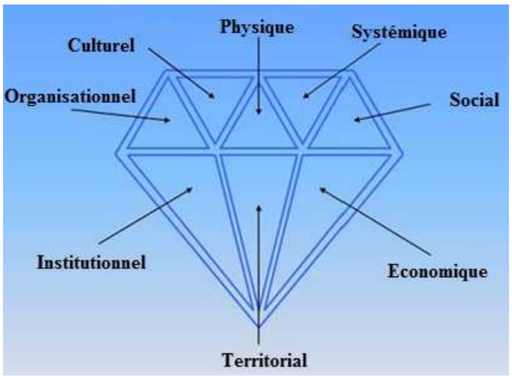

Figure 5: Diamond analogy to symbolize the multifaceted nature of vulnerability, adapted from Quenault et al. 2011

et al., 2011). It also has the flaw that it does not adequately represent the different levels of entanglement of vulnerability from the individual/plot to the company/community/territory. This limits its operational use.

In considering this multidimensional approach to vulnerability, **developing countries are likely to have a significantly greater global vulnerability than other countries, for the same risk**, because of the weaknesses of certain facets, in particular economic, organizational and institutional, that limit their resilience, and thus their ability to recover from major crises. However, **damage caused by floods in developed countries can cause much greater damage than those in developing countries.** On this basis, developed countries are actually more vulnerable, which they compensate for by better prevention and risk management.

Urban growth as a factor of aggravation of vulnerability

Urbanization has a direct influence on the risk of flooding, in particular: (Floater et al., 2014)

- **The problem of sizing sanitation or stormwater management works, in line with the needs.** Newly constructed infrastructures are often already outdated in view of the dynamics of urban growth, which could not have been anticipated at the time of the structures were designed.
- **The limits of application in growing cities of methods or standards which prove to be effective in developed cities** (in terms of land use management, for example), mainly because of often informal urban growth and governance often weak (lack of control).
- **The problem of financing infrastructure or policies of flood risk management.** The main financial resources are absorbed to meet the growth of the city, to provide essential services such as electricity and drinking water, development of the transport network and economic development. Thus the development of the city is not synonymous with the development of the resources available for flood risk unless the level of wealth and governance allows it.

Other factors aggravating vulnerability

The multidimensional approach to vulnerability highlights the role of institutions in the vulnerability of a territory or population. Many human factors can lead to increased vulnerability, in particular:

- **Poor governance,** for example in the form of a lack of a reference institution for flooding, or a number of institutions involved whose missions and perimeters of action are unclear, thus complicating their coordination;

- **Absence or insufficiency of land use planning** and housing policy control leading to uncontrolled urbanization, particularly housing construction (informal or formal) in flood-prone areas.

Within the same society, certain groups of people will also be more vulnerable than others. Poor people are overexposed to flooding in developing countries (because they are often located in high hazard areas), where they are more than 50% more likely to be victims than the rest of the population (Hallegatte et al., 2017). They have less capacity to cope with and recover from a disaster: they often do not have the means to protect themselves (their homes which are often very poorly constructed are particularly fragile in the face of floods), and their financial means do not necessarily enable them to repair or replace damaged or destroyed equipment (although in financial terms poor people have less to lose than the rich), nor to relocate after a disaster. Older people, young children, and the disabled are also particularly vulnerable because of their lack of mobility, lack of independence, and physical weakness.

Box 1: What is the link between development and vulnerability?

The analysis of natural disasters, both in developing countries (Thouret and Leone, 2003) and developed countries (Townsed, 2006) shows that "vulnerability is not the strict inverse function of the degree of economic development" (Leone & Vinet, 2011): the issues and the potential damage associated with a flood are greater in developed countries, but the risk situation is better controlled and the risk is therefore lower. Thus **economic development and wealth influence vulnerability in two antagonistic directions**: on the one hand, they can allow a territory to have tools for forecasting or knowledge of flood risk (vulnerability reduction and improvement of crisis management), and on the other hand they involve increased issues, potentially located in a flood zone (increased vulnerability).

The flash floods of Port-Louis in Mauritius in March 2013 are a good example: the current development of the island generates in a contradictory way an increase of technical means of response but also an increase of the issues in the zones subject to a hazard, which therefore become at risk, and probably a decrease in the collective awareness of risk. Thus the relatively recent development of the island has led not to a disappearance but a modification of the risks which become systemic and structurally more difficult to grasp. (Asconit, 2013)

2. The flood hazard

The determination of the hazard, i.e., the identification of the flood zones and the evaluation of the return period associated with submersion, the depth and duration of submersion, and the speed of the current, presuppose the analysis of several characteristics of the catchment area.

Rainfall regime, land use and vegetation influence the formation of runoff, while physical, topological, topographical and geological features affect the concentration of runoff. Once the water has reached a watercourse, the flows are governed mainly by the morphology of the watercourse and the laws of hydraulics. The key concepts for causing the hazard are described in the annex.

Box 2: Return periods and rising river frequencies

Crue		Risque de voir la crue caractéristique atteinte ou dépassée au moins une fois		
Fréquence	Période de retour	Sur un an	Sur 30 ans	Sur 100 ans
Décennale 0,1	10 ans	10% 1 « chance » sur 10	96% Soit presque sûrement une fois	99,99% Soit sûrement une fois
Trentennale 0,03	30 ans	3,3% 1 « chance » sur 30	64% Soit 2 « chances » sur 3	97% Soit presque sûrement une fois
Centennale 0,01	100 ans	1% 1 « chance » sur 100	26% Soit 1 « chance » sur 4	63% Soit 2 « chances » sur 3
Millennale 0,001	1000 ans	0,1% 1 « chance » sur 1000	3% Soit 1 « chance » sur 33	10% Soit 1 « chance » sur 10

The return period of a rising river is by definition the inverse of its annual exceedance probability (table above) (Ledoux, 2006). This is often different from the return period of the rain event that generated it, insofar as it is a function not only of the rain event, but also of the catchment area characteristics, the characteristics of the rain season, the water and weather conditions prior to the rain event.

The return period of an observed rising river is defined for a specific location: the same rising river may have a return period of 10 years at one point and 100 years at a downstream point. It may be different depending on whether the analysis is performed on the volume flow or the peak instantaneous flow. Finally, any development must deal with the whole range of possibilities defined by the rising river regime. It is therefore the latter that we must try to grasp.

Two main types of flood: runoff and rising river

Runoff flooding is the runoff resulting from urbanization, which leads to other developments (roads, buildings, parking lots) and reduces the infiltration of water. For smaller catchment areas (of around 1 km^2 - beyond 100 km^2 the impact is difficult to measure), this is reflected graphically on the rising river hydrograph by the increase in peak flow, and by the reduction of the concentration time (Figure 6).

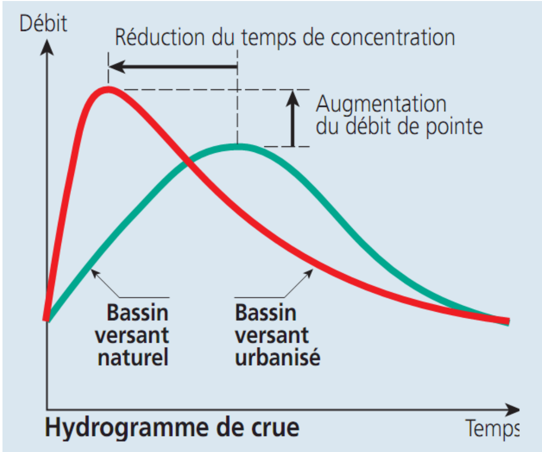

Figure 6: Illustration of the influence of urbanization on the rising river hydrograph (MEDDE France, 2004)

Water that cannot infiltrate the soil flows into the sewer systems (if they exist and are not already saturated) and directly to the surface for the rarer events and accumulates in the low points. The times of anticipation for this type of flood are very short (1 to 2 hours).

Flooding in lowland areas, or **rising river**, result from the exit of a river from its ordinary or minor bed to reach its major bed. This type of flood is characterized by a rather slow rise in water and recession. Submersion can last from days to weeks or even months. The damage is mainly a function of the depth and duration of submersion. The repetition of rain events can be a determining factor in this type of flood: the rain of the first events infiltrates the dry soil, without giving rise to an important response from the river in terms of flow. The last of the runoff events flows completely on a soil saturated with water and causes the rising river of the river. The time of anticipation of this type of flood is greater (from a few hours to a few days depending on the size of the catchment area concerned).

On mountain or piedmont areas and small to medium catchment areas (from a few tens to a few hundred km^2) with an accentuated relief, river overflow flooding may be described as **"flash", when the rapid concentration of water from intense showers leads to extremely brutal flows and submersions.** The strength of the current also generates a solid transport of materials (such as branches but also much heavier and bulky materials such as cars), increasing the risk of human and material damage and may disrupt the flow.

Climate change as an aggravating factor of the hazard

Many impacts directly or indirectly related to climate change are likely to **change the flood hazard** (Quenault et al, 2011):

1. **Changes in the rainfall characteristics, in particular the intensity of the precipitation and the amendment of probability of exceptional events.** Thus, even in areas where a reduction in annual rainfall is assumed, an increase in the frequency and importance of intense rainfall events could lead to an increase in hazard. It is important to remember **that precipitation projections are more uncertain than temperature projections** because of the complexity of the phenomena involved;
2. **Increased temperatures leading to an acceleration of ice melt, and thus an increase in the flow of water in rivers,** may encourage flood generation along rivers at nival or glacial regime, such as Chilean Patagonia;

Other factors aggravating the hazard

Beyond the specific characteristics of the catchment area, **human or meteorological factors are likely to aggravate this hazard.** The anthropogenic change of river beds (including, for example, the cutting of meanders, the suppression of wetlands, the construction of bridges or culverts) modifies the flow in the major or minor bed, and therefore the propagation of the wave of rising river. For example, cutting the meanders of a watercourse results in an increase in slope and thus an increase in speeds and solid transport. The temporal dimension with regard to the succession or combination of events is of particular importance with regard to the flood hazard. Thus the accumulation of rain episodes can lead to the progressive saturation of the soil, which ends up leading to a flood for average accumulations (for example, in Pikine in the suburbs of Dakar): so **it is not necessarily the most major rain event that is going to be at the origin of the flood.**

Finally, debris and waste carried by rising rivers are likely to aggregate up to the point where they become obstacles to the flow of water (ice jam phenomenon). The breakup of these natural obstacles will modify the manifestation of the hazard insofar as, on the one hand, this important release of energy can aggravate the damage of the rising river, and on the other hand the transported debris itself is likely to hurt or mow passersby. This type of phenomenon is particularly important in developing countries, especially because of the lack or under-efficiency of waste collection.

3. A territorial scale to be adapted

Flood risk diagnosis involves identifying the territorial scale concerned. **The scope of analysis and action to limit the risk(s) of flooding varies according to the hazard considered but also according to the issues and their vulnerability**, so as to integrate at the same time the issues directly affected (located in the flood zone) and those indirectly affected (located outside the flood zones but whose operation will be affected by the flood - example inaccessibility to the site or power cut).

Also, the analysis of the only urban territory may be sufficient for runoff-type floods, subject to very localized rainfall over limited catchment areas. On the contrary, it is necessary to take into account the entire hydrological catchment area for rising river floods: the study area must then include a succession of urban and rural areas, so as to both better understand the phenomenon of flooding and act on all the factors at the origin of the rising river.

II. Towards integrated flood risk management

As previously highlighted, the risk of flooding is structurally systemic and inclined to evolve over time, depending in particular on climatic, geomorphological, anthropic and socio-economic influences. Therefore, the response to this risk cannot be unique or simply defined: on the contrary, it must adapt to local specificities and be part of a continuous updating process.

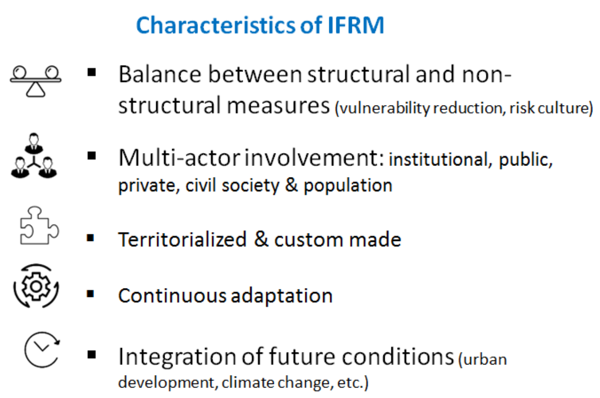

Figure 7: The main features of integrated flood risk management

Integrated flood risk management (IFRM) is a global response to flood risk combining knowledge and risk management, vulnerability reduction and catchment area approach, political will, coordination and integration of all stakeholders. It integrates a dynamic of linking the different components of risk and relevant stakeholders (including institutions, private sector, and civil society).

The value of an integrated approach to flood risk is growing. Indeed, **traditional measures to control floods only through the construction of protective structures have in many cases reached their limits.** On the one hand, following the demonstration of the recurring insufficiency of these measures alone with regard to the exceptional hazards that continue to affect even the developed countries despite the considerable investments made. On the other hand, on the realization of the need to develop a culture of flood risk incorporating awareness and communication, change of planning, non-structural measures, crisis management, even in areas considered protected.

Several operational approaches towards integrated flood risk management have been put in place, mainly in developed countries. One of them, which we will use as a reference in this technical report, takes into account **three complementary and interconnected components of a flood risk management policy: prevention, preparedness and risk culture.** Other approaches to integrated flood risk management are presented in detail in annex.

1. Preventing flood risk at the heart of damage limitation

Flood risk prevention consists of **organizing the territory in order to anticipate the occurrence of floods well in advance of the crisis, to limit damage and to promote resilience.**

Prevention thus brings together different actions, both in terms of the **rational management of land use, and the reduction of vulnerabilities and the protection of populations.** They aim in particular to: (Doussin, 2009)

- Limit urbanization in a flood zone,
- Manage land use to avoid increased flows and preserve rising river expansion zones,
- Reduce the vulnerability of the issues at risk,
- Protect issues and populations by investing in dedicated works,
- Maintain existing works.

It therefore requires sound knowledge of the flood zones and works to continuously improve the knowledge and understanding of the flood hazard based partly on the acquisition of hydrological data over the long term.

The flood risk prevention approach also involves asking questions about the **long-term development of the territory**, so as to integrate in the reflections and actions carried out, the population growth, the economic development of the territory and the possible impact, of climate change.

This approach must be based on the definition of an acceptable level of risk, recognizing the impossibility of protecting oneself from the most extreme events for which the measures of the next component will be preferred.

2. Preparedness for crisis management to facilitate reaction to the occurrence of a flood

The objective of this component is to **strengthen flood preparedness** in a way that will promote:

- **The anticipation and effectiveness of the actions** of security of the populations and the issues. Crisis management is as much about the warning, the intervention of the emergency services as the coordination between these different services, the deployment of the means of intervention, the communication capacities, etc.
- **A rapid return to normal** of the services (drinking water, sanitation, energy, transportation, etc.), activities and living conditions of the affected populations. This component must prevent a strong flood from becoming a disaster;
- **Continuous improvement,** drawing on past events to avoid repeating mistakes and filling identified shortcomings. *In addition, past disasters worldwide have shown that the post-disaster reconstruction phase is a critical opportunity to* ***rebuild better and promote resilience of territories (UNISDR, 2015).***

While flood risk prevention applies at the global catchment area level, it is important to focus the preparation (integrating both forecasting and crisis management) giving priority to the areas where the vulnerability is concentrated.

3. Risk culture, a prerequisite for the operational success of integrated flood management

The application in the field of integrated flood management is not always in line with the strategy set "on paper". **To achieve this, it is necessary to strengthen the culture of risk until all stakeholders**, not only public and private institutions but also civil society and the population aware of the importance of treating these issues, especially in developing countries. Thus the motivation of stakeholders is, in fact, more important than the way integrated flood risk management is defined. Risk culture is paramount since it makes it possible to: (CEPRI) (Doussin, 2009)

- **Reduce the overall feeling of anguish and anxiety during rising river levels;**
- **Adapt behaviour of populations,** reduction of negative consequences of floods;
- **Ensure good efficiency of risk management systems** (preventive measures, preparedness, monitoring, warning and crisis management).

Risk culture through different levels of appropriation of the information by the population: (CEPRI)

1. **Knowledge of risk.** Risk information which is correctly interpreted develops a state of knowledge of the risk in individuals. However knowing the risk does not involve the sense of being directly concerned by that risk.
2. **The awareness of risk.** It is characterized by a personal appropriation of risk information. To be aware of flood risk consists in taking this risk into consideration as an event that may have an impact on one's personal or collective sphere (it is even more present in individuals who have experienced flooding). However, the awareness of what is the risk to themselves or a group does not necessarily lead to appropriate behaviour to protect themselves against that risk.
3. **The acceptance of risk.** It leads people to seek more information, including targeted information on the operational side, as, for example, the means to be informed in case of warning. It is necessary to initiate real behaviour change in individuals.
4. **Adapting behaviours to risk.** These behaviours fall into three distinct phases: in anticipation of the event (reducing vulnerability), at the time of the crisis (appropriate response to mitigate the impact of the flood), and post crisis (facilitation of return to normal).

Figure 8 Illustration of the importance of appropriate behaviour to flood risk (CEPRI)

The implementation of effective prevention of flood risk

I. The vulnerability reduction tools

Reducing vulnerability of a territory is an essential component of preventing the risk of flooding. It has the advantage of allowing implementation with minimum investment, compared to those for structural measures (such as dams, storage tanks and storm water drainage systems). But **the institutional organization is a prerequisite**, in particular the cooperation of the institutions involved, the ability of institutions to enforce the established procedures, and the adequacy of staff skills with the tools in place. Moreover, the sustainability of its implementation involves technical, financial, organizational, institutional means over time, which can generate overall significant costs.

Three families of tools for the reduction of vulnerability can be identified within each non-structural measure. They are presented in detail in the following sections.

1. Identifying the issues

Identifying the issues consists of formalizing the knowledge of the land, so as to identify the areas most vulnerable to flooding, and characterize these vulnerabilities. The ultimate goal of this approach is firstly **to target areas for priority action, and secondly to provide a response in the reduction of vulnerability adapted to the local context and specificities of the territory.**

Among the tools available to carry out this work, we can mention in particular:

- ***Analysis of satellite images:*** available in most countries, these images make it possible to identify an outline of land use, particularly to distinguish urbanized areas from non-urbanized. They can provide the first information on the types of built structures.
- ***Field visits:*** The field trip is necessary to analyse in detail the vulnerability of a territory. The information collected, such as the typology of buildings, building materials generally used, number of floors, the elevation of the ground floor, are all indispensable elements. The verification of the representativeness of areas visited throughout the study area and even a brief training of persons who will have responsibility are necessary conditions for the proper use of the data.

- ***The surveys of the local population and/or participatory mapping:*** these steps assume that local communities have sound knowledge of the terrain, and are therefore ideally positioned to report on local issues. Applied to the flood risk problem in developing countries, the use of information collected in particular helps assess the damage generated by a flood, and to identify the most vulnerable areas. They help concretely improve knowledge of risk in the territory.

  Participatory mapping goes further than simple surveys in the sense that it involves entrusting to a community of people (e.g. consortium of members of civil society, NGOs, students, members of local governments) the development of a mapping on a given theme.

  These approaches (surveys, participatory mapping) must be seen as complementary tools to the field visits, but cannot function as a substitute since these visits are needed to check the reliability of data collected from the local community.
- ***The Geographic Information Systems (GIS):*** synthesis of information collected in a GIS system can generate any type of related vulnerability maps, which then will cross-check them with information about the hazard to analyse the risk of flooding.

Beyond the limits related to the tool handling (material resources - computers, electricity, GIS software - and required GIS skills), **identification of issues needs to be regularly updated to take into account developments in the territory.**

2. Urban planning and management of land use

The land use policies, through their interaction on the territory, can help reduce the risk of flooding. **Urban planning should help cities anticipate the occurrence of flooding well ahead of a crisis situation and to better control their growth and the rationalization of services** (transport, energy, waste, water, sanitation, etc.) through the implementation of master plans and urban development plans. **The integration of spatial development projections is fundamental in this process** (in the demographic and economic level).

Land use management must be organized on:

- Areas with issues and vulnerable areas (mostly urban) to allow, if possible, spreading the rising rivers despite urban development;
- The semi-urban or agricultural areas upstream to slow runoff and reduce the rising rivers.

Possible measures are attached to existing and future properties resulting from urban growth in the country, and include for example: (Doussin, 2009)

- ***Restrict or prohibit new development in flood risk areas.*** These measures can have an impact on social and economic issues (issue of renewal of the population, economic weakening of territories, etc.).
- ***Improve the management of upstream catchment areas.*** It can happen, for example, by limiting soil sealing or the adaptation of agricultural practices (e.g., demarcation of plots by transversal hedges). Many scientific studies have shown that land use management on catchment areas is effective for very frequent rising rivers (return period up to about 25 years). In addition, the effects are reduced or negligible.
- ***Eliminate vulnerable properties.*** These measures are very difficult to implement: the people who settle in at-risk areas, do so, most of the time, because those areas are the only accessible ones from a land perspective. The answer sought must fit into the more general framework of housing assistance policy: the relocation of families in illegal housing should give them alternatives, and "squatting" should be immediately destroyed to not allow another family to settle. These actions are organized within dialogue with target populations, and with the involvement of associations or district representations to educate their communities on inherent risks and work to establish acceptable relocation.

The challenge for developing countries in terms of planning is twofold. First, it is necessary to be able to rely on a land registry and clear land ownership rules, as well as effective and dissuasive control measures from the planning authorities. On the other hand, one is often faced with the inadequacy and difficulty of access to data projections of population and economic development. Past population censuses are useful information sources to identify and quantify the evolutionary trends.

3. Reducing building vulnerabilities

The decrease in building vulnerabilities is intended to reduce the damage generated by water entry, and if possible, to limit its intrusion.

It results in particular from the **implementation of construction standards** for new buildings, or reconstruction or renovation of existing buildings. For example, it may be required to elevate the ground floor, placing buildings on piles, building at least one floor, or defining the type of building material to be used. These standards are to be adapted to the characteristics of the territory's hazard as well as to the local context (taking into account, for example, the availability and supply networks of the recommended building materials). As before, the difficulty of this type of measure lies in the durability of their implementation and the challenge of their respect by the population.

II. The tools of hazard management

1. Knowledge of the hazard

Knowledge of the hazard aims to:

- Identify flood risk areas for different return periods, including exceptional floods for which flooded areas are often unknown or unknown in developing countries;
- Characterize the floods in terms of current velocity, submersion depth and submersion duration.

A better understanding of flood phenomena and their characteristics is a **fundamental prerequisite for adapting responses in order to limit the risk of flooding.** This knowledge thus makes it possible **to identify the vulnerability reduction measures that are relevant to the territory, and to correctly size the protective structures.** For example, having houses raised on piles is only relevant in areas often flooded, with little current, or even stagnant water.

The tools available to improve the knowledge of the hazard at the territorial level include:

- ***The Digital Terrain Model (DTM)***: it is a representation of the relief of a zone, indicating the altitude of the various points of a chosen mesh (more or less precise according to the needs). In terms of flood risk, the knowledge of the topography makes it possible to identify the flood zones from the knowledge of a given submersion depth (resulting for example from a hydraulic model). On flood zones, it is preferable to have it determined accurately, at + or - 20cm.

  If a DTM is not directly available on a given territory (or it is not sufficiently accurate), the topography can be studied from the analysis of very high definition satellite images, or by the use of sensors on airborne or helicopter-borne, LIDAR type (which uses light to measure distances).
- ***Rainfall and hydrological measurement tools on the ground:*** these tools, also used in support of flood forecasting (see next chapter on preparation), make it possible to gather a lot of local data on the flood hazard, in particular: precipitated water slides, flow rates and water levels of rivers. There are different types of devices, in particular:
  - **Rain gauges** or the pluviographers that collect precipitation in a collecting vessel, which measures the precipitated water slide per unit area over a given time interval.
  - **The stage recorders,** which are in the form of a graduated scale placed vertically or inclined, allowing direct reading of the water depth of a watercourse, sometimes coupled to automatic acquisition of the measurement devices.

To be reliable, these measurement tools must be placed at locations representative of local phenomena and the sampling frequency of the data must be sufficient to monitor the phenomena throughout their occurrence (rain or rising river). Note, however, that these devices are often faulty or inaccessible during extreme events.

Some devices can be installed for several decades: then they provide a historical database, which, after statistical processing, allows to build:

- **IDF curves (Intensity-Duration-Frequency Curve).** These are curves illustrating graphically and synthetically the rainfall regime at a given point by establishing the relations between the intensities, the durations and the frequencies of rainfall. They are used in particular to estimate runoff for a given type of rain, and to size structures. In many developing countries, such curves already exist, but they were often built before 1980 by ORSTOM (now called IRD) or equivalent organizations. It is always useful to update them by integrating the latest measurement data.

- **estimated rainfall**: these are artificial rain events representative of the analysed territory and for which the period of return is known. Estimated rainfall are used at the input of hydraulic models but have the defect of not representing the whole field of possibilities.

- ***QdF curves (Flow-duration-frequency).*** These curves synthesize the hydrological regime of the rivers and the statistical result of the processes of transformation of the rains on a catchment area under flow regime on a river.

- ***The hydraulic simulation model:*** it allows to analyse the propagation of rising rivers in the hydraulic network and to characterize the possible overflows in terms of submersion depth and flow rate. To be reliable, the models need to be calibrated for example from the history of measurements of flows or water levels, and rising river levels.
  There are also the so called "1D" models (1-dimensional modelling) that are most commonly used because they are simpler to implement (and require less geometric and topographical data) than "2D" models (2-dimensional modelling) (Figure 9). A 1D model approximates that the flow velocity is the same throughout the wet section of the flow. For simulations where flows in the major bed are much slower and have different directions than those in the minor bed, there are 1D models complemented by side compartments or 2D models that are more difficult to adjust. These 2D models are mainly used to study in more detail the flood phenomena on a floodplain, and for the educational side (because they are dynamic) to visualize the results.

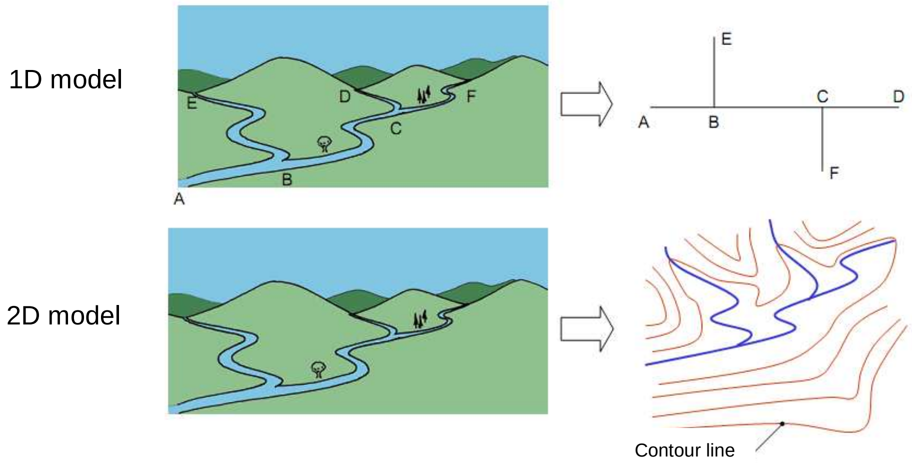

Figure 9: Illustration of a 1D model (top) and a 2D model (bottom) (Guinot, 2003)

- ***Informal knowledge of the population and local actors involved:*** as for the identification of the issues, the local population constitutes a source of information also in knowledge of the hazard, in particular concerning the maximum water depth of a flood, the approximate duration of the flood, a qualitative assessment of the currents. However, this approach is limited by the memory of the population. If it has recently been confronted with a flood, people will be able to provide relatively reliable information, which may not be the case for floods that took place several years ago. Also, it is essential to couple this approach to the use of other tools mentioned above, so as to verify the information collected.
- ***The Geographic Information Systems (GIS):*** they are cartographic representation tools facilitating the presentation of the results of hazard and vulnerability analyses in a given territory.

Box 3: Climate projections and their integration into flood risk management tools

The study of climate change is based on the modelling of the Earth system, through climate models. The main uncertainties of these models focus on: (MétéoFrance)

1. **The limits of our scientific knowledge of the phenomena involved**: different components of the climate, and their interaction are included in the models but some processes are still complex to model, especially clouds (GIEC, 2013). In general, precipitation is less well modelled than the change in mean temperature. In its last report, however, the IPCC highlights an improvement in global and regional climate models, in particular through the introduction of complementary processes (such as the carbon cycle, ice cap, and chemo-climate interactions), and the refinement of the mesh (in 2013, of the order of 150km for global models, and 25 km for regional models) (MétéoFrance).

2. Socio-economic uncertainties on the behaviour of societies, and the choices of societies (political choices) they tend to increase over time over the modelling time horizon.

Despite these uncertainties, **the results of the climate models reveal trends in climate change.** The IPCC also highlights the **added value of regional models**, compared to global models, **especially in areas influenced by topography, by rapid and/or localized phenomena.**

Predictive capacity at the local scale remains tainted with uncertainty and the impacts on the river regime are for the most part obscured by uncertainty about the knowledge of these regimes. It seems difficult to translate their results and trends into quantified and accurate input data (such as increasing the frequency of a given rainfall), which are necessary for flood risk management tools, such as Cost Benefit Analysis or CBA (see box 4). For this tool, it may for example be very interesting to carry out a sensitivity test, by setting maximizing and minimizing hypotheses of the increase in the frequency of a given rain, so as to evaluate the influence of this change on the results of CBA.

2. Structural flood protection measures

According to UNISDR (2009), structural measures refer to "**any physical construction intended to reduce or avoid the potential impacts related to hazards, or the implementation of engineering measures" to strengthen the resistance and resilience of systems or structures in the face of hazards.** The main objective is to protect property and people located in rising river zones, but often the construction of such measures is also intended to allow urban development in areas subject to hazard.

Developing countries tend to focus their efforts and funding on building such measures, while improving knowledge and reducing vulnerabilities is the main issue in reducing the risk of flooding.

Presentation and limitations of structural measures

There are usually two types of structural measures (Sayers al. 2013):

- ***"Heavy" structural measures*** including the construction of major developments such as:
  - **Drainage infrastructure** to facilitate storm drainage (networks and storage basin);
  - **Dikes** intended for close protection of the issues, by reducing the rising river expansion field, with an increase in depths and speeds in the dammed bed;
  - **Dams** ensuring flood retention upstream issues, retaining water. This type of containment plays the role of a decanter: the slowing down of the speed causes a deposition of the solid materials transported by the stream, which varies according to the granulometry of the materials;
  - **Watercourse modifications** aiming at the acceleration of the flows on the areas of issues (ex: artificial increase of the section of the minor bed, suppression of meanders).

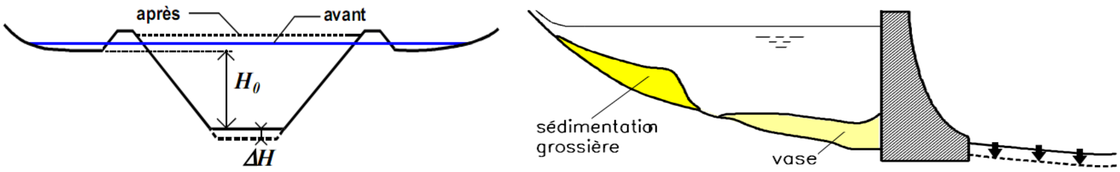

Figure 10: Illustration of a containment (left) and construction of a dam (right) (Degoutte, 2012)

Heavy structural measures have been called into question in developed countries, partly because of ***evidence that such measures are ineffective for major rising rivers****, especially when they are* *generalized, and secondly due to scientific and public challenge of* ***their ecological, economic and morphological impacts (Doussin, 2009).***

- ***Lighter structural measures, also called "dynamic slowdown", which aim at slowing down (not accelerating) flows and encouraging their retention upstream of the areas of concentration of the issues.*** They include the installation of catch basins, the preservation of flood expansion zones, the alternative management of rainwater (and the favouring of infiltration), the work on the roughness of the banks to mitigate the acceleration of flows, etc. These measures thus facilitate synergies with ecological approaches (restoration of wetlands, preservation of habitats of aquatic species), but may nevertheless present risks to the surrounding environment in the event of malfunctions or breaks, although they are minor compared to the heavy measures ***(Doussin, 2009)***.

A necessary better design of the works

Regardless of the proposed protection structure, sizing involves 1) the choice of the return period of the event for which protection is desired, and 2) the selection of a sizing method adapted to the tools available and to the knowledge of the hazard where we want to develop the structure. The various sizing methods are presented in the annex to this report.

Good practices for the concept and design of flood protection infrastructure include:

- ***Analysis of all the consequences induced upstream (for the case of water retention) and downstream of the area concerned (for the cases of acceleration of flows at problem areas).*** Upstream-downstream solidarity involves the joint involvement of the various actors. Their collaboration can bring significant benefits for the different parties. For example, to reduce the risk of flooding in an urbanized area, it may be more relevant and efficient to fund measures to limit inputs from upstream areas, rather than being limited to the construction of drainage works in the urbanized area itself.
- ***Analysis of the impact on the structure for a return period event exceeding the one used for the design,*** in particular by simulation by valuing the models used for dimensioning.
- ***Analysis of the impact on a dysfunction of the structure,*** related in particular to a reduction of hydraulic capacity of these structures (because of jams, or linear infrastructures crossing them, etc.).
- ***Conduct a cost-benefit analysis of the infrastructure*** (box 4).

In general terms, it is also essential to include the infrastructure project in an integrated flood management approach with the general goal of reducing damage to people and property and making improvements to the state of knowledge, reducing vulnerabilities, preparing, and strengthening the risk culture.

Box 4: Cost-Benefit Analysis

A Cost-Benefit Analysis (CBA) is designed to assess the economic feasibility of a project by comparing its implementation costs (initial investment and operating costs) to the damage it prevents. It is a question of elaborating numerical and consolidated arguments to justify the realization of the adjustments (for example for the search for financing).

The general recommendations and good practices for carrying out this type of analysis are described in particular in the CEPRI communication document.

The CBA is based on the comparison between an initial state (without measurement) and a projected state including the implementation of complementary measures (ex.: development of a flood protection structure). The difference between these two states corresponds to the damage avoided thanks to the implementation of the project, in other words its profit.

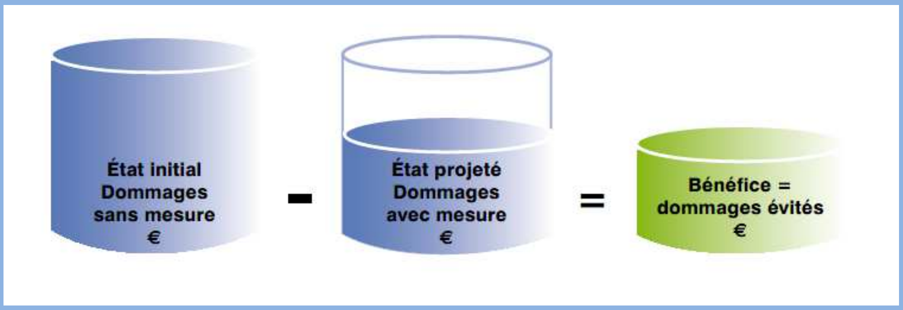

Figure 11: Principle of calculation of profits in connection to the development of measures (Source: CEPRI)

The comparison between these two states is performed **for several events with various return periods.** In particular, it is essential to integrate a frequent rising river. Indeed, in some cases, the main benefits of this type of infrastructure are generated for the most frequent events: they are the ones that will weigh the most in the CBA, because although the damage avoided is lower in absolute terms than those of a ten-year rising river, they intervene much more regularly. In addition, it may be interesting to integrate a very large event (return period of 1000 years) as a reference for potential maximum damage.

Since CBA is carried out over **a definite time horizon**, the comparison must be made both for **the current situation** (with current urban planning) and for **the**

future situation, taking into account urban growth over the chosen time horizon as well as possible impacts related to climate change.

The importance of maintenance of works

Beyond their design and construction, the problem of the maintenance of the protective works is a fundamental aspect of the flood risk prevention insofar as a bad maintenance can lead to failures in the works operation, or even the probability of rupture of the works.

With regard to drainage type infrastructure, the major problem is the risk of reducing the evacuation capacity. The latter may be related to a problem of siltation or accumulation of waste. It can also be caused by structures cutting the infrastructure (water pipes, nozzles, bridges, etc.) and causing a reduction in hydraulic capacity. In most developing countries, the volumes of waste transported by rising rivers are large (trees, cars, bicycles, shopping carts, etc.), and can cause logjams within the protection infrastructure. Even maintenance that could be called preventive, which consists of cleaning rivers or drainage infrastructure just before the rising river, could have no effect: waste that can be trapped is carried by the water from upstream of the catchment areas. To limit this risk of reducing the evacuation capacity, it is particularly important to ensure that the drainage infrastructure has a large size and a geometry that is as regularly profiled as possible, and have a gradient of at least 1/1000 (to induce a self-cleaning flow avoiding sedimentation).

With regard to dikes and dams, the problem of maintenance is related to the strength of the structure (and therefore to the materials that make it up) **and its obsolescence.** Here, it is rather a matter of regularly checking that there are no vegetations (trees) or uncontrolled use of the slopes likely to weaken the structure of the work. It is also a matter of having the work regularly checked by a civil engineer, and if possible having plans of the work and having knowledge of its components.

Maintenance problems must also be analysed by the prism of the property and of the police: it is necessary to define precisely the actors involved, as well as the actions (maintenance, restoration, surveillance) that each one is responsible for. Finally, it is important to regularly check that each stakeholder is aware of their responsibilities and accepts them to ensure the proper functioning of the work over time.

III. Institutions to involve in risk prevention

Institutions, local or not, to involve in the prevention of flood risk obviously depend on the local context. It is however possible to draw up a general assessment of the actors likely to be involved: this is presented in Figure 12.

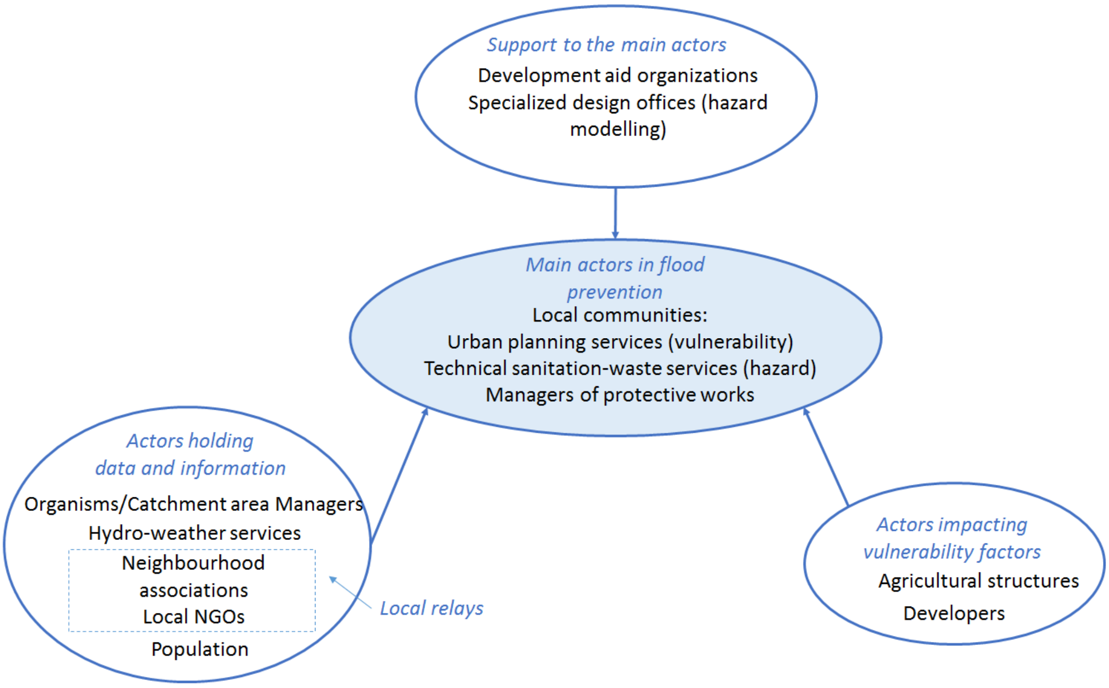

Figure 12: Synthesis of the types of main actors likely to be involved in the prevention of the flood risk of a territory

Better preparation for the crisis

In the context of floods, preparation involves **the establishment of warning systems.** According to UNISDR, these systems bring together "**the full range of capabilities needed to produce and disseminate, in a timely manner, warning bulletins enabling individuals, communities and organizations threatened by a hazard to prepare and act appropriately and in a timely manner"** (UNISDR, 2009)**.** Warning systems rely on both weather forecasts and rising river forecasts.

But the interest of these forecasts, in the context of flood risk management, resides mainly in the **implementation of actions associated with the level of risk which is forecast and defined upstream of the crisis in a planning document** of contingency plan type. These actions include the information of the crisis management actors and the population, the evacuation of the sectors most at risk, the establishment of "small" structural measures by the population to reduce the vulnerability of buildings (e.g. cofferdam installation or use of sandbags to prevent water from entering buildings), and more generally coordination and communication between the actors involved in crisis management.

Thus, to ensure an effective rising river warning system, it is essential to:

- Design the system on the basis of the understanding of the climatic hazard to which the territory is subject, and its vulnerability to this hazard;
- To find a balance between the information transmitted to the population and that sent to the services concerned by crisis management;
- Organize the basic structures so that the roles and responsibilities of each are well established, shared and accepted before the crisis. This can be complex, as several departments may have separate responsibilities for rising river forecasting and warning activities.

It should be remembered, however, that the potential timing of rising river varies greatly depending on the size of the catchment area and the type of rising river. In the case of flash floods, where the kinetics of the event are extremely fast, the time available between a reliable forecast and the occurrence of the event is often less than 1 hour which is very short to activate an effective warning - evacuation process. While it reduces the lethal risk, it has little effect on reducing economic damage.

I. Forecast tools

1. Weather forecast

In terms of flood risk management, the weather forecast makes it possible to predict the rainfall events to come on a given territory, and as far as possible to quantify them (in terms of intensity, duration, water depth precipitated, etc.). Ground meteorological tools (detailed in the previous chapter on prevention) are also used to support the forecast: they allow to gather a lot of local data on the flood hazard and, according to the density of installed devices, offer a vision of the spatio-temporal variation of the meteorological events. In addition to the ground network, forecasts can be made at different scales:

- ***Numerical prediction, at the level of a nation or even a group of nations. It relies on sophisticated forecasting models using large calculators.*** Developing countries generally do not have the resources (technical, human) to run such models. However, the need, for all the models already implemented, to solve the problem of global-scale forecasting makes these models usable by any country that may prefer to use already tried-and-tested models (even if it means improving it by providing additional data on its territory), rather than developing its own model at great expense.
  Overall, considerable progress has been made in improving numerical weather scores, although precipitation remains difficult to replicate due to the extreme spatial and temporal variability of this parameter. In the forecast of strong or extreme rain events, a regional model allows a warning of a territory with great relevance. However, a strong or extreme rain event is most often located in space and time, something that the numerical model has difficulty in specifying. This is why the numerical forecast must be relayed by the immediate forecast.
- ***Immediate forecast on a more local scale.*** It is based on the extrapolation of imagery provided by geostationary meteorological satellites and meteorological radars.
  - **Satellite observation:** Geostationary satellites provide images that continuously map cloud cover, observe its evolution and movement, and identify the most active cloud convection zones. The predictive potential of geostationary satellite imagery is particularly evident in the case of cyclones (organized wet systems with a long life cycle - weeks - and fairly predictable displacement) from the monitoring of successive satellite images.
  - ***The weather radar:*** it is the ultimate instrument for hydrometeorological surveillance and flood warning. It is the central tool of the immediate forecast, allowing to:

- compile rainfall statistics, identify the most vulnerable areas in relation to topography and urbanization, and dimension works for the sewerage network (sizing of collectors and retention ponds);
- provide data to a service platform that could (subject to the establishment of a civil protection service and the development of contingency plans) develop real-time hazard diagnoses and send appropriate warnings to the on-duty teams.

The main types of radar used in the meteorological field are presented in the annex of this document.

2. Flood forecasting

In addition to weather forecasting, there are flood (or rising river) forecasting systems. They make it possible to provide the various crisis management actors (authorities, water management body, transport services, telecommunications services, public security services, health services) with information so that they can prepare themselves for the crisis, and know how to react. (OMM, 2011)

According to the WMO, an effective rising river forecasting system consists of the following elements:

- ***Specific precipitation forecasts*** in terms of quantity and timing, for which numerical forecasting is essential;
- ***A network of hydrometric stations*** (manual or automatic) connected to a control centre by any type of telemetry;
- ***A software for modelling flood forecasts***, connected to the observation network and operating in real time; more and more, we are trying today to move towards a forecast of flooded areas but the difficulty is significant;
- ***A warning chain,*** activated when an event of significant magnitude occurs or is imminent. It is essential to check that it is aimed at actors who have an action plan and who have the operational capacity to execute it.

II. Crisis planning tools

Planning is an essential tool in crisis management, the main objective of which is to make relief operations effective in: (Ledoux, 2006)

- Ensuring mobilization and rapid implementation of available relief resources;
- Setting in advance the line of command and the sharing of responsibilities.

The planning of a national or local crisis situation can be translated into a **contingency plan** (relief organization). This type of plan must clearly, precisely and concisely define the roles and responsibilities of the various institutions involved, as well as the tools to be mobilized and the procedures to be put in place in the event of a crisis (ONU/BCAH, 2008). Many contingency planning guides exist from United Nations agencies or other organizations such as the International Federation of Red Cross and Red Crescent Societies. But it must be kept in mind that a contingency plan must be adapted to the specificity of the risk of flooding in the given territory, in terms of hazards and vulnerability. We will however retain the following few recommendations:

- ***Manage the crisis by increasing stages of mobilization*** with a sequential trigger that is the product of the ***coordinating authority*** *(ex:* Prefecture or Prime Minister) and not that of information providers (e.g. meteorological services);
- ***Reflect on a relevant scale:*** national for countries with the means, regional or even international for major crises;
- ***Take into account the means of communication*** for the coordination of actors and the dissemination of information (e.g.: crisis command post);
- ***Plan the organization of rescue and evacuation, and identify the available means and equipment.*** Relief is usually provided by firefighters: they have equipment such as trucks, ladders and even floating boats to bring the affected people back to safe places. The mobilization of ambulances ensures first aid to the wounded, or, if necessary, their transport to medical facilities equipped to treat them. Local authorities should also anticipate the evacuation of people in high-risk sectors, including by defining evacuation procedures, communication procedures among the population, and identifying, upstream of the crisis, refuge areas adapted to accommodate population: these shelters should especially be located outside of flood zones, remain accessible despite the floods and have, wherever possible, a supply of clean water. The NGOs also play a major role in the management of people affected by disaster by providing accommodation facilities (camp beds) as well as food and drinking water.
- ***Promote continuity of priority services and their rapid return to service.*** Priority services include water supply, energy, and waste management. To facilitate the return to service of the equipment, it can be envisaged to terminate services for preventive purposes at the time of crisis (for example to get electrical equipment out of water). The establishment of small structural measures such as cofferdams and sandbags can also protect equipment in order to prevent their degradation and allow a rapid return to service after the recession. Firefighters can also be equipped with pumping equipment for pumping water from submerged areas.

- ***Integrating population evacuation*** (evacuation procedures, identifying refuge areas adapted to the population to host communication with the population, water supply and food, etc.).

The limits related to a contingency plan are particularly related to:

- ***Its operational implementation.*** It is essential not to reduce the issue of crisis management to a problem of means and technical capacity. Although this is obviously essential, organizational approach is crucial. Indeed, crisis management is as much intervention as coordination between the various stakeholders, the deployment of intervention resources, communication skills, etc.
- ***Its distribution.*** To be effective, the contingency plan should be known and accepted by all involved. They must be aware of the tasks and responsibilities they deserve.
- ***The need for its regular updating*** in order to take into account the institutional changes (very common in some developing countries) and improvements in equipment and tools, and to incorporate lessons learned from recent experiences.

Crisis Management **Simulation exercises** are complementary tools to defining a contingency plan, which allow to test its effectiveness and operational status, as well as to identify potential gaps or weaknesses in the contingency plan and resources available. For it to have value, the realization of such a simulation involves formalizing the conduct of the exercise and the lessons learned in a report, which can be used later to improve crisis management, and the associated contingency plan. Note however, that the conduct of such exercises requires financial, organizational resources (continuation of activities and services during the year) and materials.

In addition, there are **assistance and international cooperation tools** to support countries in these efforts, in particular the **UNDP** and the **UNDAC**. The UNDAC (United Nations Disaster Assessment and Coordination) is part of the international emergency response system, and its mission is to:

- Assist the United Nations and the governments of countries affected by disasters during the first phase of a sudden emergency;
- Contribute to the coordination of international relief efforts at the national or local level.

The UNDAC comes at no cost from the affected countries, on request of the United Nations or the governments of the affected countries. (OCHA, 2017)

The reconstruction phase, post-crisis, is also a key step in managing flood risk. **It must be integrated into the planning of the crisis**, to ensure a return to normal as quickly as possible. The tools available for disaster recovery include in particular:

- ***The insurance systems.*** They enable the at-risk population to benefit from protection of potential damage, and so recover quickly from a disaster that would hit. They can also enable the pooling of damage, and encourage stakeholders to understand and identify the risk. There are several types of insurance systems, detailed in this report's annex. It is difficult to impose a system while in many countries the basic insurance system (comprehensive home insurance) does not exist.
  The establishment of a fund by the government may be an option (e.g. Caisse Centrale de Reassurance in France) but is not a requirement. However, the public authorities, have two responsibilities:
  - Fostering a deployment on a large scale to avoid high premiums;
  - Produce and/or disseminate the data relating to the risks and damage caused by floods.

  The GFDRR regularly organizes a meeting on the topic "Role of insurance in disaster risk reduction - RIDRR".

  The different models of insurance systems are appended to this document.
- ***The feedback*** is to investigate the causes, to try to reconstruct the course of a catastrophic event to draw important lessons in terms of prevention and crisis management. This tool should help capitalize the body of knowledge related to an event and transmit to as many as possible thereafter. It allows to keep a fine memory of the event. ***(IRMA)***

III. The institutions to involve in the preparation

The institutions to involve in the preparation to flooding are shown in Figure 13.

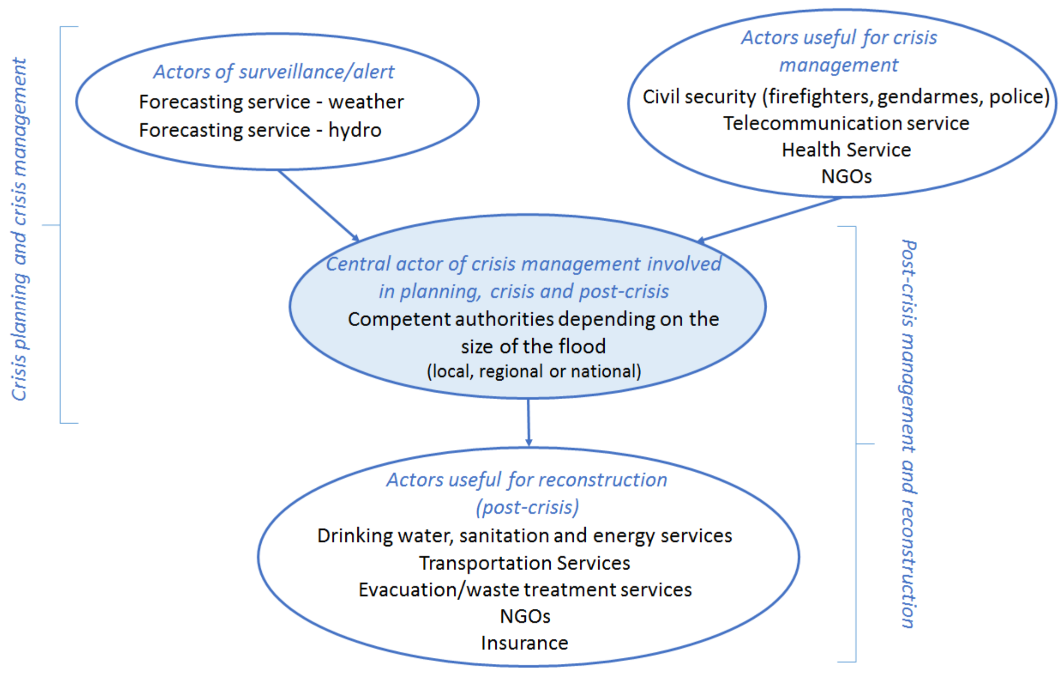

Figure 13: Synthesis of the types of main actors likely to be involved in the preparation in case of flood risk

Strengthening the culture of risk

I. The tools to improve risk awareness

Strengthening the risk culture is a key element in the flood risk management. The two main issues are the awareness of the potential flood risk and integration of behaviours in crisis. All actors are concerned by this aspect of flood risk management and especially the inhabitants, often not aware of existing risks and good practices in case of flooding.

The dissemination of information regarding the risk of flooding can be achieved by several means, including in particular:

- ***Awareness at school.*** Children are among the most vulnerable groups to disasters. The purpose is to inform them on existing risks and what to do in a crisis, participate in their own protection but also to that of the members of their community. This tool also allows to train at risk of flooding the future adults of the country.
  To generalize the teaching of knowledge about the risk of flooding on the scale of a country, it is important to have the support of the Ministry of Education, authorized to register such courses in the primary and secondary education curriculum. This is the case for example in Mexico, where the teaching subjects that educate on disasters is compulsory in schools ***(UNISDR, 2006)***.
  Awareness of the school is part of the key themes of the UNISDR in its global campaigns on disaster prevention. The UNISDR also produces guides to schools and teachers, such as the one entitled "Water and hazard in Africa: Guide for schools"[3].
- ***The "serious game":*** this educational tool allows teaching people, especially children, in a fun way, based on new technologies (computers and on smartphones), and help them understand issues of risk. The UN has set up the game "Stop disaster" (www.stopdisastersgame.org), which simulates various types of disasters, including floods. The player needs to prepare for the occurrence of a flood, with a set budget that he must spend to improve planning and preparing his territory for the crisis.
- ***The realization of simulation exercises*** of a flood, with the actors involved but also the population, especially in schools. In addition to a better organization of the services involved (see previous section), this type of exercise, if it involves the population, participates in the integration with the locals, of recommended behaviours and good practices in case of crisis, by making them face a specific situation.

[3] Available at the following address: https://www.unisdr.org/2004/campaign/docs/eau-et-aleas-ecoles.pdf

- ***The installation of flood marks.*** These tools allow to remember the heights reached by the floods to which they relate, compare them to each other and find the frequency of their occurrence ***(Site : Les risques majeurs, 2009)***. In this way, they materialize the risk of flooding and associate it with a specific place. They thus contribute to maintaining the local collective memory of past events, provided they are clearly visible and mostly well explained. It can be a relevant example to support the installation of flood marks, additional explanatory panels (explaining what the flood marks, and provide additional information on historical floods on this place or even on the town).
- ***The involvement of the population in the implementation of public policies through public information meetings and/or consultation workshops*** in order to inform people about the risk of flooding itself and existing approaches to protect themselves. These meetings can also be an opportunity to gather additional information and incorporate feedback from residents.
- ***The launch of awareness campaigns*** among the population, driven by NGOs and possibly the neighbourhood associations, local representatives who have the trust of the population.
- ***The organization of exhibitions and artistic approaches,*** linked to the risk of flooding to disseminate information in an original and informally with the population.

II. Institutional partners of risk culture

The actors and institutions involved in the cultivation of flood risk culture, national and local, are shown in Figure 14.

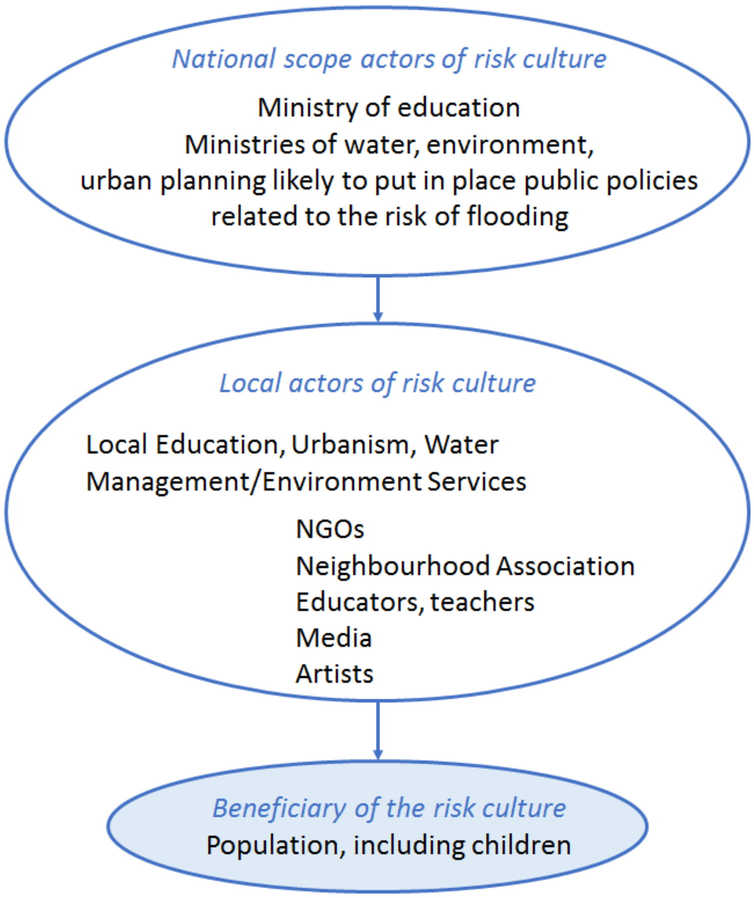

Figure 14: Summary of the main types of actors likely to be involved in strengthening the culture of risk

Examples of risk areas in developing countries

In this chapter, five cities in developing countries located in different areas of intervention of the AFD were the subject of a specific analysis. This analysis aims to study, at a fine geographical scale, flood risk in developing countries, to support, on one hand with specific examples, the results explained in previous chapters, and also bring out characteristics specific to each city, illustrative of the relevant intervention area. The five cities or territories studied are:

- **Dakar,** capital of Senegal, country typical of Sahelian context (intervention area: Sub-Saharan Africa)
- **Beirut,** capital of Lebanon, illustrating the case of the Mediterranean countries (intervention area: Mediterranean and Middle East)
- **Port Louis,** capital of Mauritius, illustrative of the island context in the Indian Ocean (area of intervention: Sub-Saharan Africa)
- **Hanoi and the Red River Delta in Vietnam** (intervention area: Asia)
- **Sao Paulo,** central Brazil and main Latin American megalopolis (region of intervention: Latin America and the Caribbean

The analysis helped identify commonalities and/or recurring elements of different territories:

- **Vulnerability in installing populations** (often the poorest) in areas at risk of flooding;
- **The increased hazard of climate change**: the effects of this global issue will be felt everywhere, with a particularly significant risk to coastal areas vulnerable to rising sea levels (four case studies are concerned with this risk);
- **The increased risk from urban development** have often led to urbanization in flood zones and increased runoff;
- **Inadequate drainage infrastructure** which is often not efficient enough to meet the growing needs associated with the development of urbanization.

In addition, the analysis also identified the specific characteristics of each city, presented in Tableau 1.

Table 1 : Key features of case studies

Case study	The key features
Dakar	**The loss of the culture of risk associated with the drought period** of the 1970s, resulting in the settlement of populations in areas at risk but dry during drought **The raising of the Thiaroye water table**, now flush **The social impacts of the highlighted floods**, leading in particular to

	tensions within a region
Port Louis	**The false sense of security** engendered by the development of the city, which has resulted in a loss of culture of flood risk; **The issue of agricultural practices**: the abandonment of cultivated lands of sugar cane, without special care, leads to an increase in runoff **The islander context of the country**, making it dependent on the activities of the port
Beirut	**The problem of refugees fleeing conflict, resulting in a specific vulnerability** **The problem of waste collection** which is not only likely to aggravate the hazard, but also likely to cause epidemics in case of contamination of water during floods
Red River Delta	**The issue of land use management upstream of the catchment area**, with more precisely a deforestation dynamic leading to an increase in runoff at the delta level; **The flood management strategy turned only towards an all-structural focus and without prioritization of sectors to be protected**: these infrastructures (dike network) are now degraded and contribute to the increase of the exposure of populations to the flood risk (not to mention that they lead to the loss of the culture of risk). The increase in population and standard of living over the last 20 years is contributing to the increase in vulnerability.
Sao Paulo	**Social inequalities** that result in the poorest populations being settled in favelas often exposed to the risk of flooding **The "megalopolis" nature of the city**, exacerbating problems linked to the sealing of soils and the increase of runoff

The detailed synthesis of case studies (Tableau 2) highlights the characteristics and impacts of flood risk, following the criteria of sustainable development: social aspect, environmental aspect and economic aspect. The detailed analyses are presented in the annex to this report.

Table 2: Synthesis of the case studies

Case study	Flood type	Social aspects	Environmental aspects	Economic aspects
Dakar (Senegal)	**Urban runoff** Marine submersion	*Characteristics:* - Vulnerability due to **loss of risk culture during years of drought**, which led to a massive settlement of populations (often poor) in flood-prone areas - Increased vulnerability due to growth of urbanization on natural waterways *Impacts:* - Degradation of the living environment and **the links between the inhabitants** (increase of tensions, especially between neighbours) - Sanitary risk of stagnant water (epidemic development) and potentially contamination of water resources	*Characteristics:* - Worsening of the hazard by **raising the water table of Thiaroye** - Increased hazard due to climate change	*Impacts:* - Risk of interruption of the city's activities, economic heart of the country
Port Louis (Mauritius)	**Flash flood**	*Characteristics:* - Vulnerability related to the **false sense of security caused by the level of development of the city** - Vulnerability related to the installation of poor populations in exposed areas (on slopes) and lack of control over land use - Increased vulnerability due to growth of urbanization on natural waterways *Impacts:* - Potential contamination of drinking water sources	*Characteristics:* - Aggravation of the hazard by **upstream agricultural practices** (abandonment of land used to cultivate sugar cane) - Increased hazard due to climate change	*Characteristics:* **- Worsening vulnerability related to the country's island context**, which is dependent on imports *Impacts:* - Risk of interruption of the city's activities, economic heart of the country, and in particular of the port
Beirut (Lebanon)	**Flash flood** Urban runoff Marine submersion	*Characteristics:* - Worsening of vulnerability by the **high concentration of urban areas in the coastal zone** - Vulnerability related to **refugee flows** (Syrians in particular) - Vulnerability due to inadequate drainage infrastructure *Impacts:* **- Sanitary risk related to waste dredged by flood waters**	*Characteristics:* **- Aggravation of the hazard by the presence of waste in the streets** (obstruction of water drainage infrastructures and drainage channels) - Increased hazard due to climate change	*Impacts:* - Risk of interruption of the city's activities, economic heart of the country, and in particular the port (where transit of 75% of Lebanon's GDP takes place)
Red River Delta (Vietnam)	**Rising river** Marine submersion	*Characteristics:* - Vulnerability related to the **degradation of flood protection infrastructures (dike network)** despite maintenance and equipment monitoring efforts - Vulnerability related to high population concentration in exposed areas	*Characteristics:* - Aggravation of the hazard by the **problem of deforestation upstream of the delta region** - Increased hazard due to climate change	*Impacts:* - Risk of interruption of activities in the region, economic heart of northern Vietnam
Sao Paulo (Brazil)	**Urban runoff** Flash flood	*Characteristics:* - Aggravation of the hazard by the **development of the urbanization of this megalopolis** (2000km2 highly urbanized) - Vulnerability related to **social inequalities**, especially in poor neighbourhoods called favelas exposed to flood risk (summary constructions, with risk of landslides) - Vulnerability due to inadequate drainage infrastructure	*Characteristics:* - Aggravation of the hazard by the presence of waste in the streets (obstruction of water drainage infrastructures and drainage channels) - Increased hazard due to climate change	*Impacts:* - Risk of interruption of the region's activities, economic heart of the country

Bibliography

ADRC. (2005). *Total disaster risk management - Good Practices.*

AFD. (n.d.). *AFD 2025 Dossier thématique Démographie et migrations.*

Ambroise, B. (1998). *La dynamique du cycle de l'eau dans un bassin versant - Processus, Facteurs, Modèles.* Bucarest: HGA.

Armand, R. (2009). *Etude des états de surface du sol et de leur dynamique pour différentes pratique de travail du sol. Mise au point d'un indicateur de ruissellement.* Université de Strasbourg.

Asconit. (2013). *Renforcement des politiques publiques et appui aux structures nationales de coordination, de prévention et de gestion des risques naturels et des catastrophes dans les pays membres de la COI.*

Banque Mondiale. (2009). *Climate Resilient Cities: A primer on reducing vulnerabilities to disasters - City Profile Hanoi, Vietnam.*

Banque Mondiale. (2012). *CLIMATE CHANGE, DISASTER RISK AND THE URBAN POOR: CITIE S BUILDING RESILIENCE FOR A CHANGING WORLD .*

Bassin de la Sarthe Amont. (2007). *Les zones d'expansion des crues.* Plaquette de communication.

BBC Weather. (2011). *Weither Beirut - Average conditions*. Retrieved février 2016, from http://www.bbc.com/weather/276781

BRL Ingénierie. (2015). *Conception et mise en place d'un système d'alerte précoce axé sur les inondations.*

CEPRI. (n.d.). *Sensibiliser les populations exposées au risque d'inondation - Comprendre les mécanismes du changement de la perception et du comportement.*

CIA. (2015). *The World Factbook*. Retrieved octobre 2015, from https://www.cia.gov/library/publications/the-world-factbook/geos/mp.html

Croix Rouge. (2013). MENA Workshop on Urban Disaster Risk Reduction and Management - Building Urban Resilience., (p. http://www.unisdr.org/files/36460_36441beirutworkshoponurbandrrreport.pdf). Beyrouth, Liban.

Degoutte. (2012). *Cours d'hydraulique, dynamique et morphologie fluviale - Agro ParisTech.*

Diongue, M. (2014). Périphérie urbaine et risques d'inondation à Dakar: le cas de Yeumbeul Nord. *ESO, Travaux et Documents*, n°37, p 45-54.

Doussin, N. (2009). *Mise en oeuvre locale d'une stratégie globale de prévention du risque d'inondation: le cas de la Loire moyenne.* Géographie. Université de Cergy Pontoise.

EM-DAT. (2015, octobre 10). *Database, EM-DAT The International Disaster Database - extrait du 10/10/2015*. Retrieved octobre 2015, from http://www.emdat.be/database

EM-DAT. (2016, novembre 25). *Database, EM-DAT The International Disaster Database - extrait du 25/11/2016*. Retrieved octobre 2015, from http://www.emdat.be/database

Fagoonee, I. (2005). *Integrating disaster-management information in Mauritius.*

Floater, G., Rode, P., Friedel, B., & Robert, A. (2014). Steering urban growth: governance, policy and finance. *The New Climate Economy Cities Paper 02. LSE Cities London School of Economics and Political Science*.

Fontenelle, J.-P. (2006). La décentralisation de l'hydraulique agricole du delta du Fleuve Rouge au Viêt-nam: rupture ou continuité? *Hérodote*, n°121, 2ème trimestre 2006, p55 -72.

FuturaSciences. (2014, février). *Climat ou météo, quelle différence?* Retrieved octobre 2015, from http://www.futura-sciences.com/magazines/environnement/infos/qr/d/meteorologie-climat-meteo-difference-5922/

Gerrits, M. (2010). *The role of interception in the hydrological cycle.* Université Technique de Delft, Pays-Bas.

GFDRR. (2011). *Climate Risk and Adaptation Country Profile ; Vulnerability, Risk reduction and adaptation to Climate Change.*

GFDRR. (2014). *Sénégal: Inondations urbaines. Le Relèvement et la Reconstruction à partur de 2009.*

GIEC. (2001). *Bilan 2001 des changements climatiques: mesures d'atténuation.* Rapport du Groupe de travail III du GIEC.

GIEC. (2013). *Changements climatiques 2013 - Les éléments scientifiques.* Glossaire.

GIEC. (2013). *Evaluation of Climate Models.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.: Climate Change

2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assess. .

GIEC. (2014). *Climate Change 2014: Impacts, Adaptation and Vulnerability. Part B: Regional Aspects. Contribution of the working group II to the Fifth Assessment Report of IPCC.* Cambridge, United Kingdom and New York, NY USA: Cambridge University Press.

Gilard, O. (2006). Risques d'inondation dans le delta du Fleuve Rouge. De la nécessité d'améliorer leur prise en compte dans le processus d'aménagement du territoire. *Hérodote*, n° 121, 2ème trimestre 2006, p52-54.

Gouvernement du Sénégal. (2010). *Rapport d'évaluation des besoins post-catastrophe - Inondations urbaines à Dakar en 2009.*

Gouvernement Français. (2012). *Portail interministériel de Prévention des Risques Majeurs - Inondation*. Retrieved Février 2016, from http://www.risques.gouv.fr/risques-naturels/inondation

Gouvernement Français. (2012). *Prévention des Risques Majeurs - Lexique*. Retrieved Septembre 2015, from http://www.risques.gouv.fr/lexique

Guinot. (2003). *Les modèes numériques en hydrologie et en hydraulique.* Ecole Doctorale Mathématiques et Informatique Fondamentale de Lyon, 17 juin 2003.

Hallegatte, S., Vogt-Schilb, A., Bangalore, M., & Rozenberg, J. (2017). *Indestructible – Renforcer la résilience des plus pauvres face aux catastrophes naturelles.* Licence : Creative Commons Attribution CC BY 3.0 IGO: Washington, DC : La Banque mondiale. GFDDR.

Hansson, K., & Ekenberg, L. (2002). Flood mitigation strategies for the Red River Delta. *The Commons in Age of Globalization, The Ninth Biennal Conference of the International Association for Study of common property.*

Hunink, J., & Droogers, P. (2013). *Agricultural runoff and urban flooding in Mauritius: evidence, methods and mitigation measures.*

Hunink, J., & Droogers, P. (2013). *Agricultural runoff and urban flooding in Mauritius: evidence, methods and mitigation measures.*

IAGU. (2009). *Préparation à la gestion des périls naturels et des risques liés aux changements climatiques à Dakar, Sénégal.*

ICLEI. (2012). *Climate Change Projections for Port-Louis: adding value through downscaling.*

INMET. (2015). *Gráficos Climatológicos (cartes climatologiques sur la base de données entre 1961 et 1990)*. Retrieved octobre 2015, from http://www.inmet.gov.br/portal/index.php?r=clima/graficosClimaticos

IRMA. (n.d.). *Les arrêtés de catastrophes naturelles en Rhône-Alpes*. Retrieved novembre 2015, from http://www.irma-grenoble.com/05documentation/04dossiers_numero.php?id_DT=2

IRMA. (n.d.). *Retour d'expérience et mémoire*. Retrieved novembre 2015, from http://www.irma-grenoble.com/05documentation/04dossiers_articles.php?id_DTart=93&id_DT=10

Kastrissianakis, K. (2012). Transformations urbaines et affirmation de nouvelles souveraineté: la cas de Beyrouth. *Rives méditerranéennes*, n°42, p 75 - 95.

Ledoux, B. (2006). *La gestion du risque inondation.* Lavoisier, Tec&Doc.

Leone, F., & Vinet, F. (2011). *La vulnérabilité des sociétés et des territoires face aux menaces naturelles: Analyses géographiques.* PULM.

Maddox, Y. (2014, décembre). *Flood Insurance Models around the World*. Retrieved novembre 2015, from http://www.intermap.com/risks-of-hazard-blog/flood-insurance-models-around-the-world

McSweeney, C., New, M., & Lizcano, G. (2012). *UNDP Climate Change Country Profiles : Mauritius.*

MEDDE France. (2004). *Les inondations - Dossier d'information.*

MEDDE France. (2015). *EauFrance - Glossaire (Ministère de l'Ecologie du Développement Durable et de l'Energie)*. Retrieved octobre 2015, from http://www.hydro.eaufrance.fr/glossaire.php#debit

MétéoFrance. (n.d.). *Les incertitudes dans les scénarios de changement climatique*. Retrieved from MétéoFrance: http://www.meteofrance.fr/climat-passe-et-futur/les-incertitudes-dans-les-projections-climatiques

MétéoFrance. (n.d.). *Les incertitudes dans les scénarios de changement climatique*. Retrieved from MétéoFrance: http://www.meteofrance.fr/climat-passe-et-futur/les-incertitudes-dans-les-projections-climatiques

Ministère de l'Environnement de Maurice. (2012). *Technology Needs Assessment for an enhanced climate change adaptation and mitigation.*

Minsitère de l'Environnement du Liban. (n.d.). *Vulnerability and Adaptation*. Retrieved février 2016, from http://www.iisd.org/pdf/2009/rising_temps_middle_east.pdf

Mounirou, L. (2012). *Etude du ruissellement et de l'érosion à différentes échelles spatiales sur le bassin versant de Tougou en zone sahélienne du Burkina Faso: Quantification et transposition des données.* Université Montepellier II et Fondation 2iE.

Musy, A. (1998). *Hydrologie appliquée.* Bucarest: HGA.

Musy, A. (2005). *Cours d'Hydrologie Générale, Section SIE et GC, Ecole Polytechnique Fédérale de Lausanne*. Retrieved Septembre 2015, from http://echo2.epfl.ch/e-drologie/

Musy, A. (2005). *Hydrologie Générale, Section SIE et GC, Ecole Polytechnique Fédérale*. Retrieved Septembre 2015, from http://echo2.epfl.ch/e-drologie/

OCDE. (2009). *Japan: Large scale Floods and earthquakes.* Paris, France: OECD Publications.

OCHA. (2017, 01 13). *What is UNDAC?* Retrieved from OCHA: http://www.unocha.org/what-we-do/coordination-tools/undac/overview

Oliveira, C., Da Silva, C., Sosnoski, A., Bozzini, P., Rossi, D., Uemura, S., et al. (2014). Warning system based on real-time flood forecasts in Sao Paulo, Brazil. *6th International Conference on Flood Management, September 2014.* Sao Paulo, Brazil.

OMM. (2011). *Manuel sur la prévision et l'annonce des crues.* Genève, Suisse.

OMM, & UNESCO. (1992). *Glossaire international d'hydrologie*. Retrieved octobre 2015, from http://webworld.unesco.org/water/ihp/db/glossary/glu/aglu.htm

ONU. (2011). *Assemblée générale : Droit à un logement convenable, 66ème session.*

ONU. (2014). *World Urbanization Prospects : The 2014 Revision.*

ONU. (2015). *World Population Prospects: The 2015 Revision (medium variant).* DVD Edition.

ONU/BCAH, O. &. (2008). *Préparation à une réponse efficace en cas de catastrophe : Ensemble de directives et indicateurs pour la mise en œuvre de la priorité 5 du Cadre d'action de Hyog.* Genève, Suisse.

Osseiran, N. (2015, octobre). *Health crisis rears its head as rains batter Lebanon*. Retrieved février 2016, from http://www.dailystar.com.lb/News/Lebanon-News/2015/Oct-26/320237-health-crisis-rears-its-head-as-rains-batter-lebanon.ashx

Owens, J. (2015). Rainy Season Accentuates Lebanon Trash Crisis. *Voice of America*, http://www.voanews.com/content/rainy-season-accentuates-lebanon-trash-crisis/3042127.html.

PNUD. (2014). *Rapport sur le développement humain 2014 - Pérenniser le progrès humain : réduire les vulnérabilités et renforcer la résilience.* New York City, NY, USA.

PRB. (2015). *2015 World Population Data Sheet.* Retrieved octobre 2015, from Population Reference Bureau, Washington DC: http://www.prb.org/Publications/Datasheets/2015/2015-world-population-data-sheet/world-map.aspx#map/world/population/2015

Quenault, B., Pigeon, P., Bertrand, F., & Blond, N. (2011). *Vulnérabilité et résilience au changement climatique en milieu urbain: vers de nouvelles stratégies de développement urbain durable?* Programme interdisciplinaire de recherche Ville et Environnement - Rapport de recherche.

Redd, B. (2013). Why does Lebanon flood so badly? *Executive Magazine*, http://www.executive-magazine.com/economics-policy/lebanon-floods-policy.

Revista. (2013). *Harvard review of latin america – cambridge (massachussets)*.

Sachs, C. (1981). Croissance urbaine et faélisation des métropoles : Sao Paulo et Rio de Janeiro. *Economie et Humanisme*, n°260 - juillet-août 1981.

Sauvageot, H. (2000). Le radar polarimétrique, une nouvelle approche pour l'observation des chaps de précipitations. *La Météorologie*, 8ème série - n°31 - p 25 à 41.

Simas, I., Rodrigues, C., & Sant'Anna Neto, J. (2015). Inondations dans la métropole de Sao Paulo: analyse détaillée des évènement pluvieux. *XXVIIIe Colloque de l'Association Internationale de Climatologie, Liège 2015*.

Site : Les risques majeurs. (2009). Retrieved from Les repères de crue: http://www.risquesmajeurs.fr/les-rep%C3%A8res-de-crues

Sueur, J.-P. (2011). *Villes du futur, futur des villes : quel avenir pour les villes du monde ? (Analyses).* Rapport d'information n°594 (2010-2011) à destination du Sénat français.

Thanh Pham, X. (2008). *Etude lcimatique de la mousson vietnamienne et applications à la prévision saisonnière.* Thèse de doctorat. Climatologie, Université de Bourgogne.

Townsed, F. F. (2006). *The federal response to hurricane Katrina: lessons learned.*

UNDP. (2015, novembre). *Launching of Flood Risk Assessment and Mapping for Lebanon*. Retrieved février 2016, from http://www.lb.undp.org/content/lebanon/en/home/presscenter/articles/2015/11/26/launching-of-flood-risk-assessment-and-mapping-for-lebanon.html

UN-Habitat. (2011). *Mauritius : Port Louis urban profile.*

UNHCR. (2014, avril). *Syrian refugees in Lebanon surpass one million*. Retrieved février 2016, from http://www.unhcr.org/cgi-bin/texis/vtx/search?page=search&docid=533c15179&query=lebanon%20syrian%20refugees#hit1

UNHCR. (2015). *Registration Trends for Syrians in Lebanon.* Weekly statistics as of: 05/03/2015.

UNISDR. (2006). *La réduction des risques de catastrophes commence à l'école - 2006-2007 Campagne mondiale pour la prévention des catastrophes.*

UNISDR. (2009). *Terminology.* Retrieved Septembre 2015, from UNISDR: http://www.unisdr.org/we/inform/terminology

UNISDR. (2013). *Consultation nationale sur le cadre d'action post-2015 pour la réduction des risques de catastrophes.*

UNISDR. (2013). *Lebanon embarks on regional first with disaster risk plan*. Retrieved février 2016, from https://www.unisdr.org/archive/34432

UNISDR. (2015). *Cadre d'action de Sendai pour la réduction des risques de catastrophes 2015-2030.*

UNISDR. (2015). *GAR - Réduction du risque de catastrophe : Bilan mondial.* Nations Unies.

UNISDR. (2015). *Review of Mauritius: UNISDR working papers on public investment planning and financing strategy for disaster risk reduction.*

Wikipédia. (2016). *Beyrouth*. Retrieved février 2016, from https://fr.wikipedia.org/wiki/Beyrouth#Beyrouth_d.27une_reconstruction_.C3.A0_l.27autre_.28apr.C3.A8s_1990.29

Annex 1 - Glossary of technical terms

Hazard: The notion of hazard is defined in France as a phenomenon of natural or human origin more or less harmful according to its intensity, according to the interdepartmental portal of major risk prevention (2012). Internationally, UNISDR (2009) proposes a similar definition specifying the types of damage in human terms (deaths, injuries or other health effects), material, environmental and/or socio-economic [4].

Catchment area or watershed: hydrological unit draining the surface water and discharging it to the most downstream point of the river system

Infiltration capacity - also called infiltrability or absorptive capacity: the maximum flux that the soil is able to absorb when subjected to heavy rainfall or is covered by a water surface.

Disaster: any significant disruption of the functioning of a community or society involving major human, material, economic and environmental impacts and losses, leading to an overcoming of the capacities of these communities or societies to cope with [....] Disasters are often described as the result of the combination of exposure to a hazard, the conditions of vulnerability in place, and an inability to cope with or reduce potential negative consequences. (UNISDR, Terminology, 2009)

Climate: a statistical description based on averages and variability of relevant quantities over periods ranging from a few months to thousands to even millions of years (the typical period defined by the World Meteorological Organization is 30 years). These quantities are most often surface variables such as temperature, precipitation height and wind (GIEC, 2013)

Intensity-Duration-Frequency Curve - IDF Curves - : a curve which graphically and synthetically illustrates the rainfall knowledge of a given point by establishing the relations between the intensities, the durations and the frequencies of the rains. They are used in particular to estimate flows for a given type of rain, and to size structures.

High flow / flood / rising river : increase of the flow of a river (MEDDE France, 2004). Therefore, a rising river does not systematically cause flooding.

---

[4] UNISDR's website. Definition in English: "A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage".

Logjam: aggregate of debris carried by the water during a high flow until forming an obstacle obstructing the flow of water (MEDDE France, 2004)

Breakup: brutal rupture of natural plugs formed by debris transported by water during a rising river (MEDDE France, 2004)

Issues: people, property and infrastructure located in flood-prone areas and thus subject to potential losses (UNISDR, 2009)

Low flow period: period of low water during which the flow of a watercourse reaches its minimum (MEDDE France, Les inondations - Dossier d'information, 2004).

Evapotranspiration: processes that transfer soil from the ground to the atmosphere of the intercepted water by combining evaporation from bare soil and open water surfaces and transpiration from vegetation. Evapotranspiration is an important part of hydrological cycle transfers: this process accounts for 62% of incident precipitation globally, and 55% for a temperate climate catchment area (as in France for example) (Musy, 2005).

Outlet: catchment area point furthest down the river system

Flood flow for a given year: One of the ways to characterize a year's flood is to use either the highest instantaneous flow or the highest daily flow. Over several years, the value of the flow rate associated with different theoretical return periods (2, 5, 10, etc.) is determined statistically from a sample providing as much as possible of annual flood flows. (MEDDE France, 2015)

Low water flow: minimum flow rate of a watercourse calculated over a given time during periods of low water. So for a given year we will talk about: daily low water flow (MEDDE France, 2015)

Production function: procedure to convert the gross rain into clean rain. It is specific to a given catchment area and includes, in particular, the characteristics of soil and vegetation occupation and weather conditions (Musy, 2005).

Transfer function: procedure for converting net rain into flow at the outlet. It integrates the physical, topological, geological and meteorological characteristics (Musy, 2005).

Hyetograph: curve representing the evolution of the intensity of a precipitation at a given point over time

Hydraulics: a branch of fluid mechanics dealing with so-called free-surface flows, gradually varying, occurring in natural or artificial streams.

Hydrology: science studying the processes that govern the fluctuations of the water resources of the emerged lands and deals with the different phases of the hydrological cycle (OMM & UNESCO, Glossaire international d'hydrologie, 1992). It should be noted that the methods used in prevention (statistics) have nothing to do with those used in the forecast (rain-flow model). We can therefore distinguish at least two hydrological "schools"

Flood hydrograph: curve representing the evolution of flow at the catchment outlet based on the time (Musy, 2005)

Infiltration: vertical transfer of water from the soil surface to the upper layers of the soil, under the effect of gravity and pressure, provided that the latter is not saturated.

Flood: **temporary submersion, by water, of lands that normally are not submerged.** This concept covers floods caused by river floods, mountain streams and intermittent Mediterranean watercourses as well as floods due to the sea in coastal areas. (Gouvernement Français, 2012)

Interception losses: share of precipitation halted by vegetation or urban infrastructure (roofs, low permeability soils, roads, etc.) and restored to the atmosphere by evaporation (Gerrits, 2010) (Musy, 2005). The waters thus intercepted do not therefore participate in the flows.

Isochrone: curve corresponding to zones with equal water concentration times. The determination of isochrones makes it possible to better understand the hydrological behaviour of a catchment area and to characterize the relative contributions of the subcatchment areas. (Musy, 2005)

Major bed (or flood plain): zone comprising the low areas on both sides of the minor bed, ranging from a few meters to several kilometres depending on the rising river magnitude. The major bed corresponds to the limit of exceptional high flow. (MEDDE France, 2004)

Minor bed: ordinary bed of the watercourse. (MEDDE France, 2004)

Reduction measures: all measures resulting from a human intervention to reduce the sources of greenhouse gases or to enhance their removals by sinks (GIEC, 2001). This type of measure is not directly related to the risk of flooding

Adaptation measures: set of measures of appropriation of natural or human systems to the conditions of a new or changing environment.

Meteorology : science of meteorological event , in particular, rainfall regime.

Climate model: numerical representation of the climate system based on the physical, chemical and biological properties of its components and their processes of interaction and feedback, taking into account some of its known properties (GIEC, 2013).

Module, also called interannual module: interannual flow defined as the average of the annual flows over a period of observation long enough to be representative of measured or reconstructed flows. It characterizes the "average" flow of a year; (MEDDE France, 2015)

Return period *of a high flow :* inverse of the annual exceedance probability of the flow (Ledoux, 2006)

Precipitation: all waters (in liquid or solid form such as snow or hail) falling on the surface of the ground, under the effect of change of temperature or pressure.

QMNA: minimum monthly flow of a hydrological year. It is calculated statistically, for some return periods (for example 5 years, which will be written QMNA5), from the average monthly flows (per calendar month); (MEDDE France, 2015)

Steady regime: flow regime of water for which the flow rate is constant over time (adapted for example for river flows at low water or average flow). The steady state can be uniform (the geometrical characteristics of the channel and the roughness are constant on the section considered) or varied (the geometry and the roughness varies along the section). (Degoutte, 2012)

Transitional regime: flow regime of water for which flow varies with time: the flow of a flooded river typically focuses on a transient regime. (Degoutte, 2012)

Hydrological response: how a territory reacts when it is subject to precipitation.

Waterway/water system: all channels, streams and rivers, natural or artificial, permanent or temporary, involved in the flow of water on a given catchment area. (Musy, 2005)

Resilience: the ability of a system exposed to a hazard to resist, cope, or recover in a timely and effective manner (UNISDR, 2009)

Disaster risk: the potential for catastrophic loss of life, health status, livelihoods, assets and services, which may affect a community or society, specified over a future period (UNISDR, Terminology, 2009)

Basin lag or lag time: time interval between the centre of gravity of the net rain and the flood peak;

Rise time: time interval between onset of runoff and peak flow;

Basic time: total runoff time interval due to precipitation;

Time of concentration: the time interval required for a water particle to fall on the part of the catchment area that is furthest away from the water to reach the outlet.

Vulnerability: propensity to damage or dysfunction of various exposed elements (property, persons, activities, functions, systems) constituting a given territory and society (Leone & Vinet, 2011)

Annex 2 - The impact of floods in AFD's intervention countries since 1990

According to the EMDAT international database (D. Guha -Sapir, R. Below, Ph. Hoyois - EM-DAT: The CRED/OFDA International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.)

Name	Number of floods	Number of deaths	Number of people affected	Estimated amount of damages ('000 $)
Afghanistan	69	4,136	617,539	87,000
South Africa	25	517	506,471	909,724
Algeria	35	1,494	238,442	1,480,917
Angola	29	561	1,098,219	10,000
Bangladesh	58	5,605	127,170,897	8,044,300
Benin	15	122	2,047,547	3,315
Burma	19	462	1,118,412	136,655
Bolivia	24	674	2,820,455	1,139,500
Botswana	7	35	158,102	5,000
Brazil	76	2,756	7,234,065	4,832,670
Burkina Faso	13	131	548,961	150,176
Burundi	20	132	90,638	-
Cambodia	18	1,641	13,275,587	1,419,100
Cameroon	14	126	374376	-
Cape Verde	1	3	150	-
China	201	28,196	1,830,502,400	203,998,228
Colombia	53	2,091	10582299	3,443,003
Comoros	2	6	67,637	5,000
Congo	9	28	173,114	59
Ivory Coast	8	114	8,875	-
Djibouti	3	196	240,000	2,119
Egypt	9	669	168,498	141,000
Ecuador	18	505	793,858	1,309,800
Ethiopia	42	1,905	2,243,256	18,300
Gabon	1	1	77,845	-
Ghana	16	427	3,857,190	33,500
Guinea	10	19	371,426	-
Guinea Bissau	4	5	58,542	-
Haiti	35	3,100	561,088	1,000
India	178	35,775	555,474,809	48,025,329
Indonesia	121	4,269	6,844,634	6,528,609
Jordan	2	10	18,000	1,000
Kenya	43	1,175	2,922,123	148,338

Name	Number of floods	Number of deaths	Number of people affected	Estimated amount of damages ('000 $)
Laos	16	144	3,832,743	143,828
Lebanon	1	-	17,000	-
Madagascar	6	66	159,987	150,000
Mali	19	106	252,692	-
Morocco	20	1,150	232,896	295,200
Mauritius	1	11	82	-
Mauritania	14	53	173,419	-
Mexico	41	1,719	4,376,674	4,215,000
Mozambique	26	1,291	7,274,644	668,600
Namibia	13	264	1,099,450	20,490
Niger	19	288	1,527,381	67,474
Nigeria	40	1,281	9,985,009	613,422
Uganda	18	268	1,062,845	4,171
Pakistan	64	10,302	62,862,129	19,798,378
Peru	33	798	3,026,364	50,000
Philippines	113	2,169	23,988,789	3,511,882
Central African Republic	14	16	170,396	-
Democratic Republic of Congo	21	358	265,960	15,000
Dominican Republic	21	780	216,280	97,725
Rwanda	10	132	64,061	9
Senegal	15	80	1,180,211	50,979
Seychelles	2	5	5,672	1,700
Sudan	30	758	4,346,457	533,200
South Sudan	4	146	738,000	-
Sri Lanka	44	826	10,951,003	925,130
St Lucia	2	6	21,984	-
St Vincent and Grenadines	3	15	17,897	108,000
Suriname	2	5	31,548	-
Syria	1	6	-	-
Tanzania	29	673	615,999	3,790
Chad	15	258	1,389,544	11,000
Palestinian Territories	4	5	14,500	-
Thailand	60	2,734	46,742,347	442,99,762
Togo	11	72	591,600	-
Tunisia	6	82	185,508	242,800
Turkey	29	503	1,713,820	2,180,500
Vietnam	67	4,513	23,429,563	3,746,227
Zambia	16	60	4,349,008	20,700
Zimbabwe	12	298	345,522	296,500

Annex 3 - Key concepts of genesis of the flood hazard

Hydrology is one of the key factors influencing the flood hazard. There are different types of approach to hydrology. A first approach is **deterministic hydrology**: The aim is to analyse hydrological processes using a deterministic approach, to study the responses of hydrological systems by acting on various parameters (such as land use and topography, for example). A second approach is **statistical hydrology**, which relies on the statistical analysis of the data acquired from the measurement stations of heights converted into flows, by different methods. The accuracy of the results of this statistical approach depends on several factors, mainly:

- The quality of the method of converting heights into flow rates (we often use rating curves, which give the law of flow height conversion, but which are more or less well calibrated);
- The size of the measured data history. The more old data available, the more reliable the statistical extrapolations can be considered.

In deterministic hydrology used primarily for small catchment areas smaller than 200 km^2, the hydrologic response of a given catchment area can be studied from the **rainfall-runoff transformation** analysis to determine the **rising river hydrograph**, that is, the changes in the flow at the outlet of the catchment area based on the time. One of the complexities comes from the spatial distribution of rainfall, often unknown, but whose knowledge is essential to evaluate the good volumes that have been precipitated. This transformation is performed by successively applying two functions (Figure 14):

- The production function: it allows to convert the gross rain into clear rain. It is specific to a given catchment area and incorporates in particular the characteristics of soil and vegetation occupation and the meteorological conditions (see chapter 0);
- Transfer function: it converts net rain into flow at the outlet and incorporates physical, topological, geological and meteorological characteristics (see chapter 0).

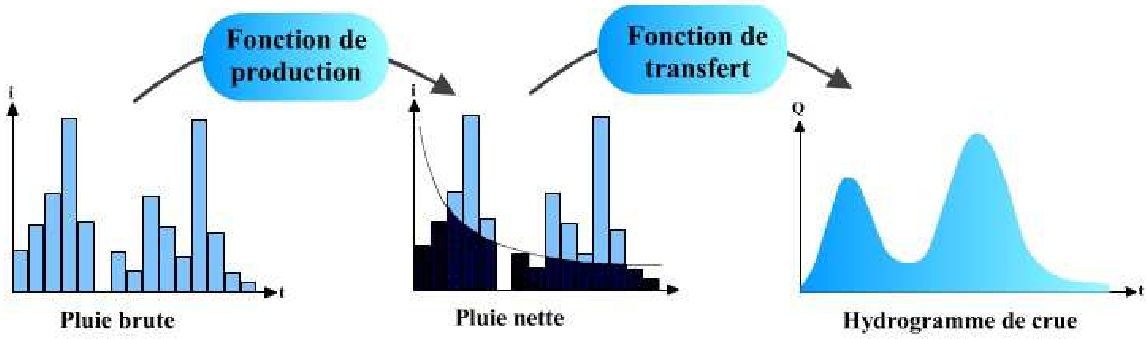

Figure 15: Rainfall-Flow Transformation: production function and transfer function (adapted from Musy 2005)

Once the water has reached a watercourse, the flows are governed mainly by the morphology of the watercourse and by hydraulic mechanisms (see chapter 0).

From rainfall to runoff (production function)

The analysis of precipitation is complex because of their spatio-temporal variations (due for example to the displacement of the disturbance or to the modifications of the conditions of temperature or pressure). The main parameters studied are the **depth of water** or **depth of runoff** on a unit of surface, and the **intensity**, meaning the rainfall per unit of time. The variation of the intensity at a given point over time can be represented graphically in the form of a **hyetograph**.

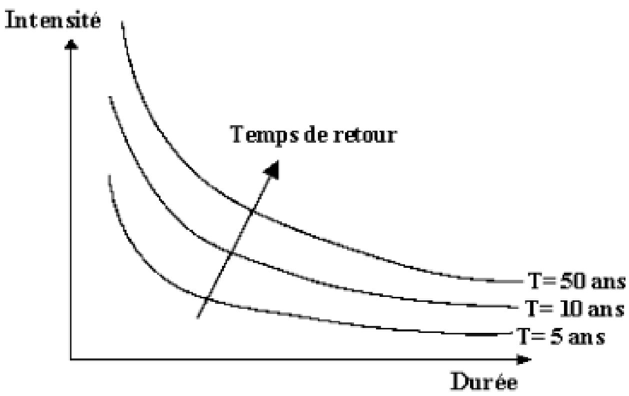

Figure 16: Representation of IDF curves (Musy, 2005)

The statistical analysis of the precipitation data makes it possible to establish **Intensity-Duration-Frequency curves**, more often called **IDF curves (**Figure 15**).** They graphically and synthetically illustrate the rainfall knowledge of a given point by establishing the relations between the intensities, the durations and the frequencies of the rains. They are used in particular to estimate flows for a given type of rain, and to size structures.

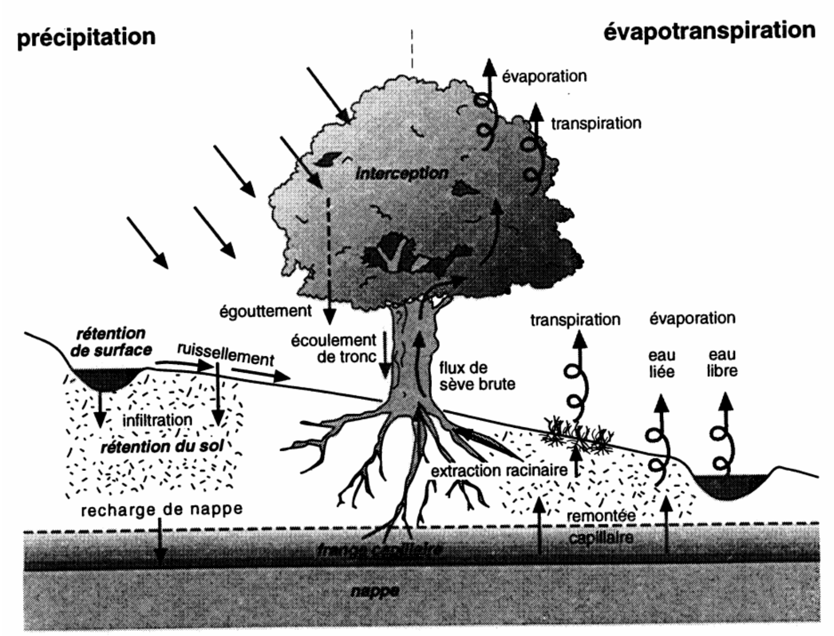

Figure 17: Hydrological processes (Ambroise, 1998, p. p 26)

Several hydrological processes are involved in the **hydrological response** of a territory, i.e., the way it reacts when it is subject to precipitation (Figure 16):

- Interception and evapotranspiration: these two processes are closely related ***(Musy, 1998)***, and are influenced by similar factors (temperature, pressure, air humidity, solar radiation, plant type, density, vegetation cover, duration, intensity and rainfall). Intercepted or evaporated waters do not participate in flows;
- Infiltration and percolation: the infiltration process varies during a rain event depending on the intensity of the rain and the infiltration capacity of the soil (these two factors being variable over time): when the intensity is greater than the infiltration capacity, part of the water does not infiltrate and accumulates on the surface. It can then escape by gravity to the soil surface: this is runoff. It is therefore directly opposed to the process of infiltration.
- Outflows, including runoff: among the different types of outflows, runoff is the one that contributes the most to the flood hazard. In the literature, there are three types of runoff, presented in Figure 17***: (Musy, 2005) (Armand, 2009) (Mounirou, 2012)***
    - o Runoff by exceeding the infiltration capacity. This type of runoff occurs particularly in poorly vegetated catchment areas, subject to semi-arid or arid climates with high rainfall intensities ***(Armand, 2009)***;

- o Runoff by saturation of the soil. This type of runoff occurs especially for low intensity rainfall falling on soaked soil, particularly because of the presence of a water table near the surface or after long-term rain. ***(Mounirou, 2012)***
- o Runoff by exfiltration.

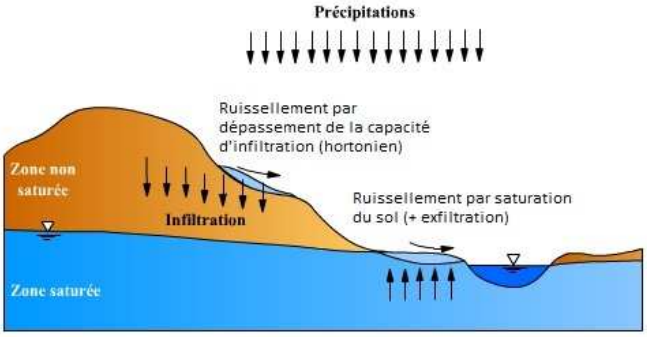

Figure 18: Types of runoff (adapted from Musy 2005)

The concentration of flows within a catchment area (transfer function)

In a given **catchment area**, flows occur along the catchment area's own drainage system and move towards the concentration of water at the outlet, which is the lowest point in the downstream catchment area (Figure 18). (Musy, 2005)

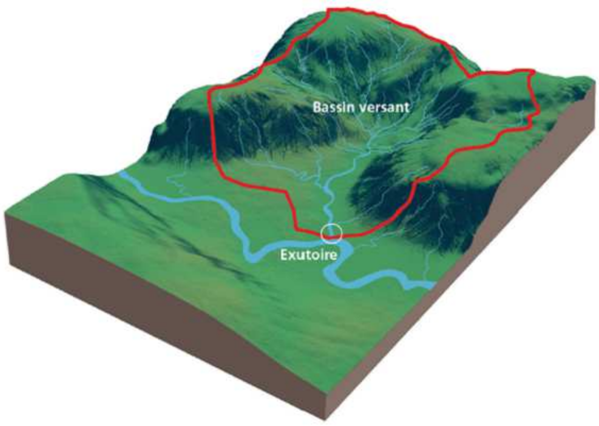

Figure 19: Illustration of a catchment area and its outlet (MEDDE France, Les inondations - Dossier d'information, 2004)

The flood hydrograph summarizes the hydrologic response of a given catchment area for a given rainfall event. This response depends in particular on the topography of the **catchment area** (the more significant the slopes are, the faster the hydrological response will be - bell-shaped hydrograph) and the land use (the more urbanized the basin is and the faster the flows will be, conversely, vegetation tends to slow down the flow and favour the infiltration process).

Figure 19 presents an example of a flood hydrograph of a catchment area in response to precipitation. The flood hydrograph is broken down into two main parts: **the rising river** (corresponding to the time when the flow increases until it reaches the maximum flow: the peak flow) and the recession (where the flow at the outlet begins to decrease until the initial flow). The rising river spreads from upstream to downstream of the watercourse, creating a **rising river wave**. The different times identified in the Figure are defined in the lexicon of the report. Note in particular the **concentration time**, which corresponds to the time required for a water particle to fall on the part of the catchment area that is furthest away hydrologically to reach the outlet.

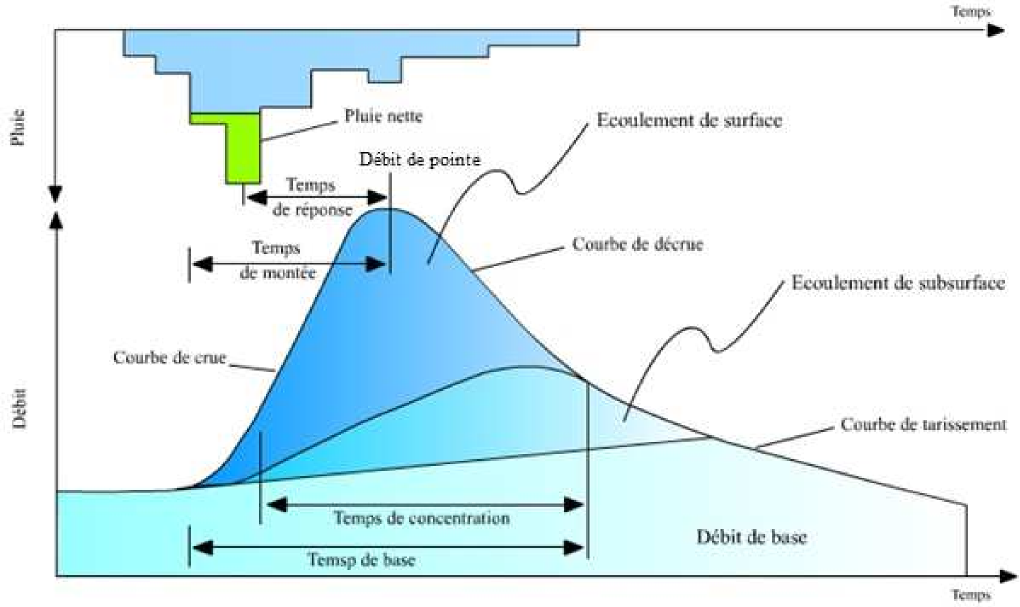

Figure 20: Example of a hyetogram and a hydrograph in response to a rain event (Musy, 2005)

Large catchment areas (large rivers) are associated with long concentration times (weeks), while small mountain catchment areas respond to rainfall in a few hours. Urban catchment areas, with generally highly water-proofed surfaces (little delaying effect of infiltration), respond within a few tens of minutes.

Flows within a watercourse - notion of hydraulics and fluvial morphology

Fluvial hydraulics

Once the water has reached the river, the mechanisms involved are drawn from fluvial hydraulics. It is important to distinguish the difference between the notion of flood and that of rising river. As mentioned earlier, flooding refers to a temporary submersion of land which normally is out of water. rising river corresponds to the increase of the flow of a river (MEDDE France, 2004). Therefore, a rising river does not systematically cause flooding. Conversely, **low flow period** is defined as the period of low water during which the flow of a watercourse reaches its minimum (MEDDE France, 2004).

Water can flow in different flow regimes: (Degoutte, 2012)

- Steady regime for which the flow rate is constant over time (adapted for example for river flows at low water or average flow).
- Transitional regime for which flow varies with time: the flow of a flooded river typically focuses on a transitional regime.

Fluvial hydraulics play a role all the more important with respect to the flood hazard when the catchment area is large. When the slope is strong, and when the flood field is reduced, the rising river propagates without amortizing, and the relation (Qy) remains univocal (kinematic wave). When the slope is slight, the flood is absorbed and the relation (Qy) is not univocal (diffusive wave). The damping of a flood highlights the beneficial role of flood fields. Dikes or embankments in a major bed have the effect of eliminating these absorptions. By ignoring it, a diffusive wave is transformed into a kinematic wave. The consequences can be very serious for residents downstream.

<u>Hydraulic modelling</u>

Hydraulic models (such as Infoworks, Mike Urban, Mike Flood, HydraRiv, HydraNet, Canoe) are used primarily to **simulate a fictional reality** (which has not yet arrived, including **testing the effects of a new development**) or to **understand the hydraulic functioning of a past reality such as a flood**. They make it possible to calculate values of flow rates, velocities and water heights, and overflowed volumes (coming out of a closed drain system, or flowing in the major bed of a watercourse) at each time step, and to the different nodes of the modelled waterway, for a particular hydrological event.

There are also the so called "1D" models (1-dimensional modelling) that are most commonly used because they are simpler to implement (and require less geometric and topographical data) than "2D" models (2-dimensional modelling) (Figure 20). The specificities of each type of model are detailed in Annex 2 of this report.

To be reliable, the models need to be calibrated for example from the history of measurements of flows or water levels, and rising river levels.

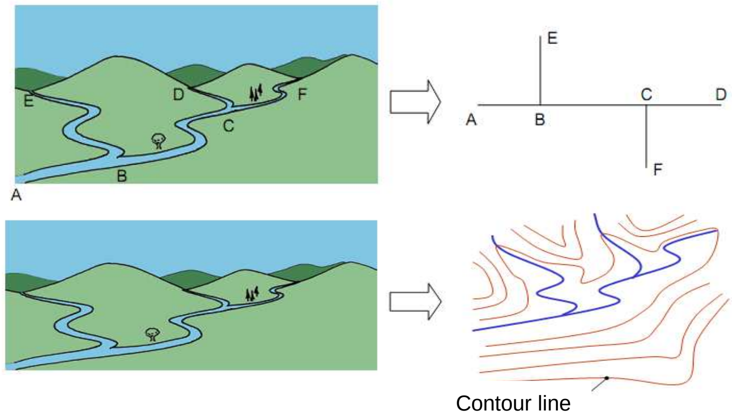

Figure 21: Illustration of a 1D model (top) and a 2D model (bottom) (Guinot, 2003)

River morphology

A rising river can reach different levels of importance depending on the water level reached. A river consists of several types of beds (Figure 21): the **minor bed** and the **major bed**. In the major bed, there are two types of zones: (MEDDE France, 2004)

- Flow areas located in the vicinity of the minor bed, presenting a significant risk due to the strength of the current;
- Rising river expansion areas where speeds are low and which can reduce downstream flows and extend the duration of flows ***(Bassin de la Sarthe Amont, 2007)***.

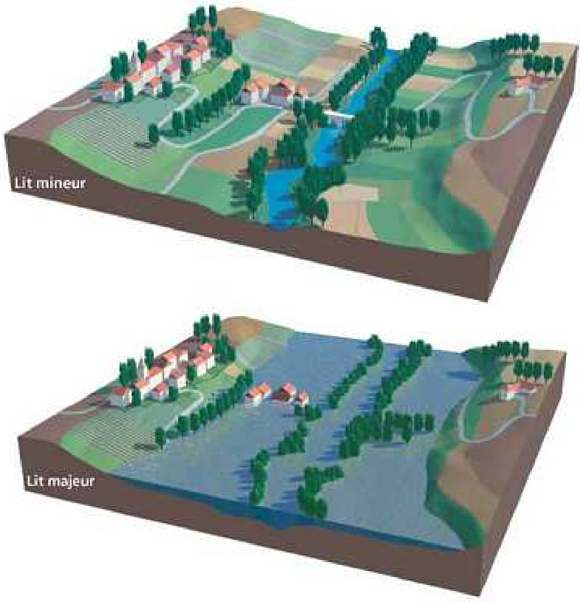

Figure 22: The different beds of a river (MEDDE France, Les inondations - Dossier d'information, 2004)

During a rising river, debris transported by water may aggregate to form an obstacle obstructing the flow of water: this is the **ice jam** phenomenon (MEDDE France, 2004). **Breakup** denotes the sudden breakage of these natural plugs.

Annex 4 - Different Operational Approaches to Integrated Flood Risk Management

Several operational approaches towards integrated flood risk management have been put in place, mainly in developed countries. The next paragraphs present the main approaches put in place, each of which has its own relevance to the risk of flooding.

Experience has shown the difficulty of finding operational models that can work on the population and the institutions involved. Indeed, the application in the field of integrated flood management is not always in line with the strategy set "on paper". To achieve this, there is a need to reinforce the risk culture until stakeholders become aware of the importance of addressing these issues, especially in developing countries. Thus, **the motivation of stakeholders is, in fact, more important than the way that integrated flood risk management is defined.**

The international approach of the Sendai Framework

At the international level, the **Sendai Framework for Disaster Risk Reduction** (3rd World Conference on Disaster Risk Reduction held in Sendai in Japan in March 2015) is the **reference in terms of disaster risk reduction strategy** in the broad sense, which includes in the first place the risk of flooding. (UNISDR, Cadre d'action de Sendai pour la réduction des risques de catastrophes 2015-2030, 2015)

Its objective is **to prevent new factors** that pose a risk of disaster and **reduce existing risks** through integrated and comprehensive measures in the economic, structural, legal, social, cultural, environmental, technological, political, institutional, health and education sectors that prevent and reduce hazard exposure and vulnerability to disaster, improve preparedness for disaster response and recovery activities, and strengthen resilience.

The Sendai Framework sets out four priorities for action, which are needed to target actions within or across different sectors by contributing States at the local, national, regional and global levels. These priorities of actions are:

- **Priority 1 - Understanding Disaster Risk:** Disaster risk management policies should be based on an understanding of disaster risks in all their dimensions: vulnerability, capabilities and exposure of people and property, characteristics of the hazard and the environment.

- **Priority 2 - Strengthen disaster risk governance to better manage it**: Such strengthening promotes collaboration and partnerships between mechanisms and institutions for the implementation of relevant instruments for disaster risk reduction and sustainable development.

- **Priority 3 - Investing in Risk Reduction for Resilience**: Public and private investment through structural and non-structural measures is essential to enhance the economic, social, health and cultural resilience of individuals, communities, countries and their property, and preserve the environment.

- **Priority 4 - Strengthen Disaster Preparedness** for effective response and rebuilding during recovery, rehabilitation and reconstruction phase

The "3P" approach: Prediction, Prevention, Protection

The global approach "Prediction, Prevention, Protection", also called "3P", has the advantage of being easy to apply, from the starting point of taking into account the risk of flooding. This triptych refers to: (Doussin, 2009)

- "***Prediction***: *to better forecast the occurrence of floods, their consequences, their management. This component includes tools for weather forecasting and hydrology measurements, as well as means of warning and disseminating pre-crisis information to exposed individuals and organizations. This component should facilitate the response to a flood.*

- ***Prevention****: organize the life of risk-prone areas in order to reduce the vulnerability of territories and exposed issues. Prevention includes actions to better understand the flood risk areas, disseminate information and promote awareness among residents, to limit urbanization in flood risk areas, reduce the vulnerability of exposed issues, maintain the bed and existing structures, preserve rising river expansion areas and manage land use to avoid increased flows, etc. Prevention is also the preparation for the event and crisis management to return to a normal operation of networks and structures. This component must prevent a strong flood from becoming a disaster.*

- ***Protection****: to protect the issues and people at risk by providing local structures (dikes containing rising rivers) or distant structures (works intended to slow down and to retain the flows upstream of the exposed zones, etc.)".* This approach therefore also integrates infrastructure as such, in addition to non-structural measures.

The cyclical approach to disaster management

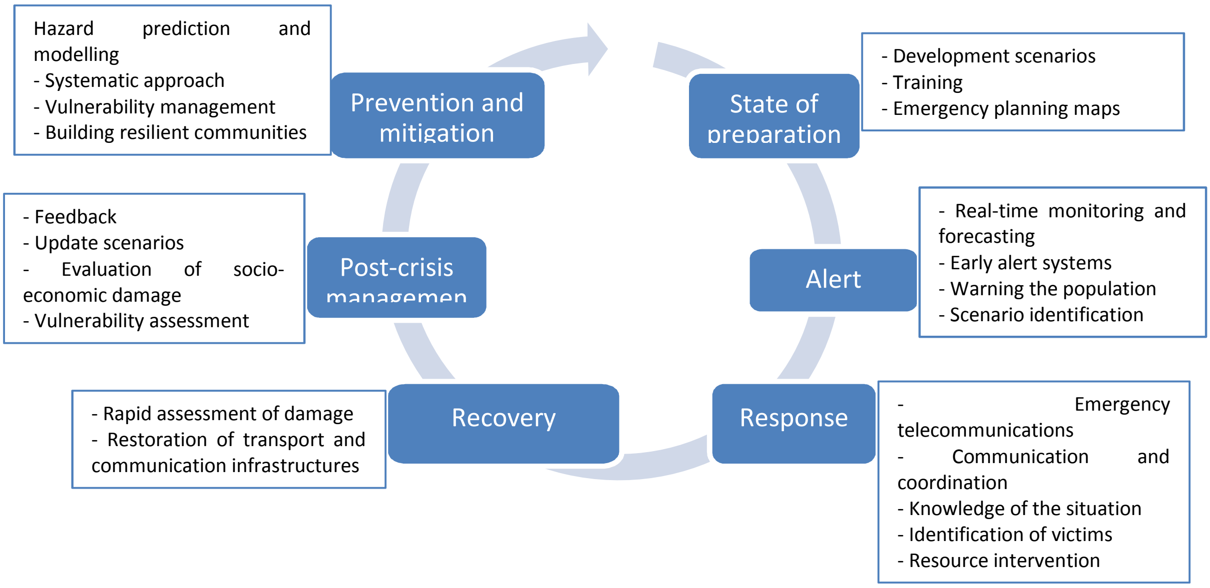

Figure 23: The disaster management cycle, adapted from the OECD, 2009

A classic way of understanding flood risk management in Europe is to take into account, in a cyclical approach, all the activities, programs or measures that can be put in place before (prevention, mitigation, preparation state), during (warning, response) or after a disaster (recovery, post-crisis management, and again prevention and mitigation): this is **the disaster management cycle** (Figure 22) (OCDE, 2009).

This approach has the advantage of integrating the temporality of disaster risk and the repetition of events. However, it is the subject of some disputes, some considering it too simple or believing that the cyclical vision is not totally complete or adapted to disaster risk management. Nevertheless, it provides an interesting and initiating framework for an integrated approach to flood risk management, insofar as it involves all of its major components.

A coupled approach between Integrated Water Resources Management (IWRM) and the consideration of flood risk

Integrated Water Resource Management (IWRM) is based on a global vision that takes into account the dynamics of water resources in natural areas such as catchment areas or aquifers. It is based on the involvement of all stakeholders in the field of water in a new management framework, allowing the best possible reconciliation of the different uses for the continuous development of a region or a country, while preserving the resource for the needs of future generations. It thus integrates the concerns of the sustainable management of the resource, the balance between the demand for water and the available resource, the definition of priorities and accepted rules because they are co-constructed to manage the different uses of water and their potential conflicts.

It is particularly interesting to **link IWRM to an integrated flood risk management approach in countries with water stress.** IWRM considers flood risk management a component of water management since water management arrangements or patterns affect vulnerability to flood risk. IWRM implies a transverse approach to water management in its reference hydrological territory, the catchment area, and in its interactions with sectoral policies (water, energy, agriculture and fisheries, industry, tourism, etc.). Water management is based on a participatory approach involving users, planners and policy makers at all levels, from local management to global management: thus it implies upstream-downstream solidarity at the catchment area level. It takes into account the fact that the water resource is unequally distributed over the territory and over time, and that "equitable" access to water according to uses implies a concerted and collective mode of management.

Depending on the nature of water resources, surface water or groundwater, integrated management can take into account all aspects related to flood risk:

- the reduction of flood risks by structures for retention, storage, slowing or protection upstream, or the development of flood expansion zones in rural areas upstream of urban areas;
- rainwater management in urban areas: structures for the rainwater network, development of outlets, rainwater storage structures that can then be reused for human activities outside drinking water consumption (washing, cooking, watering livestock, etc.);
- the protection of drinking water supply networks and reservoirs, to prevent contamination in the event of flooding;
- wastewater collection (sanitation) and works (uses, gutters under bridges): taking into account the flood risk for the sizing of structures;
- and river management methods: alternative management of flows, pluvial management at the plot, rising river expansion zone, transit strategy.
- Groundwater management helps prevent soil subsidence, which mitigates the risk of flooding in the lowlands and protects buildings and infrastructure from the risk of collapse due to soil subsidence.

Annex 5 - Sizing Methods for Flood Protection Works

Regardless of the proposed protection structure, the sizing methods go through several stages presented in this annex. The first step is to choose the return period of the event against which we want to ensure protection, or choose the event against which we want protection. In the latter case, we generally try to evaluate the return period of this event. Then, according to the knowledge of the hazard where we want to build the structure, the sizing methods use the following tools:

- ***For catchment areas or subcatchment areas smaller than 200 ha:*** we use an estimated rain, built most often with the knowledge of the coefficients of Montana, or, if they exist, by using the IDF curves.*.* Then, using a simple rain-flow transformation model, we calculate the peak flows at the outlets, and the overflowed volumes. This makes it possible to size the drainage or storage structures required to drain the peak flows, or store the volumes to limit the peak flow to the outlet. If a rainfall event and its consequences are known, we can check the waterproofing coefficient of the model and better calibrate the model if necessary. It is indeed the coefficient of waterproofing which conditions the most strongly the results of the model. Mapping of the catchment area is therefore very important, but in the absence of mapping, it is a field work and knowledge in soil that will evaluate a good coefficient of waterproofing. Even when there are no rainfall data, there are Montana coefficients in almost every country that can be used to calculate estimated rainfall. These Montana coefficients can sometimes date back to the 1960s, since they were largely calculated in the countries where ORSTOM was established. At worst, there is information on the country's general rainfall, and a seasoned expert will be able to extrapolate representative Montana coefficients, and will have a margin of safety to at least evaluate a 10-year event;
- ***For catchment areas of between 200 ha and tens of thousands of hectares:*** everything that has been said above applies, but it is also necessary to build a model of hydraulic propagation to simulate flow in free surface and in pipeline. These models simulate flow variations, volumes overflowed or stored at the various "nodes" of the natural or artificial network, such as canal and drainage networks. The construction of a hydraulic model, if it is performed to simulate the flows in an existing network, requires knowledge of the geometry and the slope of the structures. Here again, a field visit will make it possible to check the existence and the condition of the structures to evaluate their roughness, to verify if necessary their slope and their real section (meaning for example their level of siltation, or the existence of linear infrastructures

crossing them and thus reducing their hydraulic section). The calibration of the hydrological model is done on the same basis as for the case of small catchment areas, and the calibration of the hydraulic propagation model is done a priori from observations of flooded areas and knowledge of the rains that caused these floods. The results of the hydraulic model are conditioned by the accuracy of the geometries and slopes of the structures, as well as by the estimation of a coefficient of roughness of the walls of the hydraulic network, also called the Strickler coefficient. Since the model is likely to simulate events that lead to overloads and overflows, model calibration requires evaluating overflowed volumes. So sound knowledge of the topography of the flooded areas is a plus, because it allows to better evaluate the flooded volumes (meaning the volumes that leave the hydrographic system). One of the difficulties is knowing where and how to re-inject the overflowed volumes into the system. The assumption most often retained is to reinject into the network the volumes overflowed to the point where these volumes overflowed.

- ***For catchment areas of more than 300 km2 which are drained by a natural waterway, and generally by a perennial river flow rate*** : (or flow rate) data measured at existing hydrological stations are used. Most stations are in fact just a simple ladder taken every day or sometimes less often by an officer who records the height he reads on this scale. We put the model on the flow recorded at these stations. Nevertheless, to estimate extreme events, for which the hydrological series are too short to be accurate, a statistical hydrological approach can be coupled with a rainfall-runoff approach to determine an event that will be used to test flood zones and test the effects of works to reduce these flood zones.

Once the simulation tools are built, it is good to look for several solutions and to evaluate, with the tools built, the most efficient of them. With equal effectiveness, the solution to be implemented will be chosen on the basis of the following factors: its cost, its risks of failure, its cost of maintenance, the land space possibly used, and/or the impact that it has on the urbanization and the landscape.

Annex 6 - The different types of radar used for weather forecasting

There are several types of radar, depending on the chosen electromagnetic frequency. We will look at three types of radars mainly used in the meteorological field: (MétéoFrance s.d.)

- ***X-band radar (high frequency):*** they are new generation radars. Their cost is lower than other types of radars. The main drawback is the strong attenuation experienced by the signal, which can cause for example an absence of detection of a storm band, located behind another stormy band;

- ***the S-band radar (low frequency):*** it can detect intense rainfall (showers), but it has a weak echo, meaning that it is more difficult to detect the signal backscattered by raindrops;

- ***the C-band radar (average frequency).*** According to MétéoFrance, it can offer a good compromise between the other two types of frequencies.

Annex 7 - The different models of insurance systems

The concentration of human lives, wealth and economic activity in areas exposed to natural hazards has led to the establishment of mechanisms to reduce the harmful consequences of their occurrence. Of these, insurance plays a central role. To agree to continue settling in the most conducive to economic development areas, it appears essential that the population enjoys adequate protection for a sustainable and accessible cost.

For countries with an insurance system, there are four main types of system (Maddox, 2014):

- ***inclusive private and public systems***
- ***optional private and public systems***

Setting up one system or another is often based on the history of the country.

The private inclusive system is the system in place in England, Hungary, China. It is an effective system where the risk of flooding is systematically included in all insurance policies to maintain a relatively low cost taking into account the overall tax base.

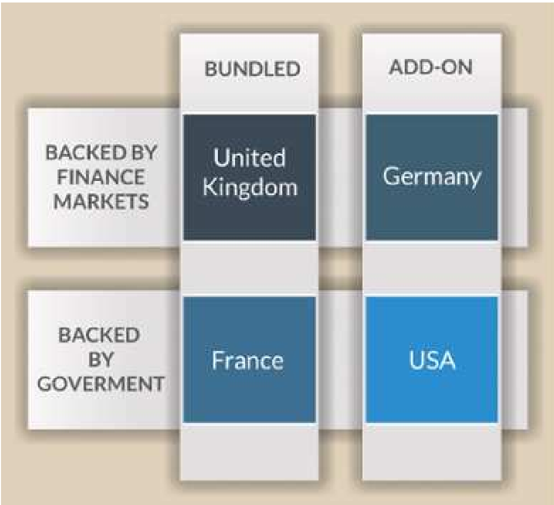

Figure 24: the different types of flood insurance (Maddox, 2014)

The inclusive public system is quite similar except that the state manages the mandatory cover and the mutual fund. This system is very secure for insurers. This system is an incentive for public authorities to work on land use management so that compensation does not fly away. On the other hand, it would disempower the citizens and to a certain extent the insurers.

The optional private system is present in many countries: Germany, Austria, South Africa, etc. The problem with this system lies in the weakness of its base, the number of subscribers being low, the insurance premiums are high not allowing to encourage the insurance against this risk.

The public option is the system of the United States where a fund is managed by the authorities: National Flood Insurance Program. The difficulty is found in political pressure to maintain lower premiums than actuarial premiums resulting in a capital deficit. Moreover, this system does not encourage public authorities to update the maps describing the risk.

Description of insurance systems in Europe

The description of the insurance system that follows is based in particular on the special report produced by the Institute of Critical Risks (IRMa) in Grenoble which compared the French system with the systems in other European countries in 2007 (IRMA, Les arrêtés de catastrophes naturelles en Rhône-Alpes).

- ***France***

The compensation of victims of natural disasters system came into force in France with law 82-600 of 13 July 1982, now codified in the insurance code (Articles L125-1 to L125-6). It is based on the principle of national solidarity by establishing a mandatory additional contribution of any person who subscribes a **comprehensive residential property and casualty insurance policy**. This additional contribution of all insureds allows the extension of the guarantee against the effects of natural disasters in the case where a state of disaster has been found by a ministerial decree. This recognition of the state of natural disaster is based on the "abnormal" intensity of natural phenomenon causing damage.

Nat Cat orders represent one of the important criteria for judging the vulnerability of territories facing the natural hazard. They also raise the question of what is a natural disaster for a company from the moment a municipality can be recognized NAT CAT for a 10-year flood (10 year return frequency) several times and closely.

- ***Great Britain***

The British system is based on four major characteristics:

- claims are paid by private insurers, as part of a free and competitive market.
- the insurance sector covers just about all the risks of natural disasters, including drought, but this at price of easily voidable contracts, highly volatile customers, highly modulated premiums and certain exclusions due to excessive risk.
- British authorities do not intervene either in insurance or in the reinsurance of natural disasters. They hardly give financial support from public funds for victims when disaster occurs
- However, they lead, in several forms, a fairly active prevention policy.

This system explains that identifying risks rests with each of the owners who must appoint a company in order to appraise the risk to which it is subject

- ***Spain***

The Spanish system is characterized by strong state intervention in natural disasters, through the "Consorcio de compensaciôn de seguros" public insurance agency (but not of reinsurance). This one has a monopoly on insurance of major natural hazards. It enjoys an unlimited State guarantee (which, however, has never had to be implemented). As in France, the plan is based on the principle of widespread pooling, which involves compulsory insurance and the non-modulation of premiums according to the risk level. Unlike France, the Spanish regime has even had since 2004, a lack of openness in the comprehensive home and car compensations. Also Spain has a policy of prevention of natural disasters, component of its planning policy and environmental protection.

- ***Germany***

The German regime is characterized by:

- a free insurance system: coverage conditions are free in terms of pricing, deductibles, modulation of premiums and compensation based on the risks covered, resulting in relatively low effective insurance rates and quite a few cases of exclusions. The risk of drought is never assured and there is no coverage for these risks.

- the non-intervention of the state, Bund and Länder.

However, when the scale of claims is large, public finances are involved in a massive way. The most significant event of this intervention was the Elbe flooding in 2002 that triggered public support of around 7.1 billion euros.

Germany sets up a fairly active policy of prevention of natural disasters, especially regarding flooding.

- ***Switzerland***

The Swiss system is characterized by the coexistence of a private and a public insurance model, based in 19 cantons, the local monopoly of cantonal insurance establishments (ECA). Insurance against damage due to natural events is now a mandatory extension of fire insurance contracts. Private insurers are grouped in the Swiss Pool for coverage of damage caused by natural forces. This pool establishes a double solidarity between insurers and policyholders. The ECA's have established a risk pooling system with several reinsurance levels:

- Intercantonal Reinsurance Union (UIR) is similar to a reinsurance organization providing privileged conditions.

- when the total losses due to natural elements reach a certain amount, the CIREN (Intercantonal Community of Natural Risk Elements) fund supports the excess of loss beyond that ceiling.

Furthermore, Switzerland runs a particularly elaborate disaster prevention policy. This policy combines a strong involvement of public authorities (regional planning, urban planning, risk reduction, building standards) and an active role of insurers.

Annex 8 - Detailed analysis of the at-risk territories

Dakar (Senegal)

❖ ***General presentation***

Dakar is the capital of Senegal, a country in West Africa bordered to the west by the Atlantic Ocean, north by Mauritania, east by Mali and south by Guinea-Bissau and Guinea. While Dakar occupies only 0.3% of the country, the city concentrates more than 20% of the population and the majority of economic activities and public services (GFDRR, 2014).

Table3: General information on Senegal and Dakar

Type of Information	Value	Date	Source
Population of Senegal	14.1 Million inhabitants	2014	Prevention Website
Population of Dakar	3.1 million inhabitants (23% of the country's population)	2013	National Agency for Statistics and Demography
Population density	73.4 inhab/km^2	2014	Prevention Website
UNDP Ranking	163/187	2013	UNDP 2014 Report (ranking from 2013)

❖ ***Characterization of the hazard in Dakar***

Climatic and rainfall regimes

The region of Dakar is located in the central part of Senegal (at the level of the peninsula of Cape Verde) between, in the north a desert and hot climate, and in the south a tropical climate. The climate is punctuated by two main seasons:

- a rainy season, also called wintering, extending from June to October (summer period);
- a dry season, from November to May (winter period).

The Dakar region has a coastal microclimate influenced by the maritime trade winds (November to June) and the rain season. Precipitation is generated by the trade wind from the Saint Helena high pressure. The annual rainfall amounts in Dakar are generally between 400-500mm. The month of August is particularly rainy (BRL Ingénierie, 2015).

Hazard aggravating factors

The main factors aggravating the hazard are:

- **raising the water table** of Thiaroye (located near the town of Pikine) due mainly to (i) reduced groundwater exploitation due to high nitrate concentrations making the water unfit for consumption, and (ii) rainwater infiltration to wintering and wastewater ***(Gouvernement du Sénégal, 2010)***;
- **the impact of climate change in terms of:**
    - precipitation: rainfall modelling for West Africa is uncertain as to both the magnitude of the change and the type of change (increase/decrease), despite the observation from the 1970s of a global decline in precipitation and a decrease in the duration of wintering. Several global climate models of the CMIP5 indicate an increase in rainfall in the middle of the rain season, and a delay in the start of the rain season. But regional climate models may change these indications. Regional models, on the other hand, suggest an increase in the number of extreme rainfall events in the Sahel between May and July ***(GIEC, Climate Change 2014: Impacts, Adaptation and Vulnerability. Part B: Regional Aspects. Contribution of the working group II to the Fifth Assessment Report of IPCC, 2014, pp. p 1209-1211) (Gouvernement du Sénégal, 2010)***.
    - of sea level and coastal erosion: in its latest report, the IPCC estimates that sea level should continue to rise in the 21st century and even accelerate. Coastal erosion, started since the 1980s, is mainly due to the rise of the sea, but also to human activities (sand extraction, construction on the coast). Erosion is likely to increase the risk of coastal flooding in Dakar ***(GIEC, 2014, p. p 1140)***.

❖ ***Characterization of issues and vulnerabilities in Dakar***

Characteristics of urban planning

The Dakar region is made up of 3 main zones:

- **an urban area** located at the end of the peninsula of Cape Verde. This zone is characterized by a physical isolation and a concentration of activities (port, ministries, administrations, embassies, banks, import-export industries, etc.);
- **a peri-urban area** corresponding to the communes of Pikine and Guédiawaye. This area is mainly residential but also has some areas of activity. It is characterized by a lack of urban structuring (multiplication of housing estates, including in areas of high insalubrity and/or areas at risk of flooding, destruction of public property such as coastal sand and green spaces).
- **a rural area** corresponding to the municipality of Rufisque. It is composed mainly of farmland.

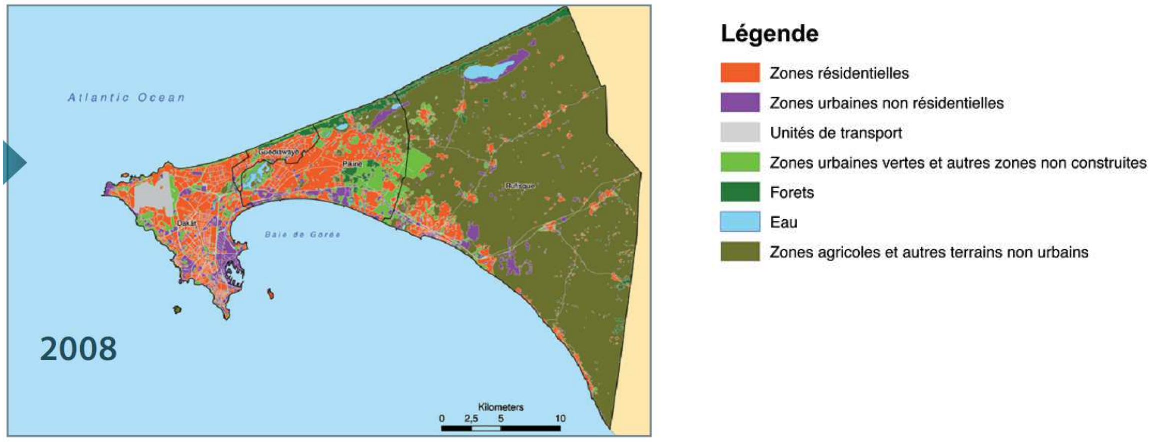

Figure 25: Land use in the Dakar region (IAGU, 2009)

Factors aggravating the vulnerabilities

The main factors aggravating the vulnerabilities are:

- **the development of urbanization** which leads, in addition to an artificialization of the soil, to an obstruction of the natural channels of flow of the rain water. For example, the motorway crossing the Dakar region serves as a dike because of the lack of nozzles allowing the flow of water;
- **the standard of living of the affected populations.** In the Dakar region, the populations living in the flood zones consist mainly of poor households. The drought in the period between the 1970s and the 1990s led to a strong rural exodus to Dakar, the main centre of economic attraction, and a drying up of soils in the Niayes district of Pikine. To compensate for the lack of space, the populations settled in the newly drained areas (but located in the depressed areas). Nearly 40% of new installations were in areas potentially at high risk of flooding, coastal erosion or sea level rise. This urbanization process has escaped the control and regulation of the authorities. lack of control of land use. ***(IAGU, 2009) (Diongue, 2014)***
- **lack of control of land use.** Urban Plans provide "no aedificandi" zones, to preserve the lowest points from any urbanization, likely to be flooded most easily during the wintering period. But in fact, these areas with many advantages for the populations (virgin areas of any urbanization, close to the city centres, planes, etc.) are transformed into irregular habitat.
- **lack of cooperation between institutions.**

❖ ***Synthesis on the risk, past floods and their consequences in Dakar***

Flood typology in Dakar

The floods affecting Dakar are mainly of the urban runoff type, but the effects of climate change raise fears of an increased risk of submersion. The risk of flooding (Figure 25) comes from the conjunction of multiple conditions (cumulative and intense rainfall during wintering, the raising of the Thiaroye water table, inadequate drainage infrastructure, inadequate sanitation networks, uncontrolled urban development, occupation of depressed areas, deforestation, etc.).

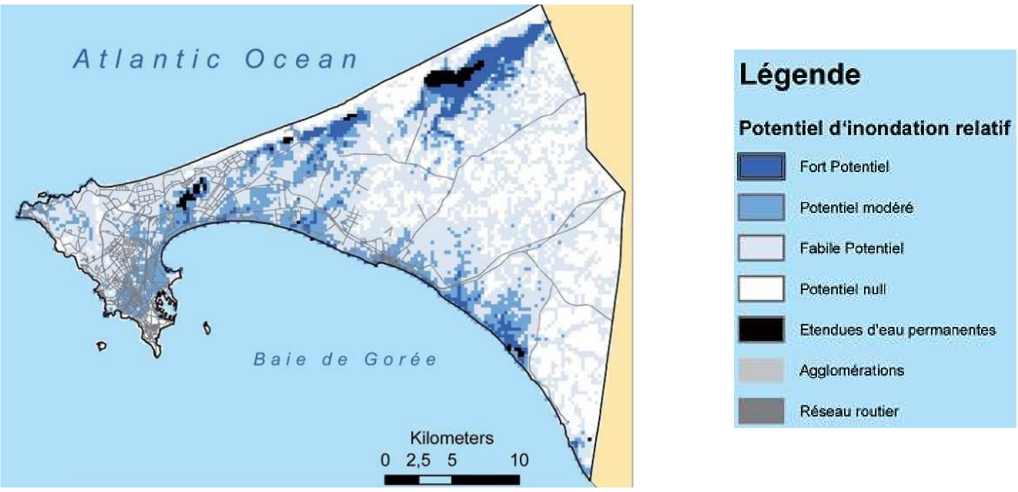

Figure 26: Flood potential in the Dakar region (IAGU, 2009)

Past floods and their impacts

The major events of recent years in Senegal are summarized in Tableau 4. According to the Post-Disaster Needs Assessment Report prepared by the Government of Senegal (2010), flood damages nationwide between 1980 and 2009 (inclusive) amounted to USD 142 million and affected 900,000 people.

The main impact of the floods are:

- **Economic:** degradation of buildings (including dwellings), cessation of activities (agriculture, health posts, education, local markets, etc.);
- **Social:** deterioration of the environment and living conditions (for example, loss of use of toilets) and links between inhabitants (generation of conflicts between neighbours, increased insecurity, etc.);
- **Health:** disease outbreaks (cholera, typhoid, malaria, diarrhoea, dermatitis, respiratory diseases, etc.) due to stagnant water favouring the proliferation of mosquitoes. Increased risk of electrocution due to the precariousness of electrical installations. Food insecurity. The floods seem to be also likely to pollute the drinking water resources (boreholes around the region of Dakar), however little information is available on this subject.

Table 4: Summary of the major events of recent years in Senegal

Date	Consequences of the event	Source
2009	This flood affected between 485,000 and 507,000 people in Senegal. The damage is estimated at 104 million USD on Senegal, affecting mainly housing (49%), health (14%), agriculture (11%), education (10%) and transport (10%). The Dakar region is the area most affected by the flood. Nearly 360,000 people were affected: 11% of the regional population was affected and 44% of the population of the city of Pikine was directly affected. The damage was estimated at 82 million USD for the peri-urban area of Dakar alone (including 33 million USD for housing).	(GFDRR, Sénégal: Inondations urbaines. Le Relèvement et la Reconstruction à partur de 2009, 2014)

❖ *Governance and management policies/strategies in Senegal*

A wide variety of actors (ministries, public, parapublic or private structures, local authorities, civil society, etc.) are involved in the flood risk in Senegal (these actors are presented in annex 1). The roles and missions of each are not always clearly established, leading to a possible encroachment between their areas of action and their skills. This diversity is also a source of lack of cooperation and coordination at national and even local level.

Senegal is one of 187 states that have adopted the new international framework from Sendai last March. Prior to that, the country participated in the evaluation of the Hyogo Framework for Action. Regarding the national flood management strategy, Senegal has committed to a policy of recovery and sustainable flood management following the floods of 2009, particularly with the development of: (GFDRR, Sénégal: Inondations urbaines. Le Relèvement et la Reconstruction à partur de 2009, 2014)

- **PDNA (Post Disaster Needs Assessment)** : a damage, loss and need assessment program, carried out following the 2009 floods, aimed at achieving a strategic recovery and reconstruction in short, medium and long term;
- **PROGEP (Rainwater Management and Climate Change Adaptation Project):** this five-year plan aims to reduce flooding through an integrated and sustainable approach. It includes the construction of rainwater drainage infrastructure in the Dakar region;
- **PDGI (Ten-Year Flood Management Plan):** launched after the 2012 floods, this plan aims to significantly strengthen the flood management policy and identifies 10 strategic decisions (including the involvement of local authorities, the improvement of interministerial coordination).

Today, Senegal shows flood management as a national priority.

❖ *Opening on other territories in Senegal*

The Dakar region is not the only area in Senegal affected by floods (Figure 26). Urban areas are concerned by a risk of river flooding, for example, in Saint-Louis, Matam (located in the north of Senegal, and prone to the overflow of the Senegal River), and Kedougou (located southeast and concerned by the overflow of the Gambia River). Others are more concerned with issues of urban runoff such as Kaolack and Fatick. Finally the Saloum Delta and St. Louis are exposed to a risk of coastal flooding. (Gouvernement du Sénégal, 2010)

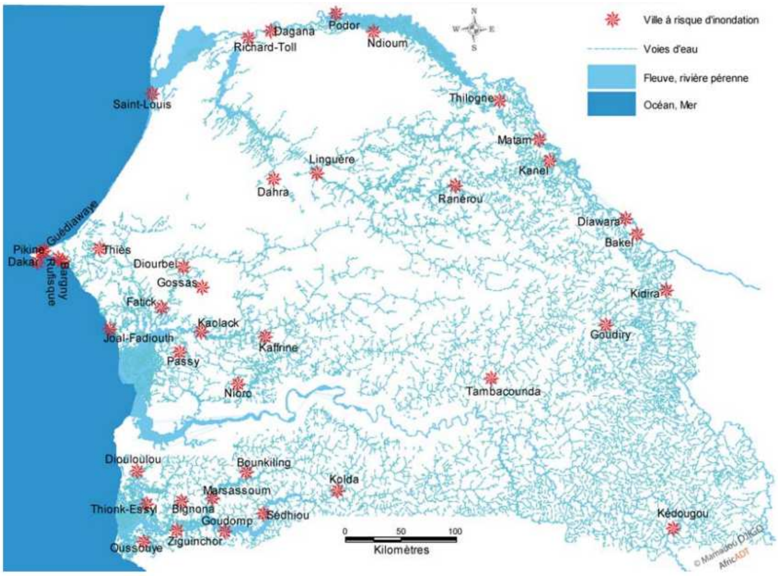

Figure 27: Senegal cities at risk of flooding (UNISDR, 2013)

Port Louis (Mauritius)

❖ *General presentation of Mauritius and Port Louis*

Port Louis is the capital of the Republic of Mauritius. The latter consists of the main island, Mauritius, and several peripheral islands (the largest of which is Rodrigues) for a total area of 2,040 km^2. It is located in the south-east of the Indian Ocean, near the Tropic of Capricorn. With a population of 135,000 inhabitants in 2014 (CIA, 2015), Port Louis represents about 10% of the population of Mauritius.

Table5: General data on Mauritius

Type of Information	Value	Date	Source
Mauritius population	1.3 Million inhabitants	2014	Prevention Website

Type of Information	Value	Date	Source
Port Louis population	135,000 inhabitants	2013	CIA World Factbook
Population density	638.6 inhab/km^2	2014	Prevention Website
UNDP Ranking	63/187	2013	UNDP 2014 Report *(ranking from 2013)*

❖ *Characterization of the hazard in Mauritius and Port Louis*

Climatic and rainfall regimes

Mauritius has a tropical climate influenced by southeast winds. The average annual temperature of the island rises to 22° C, and there is daily sunshine of 7 to 8 hours on average over the year. Port Louis, the capital, enjoys particularly mild winters and has an average annual temperature of 23° C.

The climate is punctuated by two main seasons:

- dry and relatively warm winter (May to October, October being the driest month)
- hot and humid summer (November to April, February being the wettest month), this is the hurricane season.

The spatial distribution of precipitation is influenced by winds (from the southeast) and the topography of the island (mountains surrounding the central plateau of the island). Thus the mountains protect the northern and northeastern regions, relatively drier than the south and the central plateau. The annual rainfall totals vary between 600mm (west), 900mm (north), 1300-1400mm (south and east) and up to 4000mm (in the central plateau). The intensity of a "normal" rain is distributed in the same way as the annual rainfall totals, with about 30mm/h on the coast and 50 mm/h at the central plateau. (ICLEI, 2012)

Hazard aggravating factors

The main factors aggravating the hazard are:

- **agricultural practices.** There is an increase in abandoned areas (due to the decrease in area under sugarcane, only a portion of which is converted to other crops), resulting in erosion and increased runoff, and consequently an increase in the risk of downstream flooding. In addition, soil condition after sugarcane harvest (between July and December) also tends to increase erosion and runoff. ***(Hunink & Droogers, 2013)***

- **the impact of climate change in terms of: *(ICLEI, 2012) (Ministère de l'Environnement de Maurice, 2012) (McSweeney, New, & Lizcano, 2012)***
    - Rainfall: according to global models (GCM), precipitation is expected to decrease overall. The transition period between summer and winter should be longer. Large rain events are likely to be more intense and frequent, resulting in flooding more frequently.
    - Cyclones: the intensity of cyclones should increase
    - Sea level: it would grow faster in recent years. The Meteorological Service of Mauritius has estimated an average increase of 3.8mm/year in sea level over the past 5 years (compared to an average of 2.1mm/year over the last 22 years).
    - From sea temperature: increasing sea temperatures weaken corals, reducing coastal protection (less attenuation of waves), and thus contributing to coastal erosion.

❖ ***Characterization of issues and vulnerabilities in Mauritius and Port Louis***

Characteristics of urban planning

Port Louis is the administrative and economic centre of the country as well as the main commercial centre (with the only port of the island). The city concentrates the offices of the main companies, and various manufacturing activities. The city is characterized by high density due to a large urbanization (Port Louis representing a pole of attraction) coupled with the lack of available space. Urbanization also took place on natural waterways. (UN-Habitat, 2011)

The poorest neighbourhoods (especially slums) developed on the slopes of the surrounding mountains. In these neighbourhoods, people do not always have access to essential services: drinking water, sanitation and electricity. (UN-Habitat, 2011)

Factors aggravating the vulnerabilities

The main factors aggravating the vulnerabilities are:

- The basic dwellings of the poorest neighbourhoods located on the mountainside, especially on the Tamarin Tower where the slopes exceed 20% and where buildings have been endorsed or even approved by the authorities;
- The false sense of security created by the level of development of the city. Indeed, the development of the island tends to a soil sealing (urbanization), a decrease in vegetation cover, (both factors causing an increase in runoff), an increase of the issues located in the areas exposed to the risk of flooding, as well as a decrease in the risk culture of the populations ***(Asconit, 2013)***. This phenomenon was illustrated during

the flash flood of 2013, causing the death of a dozen people in an underpass linking the waterfront to the historic centre of the capital.

❖ ***Summary on risk, past floods and their consequences***

Typology of flood in Port Louis

The city of Port Louis is mainly subject to a risk of **flash flood**. The risk of flooding (illustrated at the scale of Mauritius in Figure 27) comes from the conjunction of multiple conditions including in particular heavy rainfall, the steep slopes of the mountains surrounding the city (Figure 28), human development on the natural channels of water flow and inadequate drainage system (including inadequate maintenance).

Past floods and their impact

The major event of recent years in Port Louis took place in March 2013. Torrential rains fell on the capital: more than 150 mm of water fell within 2 hours. This flash flood killed 11 people. No damage assessment was performed.

The main impacts of the floods in Port Louis are: (ICLEI, 2012)

- **Economic:** interruption of the activities of the port (the only one of Mauritius), deterioration of the buildings and infrastructures (roads in particular) due to the strong flows of runoff and the transported debris;
- **Sanitary:** possible contamination of sources of drinking water.

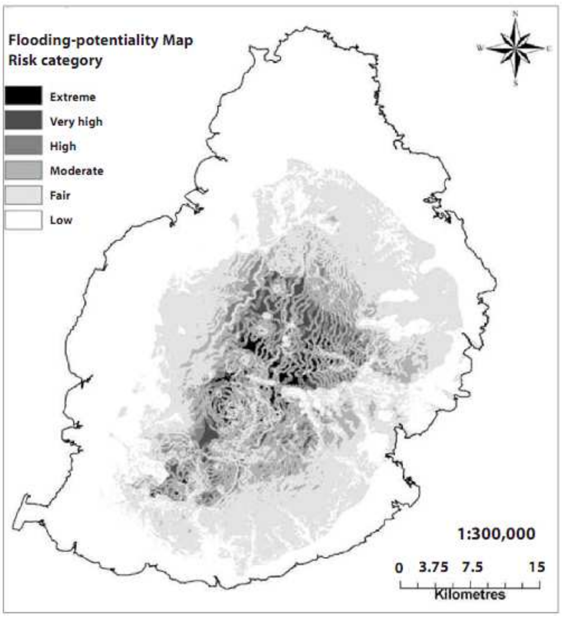

Figure 28: Mapping the flood potential in Mauritius (Fagoonee, 2005)

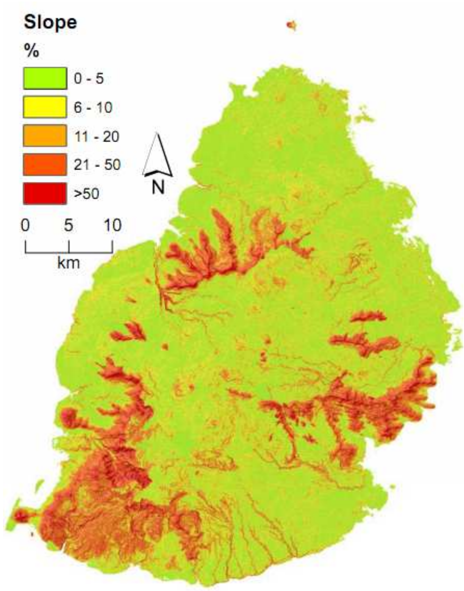

Figure 29: Slopes on the island (Hunink & Droogers, 2013)

❖ *Governance and management policies/strategies in Mauritius*

Mauritius is one of 187 states that have adopted the new international framework from Sendai last March. According to UNISDR (2015), before 2013, disasters were treated on an ad hoc basis by structures operating only when disasters were about to strike or once they had occurred. At present the main bodies for disaster risk management are: (UNISDR, 2015)

- The National Disaster Risk Reduction and Management Centre (NDRRMC) which was established in 2013 (and operational since October 2013). It is the leading institution in Mauritius for planning, organizing, coordinating and monitoring disaster risk management and reduction activities at all levels. It is under the authority of the Prime Minister. This structure is in particular responsible for the development and updating of a comprehensive and integrated disaster management information system, as well as a database, including information on risks, and vulnerabilities, data and information. risk assessment and national risk mapping on GIS;
- National Risk Reduction and Management (NDRRM) Council which has been put in place pending the promulgation of the new framework of the general policy on risks. It is similar in composition to the former CCNDC (Central Cyclone and Other Natural Disasters Committee) and focuses on readiness and post-disaster response;
- The Local Disaster Risk Reduction and Management Committee set up in each city council or district council to manage disaster risk reduction at the local level.

Beirut (Lebanon)

❖ *General presentation of Lebanon and Beirut*

Lebanon is a country in the Middle East, located on the eastern coast of the Mediterranean Sea. Lebanon shares borders with Syria (north and east) and Israel (south). Beirut is the capital and the most populous city in the country it represents nearly 50% of the country's population. The city is located on a rocky cape, bordering the Mediterranean and close to the mountain range of Mount Lebanon. Beirut is the administrative and political centre of Lebanon, but it is also the economic heart of the country. As an illustration, the port of Beirut passes 75% of Lebanon's GDP (Croix Rouge, 2013).

Table 6: General data on Lebanon and Beirut

Type of Information	Value	Date	Source
Population of Lebanon	4.5 Million inhabitants	2014	Prevention Website
Population of Beirut	2.2 million inhabitants *(nearly 50% of the country's population)*	2015	CIA World Factbook
Density of the population of Brazil	437 inhab/km^2	2014	Prevention Website
UNDP Ranking	65/187	2013	UNDP 2014 Report *(ranking from 2013)*

❖ ***Characterization of the hazard in Beirut***

Climatic and rainfall regimes

Beirut has a Mediterranean climate (climate Csa in the Köppen- Geiger classification), punctuated by two seasons: (BBC Weather, 2011)

- A hot and dry summer between May and September, with average maximum temperatures above 30° C, and average monthly rainfall below 20mm.
- A mild and humid winter between October and April, during which the majority of the precipitation is concentrated (between 50mm and 200mm per month). The average minimum temperature is 10° C (in January and February).

The average annual rainfall in Beirut amounts to nearly 900mm, the rainiest months being December and January (about 200mm per month). On the other hand, during the summer months it hardly rains. (BBC Weather, 2011)

Hazard aggravating factors

The main factors aggravating the hazard are:

- Clogging of drainage infrastructure and waste water channels. Due to the lack of waste collection system, the inhabitants of Beirut have become accustomed to throwing their waste into the river. These are transported into the drainage system of the capital, accumulate to form dams obstructing the flow of water and causing surface flooding (network backflow). Thus, in January 2013, this phenomenon led to the flooding of a main road in the Karantina district east of Beirut ***(Redd, 2013)***.

- the effects of climate change on rainfall but also sea level rise. The PRECIS climate model has allowed to present the following projections for Lebanon: ***(Minsitère de l'Environnement du Liban)***
    - a rise in temperatures of 1° C by 2040 and 3.5° C by 2090 on the coast (this increase should be more pronounced inland)
    - a decrease in annual rainfall of around 10 to 20% by 2040, and 45% by 2090
    - an extension of the average duration of drought periods from 9 to 18 days by 2090
    - a decrease of 40 to 70% of the snow cover for a respective temperature increase of 2° C to 4° C. This should influence river regimes and recharge groundwater

❖ ***Characterization of issues and vulnerabilities***

Characteristics of urban planning

Beirut's urban planning has been strongly marked by the various conflicts over the last decades. Formerly organized around a strong city centre and various concentric circles in outlying districts, the city is completely reorganized during the civil war that took place between 1975 and 1990. This war resulted in the destruction of the city centre and the division of the city into community neighbourhoods: the city was separated by a line of demarcation, called Green Line, separating Muslim neighbourhoods in the west mainly Sunni), Christian neighbourhoods in the east. Shiite Muslims are mainly settled in the southern suburbs of Beirut. (Kastrissianakis, 2012)

At the end of the war, the government launched a reconstruction program for the city in May 1991. But this one is badly accepted by the population who sees there a confusion between the public interest and the private interest, as well as a lack of respect for the private property (the State imposes many evictions without a policy of rehousing satisfactory). In 2006, a new conflict (with Israel) led to further destruction of many neighbourhoods and infrastructure, followed by a new phase of reconstruction. (Kastrissianakis, 2012) (Wikipédia, 2016)

Finally, in recent years, the Syrian crisis has led to large influxes of refugees into Lebanon, including Beirut, contributing to increased housing and employment opportunities (Wikipédia, 2016). According to UNHCR (2015), **Lebanon had hosted nearly 1.2 million refugees in March 2015, of which more than 32 000 in the city of Beirut alone.**

Factors aggravating the vulnerabilities

The main factors aggravating the vulnerabilities in Beirut are:

- **Concentration of coastal urbanization** and flood expansion areas, resulting in soil sealing and increased runoff. In addition, according to Dr.

Farajalla, Professor of Hydrology and Water Resources at the American University of Beirut, the construction of houses on the banks of rivers in recent years limits the flow of water during rising rivers and creates the effect of a dam, which leads to rising water levels upstream ***(Redd, 2013)***.

- **Flows of refugees fleeing conflict** (especially Syrian). The number of Syrian refugees has increased exponentially in the last years of the Syrian civil war. In 2014, refugees accounted for nearly 20% of the Lebanese population. These populations are particularly exposed: refugees find it increasingly difficult to get (or to pay for) decent housing and often settle in precarious housing (such as tents and garages). In addition, Lebanon is struggling to respond to this pressure from refugees: the country has experienced significant economic shocks as a result of the Syrian conflict, resulting in a decline in trade and tourism, and an increase in public spending to meet the ever-increasing demand for healthcare, education and other essential services such as water, sanitation and electricity. The World Bank estimated that the war in Syria cost Lebanon $ 2.5 billion during 2013. ***(UNHCR, 2014)***

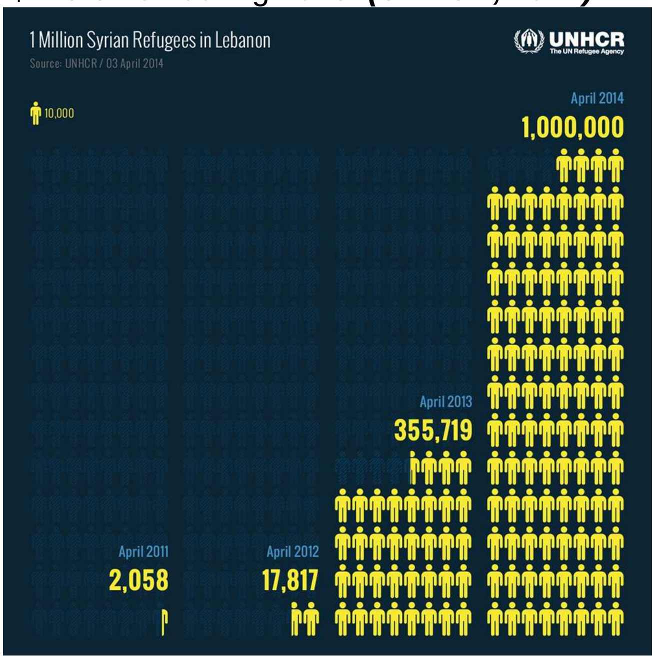

Figure 30: Increase in the flow of Syrian refugees to Lebanon (UNHCR, 2014)

- **The strong urbanization in coastal zone,** exposing the population to the rise of the sea level. According to the Red Cross, 50% of the population of the city is located near the coast ***(Croix Rouge, 2013)***.
- **The health risk related to waste transported by water.** During 2015, the waste problem in Beirut was exacerbated. Indeed, following the recent closure of the main dump of the city (because of its saturation) and without any alternative proposed by the government, rubbish was collected in the streets before the rain season. Beyond the risk of aggravation of the previously presented hazard, this phenomenon also

poses an increased health risk. First, the contamination of water with waste can lead to epidemics, including cholera. And contaminate the water resource (in Lebanon, the use of private wells is widespread). ***(Owens, 2015)***

- **Insufficient maintenance of drainage infrastructure.** According to Mr. Farajalla, the maintenance of the drainage works is not sufficiently regular to provide protection against the risk of flooding. In addition, there is a lack of control over the proper performance of maintenance due to the low number of staff available. ***(Redd, 2013)***

❖ ***Summary on risk, past floods and their consequences***

Beirut is mainly affected by **flash floods**, and more generally **urban runoff**. In addition, the city is exposed to the risk of earthquakes that can lead to the formation of **tsunamis**.

Recently, in October 2015, heavy rains caused flooding in the streets of the Lebanese capital, already buried under the garbage, following the closure of the city's garbage dump. This waste has been transported to the streets, creating real solid waste streams in the capital (Figure 30).

Figure 31: Waste streams in the streets of Beirut during the flood of October 2015 (Osseiran, 2015)

❖ ***Governance and management policies/strategies***

In recent years, Lebanon has sought to become the first country in the Arab region to put in place a comprehensive national strategy for disaster risk management. The UNDP Disaster Risk Management Unit, as Chair of the Council of Ministers, launched on 25 November 2015, in collaboration with the National Centre for Scientific Research of Lebanon (CNRS), the project " flood risk assessment in Lebanon and mapping ". This project aims to assess the risks of flooding in the different catchment areas of Lebanon, and to develop a comprehensive methodology to determine risks to protect lives and property, support crisis management and strengthen the risk culture with the population. (UNISDR, 2013) (UNDP, 2015)

The Red River Delta (Vietnam)

❖ ***General presentation of the Red River Delta and Vietnam***

The Red River Delta is located in northwestern Vietnam and includes two of the country's largest cities Hanoi (3.6 million inhabitants) and Hai Phong (1.1 million inhabitants) (Figure 31). This region with an area of more than 10,000 km^2, has a population of about 15 million (17% of the country's population) and has one of the highest densities on the planet with more than 1,500 inhabitants/km^2 (Sueur, 2011).

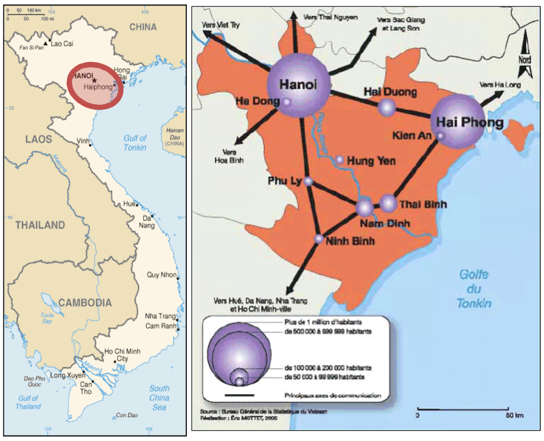

Figure 32: Location and map of the Red River Delta, adapted from the CIA World Factbook and of Sueur 2011

Table 7: General data on Vietnam and the Red River Delta

Type of Information	Value	Date	Source
Population of Vietnam	89.7 Million inhabitants	2014	Prevention Website
Population of the Red River Delta	About 15 million inhabitants (about 17% of the country's population)	2010 - 2011	Information Report to the French Senate written by Sueur in 2011: "*Cities of the future, future of cities: what future for the cities of the world?*"
Density of the population in Vietnam	289 inhab/km^2	2014	Prevention Website

Type of Information	Value	Date	Source
GDP/inhabitant	2,052 $US/inhabitant	2014	World Bank website

❖ *Characterization of the hazard in the Red River Delta*

Climatic and rainfall regimes

Vietnam has a tropical climate with monsoons, with differences between north and south (the latter, for example, does not have a winter season). The climate of the north of the country is punctuated by two main seasons:

- the mild and dry winter (October to April) with daytime temperatures;
- Hot and humid summer (May to September); July and August being the rainiest months).

In the Red River Delta region, the average annual temperature is about 23° C, with about 16° C in winter (January) and about 29° C in summer (July). Rainfall distribution is relatively homogeneous at the delta scale with an annual cumulative 600mm, of which over 80% is concentrated between May and October. (Thanh Pham, 2008)

Hazard aggravating factors

The main factors aggravating the hazard are: (ADRC, 2005) (GFDRR, 2011)

- **deforestation upstream of the delta region** leading to increased runoff (in volume and flow) and consequently an increased risk of flash flooding;
- **the increase of sediment deposits** resulting in a rise in the river's minor bed;
- **the impacts of climate change** in terms of:
    - Rainfall: rainfall during the rain season is expected to increase leading to an increase in intensity, frequency and duration of floods. Extreme rain events are expected to increase in terms of frequency and quantity of precipitated water, particularly in the north of the country;
    - Cyclones and typhoons: global climate models do not simulate cyclone phenomena well enough to provide accurate conclusions about their evolution for Vietnam (in terms of frequency, intensity or direction). Nevertheless from a qualitative point of view, the cyclones could become more intense as the temperature on the surface of the water should increase;
    - Sea level: which should increase from 28cm to 33cm by 2050. By 2100, about 5% of Vietnam's territory is expected to be at risk of flooding due to rising sea levels.

❖ ***Characterization of issues and vulnerabilities***

Characteristics of urban planning

The Red River delta is representative of a new form of urban development, without a previous example. It is characterized by the simultaneous presence of agricultural areas, industrial zones and dense urban areas and residential areas. Geographer T. McGee called this phenomenon "desakota" (from the Indonesian terms "desa", village, and "kota", city). This type of town planning is characterized by: (GFDRR, 2011)

- the presence of a dense and integrated agricultural population in urban society and the economy;
- the simultaneous development of agricultural and industrial activities;
- a very dense network of cities making the delimitation of cities difficult;
- ease of mobility to major urban centres through inexpensive modes of transportation such as motorcycles, cars, buses and trucks.

Factors aggravating the vulnerabilities

The main factors aggravating the vulnerabilities are:

- **The concentration of the issues** (human - with very high density - and economic - agricultural and industrial activities making the region the economic centre of northern Vietnam) in low-lying areas and, in fact, exposed to the risk of flooding;
- **The degradation of the existing dike system *(Hansson & Ekenberg, 2002)*.**

❖ ***Summary on risk in the Red River Delta: past floods and their consequences***

Flood typology in the Red River Delta

The Red River Delta is subject to several types of flooding, mainly:

- River floods taking place mainly in July and August, during the rain season. Red River flows vary from about 400 m^3/s in the dry season to 30,000m^3/s during the rain season. ***(Sueur, 2011)***. These floods are particularly dangerous for men, particularly because: ***(Fontenelle, 2006)***
  - o they are multiple: they can occur at any time during the rain season);
  - o they are strong and relatively fast because of the combination of heavy rainfall upstream of its catchment area and its low concentration time;
- The combination of river flood and marine submersion, especially during tropical cyclones, leading to heavy rainfall (river flood) and strong tides preventing the evacuation of water to the sea and resulting in flooding of coastal areas.
-

Past floods and their impact

The last major floods of the Red River took place in 1945 and 1971. From an estimated return period of 100 years, both events have caused extensive damage and marked the collective memory of the local population to the extent that even the supposedly protected areas have been affected. In fact, these two floods have resulted in the formation of breaches and breaks in some dikes. (Gilard, 2006) There does not seem to be any record of damage caused by these floods.

Beyond these exceptional events, floods occur regularly in this region, but none of them seems to have exceeded the current level of protection provided by dikes. (Gilard, 2006)

❖ ***The flood risk management strategy in the Red River Delta***

The flood management strategy in the Red River Delta has long been translated in the implementation of purely structural measures. Thus the delta presently has a network of about 3,000 km of dikes to protect areas exposed to river floods, and about 1,500 km of coastal dikes to mitigate the effects of strong waves during extreme events such as tropical cyclones (Sueur, 2011). Two reservoirs, with a total capacity of 5.4 billion m^3, were created to reduce the risk of flooding in areas downstream of the Red River. In addition, emergency spillway systems to previously identified areas have been put in place to protect dikes and reduce the risk of breakage.

The current flood risk management strategy also seems to incorporate non-structural measures, such as reforestation (and forest protection) upstream of Hanoi, improving readiness, strengthening institutions. *(ADRC, 2005) (Banque Mondiale, 2009)*

Sao Paulo (Brazil)

❖ *General presentation of Brazil and Sao Paulo*

Sao Paulo is located in southeastern Brazil, near the Atlantic coast. The Greater São Paulo Metropolitan Area (RMSP) has nearly 20 million inhabitants, nearly 10% of the total population of the country. The RMSP includes the city of São Paulo and 39 other municipalities, which occupy an area of almost 8,000 square kilometers, of which 2,000 are highly urbanized. It is one of the most important urban and industrial concentrations in Latin America. The urbanized area occupies a large part of the upper Tieté. The city itself has 11 million inhabitants (Revista, 2013).

Table 8: General data on Brazil and Sao Paulo

Type of Information	Value	Date	Source
Population of Brazil	200 Million inhabitants	2014	Prevention Website
Population of Sao Paulo (metropolitan area)	21 million inhabitants *(nearly 10% of the country's population)*	2015	CIA World Factbook
Density of the population of Brazil	24.0 inhab/km^2	2014	Prevention Website
UNDP Ranking	79/187	2013	UNDP 2014 Report *(ranking from 2013)*

❖ *Characterization of the hazard in Sao Paulo*

Climatic and rainfall regimes

The city of Sao Paulo is located about 750m above sea level. This altitude influences the climate of the city. It benefits from a subtropical climate with an average annual daily temperature of 19.2° C (varying between 22.5° in February - summer - and 16° C in July - winter). The annual rainfall amounts to about 1 450 mm, the months with the most rainfall on average being December, January and February (INMET, 2015). The climate is punctuated by a wet season from October to March concentrating most of the precipitation (> 200mm/month from December to February) and a drier season from April to September (<100mm/month).

Hazard aggravating factors

The main factors aggravating the hazard are:

- **the effects of climate change,** in terms of precipitation with, by 2050-2060: ***(Banque Mondiale, 2012)***
  - a very likely increase in the annual cumulative rainfall;
  - a likely increase in intense rainfall events, leading to increased flood risk in the city.
- **Clogging of water channels from waste** (irregularities in waste collection and the presence of more than 300 illegal landfills in the city), although more than 95% of dwellings have a garbage collection system. ***(Banque Mondiale, 2012)***

❖ ***Characterization of issues and vulnerabilities***

Characteristics of urban planning

The strong demographic (Figure 32) and industrial growth of the last fifty years has created an imbalance between water supply and demand, leading to serious pollution problems. In addition, increasing soil impermeability and wild urbanization are causing flooding. (Revista, 2013)

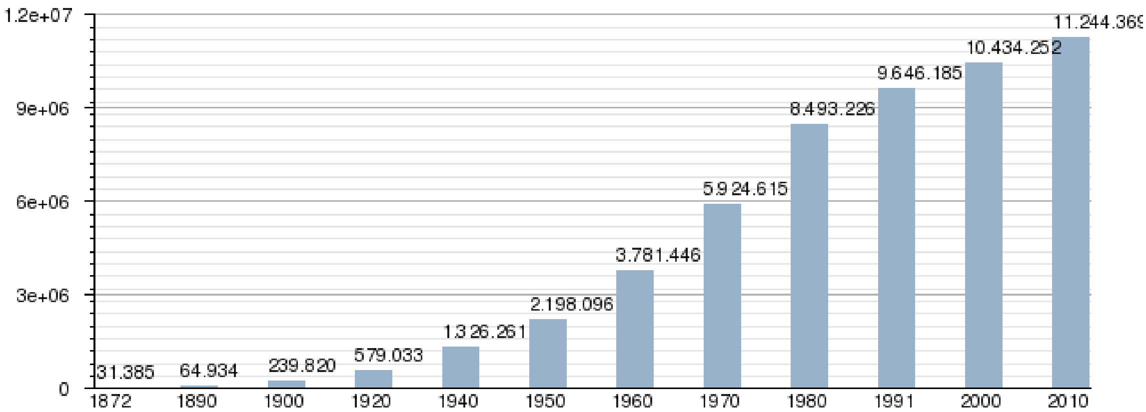

Figure 33: Demographic evolution of Sao Paulo (Wikipedia)

In the second half of the twentieth century, Sao Polo experienced extremely rapid urbanization in reference to the whole of Brazil: in 1950, 2/3 of the inhabitants lived in the countryside, in 1980 65% of the population lives in the city. In 2013, 85% of Brazil's population is urban.

The urban growth has been marked by a very important development of the favelas: between 1972 and 1980, the share of the population living in the slums has multiplied by ten to reach approximately 880 000 people (Sachs, 1981)

Figure 34: Photography illustration the cityscape of Sao Paulo

Factors aggravating the vulnerabilities

The main factors aggravating the vulnerabilities in Sao Paulo are:

- **the development of urbanization,** which entails, in particular, the sealing of soils, the channelling of water courses and the creation or reinforcement of concentration zones for runoff. Recent studies indicate that these catchment area changes tend to increase the peak runoff and change the return times of flood flows ***(Simas, Rodrigues, & Sant'Anna Neto, 2015)***;
- **The occupation of areas at risk of flooding**, with for example the construction of buildings near the minor river bed ***(Oliveira, et al., 2014)***. Moreover, due to economic inequalities, the poorest people are often forced to settle in undeveloped areas that could be flooded: the World Bank ***(2012)***estimates that 20% of shantytowns (favelas) and informal settlements in Sao Paulo are located in flood-prone areas;
- **the standard of living of the affected populations in the favelas**: they lack the means to protect themselves from floods (basic habitats) and to adapt quickly to changes in living conditions, especially following extreme rain events ***(Banque Mondiale, 2012)***;
- saturation of the drainage system ***(Oliveira, et al., 2014)***.

❖ ***Summary on risk of flooding in Sao Paulo, past floods and their consequences***

The floods affecting Sao Paulo are mainly urban runoff type, and flash flood type of urbanized watercourses. The risk of landslide also exists mainly in favela neighbourhoods that have been built on slopes. Recently, in January 2011 torrential rains have caused a dozen deaths in Sao Paulo mainly victims of landslide. The overflowing of several rivers cutting off traffic has caused huge traffic jams that paralyze the city's economic activity and endangered motorists who had to abandon their half-submerged vehicle.

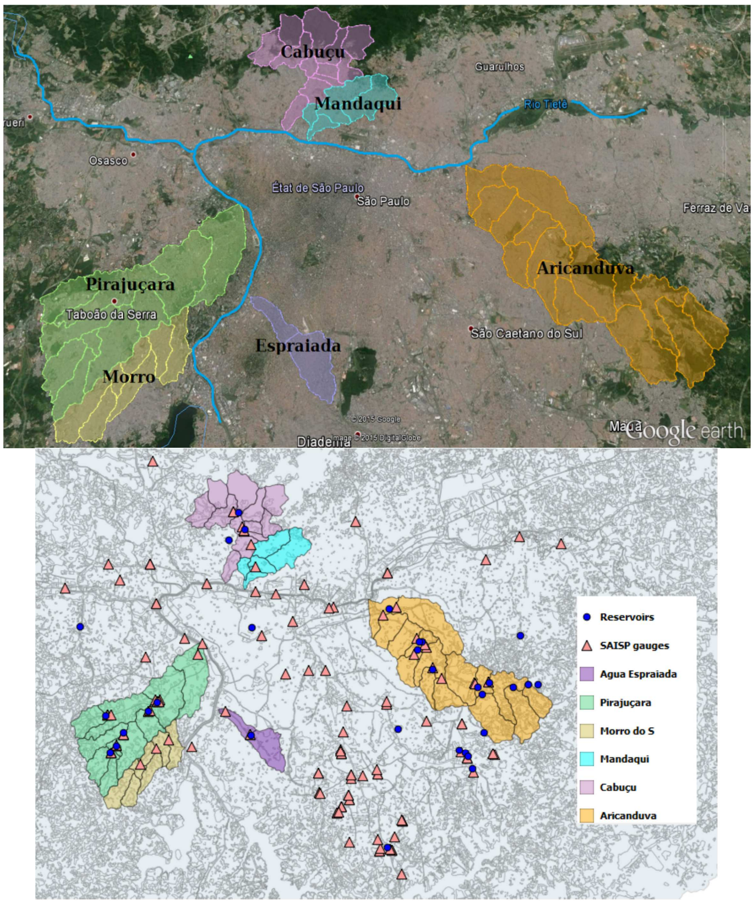

Figure 35: Satellite map of the city of Sao Paulo (source: Google) and main catchment areas monitored by the São Paulo Flood Warning System (SAISP/FCTH)

❖ ***Governance and management policies/strategies in Sao Paulo***

Due to the problems caused by the rains, the centre of emergency management was created in 1995 in the city of São Paulo (CGE-SP), It operates in coordination with the association of traffic engineering (CET). These two bodies, which are the recipients of the Flood Warning System in São Paulo (SAISP), are in charge of field interventions (closing of flood- damaged roads and tunnels, management of warnings and rescue operations).

The FCTh (Fundação do Centro Technologico e Hidraulica) manages the SAISP (Sistema de Warninga a Inundações de São Paulo), the flood warning system of São Paulo. It is an warning system based on real-time monitoring of precipitation (ground and radar data) and water levels of rivers and canals. The CTF operates an S-band weather radar in Salesopolis (75 km east of downtown Sao Paulo). It provides real-time information on the current situation and potentially flood risk areas, based on critical levels and predefined warnings.

These warnings are based on the observed water levels. In addition, two types of modelling are now integrated into the SAISP operational system:

- An warning system based on precipitation thresholds for small catchment areas;
- Hydrological and hydraulic modelling of priority catchment areas.

In 2016, through a Brazilian Franco collaboration, a new X-band weather radar will be installed in the centre of Sao Paulo and will provide greater measurement accuracy and must increase the effectiveness of flood warnings.

Another challenge is to extend the number of monitored urban basins, through hydrological and hydraulic modelling adapted to the rapid reaction time to rainfall (from 30 minutes to a few hours) and to the complexity of the network (ex: numerous retention basins).

Previous publications of the collection

Technical Report No. 1	Overview of Gender Inequalities Around the World (June 2015)
Technical Report No. 2	The Mekong Commission faces a turning point - What role can French aid play (September 2015)
Technical Report No. 3	What is the environmental effectiveness of "sustainable" fisheries and aquaculture certification? (September 2015)
Technical Report No. 4	Truth on price or socialization of cost coverage? (October 2015)
Technical Report No. 5	Technical accompaniment and capacity building: lessons from experience (October 2015)
Technical Report No. 6	Actors and networks of agroecology in the Greater Mekong Subregion (October 2015)
Technical Report No..7	Creating Alliances to Accelerate Commercially Viable Sanitation (November 2015)
Technical Report No. 8	French research on education in developing countries: an inventory (November 2015)
Technical Report No.9	Facilitating green skills and jobs in developing countries
Technical Report No. 10	Study on the development of social entrepreneurship in Madagascar

Technical Report No. 11	School and Reproductive Health An action research in the Littoral and Atlantic departments of Benin (Nov. 2014 - July 2015)
Technical Report No. 12	Spatial Observation for Agriculture in Africa: Potential and Challenges
Technical Report No. 13	Improve the inclusion of nutrition in rural development and health projects
Technical Report No. 14	Cities and climate strategies: five case studies
Technical Report No. 15	Sahelian Youth: exclusion dynamics, means of insertion
Technical Reports No.16	Supporting Access to and Retention in Employment for Women by Enhancing Child Care Services in Turkey
Technical Report No. 17	Method of investment monitoring, reporting and verification of climate impact (MRV) applied to agricultural and forestry projects of the National Development Banks
Technical Report No. 18	Management of groundwater resources as common assets
Technical Report No. 19	Urban water, sanitation and precariousness - contrasting realities in Ouagadougou (Burkina Faso) and Niamey (Niger)
Technical Reports No.20	The effectiveness of an environmental credit line in Egypt: Synergies between market incentive and binding regulations
Technical Report No. 21	Rural development at co- benefits - Governance, monitoring, certification

Technical Report n ° 22	Dynamics of agrarian systems and the future of family farming in Guinea
Technical Report No. 23	Evaluation of the regional planning policy in Tunisia from 1995 to 2010
Technical Report No. 24	Cocoa farmers' agricultural practices and livelihoods in Côte d'Ivoire
Technical Report No. 25	Socio-physical Vulnerability to Flooding in Senegal
Technical Reports No.25	Socio-physical Vulnerability to Flooding in Senegal
Technical Report No. 26	Income and agricultural trajectories in Africa by 2050: towards an overflow of farmers?
Technical Report No. 27	Understanding the installation process of young people in agriculture to better support them - Analysis grid and first results
Technical Report No. 28	Dynamics of inclusion/exclusion of youth in the MED zone
Technical Report No. 29	Competitiveness of Côte d'Ivoire, Senegal and Tunisia - An inventory of new data from the Observatory of Sustainable Competitiveness
Technical Report No. 30	Emergencies and health crises in resource-limited countries: from preparation to response
Technical Report No. 31	Capitalization of youth training-insertion actions conducted by non-governmental organizations
Technical Report No. 32	Access and retention of women to quality employment in Morocco, Tunisia and Turkey

Technical Report No. 33	Crowdfunding and official development assistance: inventory and recommendations
Technical Reports No.34	Outlooks for flare reduction in Nigeria

What is the AFD?

The French Development Agency (AFD), a public financial institution that implements the policy defined by the French government, acts to fight poverty and promote sustainable development.

Present on four continents through a network of 75 offices, AFD finances and supports projects that improve people's living conditions, support economic growth and protect the planet.

In 2016, AFD allocated 9.4 billion euros to project financing in developing countries and overseas territories.

French Development Agency
5 rue Roland Barthes - 75598 Paris cedex 12
Phone: +33 1 53 44 48 86 – **www.afd.fr**