SMARTeST




Guidance for Flood Resilience Systems

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3. Passau, Germany (Irish Examiner http://www.irishexaminer.com/breakingnews/world/flooding-in-german-city-dramatic-596401.html)
4. Flooding Sign (Google, viewed on ITV http://www.itv.com/news/meridian/2012-04-29/rain-lashes-the-south-sparking-flood-alerts/

The SMARTeST Project

The SMARTeST project was funded under the European Union's FP7 Research Programme, in the area Technologies for improved safety of the built environment in relation to flood events (ENV.2009.3.1.5.1).

The extent and consequences of recent flood events in Europe and worldwide have shown that existing flood defence structures do not guarantee sufficient protection for people and properties. Due to climate change and rapid urbanisation the situation is likely to become more severe. In this unfavourably changing environment, a substantial rethinking of existing strategies and a paradigm shift from the traditional approaches is required in order to cope with future flooding in an adequate way.

The SMARTeST project (Smart Resilient Technologies, Systems and Tools) was conceived in order to address many of the issues of integration of flood resilience (FRe) technology into the overall approach to flood risk management. The project has developed and disseminated knowledge to help facilitate flood resilience across Europe. It has identified challenges to the design and integration of FRe technologies and isolated opportunities for their promotion. The project was designed to improve the road to market for FRe technologies, particularly those with innovative or 'smart' FRe features. These features rely less upon human intervention for their deployment, although correct use, installation and maintenance are critical to improving their overall effectiveness. Beyond innovative technologies, the project has also developed FRe modelling and decision-making, again with an ultimate aspiration to promote the growth of more resilient societies. The emphasis is on cost effective solutions to flood resilient systems in the urban environment.

The project has achieved the following:

- Development of guidance for standards makers on FRe technology;
- Understanding of FRe systems intended to incorporate FRe technology;
- Development of a series of models and tools that support integration;
- Understanding stakeholder needs for the integration of FRe technology, systems and tools;
- Production of guidance for professionals and individuals.

The project has been coordinated by the Building Research Establishment of the UK, and has involved 10 European research institutes. It has been supported by National Support Groups in each country and an International Application and Implementation Group (see www.floodresilience.eu for details).

The SMARTeST project team gratefully acknowledge the support of the European Commission through the FP7 programme and particularly the project officers from DG Environment.

SEVENTH FRAMEWORK PROGRAMME

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Other SMARTeST reports

Flood Resilience Technologies

Flood Resilience Models

Integration of Flood Resilience Technologies, Systems and Tools

Executive Summary

Development has taken place for thousands of years close to water (rivers, lakes, seas) due to the resources water brings, e.g. food, energy, capacity to economically transport persons and goods or recreation and to dispose of waste water. However, flood risk, including pluvial flooding, is a strong counterweight to these huge advantages. The constant growth of urban areas in such flood-prone zones despite these risks is a clear indication of the permanent choices of concerned human groups.

Urban flooding typically has a negative impact on the populations of cities and towns. Urban settlements can be affected by all types of flood event, from the regular seasonal swell of a river through intense rainfall flash flooding, groundwater flooding, coastal storms, and coastal erosion and subsidence.

More than half of the world population is now living in cities and the trend of rapid urban growth throughout the mid-20th century in the developed world has shifted to the transition and developing regions of Asia, Latin America and Africa. Urbanisation has led to an increase in economic and social wealth in some places, but also to continuing poverty in others.

The concentration of people and assets in flood-prone areas increases the vulnerability of the built environment in case of flood. This trend will be locally reinforced by climate change in the course of the 21th century.

Traditional means to protect exposure from flood aim to ‘hold back’ water by means of dikes or levees. Past and recent events demonstrate the limits of such an approach. Dikes may break or be overtopped. In this case, the consequences can be terrible from both a human and economic point of view. Where they are absolutely essential such as in the Netherlands, these heavy civil engineering works will be regularly controlled and maintained.

In recent years a move away from complete flood defence towards flood management systems has been undertaken, driven at least in part by legislation stemming from the EU Floods Directive (European Parliament, EC Council 2007), as well as the limitations of flood defence that are exposed by climate change, increasing urbanisation, etc. Actions supported by the Directive concern areas where potential significant flood risks exist or are reasonably foreseeable in the future. For these areas flood risks has to be mapped in order to increase public awareness and support flood risk management plans, spatial planning and emergency plans.

In this context, one of the aims of the SMARTeST project is to derive guidance to improve the design of flood management systems. In the context of SMARTeST, a “system” is an assembly of elements and the interconnections between them covering urban flood under various flood type scenarios (riverine, pluvial, flash, coastal, groundwater, etc.) and embracing all flood management elements (warning appliances, emergency services organisation, drainage networks, flood risk models, protection, equipment, etc.) and over various scales from house to street to neighbourhood to city to conurbation to region to country.

Many tools are available that can participate in the design of such systems (e.g. protection equipment, construction water-tightening processes, urban hydraulic simulation software, damages assessment methods, training, information media, etc.). Some such tools were developed during the course of the SMARTeST project.

An added-value of the SMARTeST project has been to confirm (by means of case studies) that the availability of such tools is not enough to ensure that the claimed goals of a flood management system (e.g. limit damages to persons, built assets and goods, anticipate the crisis management, recover “quickly” after flood) can be fulfilled. What is missing is a full comprehension of the scope and of the limits of these tools as well as a framework to use them in a consistent way through different spatial and time scales.

Six key words/expressions are associated to this framework:

- **Coordinated actions**: the consequences of actions at a given scale have to be analysed both upstream and downstream in order to assess their impact on the whole concerned area (in order each can understand the ins and outs of considered alternatives and final decisions)
- **Consistency**: there is a need on the whole concerned area to check prevention/protection measures are consistent at different scales. No measure should hamper or even cancel the expected effects of other measures at a different location.
- **Co-production** should be organised by all stakeholders belonging to different institutions, geographical or administrative areas (in order to fully accept consequences of measures and to define compensation if needed).
- **People resilience** should be developed through planned actions aiming to disseminate information on the importance of anticipation, reactions and behaviours before, during and after flood (in order to create conditions for an effective operation of FReS)
- **Built environment resilience** should be clearly explained (in order to avoid misunderstanding and exaggerated expectations from “resilient systems/environments”). An urban area is a man-made complex system. The resilience property of such a system can only come from the choices of successive decision makers as well as from the way the urban system is maintained.
- **Smart technologies** have a high potential to support the design, implementation and operation of FReS. They may be essential elements of FReS designed and implemented through a co-production process aiming to develop coordinated actions relying on the resilience of people and of the built environment.

This guidance targets the following audience:

Those involved in investing in FRe technology (to protect the exposed population):

- Urban planners and designers
- Developers and their consultants
- Local authorities
- Environment agencies.

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1 Introduction

Development has taken place for thousands of years close to water (rivers, lakes, seas) due to the resources water brings, e.g. food, energy, capacity to economically transport persons and goods or recreation and to dispose of waste water. However, flood risk, including pluvial flooding, is a strong counterweight to these huge advantages. The constant growth of urban areas in such flood-prone zones despite these risks is a clear indication of the permanent choices of concerned human groups.

Urban floods have specific characteristics. Urban flooding typically has a negative impact on the populations of cities and towns. Urban settlements can be affected by all types of flood event, from the regular seasonal swell of a river through intense rainfall flash flooding, groundwater flooding, coastal storms, and coastal erosion and subsidence. As urban settlements encompass the major economic and social hubs of any national population, urban flooding is often regarded as of more moment than rural floods and typically causes massive damage and disruption beyond the scope of the actual floodwaters (Jha, A. et al. 2011).

(Zevenbergen et al, 2008) state that the year 2007 marked a turning point in history: half of the world population were now living in cities (www.unhabitat.org). Moreover, the trend of rapid urban growth throughout the mid-20th century in the developed world has shifted to the transition and developing regions of Asia, Latin America and Africa. Urbanisation has led to an increase in economic and social wealth in some places, but also to continuing poverty in others.

One of the unwanted side effects of this process of rapid urbanisation is the increased susceptibility towards flooding as the result of the concentration of people and assets in flood-prone areas, as previously many new and expanding urban areas are located along major water bodies. Furthermore, climate change may cause floods to occur more frequently and severely. This combination is likely to result in substantially larger flood impacts compared with former times, in which societies and environmental change drivers developed more slowly and societies continuously adapted to environmental changes.

Traditional means to protect exposure from flood aim to 'hold back' water by means of dikes or levees. Past and recent events demonstrate the limits of such an approach. Dikes may break or be overtopped. In this case, the consequences can be terrible from both a human and economic point of view. Where they are absolutely essential such as in the Netherlands, these heavy civil engineering works will be regularly controlled and maintained. The breach of a dike providing protection from the North Sea would have such huge consequences that adequate resources are spent to reduce the likelihood of such an event to low probability.

According to specific contexts, heavy civil engineering works are not the only technical solution to cope with flood. In some contexts, more local, not to say individual solutions (e.g. building opening barriers) are widespread though they also show limitations.

The most common source of flooding is when water levels in rivers rise so that the rivers overtop their banks ('fluvial' flooding). Another familiar source of flooding along coasts results from a combination of high tides and stormy conditions. Less well known by the general public, and less well understood, are 'pluvial' (rain-related) floods which occur following short intense downpours that cannot be rapidly evacuated by the drainage system or infiltrated to the ground. Pluvial floods often occur with little warning in areas not obviously prone to flooding (Houston D. et al. 2011). They are also difficult to manage because they are difficult to predict and it is challenging to provide adequate warning times.

In recent years a move away from complete flood defence towards flood management has been undertaken, driven at least in part by legislation stemming from the EU Floods Directive (European Parliament, EC Council 2007), as well as the limitations of flood defence that are exposed by climate change, increasing urbanisation, etc. Actions supported by the Directive concern areas where potential significant flood risks exist or are reasonably foreseeable in the future. For these areas flood risks has to be mapped in order to increase public awareness and support flood risk management plans, spatial planning and emergency plans.

Interest has increased in non-structural measures flood resilience technologies (www.floodresilience.eu, www.crue-eranet.net), which represent an important potential component of flood resilient systems. Flood resilience (FRe) technologies are in reality a range of items of equipment (Gabalda V. et al., 2013).

FRe technologies have limitations were highlighted in the SMARTeST research concerned with Flood Resilience Technologies (FReT) (Gabalda V. et al. 2012). Such limitations concern the ability of FRe technologies to be installed in time, their capacity to withstand both static and dynamic mechanical efforts and their intrinsic performances (e.g. ease of installation and leakage rate). A maximum water depth of less than one metre is also a specific limitation of opening barriers for ordinary masonry buildings (CLG, 2007).

A range of other non-structural measures are also advanced for catchment, city, community and property levels. These solutions, including the choice of construction location, indoor spatial organisation of building are nevertheless difficult to implement in dense areas where the changing population may not be aware of flood risk.

Technological developments open new perspectives to improve the situation in flood-prone areas at different phases of a flood event, as follows:

- before flood (numerical simulation, rain near-casting, warning, alert, e-education)
- during flood (underground reservoirs, surface storage capacity, “smart” barriers, pumping, low vulnerable construction materials)
- after flood (drying process, web dissemination of teachings from return of experience).

FRe technologies have nevertheless to be implemented in a complex organisational context where many different and sometimes competing interests are represented. The contribution of FRe technology to flood resilient systems is described and discussed within this guidance. The guidance takes a broad view of flood resilience as a starting point and combines this with the functionality required from flood resilient systems. Examples are given based upon systems at different scales.

1.1 The SMARTeST Project

The SMARTeST project (Smart resilient technologies, systems and tools – www.floodresilience.eu) was conceived in order to address many of the issues of integration of FRe technology into the overall approach to flood risk management. The project has addressed FRe technology from the perspective of encouraging innovation and developing an approach to standardisation of the technologies. As such the research has addressed the issue of standards harmonisation and production of good practice guidance. The project has combined understanding of FRe technology with a system approach and implementation tools. The SMARTeST project had the overall aim of improving the Road to Market of FRe technologies.

1.2 About the report

The report constitutes design guidance for FRe systems, particularly in urban areas. The guidance is evidence based through the SMARTeST project research. It analysed information on flood management system (FMS) and on the emerging concept of flood resilient system (FReS) (Salagnac J-L et al. 2011). The research determined that successfully implemented FMS are based on a holistic approach, as follows:

- encompass multi-scale territories, e.g. river basin, non-urbanised expansion zones, urban areas, quarters and buildings in the case of river flood,
- design and implementation is a long term process (several decades),
- development requires long negotiations with all concerned stakeholders in order to define acceptable situations for stakeholder groups in the case of flood event as well as possible associated compensations,
- constrained and guided by multiple regulations.

The research presented a critical analysis of FMS proposed in various locations to improve exiting situations (Salagnac J-L et al. 2012), addressed through a series of case studies. The case studies confirmed the diversity in flood events and impacts throughout Europe that is underlined by the directive. The research also confirmed the great diversity of detailed objectives of flood management practices in Europe.

Different approaches were identified in the case studies; the two main aspects are described here (i.e. pragmatic and systemic). The research has shown the gap between an existing situation and the conditions required to design and implement FMS leading to FRe systems.

Pragmatic approach

The pragmatic approach is mainly found in community scale situations. Solutions are developed that are based on responses to past flood events, e.g. observed flood situation in conjunction (when available) with flood patterns. It may consist of the implementation of aperture barriers in order to avoid flooding of specific buildings where possible future events are “similar” to the reference flood.

Systemic approach

The systemic approach tries to encompass several spatial scales in order to identify measures along the flood pathway that can limit impact on receptors. It may consist of the examination of several scenarios where measures are defined on different scales (e.g. an upstream expansion area or storage capacity in an urban area). The design of these measures has to be consistent with the overall objectives to be defined for the concerned area (more or less important protection of designated sub-areas).

Both approaches seek to reduce the vulnerability of urban areas, but they differ from a methodological point of view. Nevertheless, in both cases, it is very important to emphasise that the proposed measures are valid below a certain hazard level and are no more valid beyond this level.

This report constitutes guidance and a ‘manual’ for the development of flood resilience of the built environment based on the evidence from the research. The guidance targets the following reader groups (Figure 1):

Figure 1: target groups of the FReS guidance source TUHH

The structure of this report mirrors the topics that were debated between SMARTeST partners:

- Chapter 2 addresses system resilience issues
- Chapter 3 presents prerequisite for successful FReS implementation as well as a generic approach of FReS
- Chapter 4 illustrates the FReS approach with some examples
- Chapter 5 presents guidance for FReS design and implementation
- A concluding chapter gives perspectives for the use of the proposed guidance.

2 Flood resilience

2.1 Why is flood resilience required?

Flood scientists, engineers and policy makers have proposed that resilience to flooding can be obtained through a systems approach (de Bruijn, 2005). It is expected that flood resilient systems will be better able to cope with flood events. In the Floods Directive (European Parliament, EC Council 2007), on water management, however, 'resilience' and 'resilient water systems' are not clearly defined. Resilience has a positive connotation although it is difficult to explain what the positive aspects of resilient systems for flood management are exactly.

As resilience is a system property, it should be applied to flood risk management by adopting a systems approach. Resilience is defined as the ability and the ease by which a system can recover from floods, but as this chapter explains that is a complex situation and an understanding of the system is necessary.

The resilience of a system can be assessed through qualitative or quantitative means. For example, in SMARTeST the development of flood damage models (HOWAD-PREVENT and FLORETO-KALYPSO), can be used to provide information on the extent and cost of damage to property in a flood. The intervention of, for example, FRe technology can result in the reduction in physical damage and reduce repair costs for a property. More basics measures such as a reduction in the loss of life can also be addressed.

This Chapter introduces the user to the scope and concept of flood resilience. It places into context the potential for individual measures (e.g. FRe technology to contribute to the resilience of an urban system).

2.2 Contents

2.2.1 The scope and concept of flood resilience

Resilience was introduced some years ago as a means of managing natural and industrial risks in urban areas (Vale L.J., Campanella J.T. 2005). The audience for resilience is international, e.g. in the United Nations Office for Disaster Risk Reduction campaign: "Making Cities Resilient" (UNISDR 2010). The resilience concept was earlier introduced in several domains, e.g. mechanics (ISO 2009), acoustics (ISO 1989), ecology (Holling C.S. 1973) and human psychology (Tisseron S. 2011). Each domain has its own definition that looks to share some common elements. The often quoted property: "bouncing back to the initial stage" used to describe how a system recovers after a 'shock' or an adverse event is perhaps too simplistic and it is necessary to analyse complex interactions in order to develop an understanding of system resilience.

The following questions could for instance be addressed in line with theoretical frameworks addressing complex systems issues (Le Moigne J-L. 1977).

> *Question*: Is (flood) resilience an attempt to qualify how an urban system can be regulated, i.e. how the functions of this system can still be fulfilled in case of a moderate flood?
>
> *Answer*: In this case, simple and routine measures can be enough to face rather frequent situations. An example could be the “acqua alta” phenomenon in Venice. During these frequent events, several per decade, city-dwellers and tourists adapt to the temporary situation by installing opening barriers to limit water ingress into buildings and by using raised walkways.
>
> *Question:* Is resilience an attempt to qualify how an urban system can adapt in case of major flood, i.e. how expected functions can still be partly fulfilled with an acceptable/accepted level of performance?
>
> *Answer*: In this case vital infrastructure can be impacted by a major flood. Some fatalities can be recorded. The economic impact can be significant. But the context is such that the behaviour of the population and of concerned stakeholders does not make the situation worse. The population is an informed one and is aware of the flood management strategy of flood authorities. Communication on the flood events and actions being taken is frequent, via mobile phone networks for instance. Technology to manage flood water can be so that critical infrastructure can be operational again a few days after the event. A reduced mode of operation can be accepted (e.g. lower safety) as it is known to be temporary and the trust of the population is maintained through communication. An example could be the October 2012 Sandy event in New-York. The metro network stopped for a number of days until water was pumped from tunnels. The traffic then started again though all signals and controls were not in operation (Guillois R. 2012).
>
> *Question*: Is resilience an attempt to qualify the possibility for elements of an urban system to reorganise after an extreme flood event, i.e. to create a new urban system?
>
> *Answer:* A dike breach may cause a significant number of fatalities and a large area will remains inundated for days or weeks. Economic consequences are substantial and some activities may not recover at the same place even years after the event. After the flood water recedes it is not possible to “bounce back to the initial state” as buildings and infrastructures have collapsed and the population is not able to come back for economic, human and social reasons. Some of the technical elements (e.g. communication networks) mentioned during the previous example can help the population to be rescued, but the ‘shock’ is extreme and can result in a complete change of the urban area after the event. An example could be the New-Orleans Katrina event in 2005.

This latter case shows that the consequences of an extreme event could not be readily anticipated. Even for less important events a thorough flood risk assessment with defined events and consequences is a key component of resilience.

2.2.2 Current flood management practice and resilience

Flooding is the most frequent and devastating natural disaster (Guha-Sapir D. et al. 2012) in terms of both human and economic damages. There is a concentration of damages in the urban environment due to the high exposure. Unlike some natural hazards (e.g. earthquakes), flood hazards are clearly linked to human interventions that modify water flow patterns in an area. Some man-made issues are as follows:

Impervious surfaces are constantly increasing so that rain water cannot seep into the ground and instead it runs off artificial surfaces:

in France, these surfaces covered 5% of the metropolitan territory in 2006 and increased by 3% between 2000 and 2006) ((MEDDE-CGDD 2012),

In Greece, impervious surfaces have noted an increase of 4% in 2009, towards the corresponding sealed area of 2006. The increase of 4% corresponds to 91km^2, resulting to an overall of sealed area is 1.8% of the total country area by 2009 (Boulougari E. 2012). In 2004, Greece was considered as one of the top 100 countries in terms of constructed impervious surface area (ISA) with 1.543 ISA km^2, a population of 10.090.290 and 153m^2 ISA per person) (Elvidge C.D. et al. 2007).)

Increasing urbanisation creates routes for water that can lead to devastating effects due to torrential flow (i.e. water can run along streets),

Drainage systems (aiming to “compensate” the lack of water infiltration on artificial surfaces) represent huge investments and are not always constructed to meet the pace of urban growth. In addition, the maintenance of the drainage system may not always be effective and the drains can become clogged and consequently inefficient.

Dikes and levees confine water up to a certain limit, but when the limit is exceeded, a flood occurs with devastating effects. Buildings close to the overtopping generally collapse or are at least severely damaged.

Other concerns are as follows:

Although they are frequent at the world scale (EM-DAT 2008) flood events are generally rare at a local scale during a human-life time so that the memory of past events is often lost and the awareness of population and decisions makers remains low,

The maintenance of infrastructure that aims to prevent flooding or to protect urban areas from flood is faultless,

The ageing of the drainage infrastructure, as a lot of the sewerage and drainage networks in Europe are old and their condition is unknown,

- Unplanned urbanism increases flood impacts due to unsuitable land use change (UNISDR 2012). Surrounding changes in land use such as deforestation lead to decreases in natural capacity to slow down water flow. Soil erosion can also be increased.

Intense flood events in urban areas and specifically drainage overflow may lead to serious cases of pollution.

2.2.3 On the road to resilience

In flood resilience systems an early warning, coupled to efficient weather forecasting, could trigger the installation of measures designed to ensure the protection of people, property and possessions. The detailed design should be system specific so as to take local factors (topography, type of flood, surface and underground built environment, etc.) into account. Measures such as raised kerbs could channel flood water to limit contact with buildings (Figure 2). However, a "one-size-fits-all" solution is not possible.

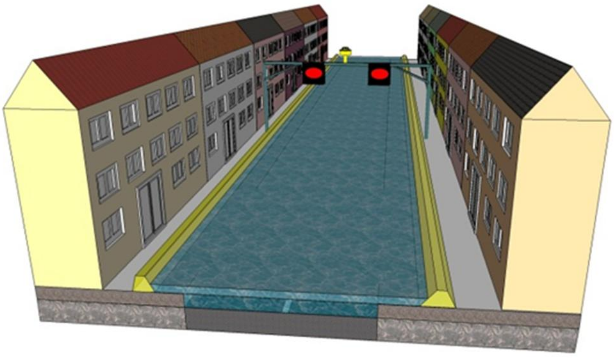


Figure 2: raised kerb (source: Palmarricciotti et al, 2012)

In this ideal system, protection measures and organisation of rescue teams (before, during and after the event) would be designed so that the recovery period after the flood event would be simple. The urban area could quickly forget the inconvenience caused by the flood and business would rapidly be as active as before and could even remain undisturbed. Weak points of the system would be identified, analysed and improvement actions taken to strengthen the system. Therefore, the system becomes a quality system with continuous improvement at its core.

The case studies examined in SMARTeST research indicate that the flood resilient systems do not typically exist today. Society typically remains removed from the situation described above. Appropriate FRe technologies may already exist or are close to being realised, but other aspects of the system mean that their effective implementation is rendered impossible. What the case studies do show is that implementation also has to take each local context into account. Moreover, flood is just one among many other concerns in an urban area. The built environment is planned, designed, built, operated and maintained to satisfy many and sometimes contradictory functions.

As with other natural hazards, flood impacts can occur over several geographical and population scales. Each geographical scale (from individual buildings to the river basin in the case of fluvial flood) has its own rules (administrative, economic, traditions, etc.) and each population scale (from individual to the regional population) has its own rules (belief, tradition, governance).

The creation of expansion areas is for example an efficient measure to limit flood hazard at the scale of an urban area making more room for the river lowers the average water height (http://www.ruimtevoorderivier.nl/). Creating such areas requires integrated urban planning and civil engineering techniques, but the decision process is complex and involves analysis of upstream and downstream consequences, acceptability, compensation mechanisms for negatively impacted stakeholders, land ownership, financing and responsibilities for maintenance.

2.3 Outcomes

Urban flooding is as ancient as the first cities that were established some millenniums ago. In the past, societies had a need to be resilient as there was limited 'state' input to flood defence. However, as engineering developed along with society the resilience of the urban environment to flooding typically reduced as flood defence became administered and standardised.

Climate change and urban development will impact on local flood management by decreasing or increasing the frequency and intensity of events. Flooding therefore becomes a manifold problem, with the following questions being asked from the system design:

- What can be done to protect people, possessions and goods?
- What level of protection is required, and what are the priorities?
- Can urban development be properly managed in flood prone areas?
- Is it possible to accurately predict the occurrence of flood events (e.g. via precipitation near-casting tools)?

In recent years there has been a realisation that flood management rather than defence is required, as it is accepted that flood events cannot be completely avoided. The principles driving flood resilience are as valid today as they were to past societies. The development of flood resilient systems can be helped by advances in technology. However, urban designers should understand that the availability of FRe technology alone is only part of the design flood resilient systems.

The following chapter outline some key elements to be considered on the road to FReS development.

This chapter is mainly based on data collected from SMARTeST case studies (Table 1) and from participant's contributions during the National Support Groups (NSG) meetings organised locally by partners. Several of these case studies were further analysed using the SMARTeST tools. These case studies cover the most important types of flood.

Partner	Partner country	Case study location	Flood type
Dion Toumazis & Associates	Cyprus	Paphos	Coastal
ENPC-CSTB	France	Villecresnes Jouy-en-Josas	Pluvial Fluvial + pluvial
IOER	Germany	Dresden	Fluvial
NKUA	Greece	Athens	Fluvial
TU-DELFT	Netherlands	Rotterdam	Pluvial
UPM	Spain	Valencia	Fluvial/coastal
UNIMAN-BRE	UK	Heywood	Pluvial

Table 1: list of SMARTeST case studies

3 Flood resilient system approach

3.1 Introduction

3.1.1 Choice of a generic situation

The main goals of a FReS do not fundamentally differ from the goals of a traditional flood management system. They both aim to limit damages to people, property and possessions as well as to create conditions for the recovery of flooded areas as fast as possible.

The main difference lies in the approach of the situation. FReS development tries to encompass a multi-scale territory and to create favourable conditions for a co-production of acceptable decisions for the concerned stakeholders.

By principle, such an approach rejects “not in my back-yard (NIMBY)” attitudes that could lead to decisions having negative consequences to neighbouring areas (e.g. a protection installed to protect a building or an area could divert water to neighbouring buildings/areas that were not previously inundated).

On the contrary a flood resilient approach tries to anticipate the consequences on other areas of decisions aiming to protect urban areas. The prerequisite for such an approach that are needed are presented in the following sections.

A particular flood type (i.e. fluvial type) has been chosen to present the proposed approach. This choice does not restrict the view of the SMARTeST project to this type of flood. The reader interested in other flood situations should easily transpose proposed developments to other contexts using the “source/pathway/receptor” (SRC) scheme.

For instance, pluvial flood, that has particular importance in urban areas, can be easily addressed using the proposed generic approach. In this case, the source is precipitation, streets and drainage networks are respectively surface and underground pathways and the built environment is the receptor.

Table 2 summarises the connections between the chosen generic situation and other current flood situations.

Type of flood	Source	Pathway	Receptor
Fluvial		River course	
Pluvial	*Precipitation*	Streets drainage network	Urban areas District Buildings
Flash			
Coastal	Sea water level	Sea shore	

Table 2: correspondences between SRC scheme and flood types

3.1.2 Representation of territories

Figure 3 is a simplified representation of a river basin territory. It includes different spatial territories along the water course, as follows:

- the river basin,
- expansion zones that are generally non- constructed areas,
- the urban area with sub-scales: districts and buildings. Buildings include any kind of construction hosting any kind of activity (e.g. industry, hospital, school, shops, offices, housing). Water can flow above and under the ground surface.

The boundaries between territories are convenient for presentation purpose. Flood prevention/protection measures that are elements of the flood resilience system covering the river basin, can be clearly located on such a figure. In reality, concrete situations are much more complex than the representation might suggest.

A system is not just a matter of spatial scales. The connectivity between the elements of a system is not limited to the boundaries between spatial areas, but also includes relations between stakeholders, institutions, administrations acting in the concerned territory.

This complexity is not explicitly shown on Figure 3 but will be addressed in the following sections.

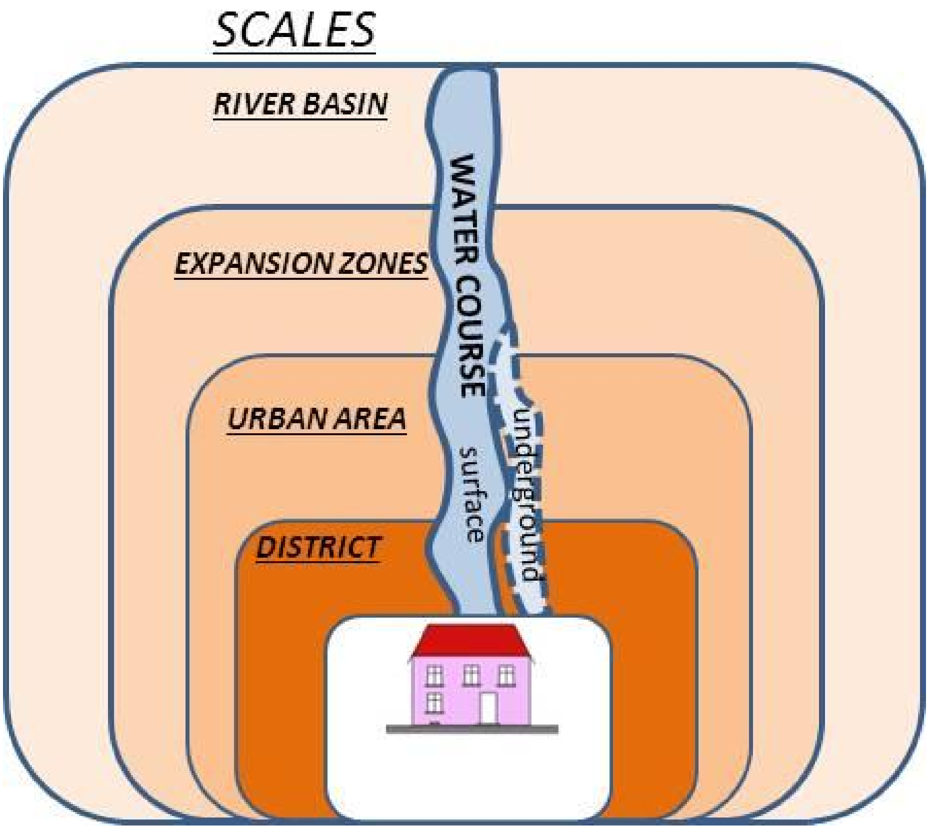


Figure 3: simplified representation of a river basin Source SMARTeST

Of course, it must not be forgotten that the concerned territory is a tiny part of wider domains in which it is embedded (Figure 4). This means that the design and implementation of FReS has to be considered in the long term perspective linked with climate change issues.

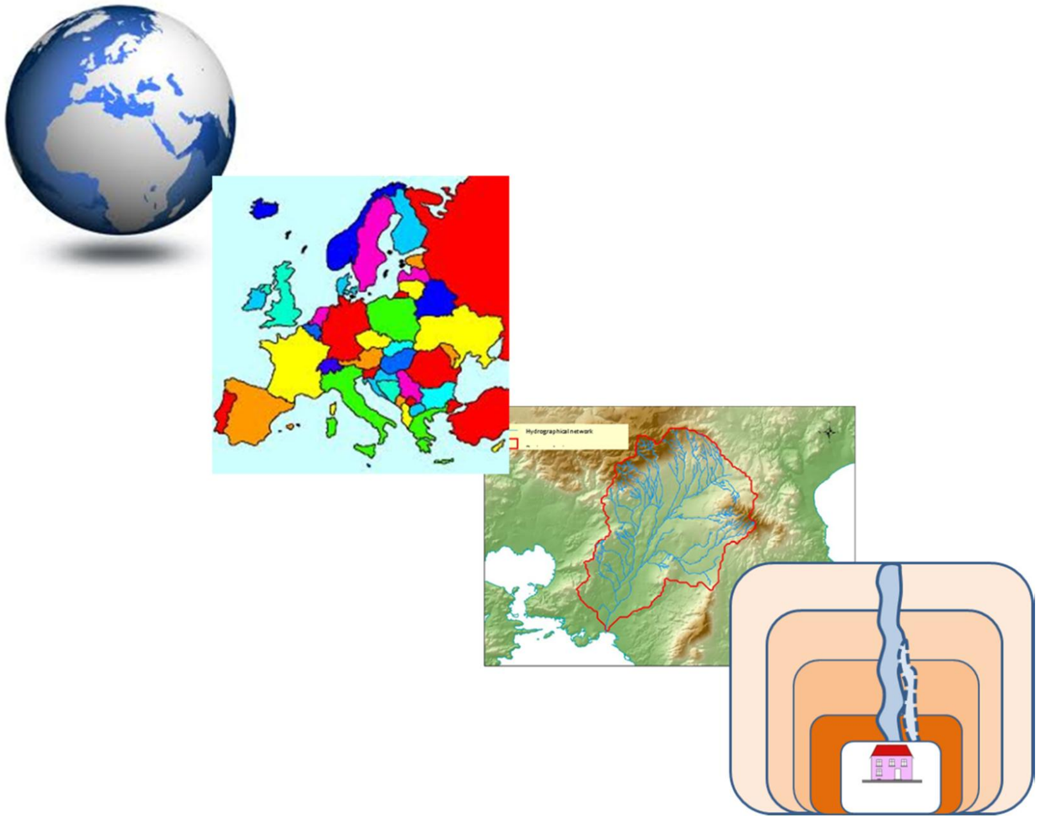


Figure 4: embedded scales

3.1.3 Representation of the FReS design process

For presentation purposes, the generic approach presented in 3.3 is divided in to four sections that correspond to four “steps” as shown in Figure 5. This presentation might suggest that the proposed method is linear, starting from step 1 and ending at step 4.

In reality, the process that ends by the implementation of a FReS is all but linear. Constant feedbacks between “steps” are essential. They depend on each particular situation so that it is not possible to show them once and for all.

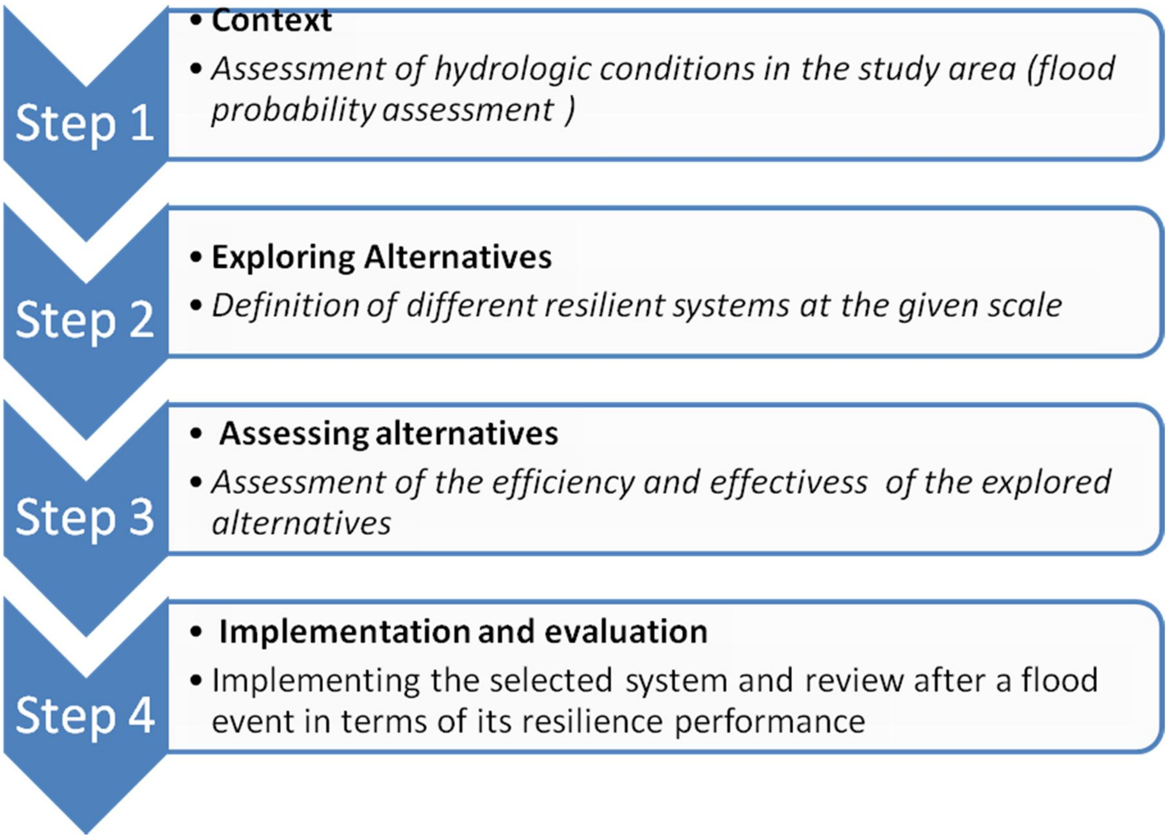


Figure 5: representation of the “steps” of the generic approach
(feedbacks between steps not represented)

3.2 Prerequisite

In the context of SMARTeST, a “system” is an assembly of element. The interconnections between them covering urban flood under various flood type scenarios (riverine, pluvial, flash, coastal, groundwater, etc.) and embracing all flood management elements (warning appliances, emergency services organisation, drainage networks, flood risk models, protection equipment, etc.). It includes various scales from house to street to neighbourhood to city to conurbation to region to country (Lawson N. et al., 2011).

An urban area is a man-made complex system that is designed, built, transformed and maintained by many different loosely coordinated stakeholders over a long period of time. During this period the “environment” of the urban area is highly variable. It may change because of many factors, e.g. general economy, increase/loss of local attractiveness, exploitation of local natural resources and abundance or scarcity of fundamental resources such as water.

The time horizon of local authorities and of city-dwellers is up to one, maybe two decades and the emergence of one of the above mentioned factors and their interactions is difficult to anticipate.

Decisions concerning natural risk management have to take an uncertain future into consideration. All information that can guide such a future is necessary to start thinking of a flood resilient urban system. The following list is not exhaustive but contains relevant items:

- long term (decades ahead) vision on the local development (strategic planning),
- consider flood as one among other hazards according to the local situation,
- strong commitment of local authorities and other decision makers to keep an open vision of the urban area development,
- coordination between private/public decision makers to avoid silo-thinking,
- reflexion on priorities according to the local situation,
- permanent concern to inform, educate, raise awareness of the concerned population,
- assessment of FRe technology to provide sound information to different groups (designers, contractors, facility managers, individuals) on the performance of these technology as well as on the conditions to obtain these performances (design rules, implementation, maintenance),
- update plans (alert, evacuation, rescue, recovery),
- Climate change and its potential impacts.

Many of these items should be addressed when designing a flood management system or when planning the development of an urban area. Thinking in terms of resilience may be favourable to effectively address these items from a global point of view.

3.3 Generic approach

3.3.1 Context

According to local contexts, different kinds of actions and measures can be implemented at the different scales of the domain. Figure 6, based on the spatial representation of Figure 3, gives examples of such measures. Such measures aim to mitigate the impact of flood by delaying water flow along the water course, limiting run-off or limiting direct water ingress in buildings. At the building scale, an alternative strategy (i.e. wet proofing) is to allow water in the building. The use of appropriate construction materials is likely to limit damages. FReT at the building scale was extensively developed in the project.

The flood warning and alert system is also represented on figure 6. Messages can be transferred to the most appropriate scales according to context.

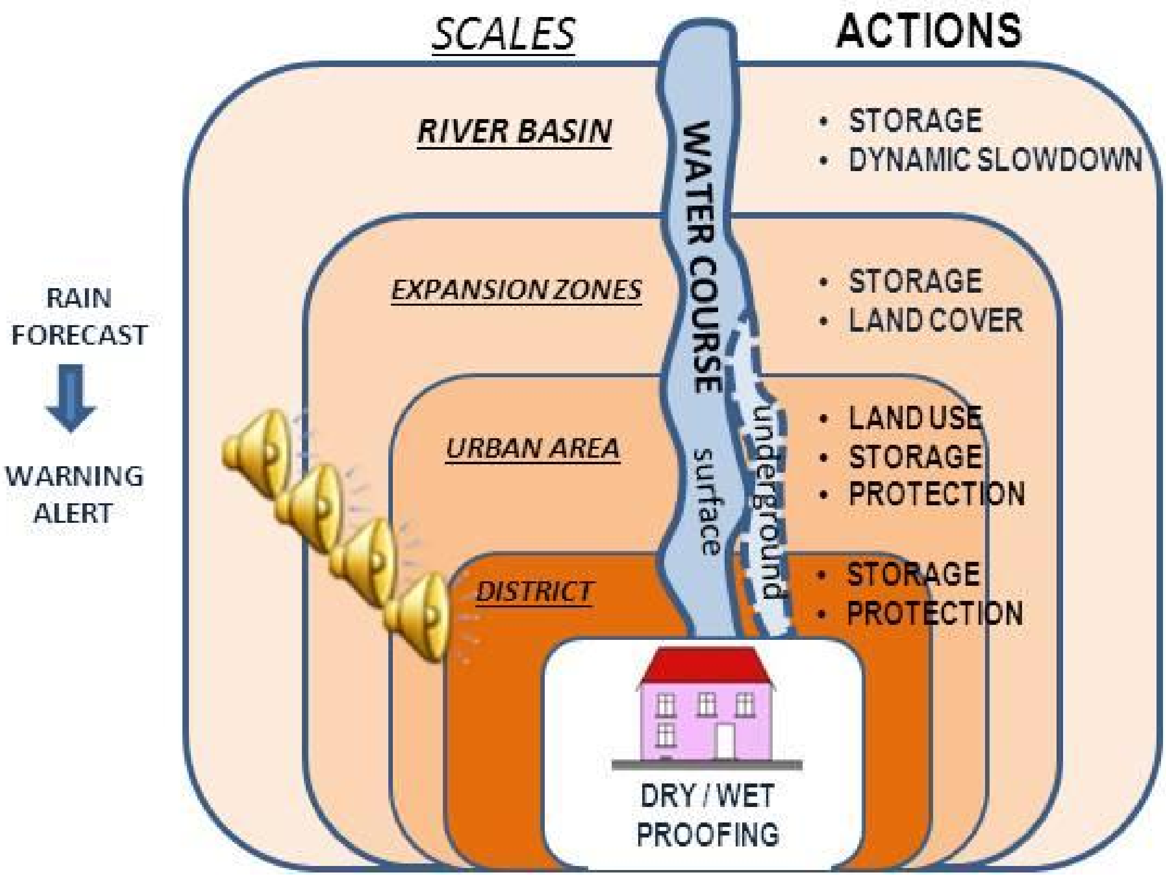


Figure 6: examples of actions at different scales of the domain Source: SMARTeST

3.3.2 Exploring alternatives schemes

The expectations from FMS are as follows:

- To limit damages to persons, built assets and goods,
- To anticipate the crisis management,
- To recover quickly after flood.

Combining different possible measures at different scales gives many possibilities to be considered when addressing flood management in a specific area.

The added value of FReS comes from the association of measures and corresponding actions that are selected according to the following rules:

Coordinated actions: the consequences of actions at a given scale have to be analysed both upstream and downstream in order to assess their impact on the whole concerned area. The SMARTeST project developed tools that help assessing such consequences. Tools developed in the SMARTeST project (FRe technology implementation tools) allow the assessment on both the hydraulic pattern (MULTI-HYDRO tool) and the buildings damage (FLOReTO, HOWAD-PREVENT tools) for a given set of prevention/protection measures.

- **Consistency**: there is for instance no need to design for aperture barriers at the building scale if the water level is likely to be more than a meter in depth. More generally there is a need on the whole concerned area to check prevention/protection measures are consistent at different scales. No measure should hamper or even cancel the expected effects of other measures at a different location. Resources spent to check consistency are useful to avoid misleading decisions. Checking consistency is not a decision process in itself but it participates in the decision. The implementation of consistency checking actions has to take the institutional, administrative and organisational complexity of a territory into account as highlighted by investigations of WP5 (Integration and practice for FRe technology).

- **Co-production** should be organised by all stakeholders belonging to different institutions, geographical or administrative areas. This would create favourable conditions for full acceptance of the consequences of measures. Both positive and negative consequences must be exposed and debated. If necessary, compensation mechanisms must be defined to balance the acceptance by some members of a temporary burden for the benefit of the community.

- **People resilience**: FReT can contribute to limit damages but a FReS cannot just rely on technology. For long, information dissemination, awareness raising or training actions have been identified as key issues in addition to technology implementation (the flood guides developed within the SMARTeST project are examples of awareness raising documents for the public). These actions contribute to capacity building of the exposed population in order to better cope with flood situations. They have to be organised in a long term perspective, for a constantly renewing population. People resilience is essential for a successful operation of a FReS. The way the exposed population anticipates, reacts and behaves before, during and after flood creates the conditions for an effective use of FReT. These points were addressed through integration of good practice in FRe technology within the project.

- **Built environment resilience**: the intrinsic capacity of buildings to withstand physical and chemical impacts of (polluted) water can be improved by means of FReT measures. The work carried out in SMARTeST confirmed that the scope and limitations of such measures must be acknowledged. Ordinary buildings (e.g. individual housing, warehouses) cannot be waterproof for any water depth. Moreover, waterproof buildings would support static pressure and buoyancy forces that are not compatible with the mechanical resistance of ordinary buildings. This fact must be understood by all stakeholders in flood-prone areas. Unless the water depth is less than a meter at the building level, wet proofing is the only alternative to be considered. As flood water will penetrate buildings, measures have to be anticipated to limit damages (e.g. raising equipment and furniture, use low vulnerable construction materials). This latter measure must be considered with precautions as a construction work results from the assembly of materials: the use of “flood-resilient” materials does not guarantee that the building will suffer no damage.

- **Smart technologies**: where and when automatic actions are pertinent (e.g. continuous surveillance, assistance to alert, possible absence of operator, necessity to move heavy equipment), smart technologies can provide smart solutions. This is particularly true for precipitation near-casting: the reliability of the alert depends on accurate information that can be produced by e.g. X-band radars (appendix 5). Whatever smart technology is implemented, maintenance of the concerned equipment must be carefully planned. The reliability of these technologies is essential. Some of them are likely to be activated rather frequently such as rain radars but some others will be activated only from time to time (once/twice per decades). In this latter case, frequent training will ensure that instructions are transferred to operators.

According to each context, the identification of possible measures and of their pertinent combination allows setting alternative schemes as illustrated on Figure 7.

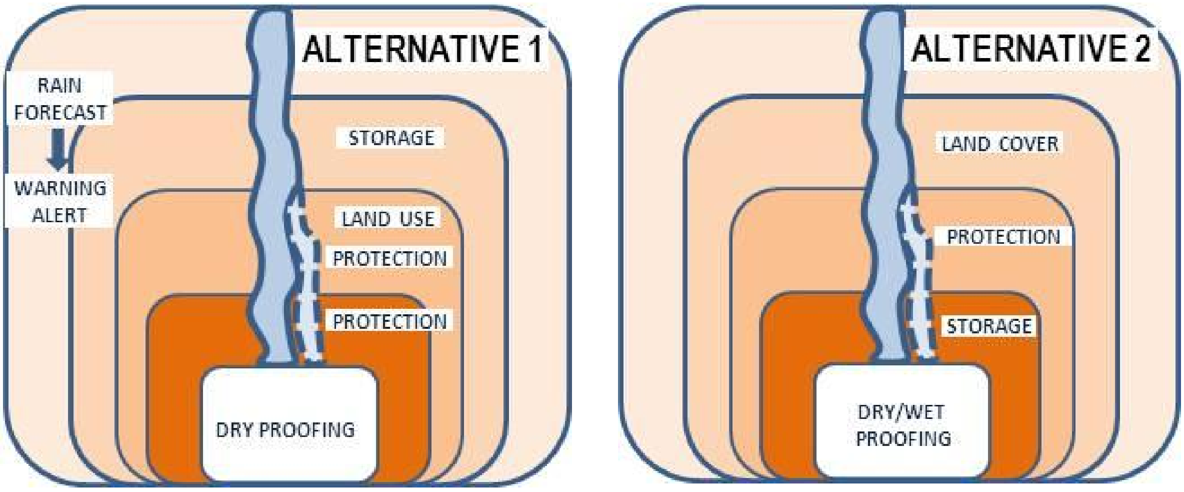


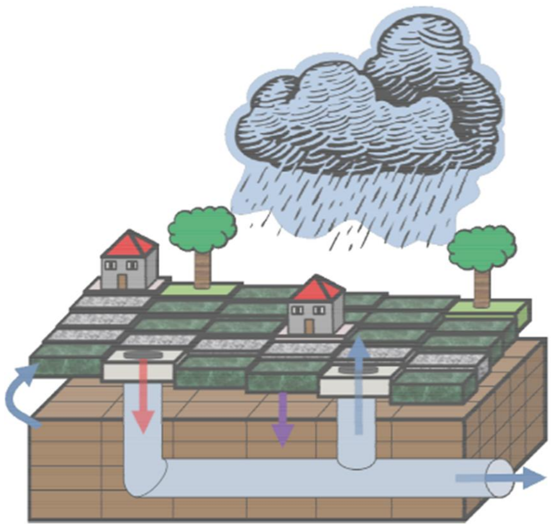
Figure 7: examples of alternatives FReS Source: SMARTeST

3.3.3 Assessing alternative schemes

The SMARTeST project has developed tools that allow the assessment of the following aspects for each identified scheme:

Surface and underground water-flow patterns: the MULTI-HYDRO model (Figure 8) can simulate the flow of water in a drainage network as well as around buildings. It takes into account any measure (e.g. barrier, reservoir) that could be implemented in the simulation area. Calculations are made for any virtual precipitation pattern.

Building damages: the FLOReTO tool (Figure 9) developed by TUHH and the HOWAD tool (Figure 10) developed by IOER provides damage assessment according to the characteristics of buildings and to the type of FReT used.



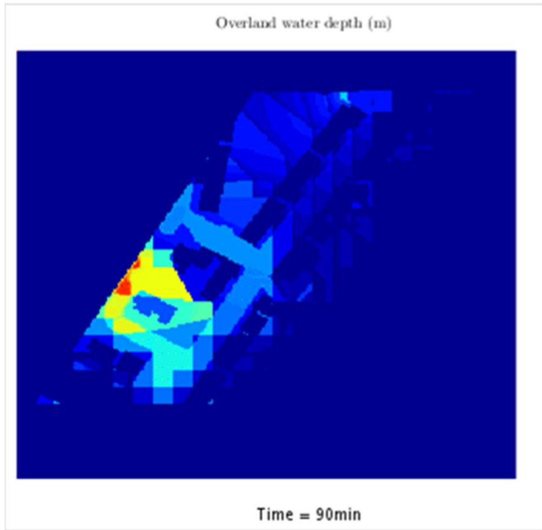
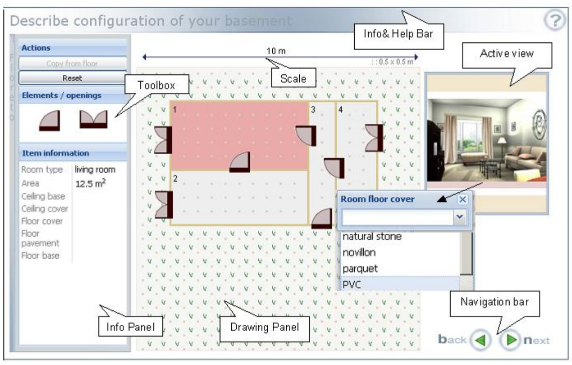


Figure 8: MULTI-HYDRO principle (left) – water depth simulation (right) Source : ENPC



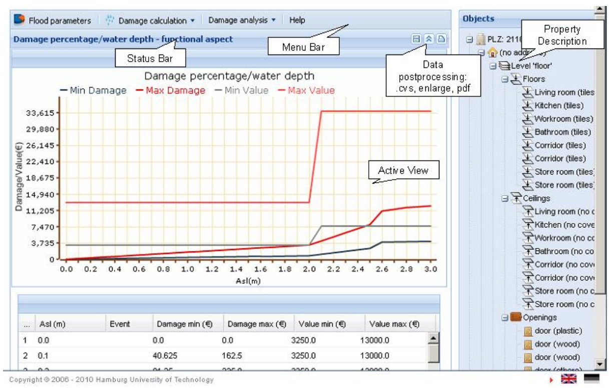
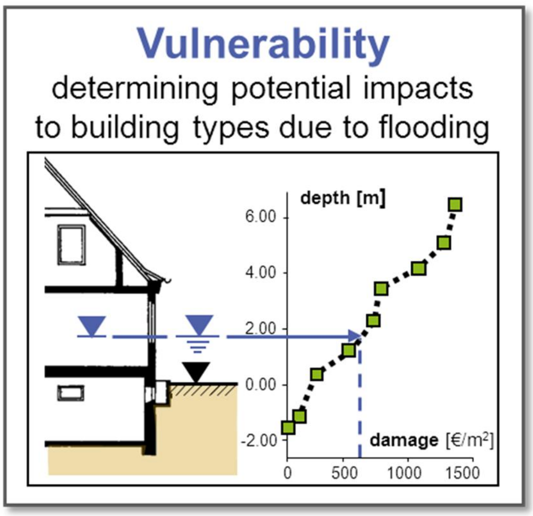


Figure 9: FLOReTO building description (left) – damage output curves (right) Source: TUHH



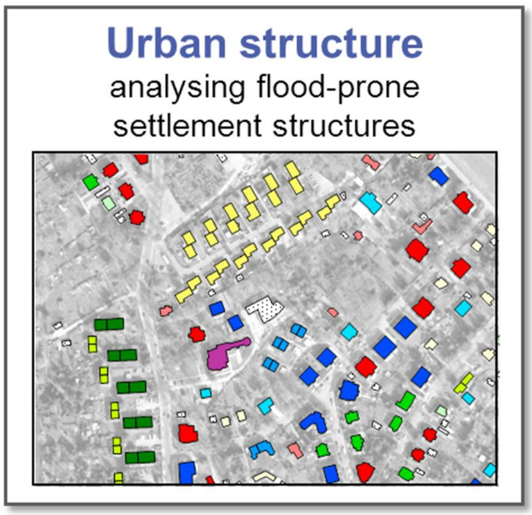


Figure 10: HOWAD – PREVENT principle (left) – district damage analysis (right) Source: IOER

3.3.4 Implementing FReS

It is clear that the process leading to the implementation of a FReS is all but linear. Strong interactions do exist between the definition of measures, their selection and association with each other.

In this last sequence, the actions to be carried out to consolidate decisions are described.

A water basin (or a coastal area) is rarely a standalone territory. There are generally many administrations and institutions that influence different parts of this territory. They all have their own prerogatives (e.g. on natural resources, on water management, on urban planning).

This situation is illustrated on Figure 11 with an administrative limit representing a simple case. If land use is for instance a key element of a FReS to be implemented in the area, corresponding decisions have to be coordinated by the two administrative entities.

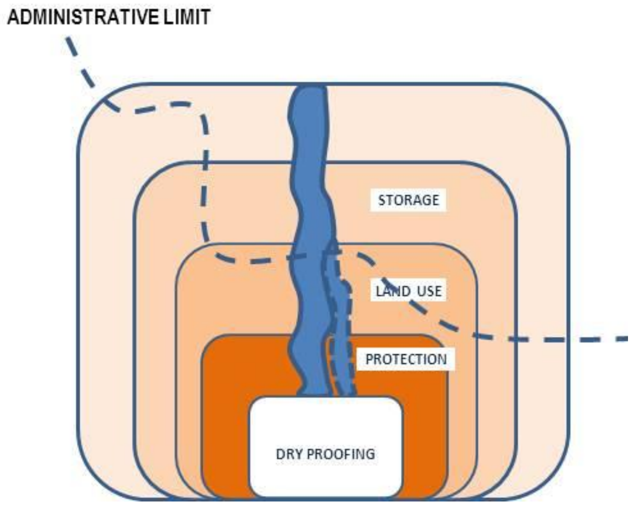


Figure 11: administrative limit crossing a flood-prone area Source: SMARTeST

An overall evaluation of many issues (e.g. technical, economic, financial, administrative, Institutional, organisational) has to be processed to come to a decision of coordinated and coherent actions.

A key element of this process is the participation of all stakeholders in order for them to share and accept final decisions.

Time is a key consideration of FReS design and implementation and can be closer to decades than years. This will be illustrated by an example in chapter 5 where thirty years were necessary to come to the implementation of a full system accepted by stakeholders.

4 Illustrations of the FReS approach

The four phase approach (description of context, alternative schemes, assessment of alternative schemes and implementation) presented in chapter 3 is illustrated in section 4.1 by three SMARTeST case studies, as follows:

- Jouy-en Josas (France)
- Villecresnes (France)
- Heywood, Manchester (UK)

In these case study examples, potential FRe systems are proposed, which include the implementation of a variety of FRe technologies and diversion, conveyance and storage measures.

4.1 Case studies

4.1.1 Jouy-en-Josas (France)

4.1.1.1 Description of context

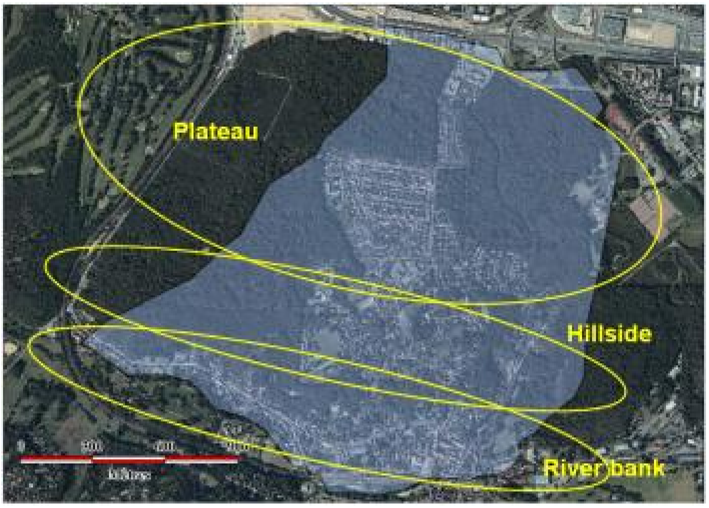


Figure 12: Jouy-en-Josas case-study area Source: ENPC

The city is located along the Bièvre River, a tributary of the Seine River in the South of Paris. This case study concerns a 2.5 km² area of the city located on the left bank of the river (Figure 12).

This area can be subdivided into:

- The river bank: a flat area where most of the public facilities are located and where the river is mainly culverted in underground pipes or in an artificial channel;
- Hillside: steep area, not highly urbanised;
- Plateau: an urbanised area, its impervious surfaces generate additional run-off to the river bank.

The last major flood experienced by Jouy-en-Josas was on July 21, 1982, where 96.2 mm of rainfall fell within one hour; causing a 20 cm deep rapid flow of water.

4.1.1.2 Alternative schemes

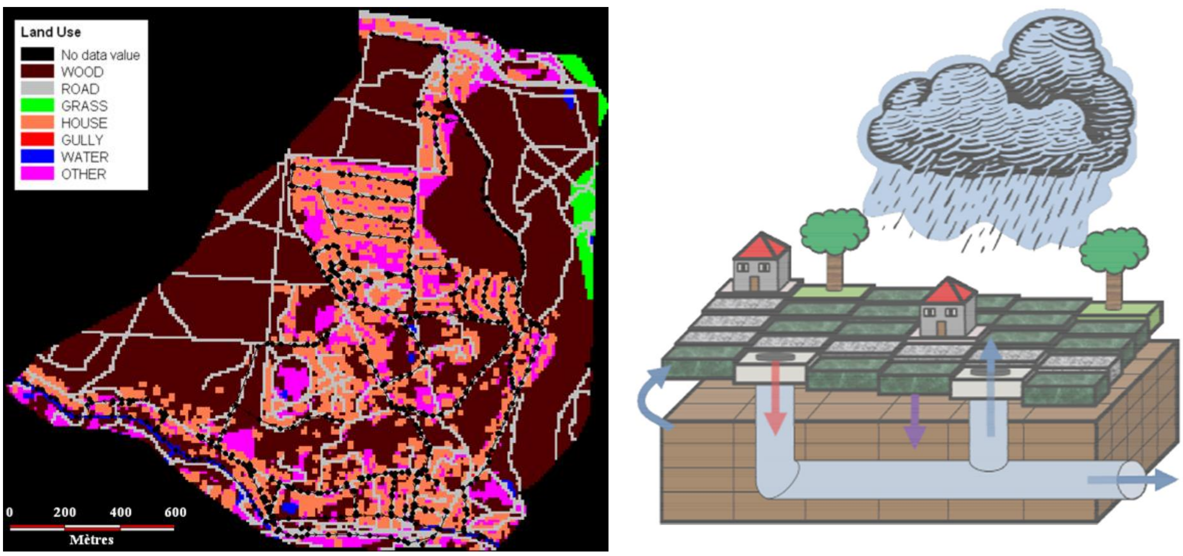


Figure 13: changes in land use proposed as a solution

Source: ENPC

The city proposed plans to develop flood-resilient buildings and sport facilities near the river. The stakeholders investigated possibilities to implement a FRe system. Public discussions were held to help determine which FRe system should be tested. Two alternative scenarios were assessed by modelling a change in land use cover in the tool MULTI-HYDRO with a 10 m resolution. MULTI-HYDRO is further discussed in Appendix 4.

4.1.1.3 Assessment of alternative schemes

MULTI-HYDRO was adopted to assess the proposed alternative schemes.

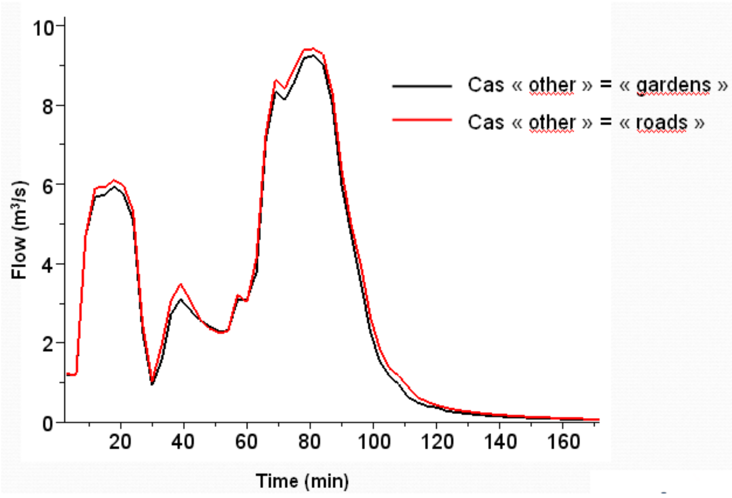


Figure 14: flow at the outlet during a rainfall event of 100mm within 4 hours Source: ENPC

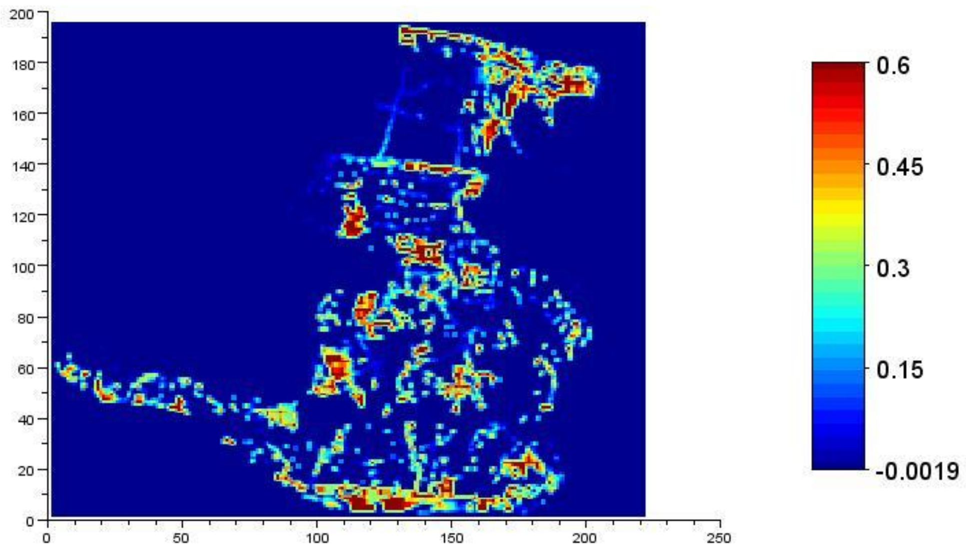


Figure 15: differences in maximum water depth of the alternative schemes Source: ENPC

4.1.1.4 Implementation

SMARTeST project partners met with the majority of the stakeholders involved in the urban planning of Jouy-en-Josas. The stakeholders explained that the main objective of a local FRe system would be to enable building in potentially flood-prone areas. The stakeholders would prefer a simple FRe system, whose functioning would be mainly automatic.

4.1.2 Villecresnes (France)

4.1.2.1 Description of context

Figure 16: location of Villecresnes Source: ENPC

Villecresnes, a city of 10,000 citizens is located in the south east of the Paris region. The city has been involved in the national strategy for sustainable development and its Local Plan of Urbanisation promotes collective housing in an aim to protect green areas from development. The last major flood in Villecresnes was on July 22, 2009. It was classed as a ‘natural catastrophe’, in French law. After the flood, the city adopted a Policy of Flood Protection and Risk Management.

4.1.2.2 Alternative schemes

The area is 7200 m^2, with a drop in elevation from 120 to 50 meters. Four FRe systems were proposed to investigate whether or not the gymnasium at the location shown in Figure 17 could be prevented from flooding. These systems are as follows:

Protection at building level;

- Adapting the adjacent tennis court for temporary retention;
- Channelling roof-collected rainwater;
- Implementing a perimeter barrier (Figure 17 and Figure 18)

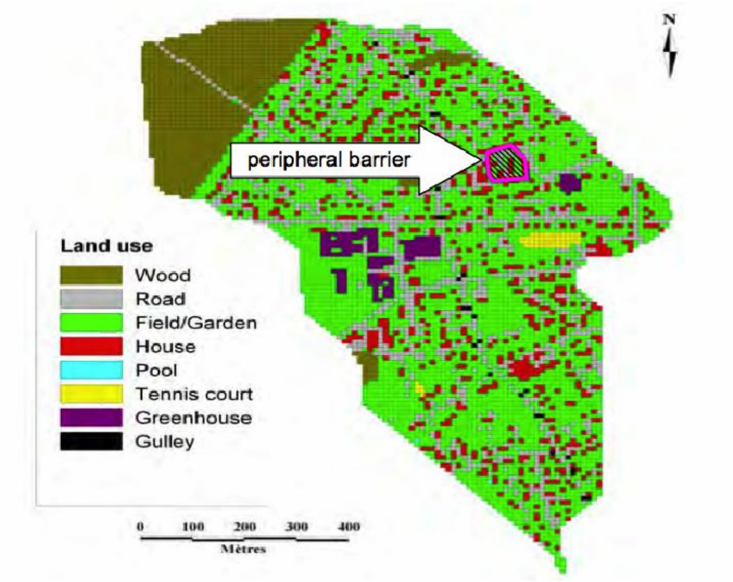


Figure 17: location of the area proposed to be protected (at 10 m resolution) Source: ENPC

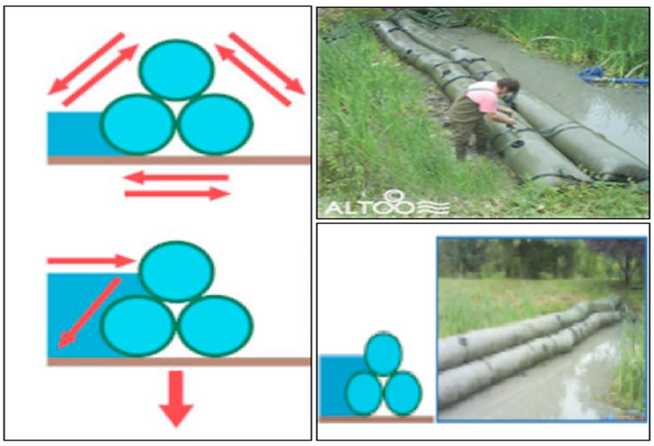


Figure 18: example of perimeter barrier Source: ALTOO

4.1.2.3 Assessment of alternative schemes

An assessment of the building protection system and the perimeter barrier system were undertaken using the MULTI-HYDRO tool. Results of this analysis are shown in Figure 19 and Figure 20.

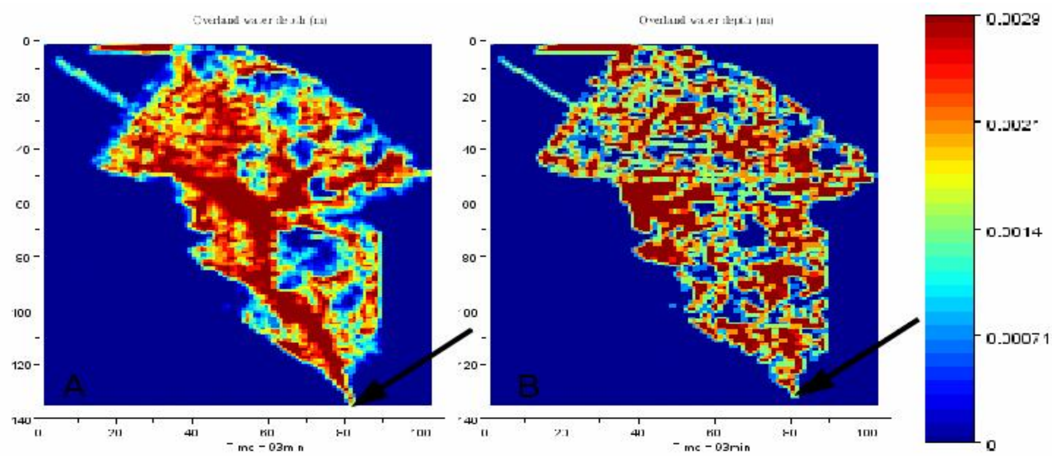


Figure 19: influence of building protection on the overland water depth Source: ENPC

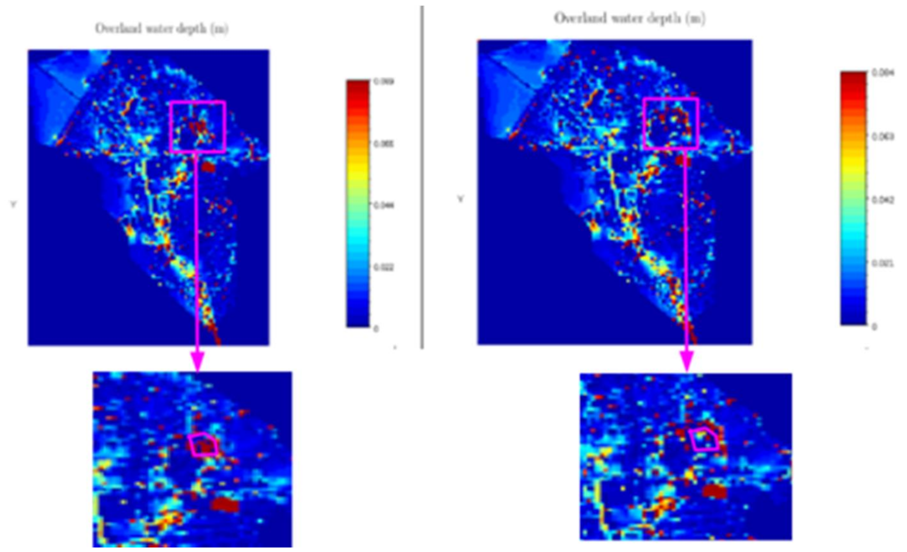


Figure 20: influence of a perimeter barrier on the overland water depth Source: ENPC

4.1.2.4 Implementation

The MULTI-HYDRO results demonstrate that the gymnasium could be appropriately protected and relocating it was not necessary. The analysis also posed many questions regarding the efficiency, cost and management of different FRe systems which must be considered across different scales.

4.1.3 Heywood, Greater Manchester (UK)

4.1.3.1 Description of context

The Heywood (Greater Manchester) has a catchment of about 8 km^2 which experienced serious pluvial flooding in 2004 and again in 2006 (Figure 21). There is no recorded history of previous flood events in the area. Since 1960, many open areas and brownfield sites have been occupied by new housing and new low-rise large warehouses on a new distribution centre. Typical of the edges of many British towns, this urban infill process adds to problems of effective surface water management.

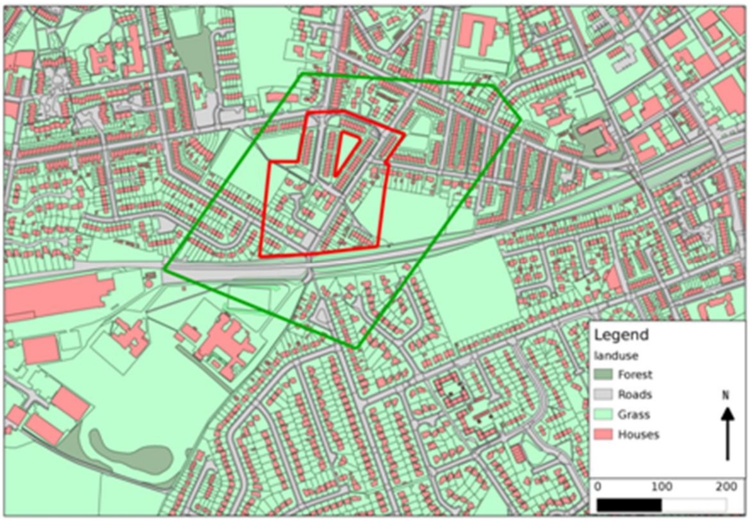


Figure 21: Heywood catchment areas
The larger catchment (green) will be used to evaluate the lateral inflow to the smaller catchment (red)
(source: ENPC-UNIMAN)

The assessment area is focused on Egerton Street and the surrounding green spaces.

4.1.3.2 Alternative schemes

It is proposed to assess three FRe systems:

- Barriers of 1 m height
- Swale of 1.5 m depth
- Barriers of 1 m height and swale of 0.5 m depth

It is planned that implementation costs can be reduced by combined FRe measures and technologies.

4.1.3.3 Assessment of alternative schemes

MULTI-HYDRO was used to model the initial situation before any intervention and the water depth was found to be 0.6 metres in Egerton Street and the surrounding areas. It was also used to assess the three different FRe system solutions proposed in 4.1.3.2. Figure 22 shows the results:

The first image shows the results from the first scheme proposed; the use of a 1 m high barrier. This resulted in flood water depths of 0.2 metres are identified in Egerton Street, and 0.6 metres in the surrounding green spaces.

The middle image shows the results from the second proposed solution; the implementation of a swale. This resulted in 0.2 metres depth of flood water in Egerton Street and the adjacent green areas.

The third image shows the results from the final proposed solution; the implementation of flood barriers and a swale system. This resulted in a 0.2 m flood water depth in Egerton Street and the surrounding green spaces.

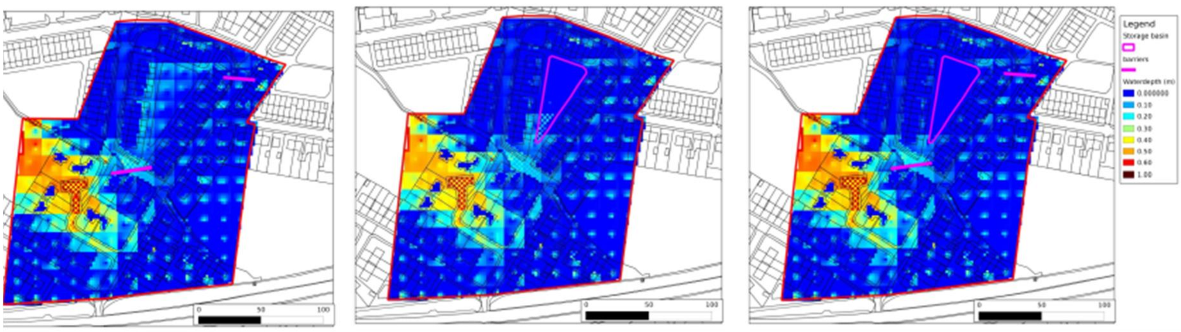


Figure 22: MULTI-HYDRO assessment results Source: IOER

The water depths identified in the MULTI-HYDRO assessments were used by FLOReTO and HOWAD-PREVENT to undertake a damage mitigation assessment.

4.1.3.4 Implementation

It is identified that a more economical yet equally efficient FRe system would be the implementation of a smaller swale of 0.5 m deep and two barriers of 1 m height which would be located across Egerton Street and the adjacent Wilton Grove. The two barriers alone would not be sufficient to improve the situation and reduce flooding. However, the implementation of a swale has not been considered by the relevant stakeholders.

4.2 Example FRe systems elements at the building scale

This section will describe resilient systems elements and the resilient characteristics they possess in terms of their restorative capacity, their coping capacity and their adaptive capacity.

These resilient systems elements are to be considered at the building scale, as follows:

- Controlled flooding of a basement;
- Sealing of a basement;

- Controlled flooding and sealing of the ground floor;
- Controlled flooding and shielding of the ground floor;
- Controlled flooding of a basement and wet-proofing of the ground floor;
- Wet proofing of a basement;
- Shielding of the building;
- Sealing of the ground floor;
- Controlled flooding of the above ground floor;
- Wet proofing of the above ground floor(s);
- Relocation.

As with the case studies examples (see 4.1) these resilient systems elements can be created by using a variety of FRe technologies, measures and conveyance and storage measures.

4.2.1 Controlled flooding of a basement (P-RS11)

4.2.1.1 Description

In this controlled flooding system, the water level is kept below the critical level by using a sump pump, regulated by pressure sensors. Resilient materials are utilised to minimise the damage to the building fabric. The targeted water level in a basement should be lower than the height of electrical appliances and power sockets, to avoid loss of power and further damage. To assess the critical water level, it is necessary to analyse the building occupancy, fabric, elevation and configuration, particularly of the basement area and compare the assessment to the design flood level. In general, the difference between the water level outside and inside the building should not exceed 1 m due to structural stability issues caused by strong buoyancy forces.

4.2.1.2 Resilience characteristics

Restorative capacity

Damage is minimised, as by wet-proofing the building fabric and services, materials are selected that remain undamaged when exposed to flooding. If the building contents have been elevated, they need only be returned to their previous locations. The time needed to return to the pre-flood state is reduced to the cleaning and drying of the building fabric; this time will gradually increase for the increasing water depth. Resilient materials and designs should be used that have less drying time.

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[1] P-RS stands for Property Scale, numbers refer to the number of the measures described in appendix 2

Coping capacity

Where this system has been adopted, the upper floors are not affected by flooding; therefore, as long as there is no danger of structural failure, evacuation may not be necessary. The weak points of this system can be assessed as follows:

- Time is needed to elevate or move building contents from the basement
- The performance of the pumps are critical; their performance should be guaranteed
- Some effort may be required to operate the pump equipment; consideration should be given to the capacity and ability of householders
- Adaptive capacity

If the difference in water pressure outside and inside the building exceeds 1 m the system should be redesigned. However, if the water level reaches the ground floor this system can be extended by using the approaches in P-RS 3, 4 or 5 (see sections 4.2.3, 4.2.4 and 4.2.5).

4.2.2 Sealing of basement (P-RS2)

4.2.2.1 Description

The basement is dry proofed using sealing measures. This can be based on the application of waterproof concrete or polymer bituminous sealing. Here, flood water is not allowed to enter the interior of the building, but the fabric (walls, floors, ceilings and staircases openings and services) are designed to resist flooding. Services and openings are raised or sealed using flood resilient products. A non-return valve is installed to prevent back water flooding from the sewerage system.

4.2.2.2 Resilience characteristics

Restorative capacity

Floodwater will not reach the building interior therefore the time needed to return to the pre-flood state is reduced to cleaning of the building exterior. However, if the design flood level is exceeded, the amount of damage will abruptly increase.

Coping capacity

In buildings where this system is applied, the upper floors are not affected and as such evacuation to an upper floor is possible. As services are protected, supply is not interrupted at the property level. This system has some critical factors which may hinder its optimal performance; the main one being the stability of the building, which can be jeopardised either by the static or dynamic pressure of flood water. An effective connection between different sealed elements is critical for the efficient functioning of this system.

Adaptive capacity

If external water pressure against the building rises; the system can suffer considerable stability problems. As such, the system may have to be redesigned if the difference between the external and internal water level exceeds a critical point. Possible redesign options are to remove sealing and apply controlled flooding (as P-RS1, see section 4.2.1) or to apply additional reinforcement of the construction to withstand water pressure.

4.2.3 Controlled flooding and sealing of the ground floor (P-RS3)

4.2.3.1 Description

This system represents a combination of the measures adopted in RS1 plus additional sealing of the ground floor, by applying a water resistant concrete or sealants on the building envelope. Thus, the basement is protected by the controlled flooding system yet the ground floor can be used, as flood water is prevented from reaching the building interior on this floor. Between the building levels, horizontal sealing measures are required in order to prevent capillary rise from the basement into upper floors. Openings are protected using building aperture technology.

4.2.3.2 Resilience characteristics

Restorative capacity

The system can quickly return to its initial state (as for P-RS1, 4.2.1) and as the upper parts of the building are protected, no additional effort is needed for cleaning of these interiors. Time is only needed for cleaning of the exterior face of external walls. The system is, however, limited by the water level and flood actions that can be borne by the sealing measures of the ground floor. If these limits are exceeded, the system will fail.

Coping capacity

Vertical evacuation is possible and a continuous supply of services is guaranteed with this system. The main limitation is the range of flood conditions it can be applied to. If the difference in water pressure outside and inside the building exceeds the threshold value the system will have to be redesigned.

In addition to the critical parameters of the system RS-1, the availability of upper floors for vertical evacuation has to be considered. In addition, the stability of the exterior walls on the ground floor can be endangered due to a potentially high horizontal pressure.

Adaptive capacity

This redesign can be either into the direction of P-RS4 or P-RS5 (see sections 4.2.4 and 4.2.5) depending on the building fabric and expected flood conditions. A possible redesign option towards P-RS3 has been depicted in Figure 23.

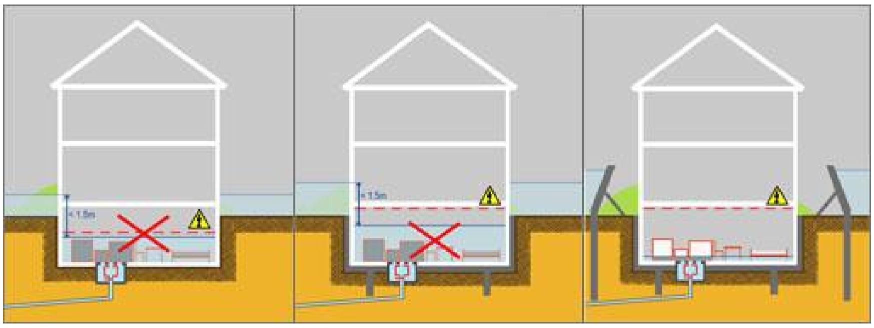


Figure 23: redesign possibilities for the system P-RS3 Source: TUHH

4.2.4 Controlled flooding and shielding of the ground floor (P-RS4)

4.2.4.1 Description

This system combines controlled flooding of the basement (as P-RS 1, see 4.2.1) and shielding techniques for the building for protecting the ground flood. A range of flood products can be applied, depending on the flood typology and the expected conditions.

4.2.4.2 Resilience characteristics

Restorative capacity

The system quickly returns to its initial, pre-flood state as with system P-RS1. As the upper parts of the building are protected by FRe technologies they will not come into contact with flood water, and therefore no additional effort is needed for the cleaning of interiors. Time is only needed for the dismounting and storage of the temporary flood barriers. The system is limited by the flood depth and flood actions that can be borne by the ground floor. If these parameters are exceeded, the system fails.

Coping capacity

Vertical evacuation within this system is potentially possible i.e. if above ground floors are available as vertical escape routes within the building. However, as the building is shielded this is only required in exceptional cases. The continuous supply of services is guaranteed with this system (VI). In addition to the critical factors for the case of P-RS1, the time required for erecting temporary barriers, especially for vulnerable groups, has been assessed as a weak point that describes the systems sensitivity.

Adaptive capacity

If a threshold value of flood water pressure is exceeded (of approx. 1m), the system has to be redesigned, either into P-RS5, a low-medium effort (see section 4.2.5) or in an extreme case, requiring greater effort, P-RS11 (see section 4.2.114.2.11).

4.2.5 Controlled flooding (basement) and wet-proofing (ground floor) (P-RS5)

4.2.5.1 Description

Controlled flooding of a basement is combined with wet proofing of the building fabric in the ground floor level. Occupants should be given suitable warning for evacuation, and building contents should be easily removed in a flood event.

4.2.5.2 Resilience characteristics

Restorative capacity

The system returns to its initial state as both the basement and the ground floor are wet proofed and as such no permanent damage is expected. Effort is needed for the cleaning and drying of the interiors and building fabric. The increase in potential damage is related to an increase in effort for cleaning and drying.

Coping capacity

Vertical evacuation is possible only where more than one floor is available above the ground floor, and where no structural problems are likely. Depending on the water level outside, horizontal evacuation may be possible using temporary footbridges. The continuous supply of services is enabled as the fittings and services are resilient and watertight. It terms of sensitivity to failure, the system inherits the weak points of the system P-RS1 (see 4.2.1).

Adaptive capacity

The system is highly able to adapt to a wide range of flood conditions. If redesign is necessary, the system can be replaced with the P-RS11 (see section 4.2.11).

4.2.6 Wet proofing (basement) (P-RS6)

4.2.6.1 Description

This system represents a simplified version of the RS1. The building fabric is prepared according to the requirements for wet proofing of building fabric combined with elevation and protection of services and fittings. Building contents are selected such that quick evacuation is possible.

4.2.6.2 Resilience characteristics

Restorative capacity

In applying this system, the damage is in general minimised as the building fabric and services are wet-proofed, meaning that resilient materials are selected; reducing the time needed to return to the initial state as only cleaning and drying of the building fabric is required. Where building contents have been elevated or moved, additional time and effort is needed to return these. As the damage is reduced to cleaning and drying, it is likely to increase gradually for the increasing water depth.

Coping capacity

Services and building fittings are either sealed or resilient therefore, the continuous supply at property level is enabled. The weak point of this system can be identified as follows:

- Time required for elevation of the building contents from the basement
- Accessibility of the building may be impaired depending on the flood depth.

Adaptive capacity

If the difference in water pressure outside and inside the building exceeds 1 m the system should be redesigned. However, if the water level reaches the ground floor this system can be extended using the systems P-RS3, 4 or 5 (see 4.2.3, 4.2.4 or 4.2.5). In this way, the system is extended and not redesigned.

4.2.7 Shielding of the building (P-RS7)

4.2.7.1 Description

This system prevents water reaching the building by applying perimeter barriers at a certain distance from the building or directly in front of the construction.

4.2.7.2 Resilience characteristics

Restorative capacity

The system quickly returns to its pre-flood state as the water does not reach the building at all and no damage occurs. However, if the design flood depth is exceeded, or flood actions exceed the expected conditions (for example, water pressure exerted on the flood barrier), the system cannot perform and damage may occur. This amount of damage may be great, as the only means of protection has failed.

Coping capacity

The continuous supply of services is enabled as the fittings and services are not in contact with flood water. The system's critical features are related to the time and effort required for mounting the barriers. In case additional pumps are used, their performance should be guaranteed.

Adaptive capacity

The potential of the system to adapt to a range of flood actions and depths is limited by the threshold value of the perimeter barriers. The system can be redesigned to P-RS9 or 10 (water proofing of the ground floor, see sections 4.2.9 and 4.2.10) or relocated (as in P-RS 11, see section 4.2.11).

4.2.8 Sealing of the ground floor (PR-S8)

4.2.8.1 Description

This resilient system implies that the above ground elements of the building are sealed against flood water. Walls and floors are protected by applying a waterproof material (e.g. concrete or polymer bituminous sealant) and openings and services protected by applying flood resilient technologies.

4.2.8.2 Resilience characteristics

Restorative capacity

This system quickly returns to its initial state as the floodwater does not reach the building interior and the recovery effort is reduced to the cleaning of the building exterior. However, the system shows non-gradual behaviour, as by exceeding the upper limit of the sealing measures, the system cannot perform and damage can occur.

Coping capacity

Depending on the water level outside, horizontal evacuation may be possible using temporary footbridges. The continuous supply of services is possible as the fittings and services will not be in contact with flood water. The systems critical performance is related to the time and effort for mounting the barriers. In case additional pumps are used, their performance should be guaranteed.

Adaptive capacity

The potential of the system to adapt to a range of flood depths and flood actions is limited by the limits of the sealing measures and FRe technologies. If these limits are expected to be exceeded, the system can be redesigned to include waterproofing of the ground floor (P-RS9 or 10, sections 4.2.9 or 4.2.10) or the building can be relocated (as in P-RS 11).

4.2.9 Controlled flooding of above ground floor(s) (P-RS9)

4.2.9.1 Description

In the controlled flooding system, the water level is kept below a set critical level by a sump pump, regulated by pressure sensors. Similar to the system P-RS1, in the necessary building levels, waterproof materials are applied and services and fittings are raised above design flood heights. In general, the difference between the water level outside the building fabric and inside the building should not exceed 1 m, as in the case of the system P-RS 1.

4.2.9.2 Resilience characteristics

Restorative capacity

By applying the controlled flooding system, damage is generally minimised as the building fabric and services are wet-proofed, meaning that resilient materials are selected which will remain undamaged when exposed to flooding. The time needed to return to the initial pre-flood state is limited to the time needed for cleaning and drying of the building fabric, plus where appropriate, the return of building contents to their previous locations.

Coping capacity

As the ground floor is being sacrificially flooded, evacuation is necessary. Services and fittings are resilient or sealed. The weak point of this system is identified as follows:

- The time necessary to remove building contents from flooded levels;
- The performance of the pumps is critical

Some effort may be required to operate the equipment; this may be critical depending on the capacity of the users.

Adaptive capacity

If the difference in water pressure between outside and inside the building exceeds 1 m the system has to be amended to relocation (P-RS11).

4.2.10 Wet proofing above ground floor(s) (P-RS10)

4.2.10.1 Description

This system represents a simplified version of the P-RS9 corresponds to the system P-RS6. The building fabric and contents are prepared according to requirements for the wet proofing of the building fabric and adjustments of the building occupancy where necessary.

4.2.10.2 Resilience characteristics

Restorative capacity

As in the system P-RS6 (see 4.2.6), damage is generally minimised as resilient building materials are selected to remain undamaged when exposed to flooding, therefore reducing the time needed to return to the initial pre-flood state; only cleaning and drying of the building fabric will be necessary plus the return of building contents. The system tends to behave gradually, as there are no obvious thresholds of the applied technology.

Coping capacity

Evacuation is necessary in this system as the ground floor is to be flooded. Services and fittings are either resilient or sealed, ensuring their continued operation. The weak points of this system are as follows:

- Time is required to elevate or move building contents
- Evacuation is necessary

Adaptive capacity

If the difference in water pressure between outside and inside the building exceeds 1 m the system has to be relocated as in system P-RS11 (see section 4.2.11).

4.2.11 Relocation (P-RS11)

4.2.11.1 Description

This system implies elevation of the building above the expected flood level (vertical relocation) or removal to another area (horizontal relocation).

4.2.11.2 Resilience characteristics

Restorative capacity

This system does not return to the initial, pre-flood state, but reaches a new equilibrium for which a high level of effort is needed. In the case of vertical relocation, the system shows non-gradual behaviour, shaped by the new elevation of the building. For horizontal evacuation, the capacity threshold will be determined by analysing flood parameters relevant to the new location.

Coping capacity

The continuous supply of services is enabled as the fittings and services are elevated above the flood level and as such are not in contact with flood water (VI). As the system is elevated or removed from flood risk, the potential for failure is low.

Adaptive capacity

This system can be applied against a wide range of flood depths and flood actions but requires considerable effort and high costs.

5 Guidance for FReS design

Previous chapters presented the objectives of FReS and illustrated how several tools developed/upgraded during the SMARTeST project (Table 3) can contribute to a FReS approach.

Tool	Function
FReT data base	Access to information on FReT: http://tech.floodresilience.eu
MULTI-HYDRO (ENPC-LEESU)	Hydraulic simulation : water flow over an urban area
FLORETO (TUHH)	Assessment of the reduction of damage due to FReT implementation at the building scale
HOWAD (IOER)	Assessment of the reduction of damage due to FReT implementation at the building/quarter scales
FVAT (LEESU)	Assessment of the vulnerability of a building or an area

Table 3: SMARTeST tools in relation with the flood resilient system approach

The Flood Vulnerability Assessment Tool (FVAT) is a web-based system with free access that can be used to help identify priorities when analysing the vulnerability of buildings in a flood-prone area. Its structure allows the identification of both vulnerable buildings and possible FRe technologies. It could be used to define the alternative schemes.

Other tools may be locally available, as follows:

- local authorities may have hired competent organisations to analyse past flood events, to update maps of flood-prone areas.
- written or oral historical records may also be useful.

This section presents steps that should be followed in order to develop a FReS according to a particular context. The chapter/sub-chapter organisation does not mean that these steps are part of a linear process. The process to develop a FReS should include steps back for instance to reconsider and check previous hypotheses.

The ambition is not to give solutions, it was already mentioned that there is no “one-size-fits-all” solution. The ambition is to present an organised “check list” of items that should be addressed in order to prepare the design of a locally adapted FReS.

This check list should be considered as a way to have a systemic view on the Flood Management System. The FRe system designer should identify links between parts and elements and to explore consequences of actions at a given spatial or temporal scale on other scales.

5.1 Diagnostic of the situation

5.1.1 Why is a diagnostic section required?

A diagnostic of the local context allows the collection and organization of data describing flood situations and their recorded consequences. It is a preliminary step to any development of a FReS.

5.1.2 Contents

Any urban area located in a flood-prone zone experienced flood in the past. A first step is then to collect information on these events, e.g. records, stories, reports from various sources (local archives of historical flooding, population impacts, insurance files, topographic mapping, site ground conditions, existing infrastructure, flood defences, etc.).

A detailed description of the existing elements implemented locally to manage a flood event should be made. This description should highlight elements concerning the different scales of the territory (Table 4) and should not be limited to technical and economic aspects. It should also address community issues as the expected efficiency of such elements highly depends on the action, reaction, awareness and readiness of people.

The analysis of return of experience is also essential. After each major event, local authorities, expert institutes or governmental bodies publish reports that contain an analysis of the concerned event as well as recommendations to mitigate the consequences of future events. The reasons for the recommendations have to be understood according to the context of the event as well as the reasons for any deviation between implementation and recommendations.

- This analysis should also highlight the following:
- how and by whom recommendations were elaborated,
- if and how the population was associated to the elaboration,
- how the system integrating the recommendations worked/behaved during flood.

The presentation of the results of the diagnostic according to a timeline as shown can help for the next steps of the guideline (Figure 24).

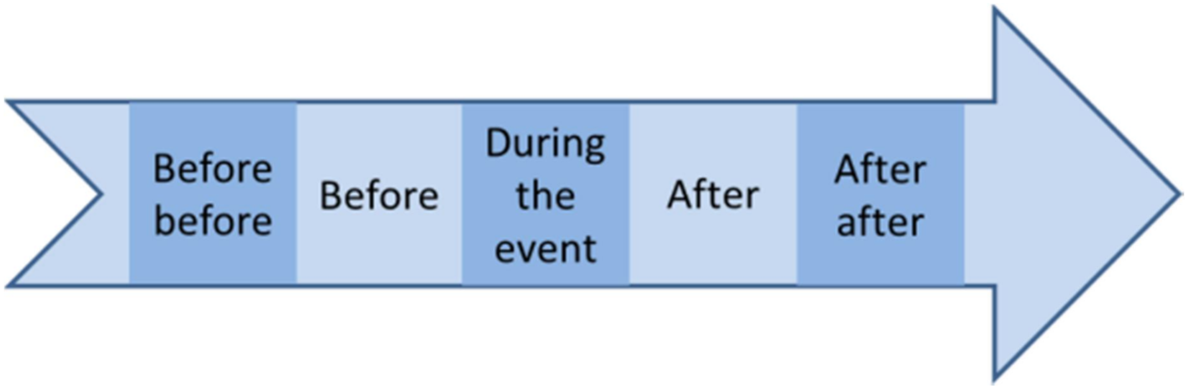


Figure 24: timeline to present the results of the diagnostic phase Source: SMARTeST

The “before-before” and “after-after” time slots allow to concentrate on actions during “before” and “after” periods that are essential to prevent damages and to recover after the event. “Before-before” and “after-after” periods can be spent to get prepared for the “before” period and take time to analyse “after” event information.

This time scale emphasises the role of time in FReS design and implementation. Time is needed to analyse events. The period during which the population is concerned with flood is not just limited to the before/during/after sequences. Time between events should be used to anticipate the next event.

This is difficult as the wish and the will to forget events is strong in the population but at least some members of the community must make relentless efforts to keep a high level of awareness and to inform new-comers and new generations of flood risk. This is a major condition for decision making at different scales of the territory. Moreover, some decisions may concern important civil works that take time to be decided, financed and realised.

Table 5 shows an example of a tool that can be used to make the diagnostic concerning different issues at different spatial scales. Answering to corresponding questions gives an image of the local situation and provides useful information to complete the contextual analysis.

	Measure	Associated functions	Scale			
			River basin	Urban area	District	Building
	Mapping of flood-prone areas	Make knowledge available	ü	ü	ü	ü
	Urban planning	Limit exposure	ü	ü	ü	ü
Hydrology (pathway)	Dyke, Levee	Confine/channel water flow	ü	ü		
	Drain	Channel water		ü		
	Retention area	Confine water	ü	ü	ü	
	Underground reservoir	Confine water		ü	ü	
	Raising sidewalk kerb	Channel water			ü	
	Green areas	Facilitated water penetration in ground		ü		ü
	Trees, vegetation planting	Slow down water flow	ü			
	Temporary barriers	Confine/channel water flow		ü	ü	
	Opening barriers	Confine water				ü
	Pumping	Evacuate water	ü	ü	ü	ü
Construction (receptor)	Non return valves	Avoid sewer/drain backflow				ü
	Green roof	Delay water flow to surface/drains				ü
	Construction resilient materials	Limit damages and facilitate cleaning				ü
	Warning system	Alert exposed population	ü	ü	ü	ü
	Emergency plan	Preparedness conditions	ü	ü	ü	ü
	Insurance	Transfer the burden of damages		ü	ü	ü
	Education/information	Awareness raising	ü	ü	ü	ü

Table 4: examples of measures and associated scales

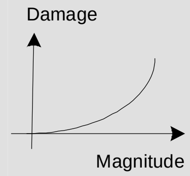
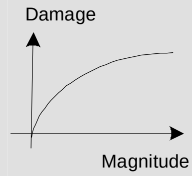
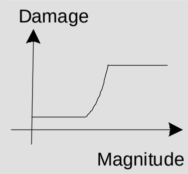
Scale	Issue	Comments
building	PEOPLE SAFETY Flexibility of the contingency measures (vertical and horizontal evacuation of the people is enabled (intangible damage)	1. yes
		2. no
		3. not required/ applicable
building/district	DAMAGE EVOLUTION How damages increases with « magnitude” (water depth, velocity, duration)	  
	RESOURCES Continuous supply of services (gas, electricity, communication) is enabled (answer is relevant to assess the conditions to make the system work). Availability of rescue team.	1. yes
		2. yes with considerable effort
		3. no
district/urban area	SYSTEM ROBUSTNESS Sensitivity of the system to malfunctioning. Failure analysis considering the following main aspects: - Controllability of the seepage water - Logistics - Controllability of the impact to the drainage system	Low- the risk is distributed over a range of elements
		High- the system depends on one factor, which in case of failure, causes the failure of the overall system
	RETURN TO ACCEPTABLE SITUATION Time to equilibrium: a) Time needed to return to initial state b) Time needed to reach the least acceptable functioning state	1. fast: less than weeks/month(s)
		2. medium: months/year(s)
		3. slow: years
		4. retreat (no recovery)
	RESOURCES TO RETURN TO ACCEPTABLE SITUATION Effort needed for reaching the equilibrium	1. low- reduced to cleaning and drying of the building fabric (opt: returning the inventory to the initial state)
		2. medium- 1+ minor (aesthetical) repairs required
		3. high- repairs of building fabric needed

Table 5: some issues to be addressed at different spatial scales Source: TUHH

5.1.3 Outcomes

The outcome of this section is the illustration of the need for a diagnostic of the local situation and some elements to organise such a diagnostic.

5.2 Define objectives and priorities

5.2.1 Why define objectives and priorities?

The diagnostic says a lot about past events and their consequences. The development of a FReS has to be considered over the long term (decades ahead) perspective. The associated decisions will also have long term consequences so that attention must be paid to the choice of priorities (in terms of protection, resilience) according to the local context.

5.2.2 Contents

The diagnostic will indicate measures that proved to be efficient, and should probably be maintained or even reinforced.

The diagnostic will also indicate local situations that impede actions before, during and after the event, for example as follows:

- **before**: the hospital could not be timely accessed by the personal staff,
- **during**: some equipment of the fire brigade could not be used because they could not be moved
- **after**: drinkable water distribution was effective three days after the event.

The urban built environment is a combination of elements (buildings, infrastructures) that support a community, region, or country. Infrastructure includes elements such as water distribution and sewer systems, road and rail networks, power and natural gas grids.

Underground elements are generally more vulnerable than elements built on the ground surface. The diagnostic helps identifying the weakest points of the built environment but also the consequences of inundated elements in areas that are not flooded.

As it is not possible to protect all the elements of the built environment, choices have to be made. The detailed choice of priorities depends on the local context but can be guided by consideration on essential functions such as the following:

- health
- communication
- drinkable water supply
- transport of people and goods
- power supply

Before determining solutions, these problems should be ranked according to local criteria. FRe system designers need to take into account the following:

- the type of flood (available time for preparation, slow rising/torrential, duration, …),
- the local context (the design, the topography of the networks).

The type of flood event is directly linked to the response of the system and the ability to foresee the dangers which may occur and the degree to which infrastructure may be affected.

A flash flood is a direct response to rainfall with a very high intensity. The water flows at high speed. Flash floods stop suddenly, just as they began. Due to the sudden onset, flash floods are deemed as particularly dangerous.

In the case of a coastal flood, the main cause is a severe storm which creates high waves which move inland towards an undefended coast or overtop or breach any available coastal defence infrastructure. A significant characteristic of a costal flood event is the constant differentiation of water level which rises and drops according to the tide. After breaching the coastal defence works the incoming sea, although it initially moves fast, it gradually slows down while spreading to a larger area. During a coastal flood event, any attempts to repair the coastal defence works should be performed when the water recedes during low tide.

River flooding is characterised by a slower progression. It is identified as an extended period of rainfall resulting in riverbanks overflowing. Due to the topography of a river area, downstream locations may mark significant damages, even when the extended rainfall did not occur in these areas to begin with. In essence, the larger the river, the slower is the process of a river flood. However, in cases when significant water volume causes a dam or a dike to break, speed can be compared to that of a flash flood. Population and infrastructure located near the breach should become a priority especially prior to the flood event. The general slow speed of the flood event allows local communities to respond better and more efficiently.

Other factors which are required to be taken into consideration when drafting an action plan with regards to steps to be taken and infrastructure to be ensured, before, during and after an flood event is the topography and the actual design, relevant to the infrastructure, i.e. whether a hospital is located downstream or near an affected coastal zone, if gas tanks are located within water courses or in an area which is remotely affected.

Making the choice of priorities an explicit step introduces an unusual process in the elaboration of a flood management system. According to the traditional way, each member of the concerned community acts individually to protect his own property. There is a risk that these actions impact other buildings/areas in the vicinity that could have not been impacted if the concerned measures had not been implemented.

In some cases, unexpected consequences can be recorded because of poor maintenance of some elements (e.g. presence of debris in sewage networks). The definition of priorities can then not only be determined from flood maps or water level records but has to take into account the level of maintenance of all vital networks irrigating the urban area (Serre D. 2012).

Another issue to be monitored and assessed concerns interdependencies between infrastructure elements and the criticality of these interdependencies, that is likely to affect the recovery time, after the flood event.

The vulnerability assessment in the context of a system or an urban area is considered a significant driving force. The analysis of local elements and properties, the urban context in relation to the catchment area, the type of emergency systems located within the area, as well as the post-crisis mechanisms and the experience in preventive actions to be taken are factors to be taken under consideration, when assessing the criticality of the infrastructure and when prioritizing activities within the local context.

5.2.3 Outcomes

Introducing resilience leads to a change to the traditional approach. Defining priority objectives is a way to prepare the consultation of all stakeholders in order to define and adopt acceptable measures ensuring expected functions of a FReS.

The availability of hydraulic models such as MULTIHYDRO creates conditions to assess such risks.

5.3 Define compensation mechanisms

5.3.1 Why define compensation mechanisms?

Defining priorities may expose some properties and areas to flood that were not inundated before. The acceptance of priority objectives by the community may lead to discussions on compensation mechanisms.

5.3.2 Contents

There are no established rules to define compensation mechanisms. The need for such mechanisms comes from the following approach:

- the diagnostic of the existing situation highlights the need to set priorities,
- this introduces new constraints for some members of the community (e.g. increase of flood hazard in their own property),
- these constraints have to be accepted in order to change the traditional way floods are managed (e.g. the acceptance of the burden allows better protection of an essential function of the urban area),
- the acceptability of these constraints has a cost for the community in order to compensate the burden that is accepted by some individuals for the benefit of the group.

Discussing these questions may not be an easy matter but it may create a thorough discussion through the community, raise side questions and put an end to silo thinking.

The following example shows how such a mechanism can be implemented.

The Entente Oise – Aisne (http://www.entente-oise-aisne.fr/) is a French territorial institution in charge of the development of the rivers Oise and Aisne as well as its tributaries. The rivers basin is located about 100 km north of Paris. The territory encompasses several medium size towns. The Oise River joins the Seine River at the west of the basin. It was created in 1968, and has the status of a public territorial basin establishment (EPTB). It is an interregional structure that encompasses several counties. The work and the actions of the institutions are bound to the administration of water in the river basin including: prevention of floods and protection of the environment. Its status and its experience allow the EPTB to coordinate projects committing the different counties, and to organise consultations between the different stakeholders. The Institution can also take on the command of projects territory wide.

In a recent document, the Entente Oise – Aisne explains its strategy to fight against flood of the Oise river by the year 2013 (Entente Oise-Aisne 2009). This strategy starts from a thorough hydraulic analysis of the territory, which takes into account not only the topography and hydrology but also the observations from past flood events. For instance, it was decided to increase the time difference between peak flows on different rivers so as to limit the amount of water at a given moment in urban areas.

Different options to reach this goal were studied and adequate infrastructure was built (weirs, automatic valves). It was also decided that the centennial flood was out of the efficiency domain of this infrastructure. Efforts were concentrated on the flood with a return period of 30 years.

The sizing of reservoirs and valves was designed for 10 year return period floods. This gives key information to people living in these areas in order to anticipate the measures to be taken at their own level.

It must be noted that this study, design, decision, construction process is long: about 20 years. It involved all stakeholders at different levels and many issues were addressed including financial compensation measures for farmers and cultivators the land of which was likely to be flooded as a consequence of the reservoirs infrastructures.

This example illustrates that time and coordination are essential items in order to build confidence between involved stakeholders.

5.3.3 Outcomes

The outcome of this anticipation and coordination approach is a better understanding of the reasons for the use of flood risk management measures, a better appreciation of their scope and limits.

5.4 Defining alert solutions

5.4.1 Why defining alert solutions?

Except for permanent protection, it is quite obvious that measures aiming to mitigate flood impacts have to be commenced on time. Nevertheless, experience shows this key issue is not always given the proper attention it deserves.

5.4.2 Contents

A reliable flood alert system is an essential element of a FReS.

Several SMARTeST partner countries (e.g. France, Spain, and UK) have implemented sophisticated regional alert systems. The hardware part of these systems process information coming from sensors (e.g. rain gauges, rain radars, water level sensors) located at strategic places in the concerned regions. Precipitation, water levels and flow rates are examples of such information.

The outcome of the data processing is for instance a level of probability a river may overflow. Flood maps are available on internet, signs and colour codes are used to qualify the severity of the event (Figure 25). These systems are reliable for slow rising flood but start being less reliable for highly dynamic events, e.g. torrential flood, coastal flood resulting from the conjunction of high tide and storm. In the urban context, more accurate sensors such as X band radar, will improve these systems. The integration of these sensors with hydraulic simulation tools such as MULTIHYDRO will create new opportunities to develop alert services in urban areas (Appendix 5).

		
Be prepared	Immediate actions	Danger to life

Figure 25: flood alert signs Source: www.environment-agency.gov.uk/

The software part of the flood alert system relies on human interpretation and on their ability to disseminate precise, reliable and trustable messages to different groups, e.g. decisions makers or the general population.

The information provided by this system has to be as follows:

- **Reliable**: the signal can be a traditional acoustic signal or any more modern way to transmit information using telephone or IT networks (smart phone, internet)
- **Understood**: the signal has to be recognised and understood without any ambiguity. This means that training has to be planned (school, community)
- **Duplicated**: training session should ensure the necessity to check that neighbours have received and understood the alarm signal
- **Credible**: the credibility of the information provided by this system has to be high in order to timely trigger measures planned during the “before” period. This is a result of a constant effort of training and awareness raising of the population.

5.4.3 Outcomes

The outcome of this section is raising the awareness of FReS designers to the importance of the alert system that should not only be considered from a technical perspective but also from a human perception and information interpretation perspective.

5.5 Defining protection measures

5.5.1 Why define protection measures?

Protection has always been the reference measure to limit the impacts of flood events. The best protection is to avoid exposure, but many examples show this is not always possible. Moreover, even when it is possible, the inconvenience of being exposed can be counterbalanced by economic advantages.

Protection measures have to be considered in this perspective: a way to limit but not to avoid flood damages.

5.5.2 Contents

Each flood situation is unique. The origin of flood, the dynamic of the phenomenon, the preparedness of the population, the topology or the urban area, the conditions of the drainage network differ from one case to another.

Defining protection measures definitely depends on the context. In some situations, raising the metro entrance by 50 cm will be adapted to limit water ingress in the underground infrastructure, through the entrance (Figure 26). In another context, a permanent dike will have demonstrated its efficiency for decades. At the building scale, opening barriers can limit water penetration in buildings.

Typical "resilient" measures at the building and the district scales are listed in appendix 2. Appendix 3 presents a set of possible measures that can become part of a FReS.


Figure 26: raised metro entrances
(Bangkok-left, Marseilles-right) Source: RATP - Rodolphe Guillois

A common feature of these permanent or temporary protection measures is the maximum height of water. None of these protections remains efficient when the maximum water height is exceeded.

The water height is not the only determinant parameter for temporary protection measures. Table 6 shows some selection criteria for different kinds of temporary flood barriers. The work carried out in the SMARTeST project is a contribution to the assessment of the performances of such barriers. A great number of products are referenced at the SMARTeST Flood Resilience Technologies Portal (http://tech.floodresilience.eu/).

Criteria / Flood barriers types	Storage	Logistics	Installation time	Leak flow rate	Shock resistance
Building aperture products	*	*	**	Adapted to application	**
Temporary products	**	**	***		**
Building skirt systems	*	*	**		*
Demountable products	**	***	***		**
Specific products	*	**	**		*

Table 6: Flood resilience technology (barriers) choice criteria (*: low importance, ***: high importance)

5.5.3 Outcomes

The outcome of this section is to raise the awareness of the FReS designer concerning the scope and the limits of FRe technologies.

5.6 Defining implementation conditions of FReS

5.6.1 Why define implementation conditions of FReS?

Flood has been experienced for millenniums in the whole world. It may then look surprising to have to reconsider each new event as if it was the first. Some may consider this is an exaggerated statement but progress in managing flood situation is always slow.

In order to benefit from technological progresses and accumulated experience, the conditions to think in term of a resilience approach have to be addressed.

5.6.2 Contents

The main difference between traditional flood management and flood resilience lies in the approach of the situations. In both cases, technology is essential but the difference is more on the soft aspect of the approach.

The resilience approach thoroughly examines the interrelation between the behaviour of the exposed population and technical aspects. The resilience approach will of course need and rely on technology but also on the capacity of decisions makers and of the population to take wise decisions before-before, before, during, after, after-after the event.

This is a shift in the way to consider the questions and to elaborate acceptable solutions.

Coherency and consistency are key words in the context of the flood resilience approach. They address actions that aim to ensure that measures taken at a given location do not hamper or even cancel the expected effects of other measures at a different location.

Terms and expression that have been used of long should also be reconsidered. For instance, the traditional statement “Recover quickly after flood” used in flood management together with “Limit damages” could probably be reworded as “Recover as soon as possible after a flood”. This would allow clarity on the meaning of “quickly” for different groups of stakeholders. This term is indeed very subjective. Quickly may for instance mean next week for a shop-keeper, in a month for an inhabitant, in six months for local authorities, in a year for the government. Quickly means urgency for injured people, the most vulnerable people and rescue teams, quickly means hours for drinkable water availability, quickly means few days for food.

5.6.3 Outcomes

Developing a resilience approach calls for a more individualised approach or at least for closer cooperation between groups of stakeholders in order to better acknowledge relationships between technical decisions, consequences for the concerned stakeholders and economic issues.

5.7 Economic issues of FReS

Economic issues are of course the core of decisions. This is not specific to FReS development and economic assessment tools used in the context of hazard prevention are valid.

A rational and responsible approach to such a complex issue is twofold:

1. The cost of action, e.g. the cost of planned investment in structural and non-structural measures,

2. The cost of inaction, e.g. the amount of possible damages.

Quite a simple balance except that the first term addresses decisions that are permanently in concurrence with many other demands of the society (infrastructure, theatre, schools, housing, …), whilst the second term is by nature uncertain, i.e. the date is unknown.

Whatever the decisions it must be clear for all stakeholders that there is no known way to reduce damages to zero. Each set of measures, any system have their “area of excellence”. Consequences can be anticipated up to a certain limit. Extreme events can have consequences that are beyond these limits. Even if prevention and protection measures look to completely fail in such circumstances, the fact that the community decided to invest has an effect. The consequences would have probably been worse in the absence of such investments.

This is not a new question but the chance to use a “resilient” approach may be a way to renew the way the question is worded and examined.

The SMARTeST project shows that there is no technological bottle-neck to make “smart” technologies available. These technologies are essential but the way there are selected, linked together, coordinated is at least as important.

The resilience approach favours cooperation through co-production of flood management systems that then become FReS. This may be an opportunity to convince stakeholders that no system, nor individual measure, will lead to zero risk. Water is by its nature ubiquitous and always finds paths to enter into any ordinary construction. Constructions can be made water-tight but it is not economically affordable for all constructions and it may not be compatible with other performances that are expected from buildings.

The balance of demands to comfortably live in and use buildings on a daily basis and of demands to be fully protected against any natural, industrial or other hazards necessarily leads to a compromise.

Depending on countries, the role of insurance plays a more or less important role in the determination of this compromise.

6 Conclusion

Cities, communities and property owners have many possible solutions at their disposal to help to manage flood events. Governments also set planning and flood management policies as well as making protection equipment available. Flood warning systems take benefit from the tremendous progresses in communication networks. Innovative protection equipment are proposed on the market as shown by the SMARTeST data base http://tech.floodresilience.eu.

In spite of such available resources flood damage still occurs with people being the main victims, but also devastated buildings and possessions. Water can in the worst cases remain for weeks or months leading to long times for flood repair of buildings. Health and psychological consequences also start to be taken into consideration as major outcomes in addition to material and economic impacts.

Water spreading and flowing can hardly be stopped so that buildings and infrastructures located in the flood area will inevitably be surrounded by water. Flood situations are nevertheless not unmanageable, as the following can be achieved:

- water flow can be slowed down by means of specific civil engineering works,
- heavy rain inflow to drainage systems in urban areas can be delayed by means of green roofs,
- water can be stored in underground or surface reservoirs in order to delay, limit and sometimes avoid water run-off in the streets,
- water can be channelled along streets with raised kerbs,
- water ingress in building can be limited by adequate barriers.

The SMARTeST project contributed to the identification, analyse, assessment and development of FRe technology. It also confirmed that flood water flows through walls of ordinary buildings. This latter property results from the lack of construction regulations and standards that take flood hazard into account. Walls are designed and built to withstand rain precipitation but not to limit the penetration of flood water. The impact of flood on buildings is traditionally addressed by urbanism rules.

Flood management systems define measures that aim to:

- limit damages to persons, built assets and goods,
- anticipate the crisis management,
- recover “quickly” after flood.

An added-value of the SMARTeST project has been to confirm that the availability of tools (e.g. protection equipment, construction water-tightening processes, urban hydraulic simulation software, damages assessment methods), is not enough to ensure that these claimed goals can be fulfilled. What is missing is a full comprehension of the scope and of the limits of these tools as well as a framework to use them in a consistent way through different spatial and time scales.

Six key words are associated to this framework, as follows:

- **Co-ordinated actions**: the consequences of actions at a given scale have to be analysed both upstream and downstream in order to assess their impact on the whole concerned area (in order each can understand the ins and outs of considered alternatives and final decisions)
- **Consistency**: there is a need on the whole concerned area to check prevention/protection measures are consistent at different scales. No measure should hamper or even cancel the expected effects of other measures at a different location.
- **Co-production** should be organised by all stakeholders belonging to different institutions, geographical or administrative areas (in order to fully accept consequences of measures and to define compensation if needed).
- **People resilience** should be developed through planned actions aiming to disseminate information on the importance of anticipation, reactions and behaviours before, during and after flood (in order to create conditions for an effective operation of FReS)
- **Built environment resilience** should be clearly explained (in order to avoid misunderstanding and exaggerated expectations from “resilient systems/environments”). An urban area is a man-made complex system. The resilience property of such a system can only come from the choices of successive decision makers as well as from the way the urban system is maintained. However, choices can be made to use FRE technology to improve the flood performance of the built environment.
- **Smart FRE technologies** have a high potential to support the design, implementation and operation of FReS. They may be essential elements of FReS designed and implemented through a co-production process to develop coordinated actions relying on the resilience of people and of the built environment.

The meaning of resilience in the flood context is still uncertain but, for the time being, it would be a lost battle to fight against the use of this word. Would this use help to improve the current situation, it would be a positive outcome. What should be avoided is abuse, misuse of this term as a communication support.

This reflexion of “FReS” opens research perspectives. Three possible subjects are proposed that would shed light on the future:

- **Past events:** each major event is followed by numerous official reports containing sets of measures to avoid the repetition of observed consequences. A subject would be the analysis of these measures, the observation of the effect of implemented measures, the analysis of these observations and the analysis of the reasons why some measures were finally not implemented.

- **Role of insurance**: there is a great variety of insurance regimes in Europe to cover the consequences of flood. The question of the positive, neutral or negative role of insurance on the development of FReS has to be explored in addition to some discussions in SMARTeST. Insurers are not only bound to the exposed population by contract, they can also play an important intermediary role between this population and institutional bodies.

- **Economics of FReS**: the proposed investigation on “past events” is likely to show the cost of measures is a key factor to trigger or to impede their implementation. This subject deserves a thorough attention as it is directly linked to decisions mechanisms in uncertain future. Such an investigation could also take future climatic into consideration with an increase or decrease of flood events according to local contexts.

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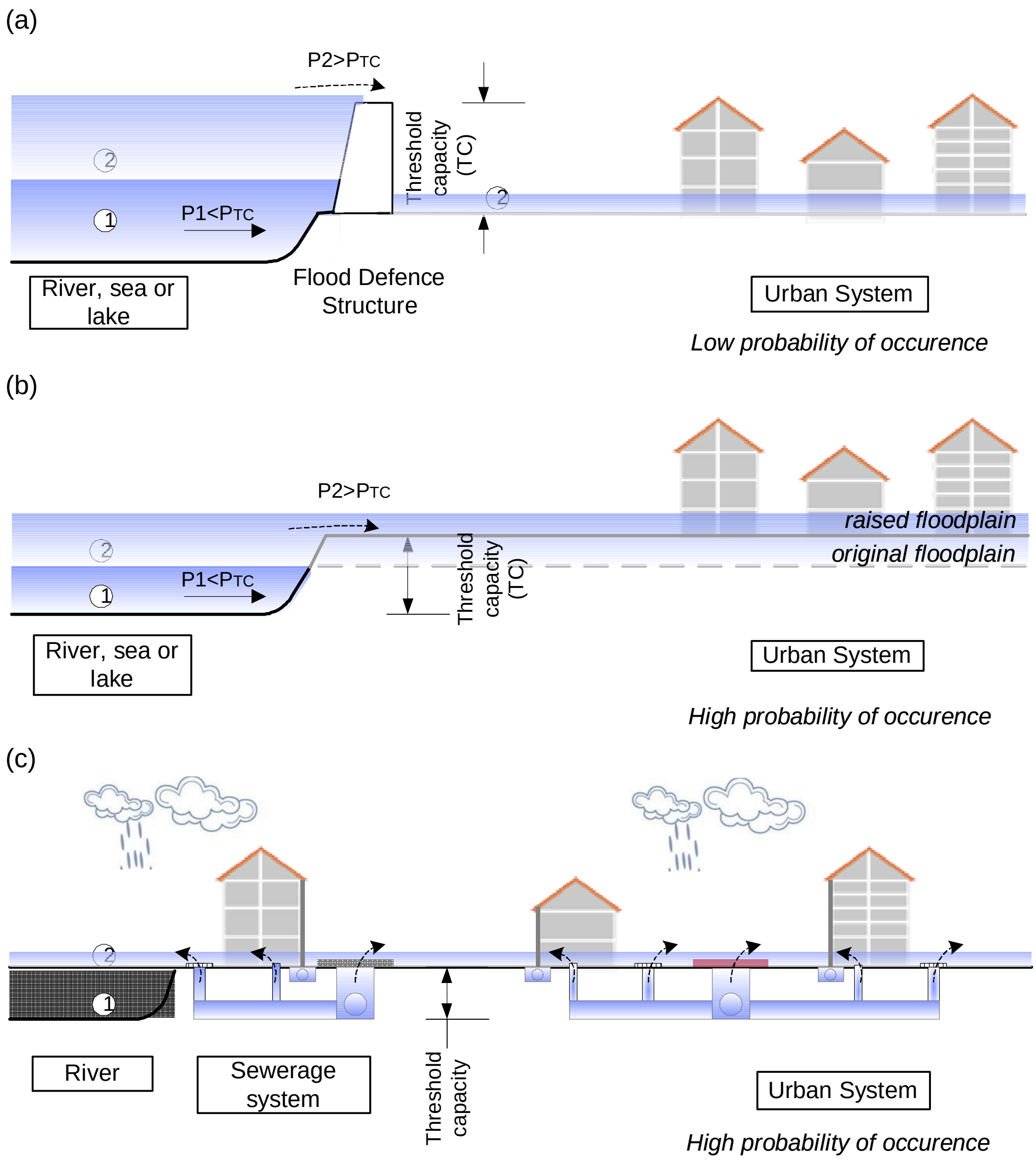
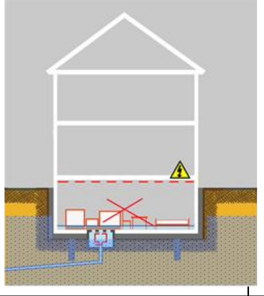
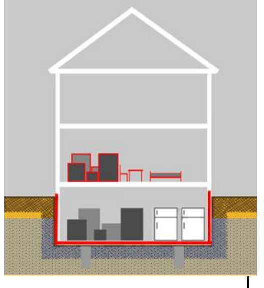
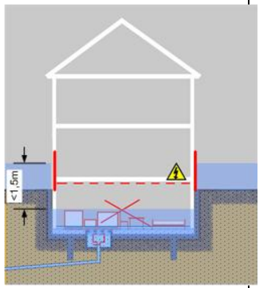
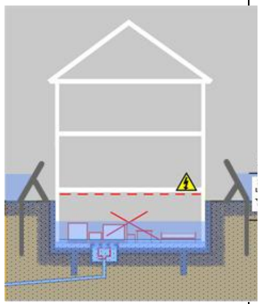
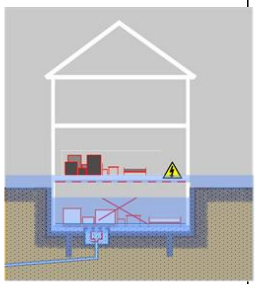
Appendix 1: Urban flood types

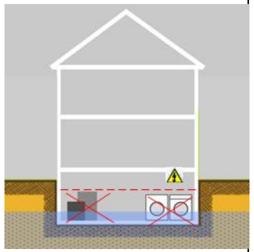
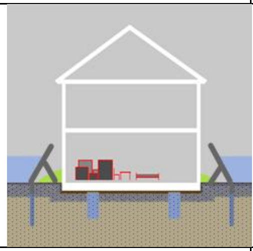
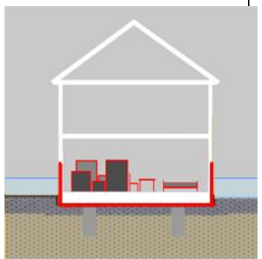
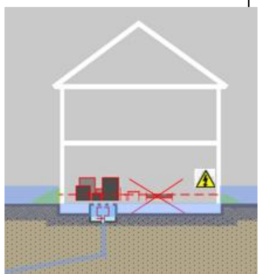


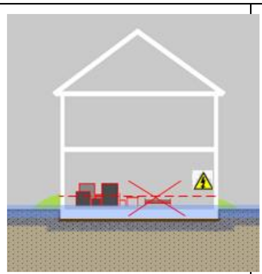
Appendix 2: Resilient measures at Building and District scales

Building scale

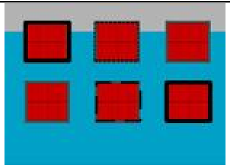
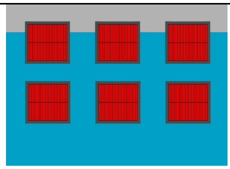
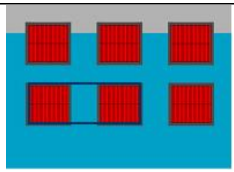
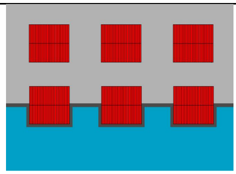
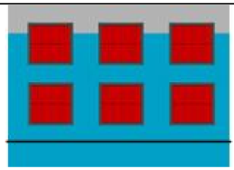
	Resilient measures		Elements			Critical parameters
			Dry proofing	Wet proofing	Building contents& occupancy	
P-RS1	Controlled flooding of basement		- horizontal sealing of the walls in ground floor to prevent capillary rise from the basement - protection from the backwater effect	-Application of water resistant materials for walls, floors, ceiling, staircases - elevation (encapsulation) of services - installation of a pump in a sump with sensors	-Change of occupancy of the basement with permanent elevation of inventory items - temporary elevation of the inventory	- time for elevation of the inventory items - effort for operating the equipment (critical in case of vulnerable groups) - terrain configuration for accessing the building parts
P-RS 2	Sealing of basement		- Sealing of walls, floors, ceiling, staircases either by application of waterproof concrete or polymer bituminous seal - Dry proofing of services (e.g. encapsulation of wiring) - closure of openings - protection from the backwater effect	-	-	- stability of the building

P-RS 3	Controlled flooding of basement and sealing of the above ground floor(s) 	**Sealing (horiz+vertical) of walls, floors, ceiling, staircases either by application of waterproof concrete or polymer bituminous seal - Dry proofing of services (e.g. encapsulation of wiring) - closure of openings - protection from the backwater effect**	**-Application of water resistant materials for walls, floors, ceiling, staircases - elevation (encapsulation) of services - installation of a pump in a sump with sensors**	**-Change of occupancy of the basement with permanent elevation of inventory items - temporary elevation of the inventory**	**- time for elevation of the inventory items - effort for operating the equipment (critical in case of vulnerable groups) - terrain configuration for accessing the building parts - stability of the exterior walls in the ground floor - availability of upper floors for vertical evacuation**
P-RS 4	Controlled flooding of basement and shielding of the above ground floor(s) 	**- horizontal sealing of the walls in ground floor to prevent capillary rise from the basement - shielding of the building applying temporary barriers - protection from the backwater effect**	**-Application of water resistant materials for walls, floors, ceiling, staircases - elevation (encapsulation) of services - installation of a pump in a sump with sensors**	**-Change of occupancy of the basement with permanent elevation of inventory items - temporary elevation of the inventory**	**- time for elevation of the inventory items - effort for operating the equipment (critical in case of vulnerable groups) - terrain configuration for accessing the building parts - time for erecting the temporary barriers**
P-RS 5	Controlled flooding of basement and wetproofing of the above ground floor(s) 	**- protection from the backwater effect**	**-Application of water resistant materials for walls, floors, ceiling, staircases - elevation (encapsulation) of services - installation of a pump in a sump with sensors**	**-Change of occupancy of the basement with permanent elevation of inventory items - temporary elevation of the inventory**	**- time for elevation of the inventory items in basement and ground floor - effort for operating the equipment (critical in case of vulnerable groups) - terrain configuration for accessing the building parts**

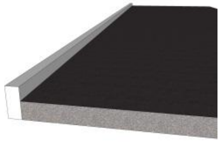
P-RS 6	Wet proofing of basement 	**- horizontal sealing of the walls in ground floor to prevent capillary rise from the basement - protection from the backwater effect**	**-Application of water resistant materials for walls, floors, ceiling, staircases - elevation (encapsulation) of services**	**-Change of occupancy of the basement with permanent elevation of inventory items - temporary elevation of the inventory**	**- time for elevation of the inventory items - terrain configuration for accessing the building parts**
P-RS 7	Shielding of the building 	**- shielding of the building applying temporary barriers - protection from the backwater effect**	**No wetproofing elements used**	**- no changes**	**- time for erecting the demountable barriers**
P-RS 8	Sealing of the above ground floor(s) 	**Sealing (horiz+vertical) of walls, floors, ceiling, staircases either by application of waterproof concrete or polymer bituminous seal - Dry proofing of services (e.g. encapsulation of wiring) - closure of openings - protection from the backwater effect**	**- No wetproofing elements used**	**- no changes**	**- stability of the building especially exterior walls**
P-RS 9	Controlled flooding of the above ground floor(s) 	**- protection from the backwater effect**	**-Application of water resistant materials for walls, floors, ceiling, staircases - elevation (encapsulation) of services - installation of a pump in a sump with sensors**	**- Change of occupancy of the ground floor with permanent elevation of inventory items - temporary elevation of the inventory**	**- time for elevation of the inventory items - effort for operating the equipment (critical in case of vulnerable groups) - limited accessibility of the building parts - limited occupancy of the ground floor**

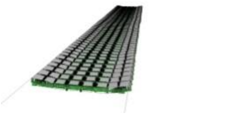
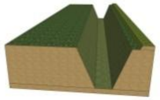
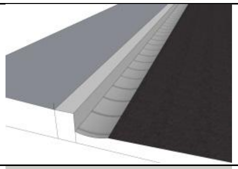
P-RS 10	Wet proofing of the above ground floor(s)		**- protection from the backwater effect**	**-Application of water resistant materials for walls, floors, ceiling, staircases - elevation (encapsulation) of services**	**-Change of occupancy of the ground floor with permanent elevation of inventory items - temporary elevation of the inventory**	**- time for elevation of the inventory items - limited occupancy of the ground floor.**
P-RS 11	Elevation/ Relocation	**The building is relocated from the existing position either by elevation or removal to other area.**	**- No dryproofing elements used**	**- No wetproofing elements used**	**- No changes**	**- not only of technical nature but of social and economic -**

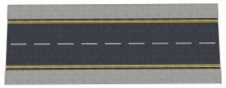
District scale

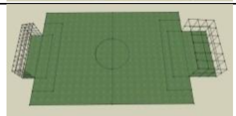
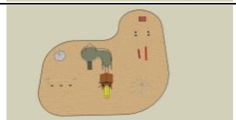
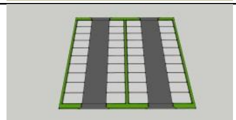
Resilient measures		Description	Elements of resilient system (4 As)		
			Alleviation	***Assistance***	***Avoidance***
Protection of single properties separately with non-uniform protection level		Each property is protected as a standalone unit for different design flood events, depending on the level of acceptable risk	- resilient buildings	- Flood forecasting and warning - Financial incentives - Insurance - Assistance in implementation	adapted land use, building codes
Protection of single properties separately with uniform protection level		Each property is protected as a standalone unit for uniform design level.	- resilient buildings	- Flood forecasting and warning - Insurance	adapted land use, building codes
Clustering of the adjacent buildings (neighbourhoods)		Clustering the neighbourhoods with the aim to develop synergetic effect, i.e. reducing costs and improving the efficiency of the flood adaptation.	- resilient buildings	- Flood forecasting and warning - Insurance - Demountable barriers	
Connecting buildings to resilience frontline		Closing the front to the watercourse. The gaps between the buildings are closed either by permanent constructions or temp containment structures, or both.	- resilient buildings - resilient infrastructure	- Flood forecasting and warning - Insurance - temp containment structures	
Combination of conventional and resilience measures		The resilience measures bear the uncertainty of the future development (unpredictable flood event), the structural measures are made used of .	- resilient buildings - resilient infrastructure	- Flood forecasting and warning - Insurance - temp containment structures	adapted land use

Appendix 3: Set of possible FRe elements

Category	Image	Description	Functionality	Remarks
Diversion Structures				
Check dams		Small constructions to create a cascade system	Reduce flow velocity and increase retention Divert water toward a conveyance system or a retention area	For longitudinal slope of the swale higher than 4%
Curbs		Edge between roadway and sidewalk	Route the water along the sides of the street	
Walls		Edge between roadway (or sidewalk) and premise	Route the water along the sides of the street	-
Earth dikes		Embankment of earth	Hold and direct water along their toe	Can be used alone or in combination with a conveyance structure e.g. with swales
Speed bumps		Traffic speed reduction feature	Stop water flow and create a small pond	Small roads in residential areas with vehicles speed limit
Flood barriers		Demountable systems to protect objects from floods	Prevent water from entering premises stopping the water from flowing in a certain direction	Basement and ground floor protection in case of conveyance or storage of water on adjacent streets

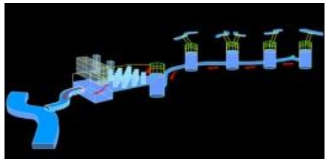
Category	Image	Description	Functionality	Remarks
Conveyance Structures				
Rills		Shallow channels with gentle side slope	Collect and convey the water to retention areas or bigger conveyance systems	Connection between roof gutters and swales Parking areas Streets with speed limit
		Narrow shallow channels	Collect and convey the water to retention areas or bigger conveyance systems	Connection between roof gutters and swale Areas for pedestrians only
Swales		Shallow channels with gentle side slope	Collect the water and promote infiltration and storage Convey the water to retention areas	
Ditches		Moderate depression	Promote infiltration and storage	
Street gutters		Depression which runs along the sides of the streets	Covey the water along the sides of the street	The channel can have different shapes
		Narrow channel with a grid on top which runs perpendicular to the flow direction	Convey the water perpendicular to the street direction Convey the water towards a lowered retention area or to a bigger conveyance system	One can drive on it

Pipes		PVC pipes	Connect conveyance elements and/ or retention areas	
Secondary streets		Small streets	Convey the water to retention areas	

Category	Image	Description	Functionality	Remarks
Multipurpose Spaces				
Green areas		Small parks in urban areas	Storage of the exceeding water	Meadows parks Might also promote infiltration and evaporation Must be equipped with alarm system
Sport courts		Areas for recreational purposes	Storage of the exceeding water	Might also promote infiltration and evaporation Must be equipped with alarm system
Playgrounds		Children recreational areas	Storage of the exceeding water	Might also promote infiltration and evaporation Must be equipped with alarm system
Parking spots		Big parking spaces	Storage of the exceeding water	Might also promote infiltration and evaporation Must be equipped with alarm system

Traffic island		Separation of traffic lines or green strips on the side of the street	Storage of the exceeding water	
Secondary streets		Small roads for light traffic	Storage of the exceeding water	Must be equipped with alarm system

Category	Image	Description	Functionality	Remarks
Green Reservoirs				
Retention basins		Artificial vegetated lakes with permanent pool of water	Collect stormwater and slowly release it	Outflow orifice higher than the bottom level of the basin
Detention basins		Artificial vegetated lakes which remain dry between storms	Collect stormwater and slowly release it	Outflow orifice at the bottom level of the basin
Infiltration basins		Shallow artificial ponds with permeable soil	Infiltration of stormwater into the groundwater aquifer	No outflow orifice but with overflow structure

Category	Image	Description	Functionality	Remarks
Underground Storage				
TARP (Chicago)		Underground tunnels and surface reservoirs	Collect combined sanitary and storm sewer flows and convey them to surface reservoirs	High costs
G-Cans Project (Kasukabe, Japan)		Underground water tanks	Collect and store flood water	High costs
Loop Road No. 7 (Tokyo, Japan)		Underground tunnel	Collect and store flood water	High costs
SMART, Stormwater Management and Road Tunnel (Malaysia)		Underground tunnel	Prevent flooding and alleviate traffic congestion	High costs

TIMA, Tunnel de stockage des eaux de pluie Ivry-Masséna (Paris, France)		Underground tunnel	Storage of the exceeding water	High costs

Appendix 4: Description of MULTI-HYDRO

MULTI-HYDRO is a fully distributed physically based model developed at the Ecole des Ponts ParisTech during the SMARTeST project (Giangola-Murzyn et al., 2012). It is built on the four open source software developed separately and widely used in the scientific world. Multi-Hydro is the core that makes them interact (Figure. A).

The MULTI-HYDRO Surface Component (MHSC) models the surface runoff and relies on TREX, which was developed by HydroQual Incorporate and the Colorado State University (Velleux et al., 2011). It uses spatially distributed data (hydrological network, land use, type of soil, elevation, overland storage depth and the initial conditions) to model the behaviour of the catchment.

The MULTI-HYDRO Ground Component (MHGC) models sub-surface processes and relies on the VS2DT model, which was developed by the U.S. Geological Survey (Lappala et al., 1987). It uses finite differences to compute the pressure head, the total head, the moisture contents and/or the saturation and the mass balance, with the help of the law of conservation of fluid mass and a non-linear form of the Darcy equation. It takes into account the structure and the composition of the soil, the amount of water entering in the system, the temperature and the initial conditions.

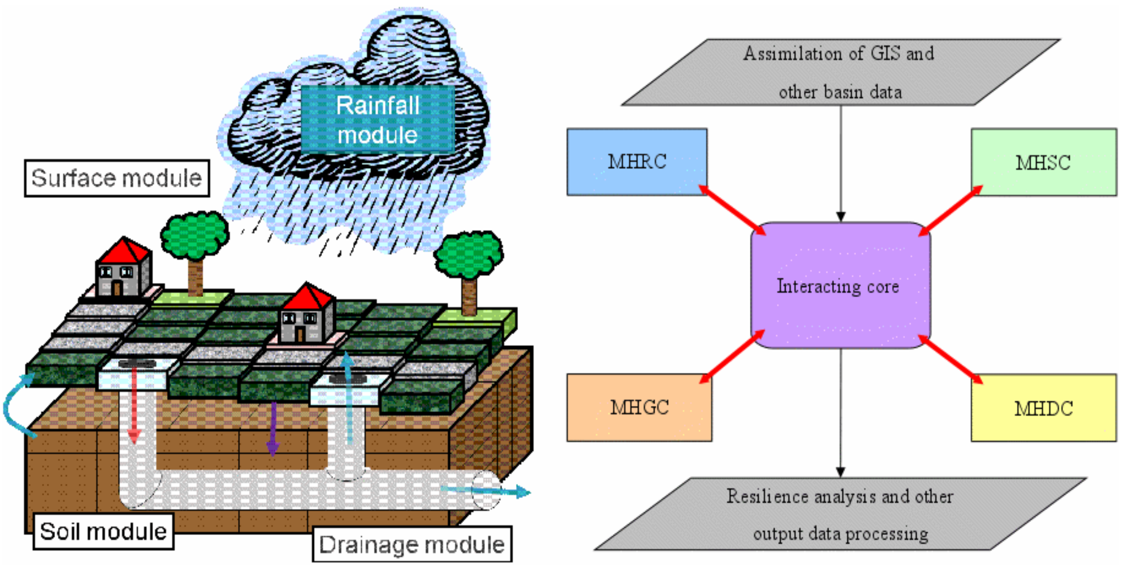


Figure A: MULTI-HYDRO model description and organisation of the interaction between each component of the MULTI-HYDRO model

The MULTI-HYDRO Drainage Component (MHDC) models flows in sewer systems and relies on SWMM, which is developed by the United States Environmental Protection Agency and the Camp Dresser & McKee incorporation (Rossman, 2010). The model basically relies on 1D Saint-Venant equations, which are used to dynamically simulate sewer flow. The sewer system is described in details (pipe, node, shape, length, slope, initial head, Manning's coefficient, etc.).

The MULTI-HYDRO Rainfall Component (MHRC) enables to downscale rainfall data. Indeed the usual C-band radar resolution of 1km*1km*5min does not enable to fully take advantage of the high resolution distributed hydrological model (10m). The space-time downscaling is performed with the help of universal multi-fractals cascades (Schertzer and Lovejoy, 1987). More details about the multi-fractal analysis and downscaling of this process can be found in Gires et al. (2011).

With its modular structure, MULTI-HYDRO can be easily adapted to the need of each case study. As it is GIS based and it don't need to be calibrated, MULTI-HYDRO is easily transportable to a case study to another one. The GIS data are quickly assimilated with the help of MH-AssimTool, an open source software developed at the Ecole des Ponts ParisTech during the SMARTeST project.

MH-AssimTool

MULTI-HYDRO requires GIS data pre-processed in a specific format. Nearly all data pre-processing could be done in ArcGIS or QGis (or any GIS software). With these generic tools, the step of pre-formatting of the data is very repetitive and data transformation may easily be time consuming. Therefore an advanced and dedicated GIS data assimilation interface is a requisite to complete a distributed hydrological model that is both transportable from catchment to catchment and is easily adaptable to the data resolution. This is achieved both for the cartographic data and the linked information data (Richard et al., 2012). The MH-AssimTool (MULTI-HYDRO Assimilation Tool) software allows MULTI-HYDRO users to easily change the case study and/or to format the input files with new, better adapted grid size data.

MH-AssimTool provides a user-friendly interface (Figure B) to create easily the set of data required for the computation and facilitate the possibility to multiply the scenarios and the case studies.

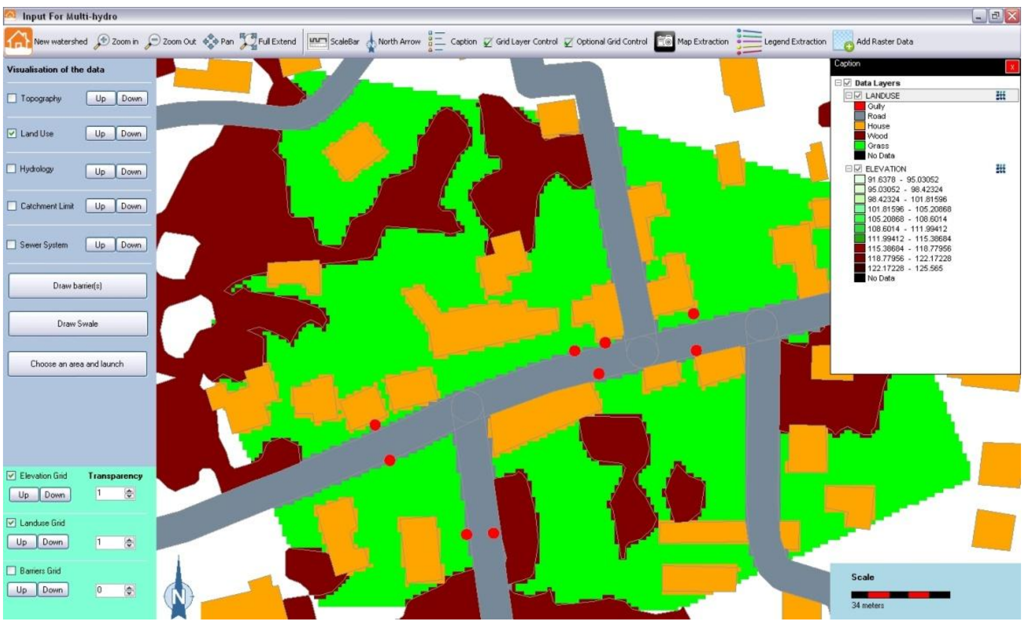


Figure B: MH-AssimTool main window

Implementation of the FRe technologies in MULTI-HYDRO

MULTI-HYDRO is developed in the aim to evaluate the impact of the small scale changes on the overall behaviour of an urban catchment. In the context of the SMARTeST project, MULTI-HYDRO can take into account the implementation of FRe technologies, simply defined as a particular category of land use at the appropriated (small) scales. Through the dedicated GIS based software, MH-AssimTool, it's really easy to implement different types of FRe technologies, as the perimetric barriers, individual barriers or alternative methods as swales (i.e., surface defined as a soil depression where the infiltration parameters are modified to facilitate the process). Moreover, as MULTI-HYDRO works on the base of time loops, it is possible to simulate the temporal variation of these devices, i.e. the progressive implementation of the barriers.

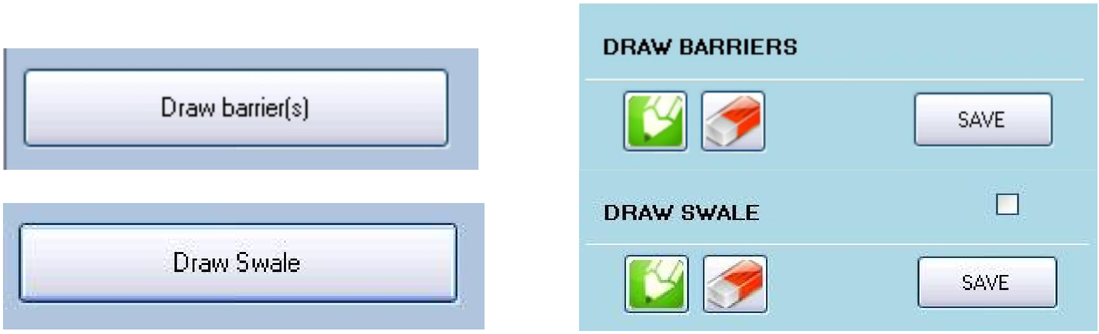


Figure C: screenshot of the part to draw FRe devices in MH-AssimTool.

MULTI-HYDRO can be used by a large panel of user, including people without particular competence in terms of computer experience. Indeed, this tool is developed to be more and more user-friendly, i.e. the parameters needed by the model are requested through several pop-up windows (Figures C-D). This easiness of use was demonstrated in February 2012, during a training event organised at Ecole des Ponts ParisTech and during which the SMARTeST project partners spend two days to use the model. During this event, each participant was able to create a catchment and test on it different scenarios. If this event was useful to people to discover the tool, it was also useful for the development of MULTI-HYDRO which benefited from the user feedbacks for further improvements.

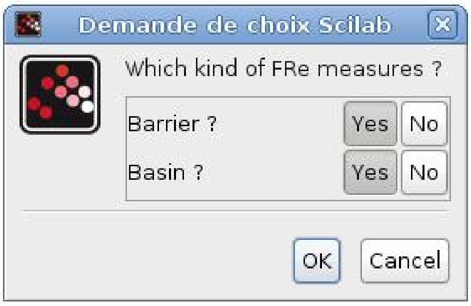


Figure D: screenshot of a pop-up window in MULTI-HYDRO

MULTI-HYDRO opens quick and easy evaluation of the hydrological impact from FRe measures. An example of their implementation is given below for Heywood (UK) for a rainfall event of 58.5mm in 2 hours. Figure E illustrates the original situation when no FRe measures have been employed. This situation results in more than 60 cm of water in Egerton street and its surrounding green areas.

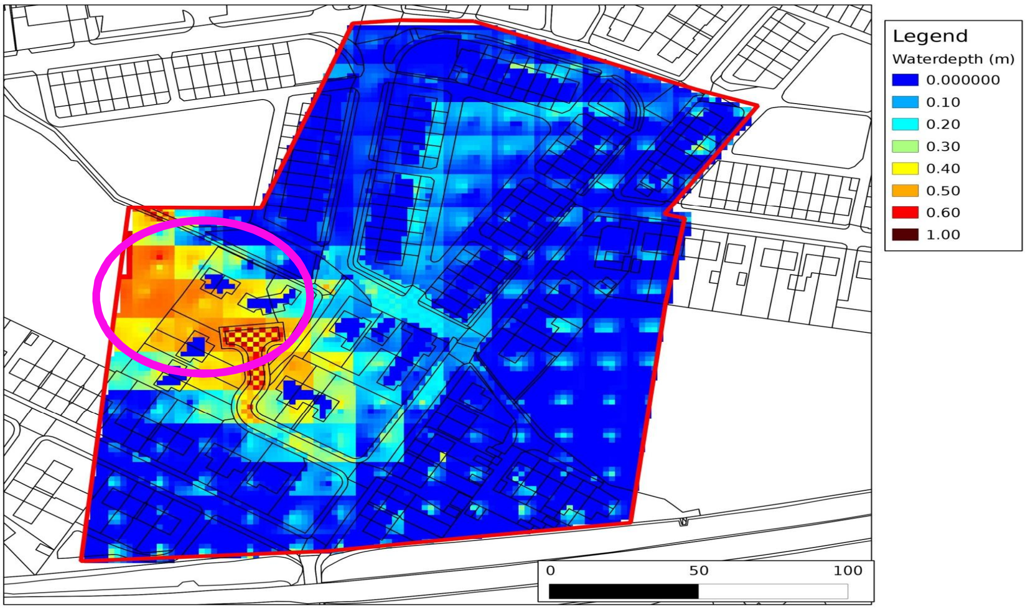


Figure E: the place circled by the pink shape is flooded by roughly 60 cm.

Then to improve the situation, three alternatives for the FRe measures have been considered: the implementation of perimetric barriers of 1 m height at two locations in the street, the implementation of a swale of 1.5 m depth and the implementation of the both (barrier of 1m height and a swale of 0.5m depth). With a numerous scenarios, MULTI-HYDRO can assess the global impact from the local implementations of FRe technologies.

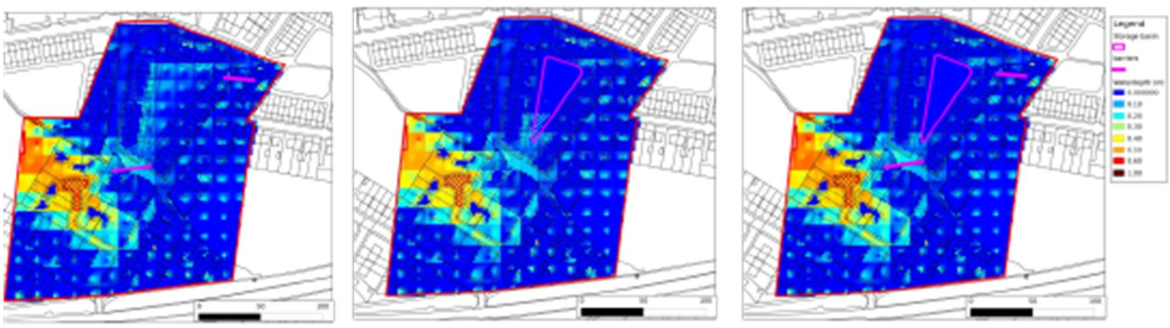


Figure F: from left to right, the results given after implementation of perimetric barrier of 1m, after implementation of a swale of 1.5 m and after implementation of perimetric barriers of 1m and swale of 0.5m depth. The FRe measure localisations are indicated by pink lines. The water depth ranges from 0 to 1m.

The obtained results (Figure F) suggest that in the case of Heywood, the most adapted solution seems to be given by the last option, i.e. associating a barrier with a swale of smaller depth. This option allows not only to reduce the implementation costs, but also to improve the visual perception by the inhabitants.

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Appendix 5: New generation radars as core devices of a Smart Flood Resilient Systems (SFReS)

SMARTeST might have brought a major paradigm change in urban flood management. Indeed, looking for smart flood resilient technologies the partners were finally and logically led to conclude that smart is rather an emerging property of (multi-scale) networks/systems of flood resilience measures. Loosely speaking smart pertains to the brain/neuron system rather than to the neurons. More precisely, these systems should generate sort of cyber intelligence when facing phenomena like rain and the subsequent runoff that have a complex structure displaying an extreme variability over a wide range of space-time scales. Many efforts have been devoted to define devices locally detecting rain and accordingly acting, but unfortunately the aforementioned complex structure of rain leads to wrong estimates and actions. Indeed, the “leopard skin” of a storm displays spotty cells and super-cells with extreme local rain rates. The time-life of these cells and other storm structures decreases with their size, i.e. their evolution is faster and faster for smaller and smaller structures, preventing any deterministic forecast. Huge economic damages and even fatalities often result from the lack of warning in due time

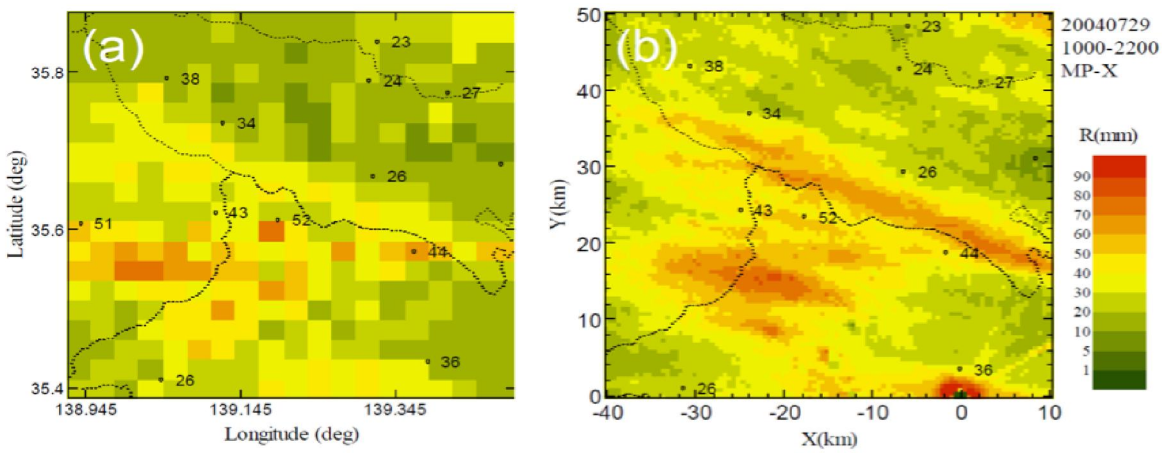


Fig 1 a-b: Fast moving rain cell over Tokyo area (27/07/04)
(a) conventional radar rainfall estimates adjusted with rain gauge network data, with a 2.5 km resolution
(b) Polarimetric X-band estimates with a 250 meter resolution
The structure of the cell is rather obvious on (b), whereas it remains almost unnoticed in (a) (reproduced from Maki et al, roc. Fifth European Conference on Radar in Meteorology and Hydrology, 2008).

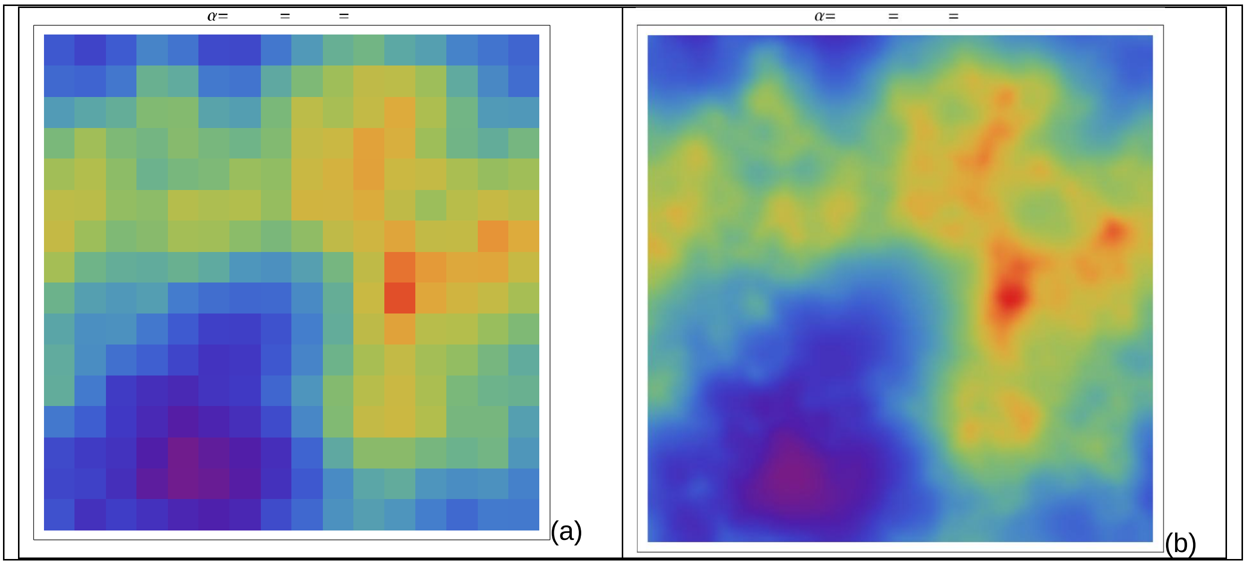


Fig 2 a-b: similar observations on snapshots of a multifractal rainfall simulation with scale resolution (i.e. the ratio of the larger scale to the observation scale): (a) □= 16 (b)) □= 128 (Schertzer et al., International Symposium on Extreme Weather and Cities, Tokyo, 24-25/10/13)

Due to the rather smallness of our urban system scales, high resolution data are already indispensable to provide the necessary time and information to take decision and activate smart technologies to reduce the immediate damages and facilitate the return to a normal functioning. The data scale resolution and accuracy as well as their fast and distributed availability is of outmost importance: every minute counts, as well as every structural detail of the storm. More fundamentally, these data should circulate within the information network of the SFReS, like cerebral signals do in neuron networks, to generate a multi-scale vision and understanding of the occurring processes.

A few decades ago, the introduction of weather radar data already brought huge impacts on rainfall forecast and water management. Radars are still the only devices providing rainfall measurements in space and time. Various rainfall now casting methods based on statistical processing of radar images have been readily developed to fill up the short term forecast deficit. Indeed, both the spin-up time and the space-time scales of deterministic weather forecast models remain too large to deliver accurate short-term forecasts. However, the standard rainfall products provided by meteorological services have remained at a scale of ten kilometres, still too large for urban water management.

The rather recent technology of the X-band radars may unlock this scale bottleneck, as well as to introduce an important socio-technological paradigm change: local water authorities may become in the near future managers of X-band radar sub-networks, rather than to only remain customers of classical radar networks. Due to their higher frequency, the X-band radars are not only offering a higher spatial resolution, but are more versatile (much smaller parabola and lighter mechanical systems) and more affordable. They may open the way to sort of close-up remote sensing by giving access to a space resolution increased by a factor of the order of ten. This means that rainfall structures that looked rather fuzzy with classical radars can become obvious with a number of pixels multiplied by a factor of the order one hundred (see Fig1a-b and Fig2 a-b).

One can infer than the already existing now casting techniques could become already more reliable, simply because of the data increased resolution. For instance, the ratio of false and missing alarms could significantly decrease, and the information distribution could be managed more directly by the local authorities and the public with the help of internet and other networks. Going a step further, he question will be how to articulate/connect at various scales and levels active resilient measures to the information network. At the same time, the gain could be much more important with the development of stochastic multi-scale forecasting techniques based on the hierarchy of rainfall structures, as well as their nonlinear interactions. Their physical basis would provide a higher predictability the present statistical now casting methods that do not take into account the strongly nonlinear dynamics of the storm cells.

Climate change and sprawling urbanization are two drivers that could increase the extremes. Both already brought into question the usual implicit approximation of statistical stationarity, and therefore classical operational notions. They reinforce the fact that the rainfall alert and forecast systems need both more detailed space-time information and more reliable now casting techniques.

Appendix 6: Is the insurance industry proactive enough in promoting the uptake of Flood Resilient Technologies? [2]

In the area of NatCat Disaster Risk Management (DRM), insurance can be considered as an economic and social resilience instrument. Referring to the priority 4 of Hyogo Framework for Action (HFA) 2005-2015, to “reduce the underlying risk factors”, “social and economic development practices” are required among which “promote the development of financial risk-sharing mechanisms, particularly insurance and reinsurance against disasters”.

This paper proposes to document and assess the current and potential commitment of insurance undertakings, in promoting flood risk management measure, and particularly in the uptake of Flood Resilient Measures (FReM)[3].

As an introduction to the insurance industry, it is useful to identify those different players at stake in this particular value chain, about which many observers are confused (section 1).

Then the article highlights the current approach of direct insurers, besides their main purpose of providing the risk transfer service, in assessing flood risk exposure and advising flood “prevention” and resilience measures, according to their customer segments, with the specific difficulty of taking into account individual and collective vulnerability levels (section 2).

Next, through the study of both their commercial and institutional activities in this particular area, it is proposed to examine how direct insurers may become even more proactive in catalysing the uptake of FReM (section 3 and conclusion).

An introduction to the insurance industry

Words, concepts and terminologies relating to “the insurance sector[4]” are sometimes misunderstood, especially when speaking of catastrophic risk, where public perception may confuse the differences between this major economic sector aimed at delivering risk transfer services and other ex-ante or ex-post, private or public sources of cost recovery.

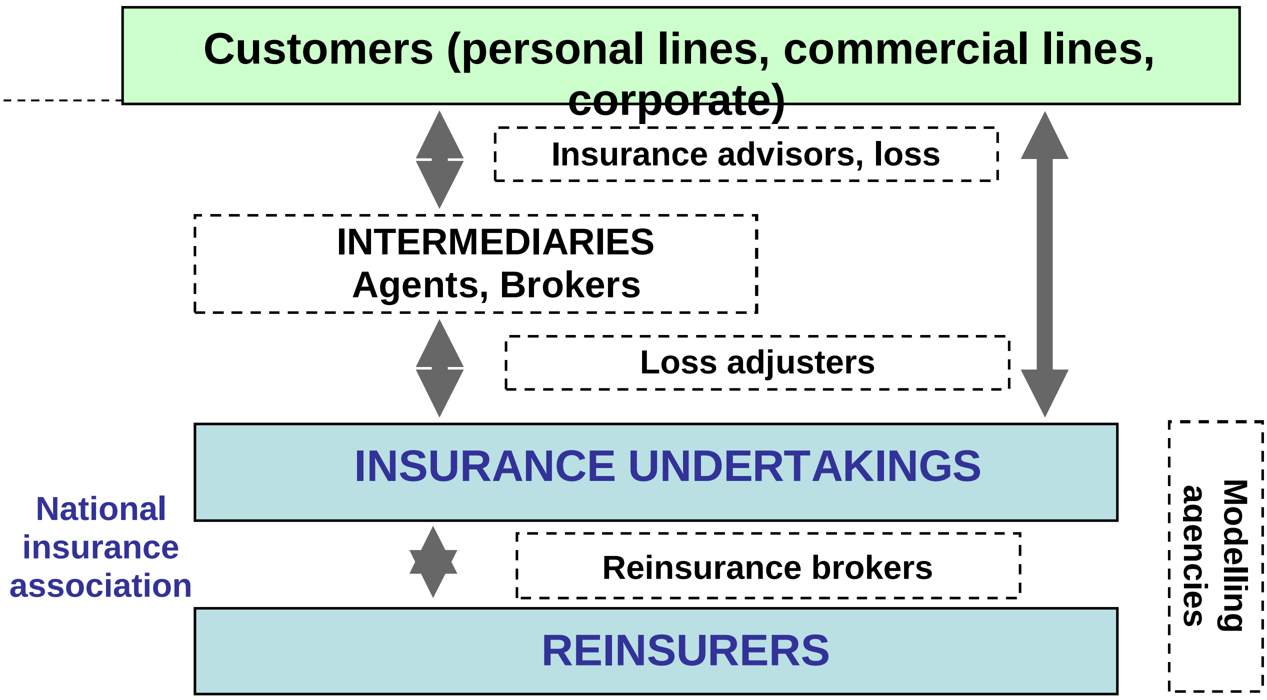
To describe the main categories of economic actors operating in this sector, one should first make a distinction between non risk taking activities and the effective risk carriers, which are coloured in blue in the boxes on the chart below.

[2] A contribution to SMARTeST project by Dr Sarah Gerin and Roland Nussbaum

[3] Here the definition of FReM available on the SMARTeST web site is considered: the flood resilience measures (FReM) are defined as the measures that improve the resilience of the receptor and/or reduce the exposure to flooding, where the urban fabric and people with their activities on the flood plain are considered the receptor.

[4] the so called “insurance industry”, even if operating solely in the service sector

The chart below displays the insurance industry chain, from the consumers to direct insurance operations, subject to agreement and control under Community law, upstream to the reinsurers, whose role is to provide technical support, risk spreading and capacity extension to the direct insurer.



The risk taking activities are those mainly covered by European financial services legislation. They include the following actors and activities, with reference to relevant Community law:

- The **insurance undertakings**, are undertakings agreed to exercise insurance operations according to directives 1992/49/EC (Non-life) and 2002/83/EC (Life), with various admitted legal forms, the list of which depends on each Member State law (stock companies, insurance mutuals, co-operatives, etc.),
- The **reinsurance undertakings**[5] and **captive reinsurance undertakings**, regulated under directive 2005/68/EC (definition in art. 2.1. b. and c.),
- **Reinsurance activities**:
  - Consist in accepting risks ceded by an insurance undertaking or by another reinsurance undertaking […] (art 2.1.a of directive 2005/68/EC).
  - Or those exercised or totally guaranteed by the government of a Member State, acting for reasons of important public interest, in quality of reinsurer of last resort, including if this role is

[5] The NatCat, geosciences, GIS, modelling teams of the largest reinsurers appear from outside this industry to be the most identified concentration of expertise in the field.

made necessary from a situation where it is impossible to obtain on the market an adequate reinsurance coverage (art 1.2.d) of directive 2005/68/EC)

In each national market where they have their head office or operate through a subsidiary or a branch, almost all (re)insurance undertakings belong to the national insurance association, for general interest as well as lobbying activities. At EU level, an umbrella association, Insurance Europe (former CEA)[6], the European insurance and reinsurance federation, represents these operators in the EU institutions. The very important role of these sectorial trade associations, both at national and EU level, in addressing the Public-Private Partnership (PPP) issues at stake particularly in the area of NatCat Disaster Risk Management (DRM), including Disaster Risk Reduction (DRR) and Transfer.

The non-risk taking activities include, in non-life business, with some specific features relative to NatCat:

- Intermediaries for direct insurance operations (agents, brokers), as defined in directives 77/92/CEE (Agents and brokers directive) and 2002/92/EC (insurance and reinsurance mediation directive),
- Insurance advisors, loss adjusters operating either on behalf of the policyholder or on behalf of the company, or both (in the case of a single loss adjuster),
- Reinsurance brokers, totally or partly specialised in Cat risks[7] reinsurance business and other service providers to (re)insurance companies, such as for instance:
  - independent actuaries,
  - CAT risk modelling firms, mainly three, from the USA[8] but also a few start-ups in the EU.

From now on, the wording of “direct insurers” will be used in the sense of private “insurance undertakings”, as defined above. This paper will concentrate on these players, as the risk takers (from the perspective of their customer) as well as one of the main risk transfer service providers. Individually and even more through their market associations (ABI, ANIA, FFSA, GDV, etc.), they are also the main counterparts of national and local governance bodies and administration, on flood risk management issues and public policies. This approach does not undermine the importance of private reinsurance market players, at a B2B level in the insurance industry itself as well as in a more macro-economic perspective (with limited if ever any interaction with customers).

How do direct insurers currently approach flood risk?

The insurance contract is an agreement which transfers the financial burden of a certain amount of damage losses (e.g. property damage) as a consequence of potential (flood) risk, from the insured to the direct insurer (the direct insurer may himself transfer a certain amount of the risk he takes to selected re-insurer(s), as explained above).

[6] See http://www.insuranceeurope.eu/

[7] Benfield, Guy Carpenter and Willis, for instance, have developed their own international research organisations/networks, together with universities

[8] AIR, ABS Consulting/EQECAT, Risk Management Solutions (RMS)

Before signing a contract, the direct insurer assesses the risk exposure (flood and others perils), with an attention, proportional to the sum insured and/or to the accumulation of individual risks in a certain exposed area. This means that the intensity of attention given by the insurer greatly depends on the customer segment:

- Case by case approaches, including site surveys, are carried out for large to medium sized commercial lines or municipality customers (no major difference of approach can be reported between the different direct insurers operating on this segment[9]);
- A much reduced consideration can be given individually to SMEs commercial lines and personal lines customers, as the insurance business model shall not allow for a site survey at the scale of each small account.

In addition to the risk exposure assessment, he may take, for risk rating purposes, other factors into account such as the loss record of the insured (insurance claims report).

In general, the higher the risk is the higher the premium and/or, at least, the deductible.

How do they develop flood risk knowledge at the appropriate scale?

Private insurers are not able to manage natural disaster risk, such as flooding, in the same way as they do for other types of risks (fire, theft, etc.). Indeed the relatively low frequency of flood events and the correlatively high intensity and variability expose insurance companies to uncertain and potential large losses.

Also the pool of consumers who consider purchasing flood insurance is relatively small, due to a contribution of factors such as: a certain "spatialisation" of the phenomenon, low flood risk awareness, or an expectation that disaster assistance will be provided by the Government and/or non-governmental entities. If the pool of policyholders consists of a limited exposed group, it can result in a high cost of coverage and reduce the market penetration even further (Kunreuther and Roth, 1998).

Insurance schemes widely vary across States. Different NatCat insurance markets are currently presented by Insurance Europe and others (CEA, 2007 ; Nussbaum, 2008). Whatever the NatCat market, to assume the "basic purpose" of allowing flood damages financing (*ex ante* risk transfer mechanism), the implementation of flood "prevention" measures, is required. Moreover, substantial flood "prevention" measures can be taken by each owner on his building, but they must be necessarily coupled with other extensive measures.

So, when direct insurers approach flood risk cover, they have to consider the flood risk exposure and flood "prevention" measures, at an individual and collective level.

On one hand, the direct insurer assesses the flood risk at an individual (site) level. Indeed, the more information about an individual risk is held, the more the insurance conditions (premium, deductible) can be tailored to that risk. But this is only conceivable when the insurance business model allows for a site survey, in other words when flood exposure and vulnerabilities are identified at a facility (case by case

[9]Although the direct insurers specialized in highly protected risks are emphasizing logically in their marketing and communication their specific risk engineering skills and efforts in this area, the composite large direct insurers have developed the same skills and approaches in their relevant branches.

approaches). A thorough analysis can be made for large commercial lines or municipality customers, with important exposure i.e. a high density of value exposed or critical equipment (process plant, factory ...) that could generate extensive supply chain interruption and/or business interruption due to inaccessibility of the facility to the workforce, etc. Such an assessment is economically efficient, when it allows the price of the insurance to reflect the cost of providing it. In such cases, the customer is likely to be knowledgeable about risk in general and flood risk in particular.

On the other hand, natural hazards such as flooding are required to be managed mainly through collective actions. Even if the insurer can hardly assess the flood risk exposure and collective risk reduction decisions taken at the level of the river basin authorities influence (at the place of or together with its customer), for general interest purposes national insurance market associations are involved in governance instances, created at national to local scales, and can assess flood risk exposure and public flood risk reduction policies taken at a collective level.

What kind of risk analysis do they perform, at individual and/or collective level?

In the UK, there is a 'Statement of principle' between private insurers, represented by the Association of British Insurers (ABI), and the Government (ABI, 2002; Treby et al., 2006). Through this 'gentlemen's agreement', cover is offered under standard conditions only within areas where flood risk is equal or less than 1.3% annual probability (or 1 in 75 years) or in more significant flood risk areas, where improvements implemented by public authorities can achieve this protection level over a five-year term (ABI, 2005). Therefore, the ABI frequently reviews the flood risk exposure and flood "prevention" measures implemented by public authorities in areas severely affected by flooding. The progress of public flood projects and achievements is frequently reviewed with regard to the evolution of insurance market conditions. The ABI mobilizes information related to these components of flood risk and Government action failures, in order to emphasise their vision of a given situation at a global scale and the improvements required (ABI, 2004). Its aim is to entitle the private insurers to deliver affordable flood insurance for the majority of dwellings and commercial customers.

Also in France, huge recent loss experience of the last decades in the hybrid public-private insurance system called the Nat-Cat regime have to some innovative initiatives, with respect to risk knowledge and reduction, from the perspective of direct insurers and their trade associations.. Through this Nat-Cat regime, a particular compensation right is offered in return for a duty of "prevention". Described shortly, to benefit from the indemnification process, municipalities and policyholders were supposed to have implemented required "prevention" measures.

Specificities of the Nat-Cat system led private insurers to create a dedicated body, called "Mission Risques Naturels" (MRN) which represents private insurers *vis a vis* their relationships with public authorities on technical matters (Nussbaum, 2000). Immediately after its launching, MRN developed methods and input data availability, for private insurers to establish their own diagnosis of flood risk exposure and flood "prevention" measures especially through a "MRN GIS". This extranet GIS application is available to member companies of FFSA and GEMA from the website of the association www.mrn.asso.fr. An "industrial" version is operational since May 2010 (first one in 2003) and provides for flood, drought, earthquake, in metropolitan France, tools for the analysis of exposure (site by site or at portfolio level) to natural hazards and their prevention. Through MRN GIS, underwriters and prevention Surveyors/Engineers can obtain, site by site, an exposure report gathers information of administrative nature (town at risk, CATNAT declarations, etc.), preventive nature (availability of informative documents at municipality level, highest-known water level, etc.), regulatory nature (existence of a PPR, deductible modulation, status of zoning regulations, associated enforceable planning/building requirements, etc.) and statistical nature (number and rate of exposed personal and commercial lines customers, etc.). It allows them to establish a pre-diagnosis.

Moreover, at a collective level, MRN also developed an observatory of assets exposure. Through these new approaches, it also started to provide to the insurance industry assessments of the main public policy tool dedicated to natural risk reduction (Gérin, 2011), the so called “Plan de prevention des risques naturels” (PPR). This land use planning tool defines regulatory zones, which impose and/or recommends “prevention” measures for both existing buildings and future real estate developments. To that extent, this tool largely contributes to regulate insurability conditions in some instances. It is set up and managed by the central government and implemented at local level.

Outside of France, most of other neighbouring national insurance markets (AT, BE, CZ, DE, IT, etc.) have also developed, during the last decade, their own innovative approaches/organizations, projects and/or tools, with an aim of improving flood risk knowledge, for use at either individual and collective level. Specialized policy advisors have be hired to interact with academic research teams as well as and GIS data management service suppliers.

As a conclusion of this section, insurance industry players need flood risk assessment at the appropriate territorial scale to increase their knowledge, assess their opportunities and threats more carefully, and be able to put the cursor between choice of protection/prevention and risk transfer solutions.

How direct insurers may become even more proactive in catalysing the uptake of FRe measures?

As it was seen before, to assume the *ex-ante* risk transfer mechanism, the implementation of flood “prevention” measures, a fortiori flood resilience measures (FReM), is required.

This leads direct insurers to develop different methods to approach flood risk at the local or global scale. Now it is proposed to examine how they may use results from such assessments to catalyse the uptake of FRe measures.

Before dealing with this point, it seems useful to clarify the important question of the prevention funding function which may often be attributed to insurance services.

What is the relation between insurance services and FReM funding?

Insurance services are exclusively dedicated to finance covered damage costs. Despite it not being its aim, in some cases under study, a prevention funding function appears to be attributed to flood insurance services as a characteristic feature of the State intervention.

Such a situation exists in France, with a levy of 12% on the product of additional premiums which is collected toward a “Fund for the Prevention of Major Natural Risks” called the Barnier Fund. This fund was initially dedicated to support purchase by the State of exposed properties and the temporary evacuation or relocation of people, after a State safety decision of unsafe dwelling has been taken for the considered property. More recently its purposes have been several times extended. It can now also be used to support part of the compulsory flood prevention and resilience measures imposed by the PPR (both at individual and municipality level). The Barnier Fund can now be considered as one of the main contributors to public flood “prevention” and resilience preparedness measures funding in France.

A similar situation exists in the USA, where there is a National Flood Mitigation Fund (NMF), supported by a $30 surcharge on insurance policies (Burby, 2001), dedicated to States and communities requiring measures, including flood resilience measures, in case of serious flood hazard. But in the USA, the National Flood Insurance Program (NFIP) is a public insurance scheme or fund, rather than a hybrid PPP scheme, like in France.

As a conclusion of this part, in any case, generally, flood insurance services do not contribute financially to the implementation of flood “prevention” and resilience measures. Resources for such measures have to be provided by public authorities (both at Government and county level) without involving flood insurance services.

Insurance services can, however, contribute to the implementation of flood “prevention” and resilience preparedness measures, through economic and normative incentives which encourage behaviour changes of policyholders.

In the cases of the French NatCat hybrid PPP system or in the USA public system, these are so to say “backed up” by the regulatory framework.

What may lead to an improvement of FReM incentivizing?

As explained above, crucial to this process are both **the relationships between private insurers and:**

(a) **public authorities**, whereby insurers’ trade association lobby Government to promote flood “prevention” and resilience measures,

(b) **policyholders**, whereby flood direct insurers can expect certain flood “prevention” and resilience conditions to be fulfilled by the policyholder, in order to provide a cover designed and rated in accordance to a certain level of protection.

(a) Between **public authorities** and private insurers:

As considered previously, for general interest purposes, national insurance market associations are involved in governance instances. It allows assessing public flood risk reduction policies and, consequently, enforcing FRe measure implementation.

This point can be illustrated in France, by the association “Mission Risques Naturels” (MRN), between FFSA and GEMA, which acts as a coordinator of the insurance sector participation to governance instances, such as:

- The Advisory Council for the Prevention of Large-Scale Natural Risks (COPRNM): created to give opinions and make proposals to the Minister of Ecology in the field of natural risk prevention. Chaired by a MP and made up of representatives of:
    - All ministries concerned,

  - National and local elected officials,
  - Civil society and experts including insurance market representatives,,

- The Joint Commission « Floods » (CMI): created from members of the COPRNM and the National Committee for Water, and extended to relevant stakeholders in flood management. CMI acts as a steering committee for the national policy on flood risk management, it has to draw up the national strategy for flood management and is responsible for giving a « label » to local flood prevention action plans
- It is co-chaired by two MP and made up of representatives of similar categories of stakeholders than COPRNM.
- « Water parliaments » at the level of each water basin, with specialized groups dedicated to the governance of the flood management policy at the district-level, which all include insurance market representatives,
- Commissions addressing at administrative district (departmental) level, public policies for natural disaster risk reduction, especially with respect to land use planning and construction codes, based on a regulatory tool operating at municipality level, called "*plan de prévention des risques*" (PPR): local insurance market representatives are involved in these commissions as well.

An additional catalyst for improving DRR decision making and governance at all scales is the creation of a kind of a national observatory on natural risks, like in France, where national public authorities represented by the Ministry of Ecology, CCR (State reinsurer of NatCat regime) and direct insurers, represented by MRN, recently joined forces to create such an observatory (ONRN, May 2012).

This really opens new perspectives in FRe management such as, for instance, technical experience feedback which could allow analysing feedback reports in particular concerning the failure of protection construction.

MRN also participates to a PPP agreement with the River Loire Floodplain Management Authority (EP Loire), on behalf of French insurance associations, where insurance companies are invited to incentivize their commercial lines customers to agree to take up a free flood vulnerability diagnosis, which is subsidized under the umbrella of a EU FEDER project, with financial participation of State and local authorities (OECD, 2010, www.plan-loire.fr/diagnostics-entreprises).

Through the insurance sector participation to governance instances and PPP agreement, insurance companies review the State's prevention strategy and thereby drive the State and local authorities to enforce flood "prevention" and resilience measures.

In the UK, a different kind of a public/private incentive relationship operates between the ABI and the State. Indeed, even if the aim of the 'Statement of principle' is to provide flood cover to the majority of policyholders, cover is offered under standard conditions only within areas where flood risk is equal or less than 1.3% annual probability (or 1 in 75 years) or in more significant flood risk areas, where improvements implemented by public authorities can achieve this protection level over a five-year term (ABI, 2005). Therefore, by linking insurability to a certain level of security achieved through measures established by the public authorities, the insurance industry, participate as well at a collective level, to encourage implementation of "prevention" measures, especially flood resilience measures at collective level (ABI, 2005; 2007).

(b) Between **policyholders** and private insurers:

In such a context, direct insurers can also be "proactive" in catalysing the uptake of FRe measures.

Indeed, premium rates can depend on the degree of exposure, the levels of community/policyholders' commitment to "prevention" and their implementation of FReM. This is substantially the situation in the UK where policyholders are not covered under standard insurance conditions, if they are located in areas considered by private insurers as insufficiently protected by structural protection measures (e.g. below the protection level required through the 'Statement of Principle'). In the USA as well the NFIP's core principle consists of allowing the subscription of flood insurance in exchange to measures taken by the policyholder, the local government and the community, in order to reduce the consequences of future flooding. This incentive aspect is strengthened by the Community Rating System (CRS). It is a voluntary programme which entitles communities participating in the NFIP to obtain a discount on their initial flood insurance rate (from 5%, up to a maximum of 45%) in return of flood risk mitigation efforts that exceed the minimum NFIP standards (FEMA, 2007). Moreover, in situations of repeated losses, insurance policies cannot be automatically renewed, unless the policyholder undertakes measures to reduce the risk.

In France, the incentive for flood "prevention" and resilience measures is mainly leveraged through an increase or a variation of the deductible. Although a direct insurer cannot refuse to compensate for an insurance claim after a disaster, the law organises the possibility for the underwriter to refuse to continue to offer its guarantee for later events if he considers being in the presence of "aggravated risk" (accumulated damages without prevention measures taken). For policyholders who may have been excluded by the market, the laws provides the possibility to take action through a specific "ombudsman like" jurisdiction, called "bureau central de tarification" (BCT) which may conclude on adapted insurance conditions, depending on the exposure level (much higher deductibles). Moreover, five years after the approval of a PPR, direct insurers can call upon the BCT if regulatory measures are not well implemented by policyholder and/or municipality. Furthermore, a variation of the initial deductible charge is applied in cases of repeated flood damages occurring without a PPR or four years after the initiation of a non-approved PPR.

Such incentive measures might be implemented through customer relationship, however, in reality private insurers face difficulties to get practical results outside the commercial line segment. As indicated above, two completely different practical situations are to be considered:

i. Large risks

A technical and economic dialogue between the insurer and the client can be opened in order to find an acceptable (and practical) solution, for both parties ("you have a better risk coverage... if Emergency Response Plan and FRe measures concerning .... are implemented"). The maintenance conditions will be regularly checked for flood protection such as levees, flood walls, flood barriers (similar to sprinkler protection). All insurance companies operating on this particular segment develop now such an approach, through the field surveys of their prevention engineers, with limited differences among national markets, and national insurance associations delivering guidelines to their members (GdV/VdS, 2009 ; FM Global).

In case of a site survey, where flood exposure and vulnerabilities are identified at a facility, recommendations will be issued by the engineer representing the direct insurer and/or the insurance broker, to mitigate the risk.

These recommendations may encompass all categories of both structural and non-structural measures, which could be taken at the liability/decision level of the customer only.

Among the important non-structural measures which are always prescribed:

- An extensive flood vulnerability diagnosis[10], in order:
  - to assess more in depth the exposure of the undertaking under different flood occurrence scenarios, in terms of direct loss and business interruption,
  - to produce cost benefit analyses of solutions and options which may reduce vulnerability under the various deterministic scenarios considered
- A Flood Emergency Response Plan. This plan will allow the site to react efficiently to the situation in case of flood (similar to the emergency response plan in case of a fire).

ii. Mass risks

On the “mass risk segment”, including both SMEs and personal lines, such a process is not feasible, for economic and organizational reasons. People want to save their lives, family and assets. They can think of implementing FRe at their property level, but unfortunately do not have the behaviour, motivation, technical support and financial help to protect their houses with FRe measures. Nevertheless, more and more State, regional and local authorities, as well as insurance companies in some national markets[11], tend to organize information campaigns to raise risk awareness of the exposed population (*do’s and don’ts in case of flood*).

Conclusion

The coupling between “insurance” and “prevention” is a key factor of economic and social resilience.

The necessity for flood insurance services development to benefit from flood “prevention” and resilience measures leads insurance industry players, and particularly direct insurers, to question the implementation of flood “prevention” and resilience measures and to undertake their own assessment processes within their classical risk assessment activity. They consider the flood risk exposure and flood “prevention” measures at an individual and collective level and try to answer the question: “what can be done to limit damages of insured elements and can they be adapted to the situation?”

Furthermore, direct insurers can also participate in supporting flood “prevention” and resilience measures through their institutional and commercial activities. Insurers’ trade association can enforce the “prevention” strategy of the Government and local authorities toward an improvement of the implementation of flood resilience measures.

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[10] One may quote as an example the PPP agreement between River Loire Floodplain Management Authority (EP Loire) and MRN, as already referred in this paper page 7 second paragraph.

[11] See for instance the booklet “*Memento pratique du particulier*” on www.mrn.asso.fr which has been reused under their own brands by insurance mutual such as MACIF and MAIF, to deliver practical information to their customers.

Within the relationship between policyholders and private insurers, direct insurers can also be "proactive" in catalysing the uptake of FRe measures by implementing economic, normative and regulatory incentives which encourage behaviour changes of policyholders and are likely to significantly reduce the vulnerability of the exposed asset. Such practical results are all a reality for the commercial line segment.

Eventually, while enforcing "prevention" strategy and encouraging behaviour changes of policyholders the insurance industry develops an increased market penetration. Indeed, flood insurance service is becoming more available and affordable, as a consequence of higher prevention standards.

It results in a dual system between private insurers and public authorities on the one hand, and private insurers and their customers on the other hand, which contributes to optimize the overall risk management process and the uptake of Flood Resilient Technologies, in particular.

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This document was produced as part of the SMARTeST project
(Smart Resilience Technologies, Systems and Tools)
an FP7 funded project (Project no: 244102)

http://floodresilience.eu