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Methodology for flood resilience assessment in urban environments and mitigation strategy development

Jelena Batica

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UNIVERSITE DE NICE-SOPHIA ANTIPOLIS
ECOLE DOCTORALE STIC
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COMMUNICATION

T H E S E

pour l'obtention du grade de

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de l'Université de Nice-Sophia Antipolis

Mention: Automatique, Traitement du Signal et des Images

présentée et soutenue par

Jelena BATICA

**Methodology for Flood Resilience Assessment in Urban Environments and Mitigation
Strategy Development**

Thèse dirigée par *Philippe GOURBESVILLE*

soutenue le 19 mars 2015

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Acknowledge

I am very glad that I had a possibility to do a thesis on flood resilience in urban environments. I enjoined working on my PhD thesis for many reasons. Some of them are working with master students that are coming from countries all around the world. I could hear their expression on different flood hazard, different protection levels available in their countries, about decision-making processes. Second thing, I was able to travel and meet many people working on the same subject and exchange experiences and findings.

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Finally, this dissertation is dedicated to my family, my daughter Sofija and my husband Vladimir. In two months, I will become mom for the second time. Thank you for unconditional support and patience during these years. With you everything makes sense.

With love and thanks.

Sujet de thèse en Français:

Méthodologie pour l'évaluation de la résilience urbaine face aux crues et développement des stratégies de prévention

RÉSUMÉ

Inondations qui se produisent dans les zones urbaines sont régies par une fréquence accrue. Structures de protection contre les inondations existantes démontrent ses inconvénients. Une des solutions est émouvant de culture du risque et de trouver l'équilibre entre la forme de l'utilisation des terres et de l'urbanisation grâce à des stratégies d'adaptation, d'atténuation, de prévention et intervention et de rétablissement. La nouvelle approche globale est basée sur le concept de résilience donner une nouvelle place pour le développement et la mise en œuvre de nouvelles approches en vertu de gestion des risques d'inondation (FRM) cadres existants. Ajout de résilience à la gestion des risques d'inondation est une première étape. Grâce à une gestion des risques d'inondation opérationnelle a pour la résilience des prestations. L'indice résilience Flood (FRI) est développé dans cette thèse est une approche unique pour l'évaluation de la résistance aux inondations dans les systèmes urbains avec la priorité principale de la structure du système lorsque l'évaluation se fait sur les micro et méso échelle et sur la dimension du système lorsque la résistance aux inondations est évaluée sur macro échelle. La réflexion est mis sur le développement de la méthode par l'évaluation de la gestion des risques d'inondation existants (FRM) cadres. Grâce à l'évaluation, il est possible de constater le niveau d'intégration et de mise en œuvre de l'élément essentiel du risque d'inondation. La méthode développée pour l'évaluation de la résistance aux inondations est potentiellement applicable à tout système urbain à une échelle géographique. Connexions et dépendances entre éléments principaux de la ville et des risques naturels (dans ce processus d'inondations urbaines de cas) sont définis. Avec sa mise en œuvre, les relations politiques, sociales et culturelles, économiques entre les villes seront plus visibles et mieux établie et la gestion des risques d'inondation ainsi mis en œuvre.

Summary

Floods that happen in urban areas are governed by increased frequency. Existing flood defence structures demonstrate its downsides. One of the solutions is moving to risk culture and finding the balance between the shape of land use and urbanization through adaptation, mitigation, prevention, and response and recovery strategies.

While managing the flood risk in urban areas, the priority is to minimize flood damages. The new holistic approach is based on resilience concept. Adding resilience to flood risk management is a first step. Through operational flood risk management has as benefit resilience. The potential of implementing resilience in urban flood management can provide a increased cost-effective component. Decrease of flood damages expresses increase efficiency and cost effectiveness of applied solution. This brings adds additional performance to flood risk management. Multidisciplinary approach that is provided by the resilience concept join forces of technical (structural) and measures on economic, environmental, social and institutional level. If established, flood resilient communities have effective means to increase adaptation capacity regarding flooding processes.

The main reflection is on the development of method by evaluation of existing flood risk management (FRM) frameworks. Through evaluation, there is a possibility to notice the level of integration and implementation of crucial element of flood risk. As defined here the main elements (i) flood, (ii) vulnerability and (iii) exposure are the main elements. Using the evaluation principles the FRM framework is evaluated regarding achieved readiness level considering its elements, level of integration and implementation. If the readiness level is achieved the FRM can be developed in order to be moved towards resiliency.

The presented case studies in Europe and Asia all of different approaches and possibilities to evaluate resilience attributes as well as capacity of these urban systems regarding flooding processes. The differences in urban flooding problems in European and Asian cities vary from levels of economic development, infrastructure age, social systems and decision-making processes, to establish drainage methods, seasonality of rainfall patterns and climate change trends.

Assessing flood resilience involves in equation flood damage, risk perception and vulnerability analysis. A role of resilience in sustainable development becomes significant. Developed methodology analyses urban system through different scales and elements (urban city functions and services). The purpose is to minimize the flood damages if possible. In most of the causes damages driven by floods can be minimized if urban system: already have implemented some of the existing active and passive protection measures, a community within the system is able to organize itself and to prevent more damages, the shape of a system is adapted to receive some

disturbance, being able to learn from past events. Differences between urban systems analyzed in this thesis differ in many ways. Differences in case study areas start from different institutional organization. The priority made in the existing FRM frameworks differs in Europe and Asia. The level of urbanization and level of available assets in the analyzed cities is not the same. This contributes to different level of disturbances made during and after flood and make reflection on flood resilience in urban systems.

A very important thing is existing risk culture among analyzed areas. The level of economic preparedness differs and it is noticeable that even there are available financial resources.

The developed method for evaluation of flood resilience is potentially applicable to any urban system on any geographic scale. Connections and dependences between main city elements and natural hazards (in this case urban flooding process) have to be defined. With its implementation, social, economical, political and cultural relations between cities will be more visible and better established. The approach should uncover the role of physical components of urban system and population in relation to urban flooding processes. A further strategy focuses on simulation of community losses and recovery measures. As a major challenge that faces urban systems nowadays, the research on resilience prioritizes in following years. A key recommendation proposes: improving resilience determines urban patterns, which are matching with optimal water distribution, waste collection, energy distribution etc.

The Flood Resilience Index (FRI) is developed as unique approach for evaluation of flood resilience in urban systems with the main priority on system structure when evaluation is done on micro and meso scale and on system dimension when flood resilience is evaluated on macro scale.

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1 Introduction

1.1 Flooding and urban systems

Floods that happen in urban areas are governed by increased frequency (Ouarda et al., 2000; Gaume, et al., 2010; Villarini, et al., 2009; Schmocker-Fackel & Naef, 2010; Greenbaum et al., 2010; Prudhomme et al., 2003; Kusumastuti et al., 2008). Existing flood defence structures demonstrate its downsides. That signifies that primary protection regarding flood is not sustainable anymore. The solution is moving to risk culture and finding the balance between the shape of land use and urbanization through adaptation, mitigation, prevention, and response and recovery strategies.

There are different approaches in solving problems connected to urban flooding in Europe and Asia. Existing case studies in Europe and Asia provide a respectful example of different approaches and possibilities to evaluate resilience attributes as well as capacity of these urban systems regarding flooding processes. The differences in urban flooding problems in European and Asian cities vary from levels of economic development, infrastructure age, social systems and decision-making processes, to establish drainage methods, seasonality of rainfall patterns and climate change trends.

Sensitivity analysis of urban systems implies a deeper investigation of urban flooding, condition of the built environment, way of mapping built environment, its interaction with nature and vulnerability evaluation. Further to that, a resilience approach to solve and assess the sensitivity of urban systems in respect to flooding becomes crucial.

Urban flooding is no longer just a natural phenomenon. The social component of urban system is contributing to the increasing trend of urban flooding. Urban spaces are facing the flood risks, nowadays. The flooding processes are now presenting the risk related phenomena. This is influenced by natural conditions, undeveloped disaster culture of urban communities, etc. The expanded urban spaces give broader exposure to flood risk and new forms of flood damage. Especially during the last century, the drastic changes were made to river environments. Natural drainage systems are mainly forced into artificial channels in favour to impervious areas. Furthermore the structural measures were more dominant. In addition to that, local communities have a declining trend in terms of considering, activities linked to awareness and disaster prevention. Accordingly, the urban flooding becomes not only the engineering problem but also calls for attention of key stakeholders. As one of the most frequent hazard on earth flooding processes, pose a significant damage to population and the urban environment.

In order to minimize the causes that flooding processes pose to urban environments the resilience concept becomes a new driving approach for assessing sustainability of urban systems. Reducing and minimizing causes become challenging. In this light adaptation actions are unavoidable. The importance of adaptation is in reducing future costs.

The traditional approaches promote the struggle against the water through implementation of structural measures while resilience approach underlines "flood friendly" approach through implementation of non-structural measures, which are more adaptable to increased flood frequency.

The impervious areas are contributing to bigger pressure on existing urban drainage networks due to a greater percentage of precipitation episodes. The produced runoff cannot be fully accommodated only by drainage network and as a result, urban flooding is unavoidable. Furthermore, climate change may cause flooding to occur more frequently and be more severe in urban areas (IPCC, 2008).

Resilience approach divides responsibility to governmental and community level regarding urban flood risk management. It also considers the resilience of a population to floods that can be measured with time. Assessment of resilience that focuses on population following a bottom-up approach starting from individuals and then assessing community level. Building resilience involves also contribution of social networks, increasing response capacity of communities, self-organization, learning and education and cheering adaptive culture. Measures for improving social side of resilience covers: raising public awareness, implementation of flood forecasting and warning, emergency response planning and training, sharing information, education and communication. As significant is also flood insurance, damage and casualties report, damage assessment facilitating claim procession, reconstruction, charity funds, social therapeutic measures, disaster recovery plans and financial assistance after a flood. Measures are incorporated in the flood management cycle. It differs from country to country but the basis is covering all three stages regarding the flood, stage before, during and stage after the flood. The role of strategies is to prevent flood damage and to save lives.

Let us start defining flood risk management approach. In this thesis flood risk management (FRM) is defined as a set of all activities that enable case study area to cope with flooding processes. The strategies under FRM should enable proper functioning of the case study during and after flooding.

Resilience on the other side is defined as a system property to cope with disturbances up to the level where the functionality of complete urban system is not jeopardized. In order to make the concept more tangible the resilience concept needs to be quantified. This was done with indicators developed to provide insight of systems resilience level flood event.

Since flood occurrence in urban systems is not a new event there are many strategies in current flood management plans with very little differences.

Introducing resilience takes into account different aspects of urban environment. As stated, structural measures cannot avoid disasters and therefore resilience approach stand as one of the solution for decreasing flood damages. Nowadays extreme events have underlined vulnerability of modern societies and unpreparedness. Of course, there is a need for reviewing an existing protection approaches. For sure, the protection is not the only way since 100% protection will never be achieved. This comes from the fact the protection structures are limited with the design period.

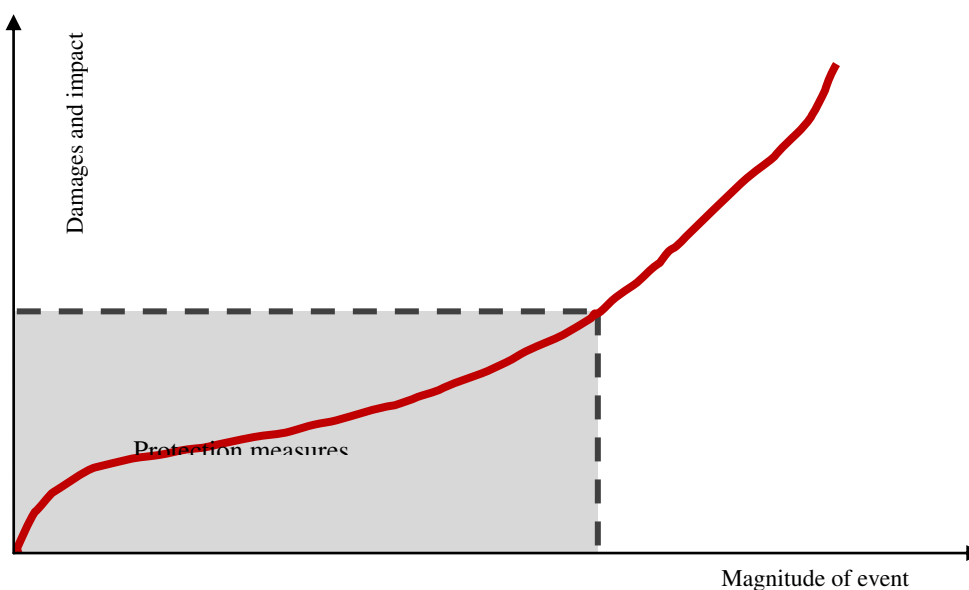


Figure 1: Presentation of flood risk management concept

The focus is on the magnitude of event on side and level of damage and impact on the other side. The representation is done in the figure above. Based on the event curve the protection measures do have influence up to the design level. However, the area above the protection line is open for holistic approach. Here comes the resilience in play. All the measures that can increase

adaptation and carrying capacity up to the level where impact and damage will be tolerable for the urban environment. The resilience concept on the would have presentation as presented in figure below.

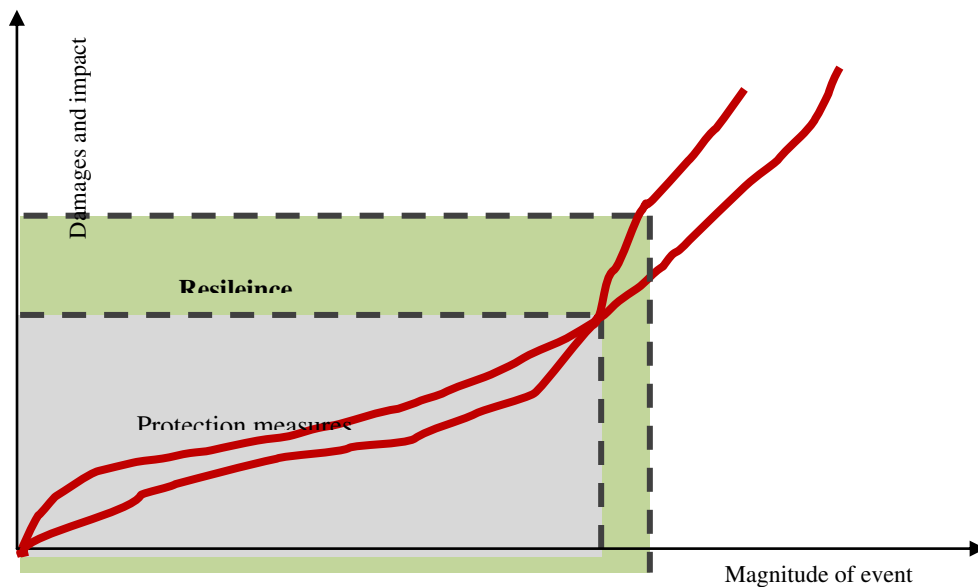


Figure 2: Resilience concept

In Figure 2 the presentation is done for resilience concept with respect to magnitude of event and damages. As presented, through resilience introduction within FRM the level of damages is reduced and relaxed. This means that urban system can tolerate bigger damages and bigger magnitudes of event. Also it is important to mention that resilience has positive and negative character. In some cases, the application of resilience strategies at currently resistant system can be costly. To conclude, the change towards more resilience or more resistant system depend the most of social system and like that defers from system to system.

1.2 Motivation for research

In recent years the direct as well indirect damages caused by floods are higher and the floods have the higher frequency (Berz, 2001; Parker, 2000; Susman et al., 1983; Takeuchi, 2002). With the increased urbanisation, change in land use there is a lack of ability to cope and the traditional flood risk management (FRM) with existing tools do not have a right response to the change.

In addition, the new tools are necessary in order to include urban planners, sociologist, urban geographers and engineers to sit together to contribute to the decision making process. Having in mind that the decision on local level is in hands of city mayor and it is not necessary that he have knowledge of natural hazard management.

The development in technology as a consequence of wider range of possible measures that can be implemented.

The research for this thesis started from the findings and conclusion of Rajib Saw (2009) and his interpretation of Climate Disaster Resilience Index (CRDI). The basis of his research and latter on application on world cities establishes on analysis of a whole city area through five dimensions (eg natural, physical, economic, social, institutional). Within dimensions the set of indicators are used to present the current level of resilience to various disasters: volcano, flood, hurricane, earthquake, and tsunami.

1.2.1 Thesis objective and research questions

The general objective is to demonstrate applicability of developed methods: (i) maturity of FRM frameworks and (ii) Flood Resilience Index (FRI).

The research within thesis focuses on the following:

- Is there a methodology that can evaluate existing flood risk management taking into account different level of content within FRM and different implementation status?
- How flood resilience of urban systems can be evaluated taking into account its characteristics?
- What are differences in resilience between different urban systems?

1.2.2 Thesis outline

The thesis comprises seven chapters:

- Chapter 1 (current question) contains problem definition, introduction, motivation for research and research question definition
- Chapter 2 focuses on the connection between flood risk management and the resilience
- Chapter 3 focuses on developed method for Flood Resilience Index (FRI) evaluation with the definition of urban system and usability of functional analysis approach in FRM

- Chapter 4 analyze FRM and resilience measures, their classification in order to fit defined scales within urban system
- Chapter 5 focuses on application of FRI method on five European and Asian cities and obtained evaluation results
- Chapter 6 contains critical analysis of the develop method and the future steps of the flood resilience within FRM
- Chapter 7 conclude the thesis

2 Resilience and flood risk management

Parts of this chapter has been published as:

Batica, Jelena, and Gourbesville, Philippe.: "Methodology for Flood Resilience Index", 3rd IAHR Europe Congress, Book of Proceedings, Porto, Portugal, 2014

Batica, Jelena, Gourbesville, Philippe and Frank Tessier.: "Methodology for maturity of flood risk management frameworks assessment – application to Asian and European cities", International Conference on Flood Resilience Experiences in Asia and Europe – ICFR, Exeter, United Kingdom, 2013.

2.1 Flood risk

In recent years, a distinctive rainfall pattern and quantity rainfall results in a greater volume of flood discharge along with a higher peak discharge than before. Furthermore, the number of heavy rainfall's, the primary external force of a flood hazard, has been in increase in urban areas in Europe and especially in Asian countries. Consequently, if this trend continues, it might become a major factor in increasing the flood risk in urban areas.

In addition, another factor that increases flood risk is occurring in the floodplains. Flood risk characterizes diversion and complexation. Flooding as a phenomenon that includes runoff, precipitation, flood wave propagation, flood damage that changes over time and have variations form region to region. Influenced with natural conditions, more often with human activities and non-sufficient disaster culture flooding represent risk –related phenomena. New flood risks are emerging in urban areas. This is in addition to extended urban spaces, bigger exposure to flood risk and new forms of flood damages.

Over the last century, the drastic changes have brought to river environments. Rivers forced into artificial channels brings less natural and more artificial environment. In addition to that, local communities have declined trend in considering activities linked to awareness and disaster prevention. Urban flooding is not anymore just a natural phenomenon. The social conditions play an important role and they have spatial and temporal variation. Increasing precipitation episodes that cities are experiencing today due to a big percentage of impervious areas imposes huge pressure to existing urban drainage system. In most cases, drainage network is able to accompany produced run-off.

Properties of precipitation (scale, pattern, distribution in time and in space) are major factors that determinate the magnitude and characteristics of flood as a hazard. Urban flooding brings a risk to an urban system. Its fundamental to have proper understanding of urban flood risks and to be familiar with the components that construct risk. This should be looked as follows; risk implies that some extreme event (in this case flood) caused by natural force or by a combination of natural and human forces. This defines a first component or flood risk. The second component is represented through vulnerability.



Figure 1: Risk definition

Vulnerability represents a notion that someone or something that is at risk. In other words, somebody or something is vulnerable to a hazard (flood) or is in the flood pathway. Term vulnerability in defining flood risk does not separate physical exposure to flood on one side of vulnerability of persons or assets to flood on the other side. This is crucial during analysis and decision regarding possible measures and their effectiveness in reducing risk. As a third component, that defines flood risk stand exposure. Within this term, the exposure is in direct connection with increase trend of urban flood damages. This triggers increased population and assets physically exposed to floods in urban systems. The most common situation related to unplanned extension of urban space in favour to limited inundation areas.

Risk minimizing with implementation of strategies engage implementation in vertical and horizontal scale.

Horizontal scale focuses on the available measures. Strategies for urban flood management include structural and non-structural mitigation measures that take into consideration climate-change variability, including changes in the frequency and intensity of tropical cyclones.

Non-structural measures should include strengthening legislation for urban flood management including coastal management, institutional coordination and cooperation, improvement in investment monitoring, capacity building and the decentralization of resources from national to local levels. “Risk-sensitive” land-use planning holds useful practices and strategies for managing river basins and water resources comprehensively. Risk sensitivity in planning can help in controlling exposure to hazards, including the impacts of upstream development on downstream areas.

The vertical scale includes institutional responsibility from national to municipal level. Looking at the institutional division in the European Union and taking France as an example structure is presented on the table below.

Authorities in horizontal scale on European Union example defined through river basin management authorities, responsible for implementation of the Water Framework Directive (WFD) (2000/60/EC Directive) and the Flood Risk Directive (FRD) (2007/60/EC Directive), and disaster planning and crises response authorities, with specific responsibilities in disaster planning and response during flood events.

Table 1: Vertical scale for risk minimizing, France flood risk management as example

LEVEL	FLOOD MANAGEMENT
European	<p style="text-align: center;">POLICY</p> <p>Flood risk management: Flood prevention, protection and mitigation Trans European Networks (TEN) (http://www.unece.org/)</p> <p style="text-align: center;">LAW</p> <p>Water Framework Directive (WFD) (http://ec.europa.eu)</p> <p style="text-align: center;">OTHER PLANNING INSTRUMENTS</p> <p>ICPR (IKSR) (http://www.iksr.org)</p>
National	<p style="text-align: center;">LAW</p> <p>Law on Natural Disasters (Loi relative aux catastrophes naturelles), (http://www.legifrance.gouv.fr)</p> <p>Law on security, protection of forests against fire and prevention of major risks, (Loi relative à la sécurité, à la protection de la forêt contre l'incendie et à la prévention des risques majeurs), (http://www.legifrance.gouv.fr)</p> <p>Water Policy, (Loi sur l'eau), (http://www.legifrance.gouv.fr)</p> <p>Law on the prevention of natural and technological hazards, (Loi relative à la prévention des risqué naturels et technologiques), (http://www.legifrance.gouv.fr)</p> <p>Legislation transposing the Water Framework Directive (WFD), (Loi portant transposition de la directive cadre sur l'eau (WFD)), (http://www.legifrance.gouv.fr)</p>
Regional	<p style="text-align: center;">POLICY</p> <p>Master Plan development and Water management SDAGE/SAGE (Schéma Directeur d'Aménagement et de gestion de l'eau SDAGE / SAGE), (http://www.eaufrance.fr)</p> <p>Flood zone Atlas (Atlas des zones inondables), (http://www.rdbmrc-travaux.com)</p> <p>Management and Flood prevention Plans (Plan d'Aménagement et de Prévention des Inondations (PAPI)), (http://www.driee.ile-de-france.developpement-durable.gouv.fr)</p>
Department	<p style="text-align: center;">POLICY</p> <p>Plan for prevention of foreseeable natural risks of inundation (Plan de prevention des risqué naturels previsibles d'inundation PPRI) (http://www.alpes-maritimes.equipement-agriculture.gouv.fr)</p>
Inter-municipal	<p style="text-align: center;">POLICY</p> <p>River contract (Contrat de rivières), (http://www.eaufrance.fr)</p>
Municipal	<p style="text-align: center;">POLICY</p> <p>Local Development Plan (Plan local d'urbanisme, PLU), (http://www.nice.fr)</p>

2.2 Flood risk management and flood resilience

Managing the flood risk in urban areas, the priority is to minimize damages caused by flood. Operational flood risk management has as benefit resilience. The potential of implementing resilience in urban flood management can provide a cost-effective component. Efficiency and cost effectiveness is in both, decrease flood damage away from existing structural measures and add additional performance to flood risk management. Multidisciplinary approach that is provided by the resilience concept join forces of technical (structural) measures and measures on economic, environmental, social and institutional level. If established, flood resilient communities have effective means to increase adaptation capacity regarding flooding processes. Despite the fact that local authorities have not yet acknowledge the concept of resilience and its implementing some of the resilience measures are fully or partly implemented in recent flood risk management approaches. That proves that implementation of resilience concept and introduction of resilience into existing flood risk management plans and strategies is realistic. Implementation of resilience is through three dimensions. Resilience relevant measures consider (i) interplay of institutions, (ii) communication regarding flood risk and (iii) development and implementation of flood modelling tools. All three of them considers as very important.

The resilience of communities to flood risks corresponds to our capability to deal with flood risk by means of integrated management of flood, exposure, and damage. Local communities, governments and residents (as individuals) may reduce the existing flood risk by implementing measures that are able to prevent certain events from occurring. Measures of this type influence of the runoff in catchment's, help the concentration of runoff in river channels, reducing exposure to flooding processes and reducing vulnerability and application of measures through mitigation processes.

New risks that are emerged with structural measures for example with the creation of embankments the inundation zones are becoming more favourable.

2.2.1 Vulnerability and urban flood resilience

Within disaster research, community the concept of vulnerability is widely used. However, due to the change of urban environment the understanding of vulnerability changed too. Many definitions of vulnerability at present define hazard exposure of social component of urban

system. By social component, the population with specific social character is understood. Some of definitions of vulnerability refer to climate change (IPCC, 2008) some refer to environmental hazard (Klein and Nicholls, 1999) and some for flood vulnerability (Veen & Logtmeijer 2005, Connor & Hiroki, 2005, Balica et al., 2009, UNDRO, 1982, McCarthy et al., 2001). General conclusion is that vulnerability is a context of risk (Gabor and Griffith, 1980)

Looking from ecological aspect resilience defines as the ability of a system to absorb changes of variables and parameters, and still persevere (Burton, 1983) Ecological resilience focuses on systems far from any equilibrium steady state, where the system could turn over into another regime of behaviour. In other words, the system from an ecological point of view doesn't need to define the conditions which will provide some functionality. On the other hand, urban systems need to have in advance defined 'conditions' in order to have the proper level of functioning.

When considering *urban resilience* the ability of system potentially exposed to hazard to resist, respond, recover and reflect up to a stage which is enough to preserve level of functioning and structure is underlined. The Urban system can be resilient to lots of different hazards. Here, one of the focuses will be flood resilience of urban systems. Urban resilience defines the the degree to which cities are able to tolerate some disturbance before reorganizing around a new set of structures and processes.

Two elements describe urban system: the build environment and population. Physical characteristic of the built environment and social characteristic of the population are to be examined in order to evaluate resilience of urban systems. The focal point of this paper is flood resilience of urban systems. Resilience of urban systems relates to adaptation of land use to flood processes. Urban system over decades change and it continues to change existing land use to satisfy the needs of residents, e.g. increased impervious areas. In order to have a high level of protection for residents the strategies and measures are developed and implemented. However, awareness to preserve natural drainage paths in urban systems was not a priority.

With urban development and increase of vulnerability, communities have to move to risk culture and to be able to accept a certain level of flooding but with decreased flood damages. Reshaping of build environment therefore stands as a one of the solution for decreasing flood damages.

According to urban geography, a systemic approach considers a city, as a complex system required numerous regulations to keep it stable. These regulations enable, at all times, to re-establish urban functions after the disturbance of external events such as natural hazard. In this

light, flood risk could be considered as one of the elements, which activate regeneration of urban systems. In this perspective, urban risk is not only a threat to the city and its inhabitants, but also one of the essential components of urban structure and the evolution of its urbanisation. For that reason, it is necessary to analyze flooding processes in the context of urban spatial development. The development of methodology and analysis of urban systems through different scales and components can provide essential information for the transformation of the urban spatial organization.

This approach has three concepts that describe and assess flood risk in urban systems (city): carrying capacity, vulnerability and resilience (Burton, 1983).

- The concept of (i) *carrying capacity* identifies the maximum tolerable damage that a community or a city could bear.
- The concepts of (ii) vulnerability and (iii) resilience serve to measure and to assess the *carrying capacity* of a community or a city. The vulnerability is to express the impact of disturbance of a system; the resilience describes the capacity of a system to absorb the shock.

In this perspective, it is necessary to develop a new methodology of urban diagnostic facing urban flood risk issue. A possible approach is based on the development of urban flood vulnerability and resilience assessment tools with indicators enables to provide a comprehensive overview of vulnerability and resilience of a city or a community. For the purpose of evaluation of urban risk, the urban structure is composed of three main components: building with its function, infrastructure and surface.

Trying to look for a sustainable solution in solving flooding problems in urban areas, the definition of vulnerability and resilience to flooding processes are important. Although vulnerability is often used in a conjunction with resilience, the meaning is following;

Vulnerability is defined as the conditions determined with physical, social, economic, or environmental factors or processes, which are increasing the weakness of community to the impact of hazard (UN/ISDR, 2004). Resilience, on the other hand, represents the capacity of an urban system or community exposed to hazard to adapt by resisting or changing in order to reach an acceptable level of functioning, organization and structure (UN/ISDR, 2004).

The defined terminology of vulnerability and resilience is very important in the analysis of urban areas and their existing flood risks but there should be a distinction between the flood vulnerability and flood resilience of people on one side and the urban structure on the other side.

Resilience doesn't have a general definition although it is increasingly used in integrated urban drainage management, (Ashley *et al.*, 2007; De Bruijn 2004; Klein *et al.*, 1998; Sayers *et al.*, 2003; Sendzimir *et al.*, 2007; Vis *et al.*, 2003;). The term resilience is often left open to debate. The diverse interpretations of resilience reflect the complexity of this concept and made it 'difficult' in implementation of integrated urban drainage management. Accordingly, it implies that the definition of what is vulnerable and what is building the resilience should be clear. Initial understanding of the various definitions that are nowadays present with its determinants is significant. Broader view of existing resilience approaches is described in table below.

Table 2: Existing resilience approaches

Resilience concept	Characteristic	Focus on	Context
Engineering	Return time, efficiency	Recovery, constancy	Proximity of a stable equilibrium
Ecological/ecosystem resilience	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibrium, stability landscapes
Social/ecological system resilience	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity, transformability, learning innovation	Integrated system feedback, cross scale dynamic interactions

According to Walker *et al.*, 2004 resilience is defined as the ability of a system to absorb disturbance and to reorganize up to the level of changes that allows the same function, structure, characteristics and feedback. If ecosystem resilience is taken into consideration the first part of the definition is fulfilled in the sense that ecosystem will accept disturbance by the level that allows persistence.

In social resilience for example the definition, by Adger (2000), relates to the ability of human communities to tolerate to external stress to services and mechanisms that ensure health care, education, community progress, profit distribution, employment and social welfare.

Properties of a system that relates to being persistent, robust to disturbance are not only one to be fulfilled in order to have resilient system. The disturbance brings beside shocks also an opportunity in the sense that the system is recombining and evolving its structure, create new

trajectories, renew itself, etc.. Consequently, resilience provides adaptive capacity that brings the continuous development of system interplaying among development and sustaining the changes. In this case balance between development and sustaining change is needed in order to avoid collapse.

Disturbance in the system depends on system reorganization possibilities. This process has spatial and temporal scale. Therefore the resilience concept brings adaptation, learning and self-organization in addition to the general ability to persist interruption.

In opposite to general resilience, **specified resilience** – resilience “of what to what” (Carpenter *et al.*, 2001) – is more concrete and open to the evaluation.

It can be defined by identifying what system attributes are to be resilient, and to what kind of disturbances. Specified resilience in the context of integrated urban drainage management (IUDM) has often been defined in a restricted sense to express the ability of the whole system to recover from the reaction of flood waves (Klein *et al.*, 1998; Sayers *et al.*, 2003; De Bruijn, 2004).

However, recent definitions of general resilience also make adaptability a property of resilience that reflects the system’s ability to cope and constantly develop with changes and trends.

From this wide sense, the concept provides a perhaps more suitable background framework to develop and assess integrated approaches to urban drainage management.

Resilience is therefore specified here in respect to the broader social–ecological context as the capacity of the whole-system to absorb flood waves in annual variability, and to reorganize while undergoing change in flood wave frequency and severity in the long term, to enable it to function normally.

From this perception, the resilience approach is aiming to prevent the urban system as whole to move to undesirable state from which is not possible to recover due to extreme flood impact, etc. These preventions are in following directions:

- Adjusting the thresholds of a system in respect to changes in response to flood waves
- Defining the level to which system is capable of self organizing
- Define the level to which system is able to build and increase capacity for learning and adaptation

This defines the resilience thinking, a different point of view for guiding and organizing of urban systems.

2.2.2 Urban flood management and flood resilience

The measures listed under flood resilience are related to strong intent to increase capacity building of human resources, better land use management, increased flood preparedness and emergency measures that are taken during mostly usually and after flood event. The lists of measures are presented in Table 3 (bellow).

Capacity building of human resources refers to increasing awareness of flood risk among key stakeholders in urban system. The awareness among population is assessed through presenting the brochures, short public presentations, creating internet portals that with useful information's. Constant communication with population and education are also one of elements for capacity building of human resources. The contribution to the capacity building of human resources comes also from the face-to-face learning activities and training. In existing urban systems, the measures are in developing stage since there is an absence of its consideration within traditional flood risk management.

Land use management refers to spatial planning and building regulations in order to create more space for water. The new buildings comes up with improved shapes that are able to accept certain amount of flood water and have minimal flood damage. The land use management contributes prevention to flood where possible. Adapting to flooding by floatable building and buildings on piles, dry and wet proofing of buildings contribute to increased flood preparedness and contributes to mitigate the effects of flood. The measures that refer to preparation to flooding processes are financial preparedness, voluntaries, shelter management, improving flood insurance schemes, evacuation and rescue plans, etc. During the flood event, these measures are tested.

Table 3: Flood resilience measures

Capacity building of human resources	Flood maps (Inundation and Risk) Info material (brochures, public presentations, internet portals etc Education - Communication	Face-to-face learning Web-based learning Training Collaborative platforms
Land use control	Spatial Planning Flood risk adapted land use Building regulations	Building codes Zoning ordinances
Flood preparedness	Flood Resistant buildings Wet-proofing Dry-proofing	Flood action plan (local scale) Infrastructure maintenance
Contingency measures	Financial Preparedness Insurance of residual risk Reserve funds Emergency Response: Evacuation and rescue plans Forecasting and warning services Control Emergency Operations Providence of emergency response staff	Emergency infrastructure Allocation of temporary containment structures Telecommunications network Transportation and evacuation facilities Recovery – disaster recovery plans, pecuniary provisions of government

2.3 Approaches and frameworks for adapting to flood risk

The flood risk management in most Asian countries is often considered under the umbrella of disaster risk management planning (ADPC, 2005). The focus is mainly on emergency response and relief activities but the damages and huge flood damages and losses to physical environment and human population caused with floods are changing the existing approach regarding risk management. The shift in the approach in managing disasters in Asia is recognized within the global initiative of the International Strategy for Disaster Reduction (ISDR). The approach brings knowledge that disasters cannot be prevented, disasters can be reduced. The focus is on flood risk reduction through risk assessment and developing and applying strategies to manage flood risk. The risk reduction activities that are aimed at mitigating flood risk and preparing people for floods are highlighted. Integrated flood risk management provides a holistic way of addressing flood risk with respect to the cooperation of stakeholders and ensuring that all phases in the disaster risk cycle are covered.

With respect to European Water Framework Directive (2000/60/EC) for flood management, the flood risk is the likelihood of a flood event along with its adverse consequences, including the loss of human life, damage to the environment, and economic impacts through reduction in activity.

From the same perspective, the flood risk can be considered as a threat, and the source of flood hazard. Further, the quantification of flood risk results in either monetary units or the potential loss of life, if the losses are quantifiable or in qualitative terms in the case of intangible damages (cultural, environmental, etc).

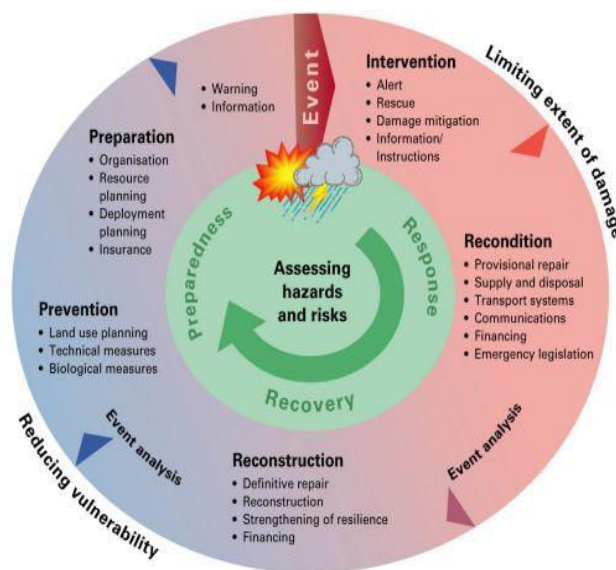


Figure 3: Risk Management Cycle (source: Integral Risk Management Cycle, FOCP 2003)

The framework for flood risk management begins with the definition of ‘flood risk’. There is no single definition for flood risk but the one that is very useful to start from says that flood risk is unity of hazard, exposure and vulnerability. These three components determine flood risk.

Hazard is defined as the potential for harm, loss or damage. In the case of flood risk, it is the threatening natural event including its magnitude and probability of occurrence. Hazard exists where land is liable to flooding. Hazard increases with probability, with flood depth, and with flow velocity.

The second component is exposure to hazard. Even where a hazard exists, there is no risk unless there are assets or people that can be damaged. The exposure to flood hazard creates the potential for personal danger or property damage to property.

The risk also depends on how vulnerable people and assets are in danger of damage. Vulnerability is defined as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard (UN/ISDR, 2004). Vulnerability is a lack - or loss - of resistance to damaging forces that are coming from a threat (hazard). Flood vulnerability can be minimized by taking actions before flooding and knowledge of what action to take in order to minimize damage and receive adequate warnings and actions during and after flood event.

Further, the basis and structure of FRM frameworks is in line with temporal scales starting before the onset of the event and continue through up to the recovery phase. This is a crucial

element of the risk management cycle. With this concept the systematic identification, assessment and prioritization of associated risks are covered. Further, the management of measures for risk mitigation, individual phases of prevention, response, preparedness and recovery are also included. Figure 3 contains presentation of different stages in the risk management cycle. The delineation between these phases is not always clear-cut.

Accordingly comprehensive flood risk management has to consider all three components: hazard, exposure and vulnerability. In addition, the focus should be also on the environment and community, which gives it a strategic characteristic. . Strategic flood risk management considers physical and social components of the urban environment. Consequently, it covers:

- The institutional and legal framework;
- Implementation of strategies;
- Social and environmental assessment.

Flood risk management aims to reduce the impact of flooding and one of most effective approaches is through developing risk management programs that incorporate the prevention or reduction of flood damage.

Flood risk management aims to be proactive and that requires the following steps:

- Risk identification;
- Development of strategies to reduce risk;
- Creation of policies and programs to implement strategies.

The integrated flood management approach (World Meteorological Organization, (IFM 2009) is based on the principle of reducing vulnerability throughout building resilience and developing a culture of prevention. This is done through preparedness rather than by reactive responses alone. The decisions are made as a part of the ongoing science-based process. This involves processes that plan, act, monitor and evaluate applied strategies. The new knowledge is then available and incorporated into management approaches. This represents a shift from traditional management, and rather views management actions as learning experiments. Integrated flood management (IFM 2009) has five stages:

- Adopting a basin approach to flood management;
- Bringing multidisciplinary approaches to flood management;

- Reducing vulnerability and risks due to flooding;
- Addressing climate vulnerability and change;
- Enabling community participation.

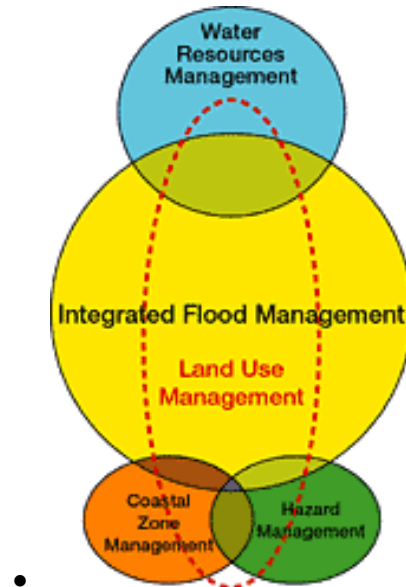


Figure 4: Integrated flood risk management (WMO, 2009)

Elements of integrated flood risk management are presented on figure below. This approach promotes integrated instead of a fragmented approach to managing flood risk, and aims to maximize the efficient use of floodplains and to minimize loss of life.

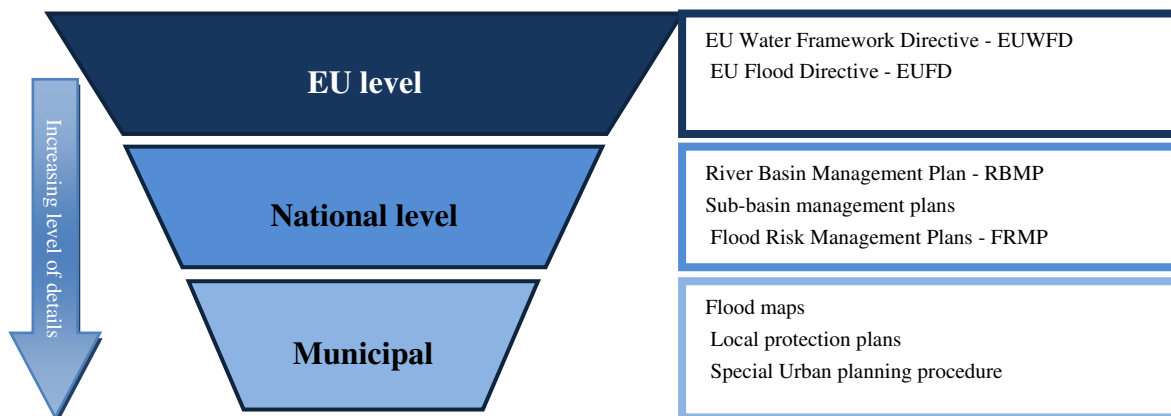


Figure 5: EU administrative framework for managing flood risk

The Water Framework Directive (2000/60/EC) focuses on achieving good qualitative and quantitative statuses of water bodies in the European Union. The Floods Directive (2007/60/EC) is focused on managing the flood risk in member states and minimizing the consequences of flooding. Each member state should undertake a preliminary flood risk assessment for each river basin district, following the articles in the Flood Directive. This preliminary assessment means the production of appropriate maps for river basins, records of past floods, existing studies of future floods, and the collection or creation of records regarding human, economic and heritage losses. This preliminary assessment creates a base for a production of flood hazard and flood risk maps. The flood risk and hazard maps should be completed by December 2013. A further development is the creation of flood risk management plans for river basin districts focusing on prevention, protection, and preparedness measures, flood forecasting and early warning systems. One of the important steps regards informing the public and providing consultation. This is set within Article 9 of the Flood Directive. This is in addition to updating and reviewing the produced flood risk management plans.

2.3.1 River Basin Management Plans (RBMP)

Plans are required by the EU Flood Directive by December 2015. Integrated River Basin Management plans are dedicated to harmonizing conflicting interests, complexity and uncertainty. Regarding floods, the main goal of these plans is to achieve the coordination of actions in the different parts of the catchment in addition to ensure protection, improvement and sustainable use of all water resources in each major catchment of the European Union. The plans are recording the current status of water bodies within the river basin districts, setting out the measures planned to meet objectives and act as the main reporting mechanism to the European parliament and to the public.

2.3.2 Flood Risk Management Plans (FRMP)

The recent events recorded in Europe have underlined the need to integrate and unify all actions related to flood risk management. In order to gather under the umbrella of flood risk management the prevention, the protection and the preparedness actions, a new legal framework was needed. This action was achieved with the introduction of Flood Risk Management Plans (FRMP). This was motivated by the flood events that occurred from 1998 to 2009 in Europe. During this period, more than two hundred floods occurred. The most devastating were floods along the Danube and Elbe rivers in summer 2002. During a period of 11 years (from 1998 to

2009) floods caused 1126 deaths, the displacement of 500 000 people and at least €52 billion of economic losses. Also the floods that occurred in 2005 reinforced the need for intensive action. Flood Risk Management Plans therefore are expected to provide all information regarding flood risk on the level of the river basin district. These plans present a legal instrument for flood risk management. Plans consider all types of flooding and focus is on five main pillars:

- Preparedness;
- Prevention;
- Protection;
- Emergency response;
- Recovery measures.

Flood risk management plans have a role to point out to policy makers, developers and the public the nature of risk and the measures proposed to manage the risks.

There is a wide range of existing frameworks that can be used as a guide to manage flood risk covering prevention, coping and recovery from flooding. These include the '4As' planned by the Scottish Government, the Floods Directive defines '3Ps an E and an R', and '4 capacities' proposed in the Netherlands.

3P's and E and R (2007/60/EC)

This approach focuses on Prevention, Protection, Preparedness, Emergency response and Recovery (the aforementioned 3Ps and E and an R). These elements contribute to the effective flood risk management program. Prevention is focused on preventing damages caused by flooding processes. This is done by avoiding future development in flood prone areas, adapting the future development of the risk of flooding and the promotion of appropriate land-use, agricultural and forestry practices. Structural and non-structural measures are focused under the protection part of the '3P's an E and an R' strategy. Measures are reducing the likelihood of flooding and the impact of flooding at the specific location. Preparedness is oriented to informing the population about flood risks and about actions that are to be taken during the flood event. Further, the emergency response tends to develop emergency response plans in the case of flooding. The final part, recovery and lessons learned, cover the set of actions taken to return to normal conditions. Mitigating both the social and economic impacts is important here.



Figure 6: Flood management cycle with 3P's and E and R, (2007/60/EC) approach

The Scottish 4A's (FIAC2005)

This approach is based on sustainability (Water Environment and Water Services Act 2003) where the primary aim is maximise the possible social and economic resilience to flooding, by protecting and working with the environment.

The set of awareness, alleviation, avoidance and assistance are in this approach. Under awareness is management on the policy level where politicians, decision makers, professionals and stakeholders on a public level (people, companies, developers, and insurance companies) are involved. The implementation of structural and non-structural measures contributed to the alleviation or mitigation of flood risk. The third element of this approach covers the avoidance of flood risk. This is done with building adaptations, and capacity building for individuals as well as institutions. Assistance as a final element provides support to recovery during and after a flood event.

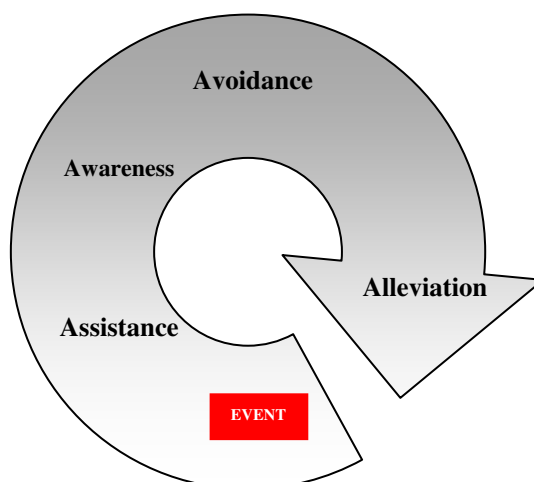


Figure 7: Flood risk management cycle with 4A's, (FIAC2005) approach

The '4 capacities' in the Netherlands (De Graaf, 2009)

The approach in The Netherlands is focused on an adaptive flood control strategy. This strategy has a need to build diversity with multiple innovations, usage of flexible and reversible infrastructure and provide space for water (De Graaf, 2009). This approach makes it possible to adapt to changing flood risk:

The associated Dutch '4 capacities' required to manage and adapt to changing flood risk are:

- a) Threshold capacity - comprised not just by the technical and infrastructural system but also by the institutional and social capacity;
- b) Coping capacity - ability to reduce the damage caused by a significant flood threat that exceeds some specified "damage threshold";
- c) Recovery capacity- ability to recover after an event;
- d) Adaptive capacity - respond using a range of diverse options (a portfolio) rather than sticking to historically tested approaches (Ashley et al, 2010).

With these capacities the necessary responses to changing the future flood risk will be affected.

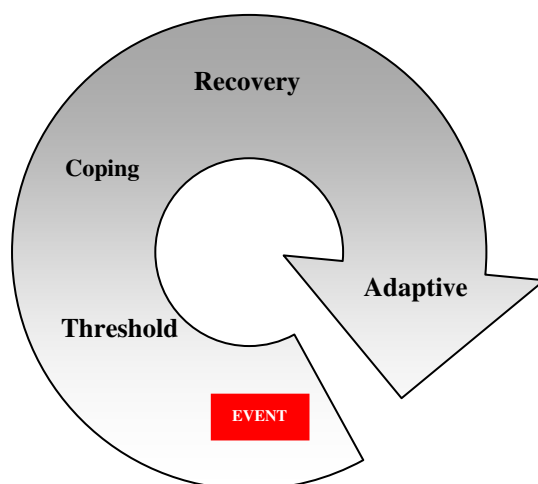


Figure 8: Flood risk management cycle with The ‘four capacities’ approach used in the Netherlands

The presented approaches have been developed to help meet the challenges. Some of the frameworks are more detailed than others. While the 4A’s framework under the Floods Directive are more focused on the pre-event actions, the four capacities approach in the Netherlands focuses more on activities during and after the event.

The table below shows a comparison of the three above discussed approaches for FRM frameworks.

Table 4: Comparing the frameworks for managing flood risks in the EU

4A’s	EU Flood Directive	Capacity type in The Netherlands
Awareness	Preparedness	Adaptive
Avoidance	Prevention Protection	Threshold
Alleviation	Protection	Threshold
Assistance	Preparedness Emergency response Recovery and lessons learned	Coping, Recovery

Strategies are needed in order to set and implement measures for managing the flood risks. Some strategies within presented frameworks focus more on pre-event actions while other strategies focus on actions during and after the flood. The ideal strategy of course should cover all three temporal scales of flood risk (before, during and after, Figure 3). The purpose of strategies is to address the defined objective of a framework. An ideal strategy is fully integrated and implemented within the flood risk management framework. It covers the whole risk

management cycle (timeframe before, during and after the event), it is implemented on urban scale, and it is contained within the local urban planning documents. Consequently this creates shift to a resilient approach towards flood risk management strategies. The concept of resilience is therefore introduced through fully integrated strategies and measures implemented on local scales.

The term ‘tool’ refers to anything used as a means of accomplishing a task or a purpose. Implementation of measures is done through different tools/instruments. The hierarchical path following up-bottom approach starts with framework, strategy, measure and tool/instrument.

Implementation of measures is done through existing directives, laws and policies. As discussed in text above there are different levels of influence: level of European Union, national, river basin, catchment, municipal (local). When analysing the Flood Risk Management Plans as a tool it can be concluded that they represent a legal instrument for flood risk management by providing all information regarding flood risk on the level of river basin. As presented in text above they have a role to inform policy makers about the risk nature and about proposed framework and strategies for assessing the flood risk. As shown there are different frameworks for managing risk: The ‘4 capacities’ in the Netherlands (De Graaf, 2009), The Scottish 4A’s (FIAC2005) and The 3P’s and E and R (2007/60/EC).

2.4 The methodology for assessing flood risk management

The evaluation of Flood Risk Management (FRM) frameworks can be done according to the different levels of integration of their elements. As it has been mentioned flood risk management cycle covers actions before, during, and after the flood. The examination will look at the integration of existing frameworks and strategies for the case studies.

The planning process for flood risk management is driven by legislation and policy at supranational, national, regional, local and site specific levels. For the European case studies all FRM frameworks are under the umbrella of the EU Flood Directive. On the other side the Asian case studies have flood risk management frameworks on national levels.

In order to evaluate different flood risk management frameworks, hazard, exposure and vulnerability are chosen to be the main elements for analysis of flood risk. Hence, the existing

FRM in the case study areas are not unified, although they all do include the elements of hazard, exposure and vulnerability.

2.4.1 The maturity levels

A possibility for assessing the different strategies is to use the concept of maturity. The principle is to compare each situation with a reference level, which characterizes the complexity and the efficiency of the implemented flood risk management strategy. These levels are determined according to different characteristics, which are presented within Table 5.

The state of maturity means being fully developed or perfected, in general usage (Cooke-Davis, 2005). The concept of maturity is being increasingly utilized to map out logical ways to improve an organization's services. It is used in "Best Practice" benchmarks, indicating increasing levels of sophistication and other features (PMI, 2002). Maturity refers to the degree that an organization consistently carries out processes that are documented, managed, measured, controlled and continually improved (CMMI Product Team, 2002).

Maturity is encapsulated within the concept of readiness. The readiness level is a measure that is used to assess maturity of evolving frameworks. This is in addition to the integration of frameworks and implementation of measures. The same approach for the evaluation of technology is done by US Department of Defence (DoD) (TRA Guidelines, 2011), National Aeronautics and Space Administration (NASA) (Sauser et al, 2006) and European Space Agency (ESA) (Sauser et al 2006).

The system must first be fully "mature" before it can be "ready" for use/implementation. Translated to the domain of flood risk management, there is a level that is defining the framework has capacity to go for higher maturity and towards integration.

The highest maturity level for a flood risk management strategy is to introduce and apply the concept of resilience in an active way: the resilience concept is introduced within the legal framework. In the same way, the EU Water Framework and Floods directives represent holistic approaches where, for example, informal ways of providing information about flooding represents the lowest level of maturity. The readiness level of a flood risk management framework is defined with the legal framework. Before reaching the highest maturity level the framework has to reach a **level where all strategies and actions are built in the legal framework – the readiness level is reached** (figure 8). The move to the integrated level where

flood risk management has a resilience approach is done through the implementation of strategies and measures on local scales (Batista, Goubesville, Tessier, 2013).

Table 5: Maturity levels of flood risk management at city scale (Batista, Goubesville, Tessier, 2013)

Level	Maturity Scale	Description
1	Informal (ad hoc)	<p>Short-term focus on flood risk management</p> <p>The perception that notifying a risk is on low level</p> <p>No standardized flood risk procedures</p> <p>Ad hoc approaches applied on a case-by-case basis</p> <p>No understanding or experience of flood risk management</p> <p>No monitoring or reporting of flood risks.</p> <p>Individual actions without institutional coordination</p>
2	Basic	<p>Knowledge of specific flood risks</p> <p>Flood risk management procedures are beginning to be identified and are communicated verbally</p> <p>High reliance on the knowledge of individuals</p> <p>Heavy dependence on historical practice</p> <p>Mainly individual actions with limited coordination</p>
3	Initial	<p>Midterm focus on flood risk management</p> <p>Flood risk management policy and procedures are implementation partially</p> <p>Some flood risk management tools and templates are developed</p> <p>Implementation of flood risk management elements is limited to few stakeholders</p> <p>Insurance scheme available</p> <p>Flood maps</p> <p>Coordination of actions by city governance</p>
4	Coordinated	<p>Risk is identified</p> <p>Best practice is incorporated into FRM framework</p> <p>Capacity building of human resources is on high level</p> <p>Availability of FRM tools</p> <p>FRM implementation plan exists</p> <p>Insurance scheme</p> <p>Flood maps</p> <p>Real time systems if needed</p>

5	Integrated	<p>Resilience concept integrated within the legal framework and at the different operational scales (country to city)</p> <p>Best practice of flood risk management – fully integrated FRM framework includes and has fully application of capacity building of human resources.</p> <p>Learn lessons are implemented in the FRM framework</p> <p>FRM is addressing key processes</p> <p>Insurance scheme</p> <p>Flood maps</p> <p>Real time systems if needed</p>
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Table 5 represents the different levels of maturity model for flood risk management frameworks. This methodology is chosen after a review of different existing methods for assessing the different strategies implemented in the case study cities. The chosen methodology evaluates the maturity (complexity) level of existing flood risk management plans in case study areas. This is chosen based after review of different FRM frameworks and the different levels of their implementation. The implementation is a crucial in this research because it is an indicator of conditions needed to reach the readiness level in setting the FRM. What does this mean? The one thing is existing set of rules and strategies within FRM and totally different thing is what is actual done on the application, implementation and integration. therefore these five levels present the different maturity levels of existing FRM frameworks and as that the FRM frameworks are evaluated and presented in the further analysis.

There are five different levels of maturity.

- a) First one is an ad-hoc where there is no high risk perception. The actions are taken in an informal way. The implementation of flood risk management strategies is not assessed for the informal maturity level. Taken actions are without institutional coordination. Risk perception is on the low level.
- b) Second level of maturity of FRM framework is basic. Here the knowledge is present but just for a specific event. Procedures within flood management cycle are starting to be identified. The risk is known just for the particular events. The reliance on knowledge of individuals is high. The actions taken to manage the risk has low institutional coordination
- c) Initial maturity has in consisted implementation of flood risk management policies. The institutional coordination is present. The coordination is under city governance level. The flood insurance schemes are available as well as flood maps.

- d) Coordinated maturity level has fully identified flood risks. Flood risk management policy and procedures integrate best practice. FRM tools and templates are available to stakeholders. FRM implementation plan exists with highly applied capacity building of human resources. Insurance schemes exist and if there is a need real time system.
- e) Fifth level of maturity is converging to resilience. On this level the best practice is not just a part of FRM framework but it is also fully integrated. The attitude of learning from past events is dominant. The FRM framework is addressing main problems.

Informal Level 1	Individual action with no coordination
Basic Level 2	Individual actions with limited coordination
Initial Level 3	Limited implementation and coordination on local level
Coordinated Level 4	Fully integration and partial implementation
Integrated Level 5	Fully integration and implementation

Figure 9: The maturity levels

A qualitative assessment of the different stages can be obtained by using the defined framework and evaluation of the maturity level can be produced for each strategy.



Figure 10: Theoretical curve for different maturity levels - adapted from (Batika, Goubesville, Tessier, 2013)

Figure above present the different maturity levels are presented with respect to a temporal scale in the flood management cycle. All case studies have flood risk management frameworks. The

maturity level of these frameworks is not the same. The evaluation principles are based on integration level of elements in the risk management cycle.

Table 6: Evaluation principles

FLOOD HAZARD	Flood control works
	Structural planning and design
	Asset maintenance
	Operations (DSS)
EXPOSURE	Land use management
	Flood zoning
	Land use planning
	Resettlement
VULNERABILITY	Flood forecasting
	Hydrological and hydraulics models
	Flood hazard maps
	Data acquisition network
	Flood warning & emergency response
	Communication system
	Preparedness exercise
	DSS
	Post flood recovery
	Support services (health, counselling)
	Material support (food, shelter)
	Infrastructure repairs
	Financial assistance & incentives
	Compensation / flood insurance
	Land use management
Building regulations	

The elements presented above are very broad but provide enough space for comparison between different FRM frameworks in the case study areas.

Existing frameworks, strategies as well as measures are based mainly on historical floods. With the flood security based on just this hypothesis, the communities had a false sense of safety. Based on historical events, this traditional approach does not consider other aspects of protection than structural. Further to that, the traditional approach is based on reducing flood hazard. Recent years brought probabilistic techniques and their improved implementation in predicting flood occurrence. Structural measures are also known, as “engineering measures” are all measures that are physically constructed to reduce or avoid possible impacts of hazards. They

also consider application of engineering techniques to achieve hazard-resistance and resilience in structures or in systems (UN/ISDR, 2004).

Urbanization processes, economic development and land use demand have created higher flood vulnerability. This happened because the protection level based on the structural measures was more dominant and therefore created as mentioned illusion that protection was very high or even almost perfect.

Flood risk management concentrates merely on long-term protection against natural hazards. Thus, the objective of studying vulnerability is to make a current actual material damage inventory and to put the geohistorical analysis into perspective. By identifying flood risk factors, urban water management should be reorganized by taking into account water shortage and its excess, as well as its social and cultural aspects. Analysis focuses on the interaction between urban structures and flood risk management, especially architectural and urban design adaptations to climate change. The objective of this analysis is intended to show different flood risk management strategies of case studies according to their physical, cultural, political and economic characteristics. The global vision of flood risk mitigation measures is captured. The different current flood risk management strategies in case studies and their weaknesses are presented as well as results from the maturity evaluation for each case study. The evaluation of maturity is a step towards the resilience approach. The resilience concept, including spatial and temporal aspects, improves flood risk management strategies. Further the flood risk mitigation measures can be analyzed through spatial and temporal criteria. The temporal scale of flood risk management covers three phases: before, during and after the flooding (figure 1):

- Before flooding: the flood risk prevention includes flood risk mitigation actions and actions related to minimizing damage;
- During flooding: the crisis management includes an early warning system and a rescue system;
- After the flooding: it includes recovery actions and the ability to absorb the perturbation and to reboot.

According to the research program, SUFRI 2011, flood risk mitigation measures could be divided into two categories: structural and non-structural as follows.

- Structural measures: All civil engineering works, for example, construction of dike and sea barrier are considered as structural measures. Architectural adaptations are also included in this category.
- Non-structural measures: All prevention and protection measures exclude civil engineering works. This category relates to policy, advocacy, research and technological development, public participation, etc.. (Graham, 1999) For example, weather forecast system and Advanced Real-Time Control (RTC) are classified in this category.

This method for evaluation of maturity of FRM frameworks is tested on five cities in Europe and Asia. During this research, I had an advantage to be part of international team of researchers on the subject of urban flood resilience. As that, I was able to develop and test. In the paragraphs below I will present what finding regarding different maturity levels in Europe and Asia I found.

European and Asian cities (I) Barcelona, (ii) Hamburg, (iii) Nice, (iv) Beijing and (v) Taipei are tested. Cities are analyzed with respect to *chosen flood events* and according to the documented actions. The maturity levels are defined for the existing flood risk management frameworks in the cities.

The analysis for each case study consists of the following:

- list of structural and non-structural measures applied based on existing flood risk management plan (Annex A)
- basic data on significant analyzed flood event (Annex A)
- recorded dysfunction of protection measures and dysfunction of urban activities recorded (Annex A)
- maturity for existing flood risk management

The result of the evaluation presented on table below shows differences in maturity levels for analyzed cities.

Table 7: Maturity levels for existing flood management frameworks in European and Asian case studies

	Beijing (China)	Barcelona (Spain)	Hamburg (Germany)	Nice (France)	Taipei (Taiwan)
FLOOD HAZARD					
Flood control works					
Structural planning and design	4	4	4	4	4
Asset maintenance	3	5	5	4	3
Operations (DSS)	3	4	4	3	3
EXPOSURE					
Land use management					
Flood zoning	3	5	4	4	4
Land use planning	4	4	4	4	4
Resettlement	1	1	1	1	4
VULNERABILITY					
Flood forecasting					
Hydrological and hydraulics models	3	5	5	4	4
Flood hazard maps	4	5	5	5	4
Data acquisition network	4	4	4	4	4
Flood warning & emergency response					
Communication system	3	5	5	4	4
Preparedness exercise	3	4	5	3	4
DSS	3	4	4	4	4
Post flood recovery					
Support services (health, counselling)	3	4	4	4	4
Material support (food, shelter)	3	4	5	4	3
Infrastructure repairs	4	5	5	5	4
Financial assistance & incentives	3	4	4	4	3
Compensation / flood insurance	1	4	2	3	2
Land use management					
Building regulations	3	3	2	3	4
MATURITY LEVEL	3.06	4.11	4.00	3.72	3.67
	initial	coordinated	coordinated	initial	initial

2.4.2 Discussion of results

Each city had a flood event for analysis. The existing structural and non-structural measures as well as existing FRM frameworks with the legal structure took part in analysis. Further the analysis of different maturity for FRM frameworks is done. The main scope was to **identify integration and implementation of measures**.

The three main elements for flood risk management are considered: (i) flood hazard, (ii) exposure and (iii) vulnerability for choosing case study areas. The main criteria explore flood risk management frameworks integrated and reached the readiness level with the level of implementation achieved. The level of integration is obtained for each case study area and in accordance with described methodology in this chapter.

In addition, the focus was on the identification, which FRM has all actions under legal framework and implementation done. The criteria provide a possibility to explore flood risk management frameworks, their integration, implementation and readiness level. The readiness level then gives a possibility to go towards achievement of resiliency.

Results provide identification of weak points in existing flood risk management frameworks. The evaluation that is taking into account elements of risk (hazard, exposure and vulnerability) disaggregated into separate components gives possibility to map the weak points in existing frameworks. The level of integration is obtained for each case study area in accordance with the described method. The results are also presented in the figure below.

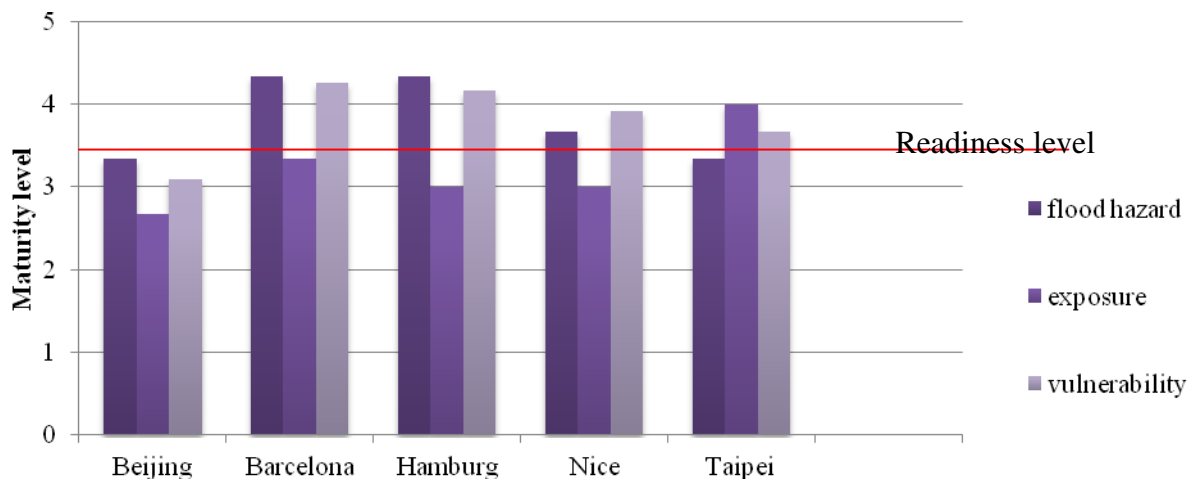


Figure 11: Results from maturity matrix for case study cities (Batika, Goubesville, Tessier, 2013)

Results show that Hamburg and Barcelona have a highest integration and implementation level related to strategies and measures related to flood control.

Exposure is the second analyzed element of the flood risk management framework. The results from the maturity matrix show that Taipei has the 'coordinated' maturity level considering land use management. Strategies and measures related to flood forecasting, recovery and building regulations are in initial and coordinated level for the analyzed cities. The highest level has Barcelona and Hamburg. Considering all seven flood risk management frameworks it can be concluded that integration and implementation is focused mainly on flood control works where the structural planning takes the priority. The flood risk management frameworks in Barcelona and Hamburg have reached a readiness level for flood hazard and vulnerability and they are moving toward resiliency. The actions related to land use management that are within the second element (exposure) have to be also integrated within the legal framework.

For all the analyzed case studies the implementation and integration related to exposure is not on high level. Therefore the flood hazard zoning, land use planning controls, resettlement and property acquisitions need to be covered with policies in order to have better implementation and coordination.

Analysis shows that existing flood risk management frameworks are based on protection strategies focusing on flood prevention for the events smaller than a certain threshold (usually designed discharge or return period). The measures related to flood hazard zoning, land use planning controls, resettlement and property acquisition are not coordinated and fully implemented. In the analyzed cities where they exist the actions are individual with limited institutional coordination. Further analyses should be focused on actions that will improve implementation of existing flood risk management frameworks, provide availability of flood risk management tools, incorporate best practices' into the framework.

The way toward resilience approach brings fully integration and implementation of strategies and measures under the legal framework. Evaluation of resiliency of physical environment and urban communities to certain flood events is expressed with flood resilience index. The flood resilience index is represented as a level of flood resilience assessment in analyzed area and for certain flood characteristics.

2.4.3 Adding resilience to flood risk management

The resilient urban systems and urban communities have ability to accept, resist, recover and learn from the events. Capacity of urban systems and communities is improved in each part of the flood risk management cycle. It covers actions related to preparedness, response and recovery. Within this research the five elements of flood risk management are developed: **relief, resist, response, recovery and reflect**.

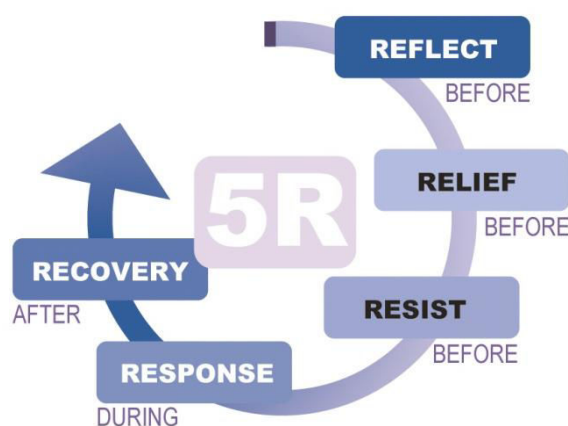


Figure 12: Elements for flood risk management cycle – CORFU project

- Reflect – Actions focus on increasing awareness and adaptive capacity, learning from past event and/or preparation for an uncertain future. Enhancing the awareness and engagement in all aspects of flood risk and the means of managing it at the policy level (politicians/decision makers), professionals (of the involved authorities and elsewhere) and at the public participation (people, companies, developers, insurance companies).
- Relief – A buffer element. The use of using existing structures and urban functions for collection of flood water (green areas, different playgrounds...) is dominant. Measures implemented before a flood. Implementation of physical, technical, non-structural and procedural measures relates to the concept “living with floods”, such as wet flood proofing.
- Resist – Prevention of flood risk if possible, threshold capacity; measures implemented before a flood. Limiting flood damage and easing recovery by planning and adapting buildings, infrastructure, surfaces and economic activity relate to the concept of resistance

- Response – Measures taken during the flood. Actions focus on crisis management coping capacity. Flood impact is reduced by implementation of physical, technical, non-structural and procedural measures relates to the concept “living with floods”.
- Recovery – Providing support to recovery processes and engaging and building capacity in communities enable to cope with the impacts after flooding events.

Actions and measures are directly connected with flood resilience. They relate a strong intent to increase capacity building of human resources, better land use management, increased flood preparedness and emergency measures that are taken during mostly usually and after a flood event.

Capacity building of human resources refers to increasing awareness of flood risk among key stakeholders in urban systems. The awareness among the population is assessed through presenting the brochures, short public presentations, creating internet portals that with useful information's. Constant communication with population and education are also one of elements for capacity building of human resources. This is achieved with face-to-face learning and training also. In present urban systems these measures are in developing stage since they were not considered under traditional flood risk management.

Land use management refers to spatial planning and building regulations in order to create more space for water. The new buildings come up with improved shapes that are able to accept a certain amount of flood water and have minimal flood damage. The land use management contributes prevention to flood where possible.

Adapting to flooding by floatable building and buildings on piles, dry and wet proofing of buildings contributes to increased flood preparedness and contributes to mitigate the effects of flooding.

The measures that refer to preparation to flooding processes are financial preparedness, voluntaries, shelter management, improving flood insurance schemes, evacuation and rescue plans, etc. These measures are to be tested during the flood event.

2.5 Conclusion

The main reflection in this chapter refers to the development of method for evaluation of existing FRM frameworks. Through evaluation, there is a possibility to notice the level of integration and implementation of crucial element of flood risk. As defined here the main elements (i) flood, (ii) vulnerability and (iii) exposure are the main elements. Using the evaluation principles the FRM framework is evaluated regarding achieved readiness level considering its elements, level of integration and implementation. If the readiness level is achieved the FRM can be developed in order to be moved towards resiliency.

3 Flood resilience assessment

Parts of this chapter has been published as:

Batica, Jelena, and Gourbesville, Philippe.: "Flood Resilience Index – methodology and implementation", 11th Interantional Hydroinformatics Conference, New York, USA, 2014

Batica, Jelena, and Gourbesville, Philippe.: "Methodology for Flood Resileince Index", 3rd IAHR Europe Congress, Book of Proceedings, Porto, Portugal, 2014

Batica, Jelena, Gourbesville, Philippe, and Hu, Fang-Yu.: "Methodlogy for Flood Resilience Index", International Conference on Flood Resilience Experiences in Asia and Europe – ICFR, Exeter, United Kingdom, 2013.

Batica, Jelena, and Gourbesville, Philippe.: "Approach developed within functional analysis regarding flooding processes in urban areas", Proceedings of the 10th Interantional Hydroinformatics Conference, Hamburg, Germany, 2012.

3.1 Urban systems: Scaling and mapping

A city exists to expedite transactions – production processes, consumption activities, social interaction, economic and political decision-making. The relationship between the nature of interaction and the structure of an urban system is fundamental. City systems (urban systems) are very complex taking into account what an urban system need to provide for the residents, or what city need to have in order to ensure an acceptable level of functioning. In this thesis, the functional analysis used to describe the structure of the city as well as implementation of measures.

This analysis represents the union of activities (functions, actions, processes, operations) that system must perform in order to achieve addressed outputs. Performing activities such as, transportation of people, assets, food, providing residential areas, energy supplies to residential areas, etc. are some of addressed outputs that urban system has to achieve. Functional analysis is important to understand how the city is carrying out.

The structure of urban system interpreted through functional analysis offer the possibility to evaluate resilience of each element of urban system as well as overall resilience. Assessing resilience of urban functions and services provide improved identification of ‘*hot spots*’ and efficient recommendation of possible flood management strategies. An urban system is defined within city boundaries. The shape of urban systems is changing over time since urbanization is also a dynamic process. Change of urban systems over time does not imply just physical change of landscape. The change of system in social aspect is significant as well e.g. population density. Contours of urban systems are influenced by many factors. With its spatial evolution, urban systems are changing environment and also change the natural water courses. Looking at a city through different spatial scales it is more likely to asses’ present issues regarding urban flooding. Smallest “unit” of urban system is represented with individual parcel. A group of parcels contoured with streets represent block. Third level of organization represents a district (group of blocks or administrative unit) and the final organization ring is the city itself (Batista, Gourbesville 2011).



Figure 13: City system represented through scales (city, district, block and parcel)

Above presented is scaled urban system with four entities: *city, district, block and parcel*. Components of urban systems are also important because there is a requirement to investigate connections and dependencies of system elements with flooding processes.

3.1.1 Mapping of urban system - urban functions and city services

Scaling of urban system allows being able to recognize main urban patterns. Common for each urban system is to have the necessary elements in order to be able to function. In order to break down the structure of urban pattern it is necessary to map system elements to physical components, map the elements to systems requirements (Daniell, K.A. Et al, 2005). This allows listing all necessary tasks that urban system is performing. Physical components of the systems are urban functions and services.

Physical components of urban system are buildings, streets, parks, water distribution networks, shops, industrial buildings, electricity networks, religion areas, etc. Some of them represent assets that the city needs to have in order to perform while others provide connections between different system components. Urban functions of a city define physical components that urban system needs to provide as fundamental needs to residents. The physical component of a city has spatial extension and the expression is through units (m^2). There are nine main urban functions, which urban system needs to have in order to fulfil requirements related to integral need provided to residents. The urban functions are listed as follows:

- housing (individual or collective),
- educational areas (for local and non-local education services),

- food (area for food storage),
- working areas (areas for industry and areas for non-industrial activities),
- areas established for location of police, fire brigade and rescue services (on local level), health areas (hospitals on local and non-local level),
- areas for leisure and tourism (on local and non-local level) and
- areas for religion activities (churches and cemeteries).

The city services give connectivity between physical components. Services in the city gives functionality to urban features (e.g. the function of a house is to provide space for living).

For example, just a house without electricity, water, communication, roads that are connecting house to other urban functions, etc. does not have operational structure. Disruption or total damage of services in the city brings serious impact on health, safety, security or economic well-being of citizens. Services are therefore a vital part of urban systems. Graphically urban functions and services are presented in Figure 15.

In order to analyze the complexity of urban systems, the functional analysis can be used to describe the structure of the city as well as implementation of measures. The main interest in this approach is to provide indicators that could be used to characterize urban resilience regarding flooding issues.

A city is the spatial expression of a system based on functions, actions, processes, operations that must perform in order to achieve addressed outputs. Performing activities such as transportation of people, assets, food, providing residential areas, energy supplies to residential areas, etc. are some of addressed outputs that urban system has to achieve.

The shape of urban systems is changing over time since urbanization is also a dynamic process. Change of urban systems over time does not imply just physical change of landscape. The change of system in social dimension is significant as well e.g. population density. Contours of urban systems are influenced by many factors. With their spatial evolution, urban systems are changing environment and also change the natural water courses. Looking at a city through different spatial scales it is more likely to assess present issues regarding urban flooding. Smallest “unit” of urban system is represented with individual parcel. A group of parcels contoured with streets represent block. Third level of organization represents a district (group of blocks or administrative unit) and the final organization ring is the city itself (Batista, Gourbesville 2011) (Figure 13).



Figure 14: City system represented through scales (city, district, block and parcel), example of scaling applied on Nice case study, France

Above presented is scaled urban system with four entities: *city*, *district*, *block* and *parcel* (Batista, Gourbesville 2011). Components of urban systems are also important because there is a requirement to investigate connections and dependencies of system elements with flooding processes.

Scaling of urban system allows recognition of main urban patterns. Common for each urban system is to have the necessary elements in order to be able to function. In order to break down the structure of urban pattern it is necessary to map system elements to physical components, map the elements to systems requirements (Daniell, K.A. et al, 2005). This allows listing all necessary tasks that urban system is performing.

Physical components of the systems are urban functions and services. The components of urban system are buildings, streets, parks, water distribution network, shops, industrial buildings,

electricity network, religion areas, etc. Some of them represent assets that the city needs to have in order to perform while others provide connections between different system components. Urban functions of a city are defined as physical components that urban system need to provide as fundamental needs to residents. The physical component of a city has spatial extension and they are expressed through units (m^2). There are nine main urban functions that urban system needs to have in order to fulfill requirements related to integral needs provided to residents. They are: housing (individual or collective), education (for local and non-local education services), food supply (area for food storing and providing), working (areas for industry and areas for non-industrial activities), safety (police, fire brigade and rescue services on local level), health (hospitals on local and non-local level), governance (administrative bodies), leisure and tourism (on local and non-local level) and areas for religious activities (churches and cemeteries). Connectivity between physical components is done through services. Services in the city gives functionality to urban features (e.g. the function of a house is to provide space for living). Graphically urban functions and services are presented in Figure 15.

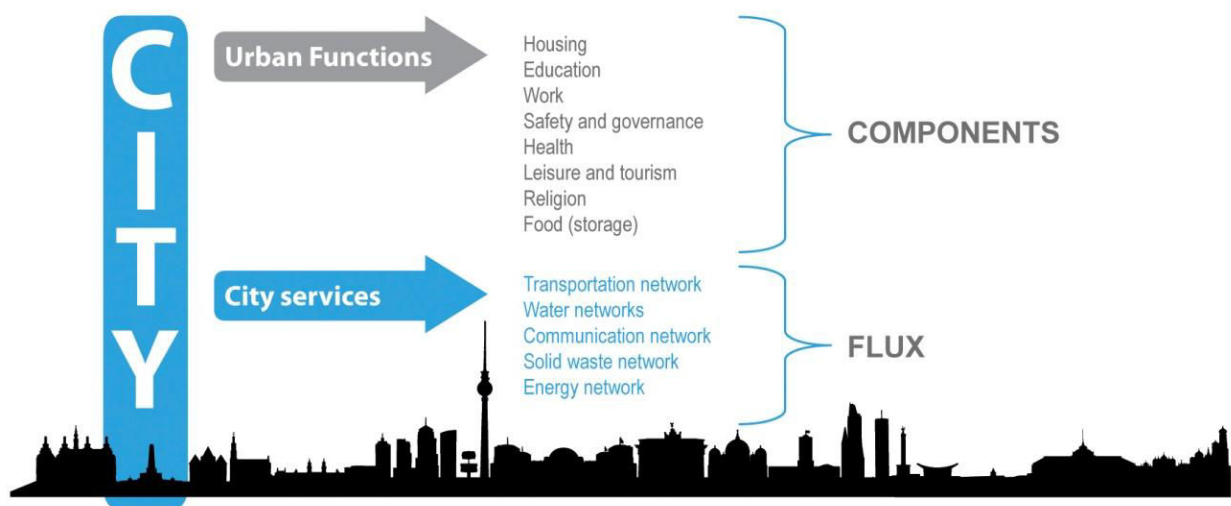


Figure 15: Mapping of the city according to urban functions and services

Representation of urban system through set of components defines two main groups, urban functions and city services. Mapping of urban systems give a possibility to investigate a connection and dependencies within the system during the flooding processes. Common for each urban system is to have the necessary elements in order to be able to function. By braking down the structure of urban patterns, it is possible to map system elements **to physical components and map the elements to systems requirements** (Daniell, K.A. Et al, 2005). This allows listing all necessary tasks that urban system is performing. Components of the systems

are **urban functions and city services**. The functions and services (Figure 15) of urban system are buildings, streets, parks, water distribution network, shops, industrial buildings, electricity network, religion areas, etc. Some of them represent assets that the city needs to have in order to perform while others provide connections between different system components. Urban functions of a city are defined as components that urban system need to provide as fundamental needs to residents.

Hence, the urban environment is mapped with the functions and services it is important to highlight the ‘strategic’ urban functions. They have vital importance for society. Under strategic urban function are following: power stations, water treatment plants, the control centre of public transport, waste water treatment plants, fire fighting stations and hospitals. In cases where strategic urban functions are dysfunctional, the significant damages for society and for economy are present.

City services are known as critical infrastructure and they represent a vital element of connectivity in built environment. Providing of flood protection to city services is a key element in providing flood resilience to public health, safety and economic vitality of urban areas. City services represent a network that exist in city with ‘function’ of providing connection between Urban Functions (UF) and brings them an operational structure. There are five elements that represent City Services:

- Transportation networks;
- Energy networks;
- Water (drinking and waste) networks;
- Communication networks;
- Solid waste networks.

City services present crucial components in the city. One of the most important characteristic of city services is their **interdependency**. This is with respect to their interconnectivity. For example, the failure of one service can have a direct damaging on other services (a fail of electricity can have a direct impact on water supply networks, metro, etc). Two different types of failure can occur, cascading and single point failure:

- Cascading failure of city service is a failure when single component failure propagates and triggers other services.

- Single point failure presents a situation when single asset provides dependency to a number of other components.
- For cascading failure, the chain of connection is not known while for single point failure the connections are well known.

Flood resilience and resistance measures of City Services take into account different levels of functioning. The methodology defines different state for functioning with respect to different spatial scale (city, district, block or parcel/building scale). The hierarchy exists between the city services. **The transportation network** is recognized as one crucial for interconnectivity and interdependency within the other city services. For example, the functionality of solid waste network is conditioned with functioning of transportation network. Commonly the energy, water, communication and solid waste network are following transportation network. Also it is important to recognize the importance of **energy network**, because the in some cases the communication network and drinking water network are conditioned with its proper functioning. The transportation network provides the essential connectivity between urban functions. In defining basic guidelines, the important steps are considered part of integrated flood risk management assessment. The scale for city services for evaluation is on city scale.

The intention is to establish a set of methods in order to assess the flooding processes in urban systems. By setting up the method for analysis of city services, the **efficiency levels** are defined for the city services (or how to map services based on their efficiency levels).

- Level 1: high impact and huge indirect influence. The rerouting is not possible;
- Level 2: medium impact on network. In case of disruption the rerouting is possible with very low efficiency and with significant indirect impact;
- Level 3: low impact on network. In case of disruption, indirect impact is not present or it is minimal. Rerouting is manageable without significant impact on network efficiency.

In order to be able to map the different dependency levels again the three levels are defined:

- 3 – Highly dependence on availability of other network;
- 2 – Medium dependence on availability of other network;
- 1 – Low dependence on availability of other network.

In the tables below the main dependences are created with respect to dysfunction of different networks.

Table 8: Dependency levels for city services with respect to different scales

		Transportation	Energy	Water	Communication	Solid waste
Parcel/building	Transportation	-	1	1	1	3
	Energy	1	-	1	1	1
	Water	1	1	-	1	1
	Communication	1	1	1	-	1
	Solid waste	3	1	1	1	-
Block	Transportation	-	1	1	1	3
	Energy	1	-	2	2	1
	Water	1	2	-	1	1
	Communication	1	2	1	-	1
	Solid waste	3	1	1	1	-
District	Transportation	-	1	1	1	3
	Energy	1	-	2	2	2
	Water	1	2	-	1	2
	Communication	1	2	1	-	1
	Solid waste	3	2	2	1	-
City	Transportation	-	1	1	1	3
	Energy	1	-	2	2	2
	Water	1	2	-	1	2
	Communication	1	2	1	-	2
	Solid waste	3	2	2	2	-

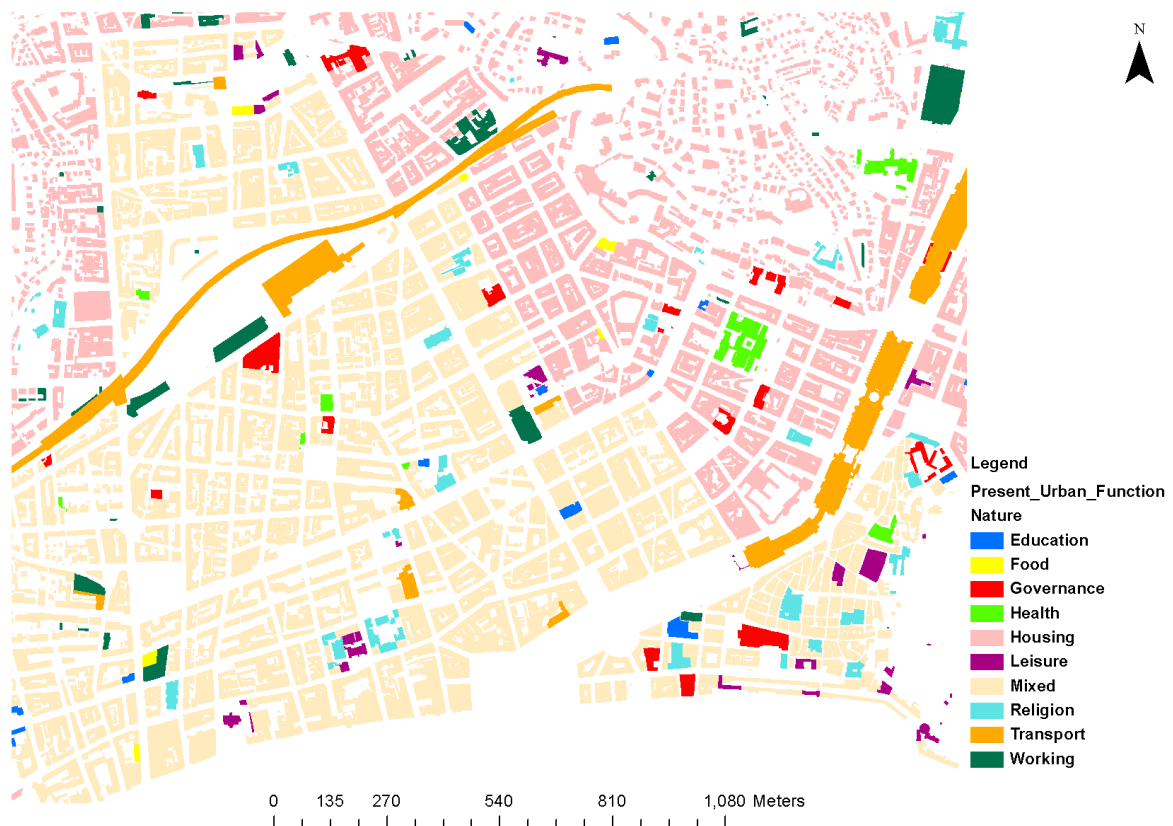


Figure 16: Mapping the urban system - Urban functions and city services, example on the city of Nice, France

3.2 Systemic analysis of a city

General overview of how the complexities of urban systems can be best gathered using integrated modelling techniques under functional analysis. This approach can show how experimental sustainability evaluation, based on system resource thresholds, and modelling, can be integrated into a framework that can be used for decision making and management relating to flood policies, regulation, planning, design and development of urban systems.

3.2.1 FAST approach

Functional analysis is a common language used in many technologies. One of the fundamental models within functional analysis is represented by FAST (Functional Analysis System

Technique) components (Kaufman 1977, 1990). A FAST diagram is a logical way of describing and analyzing defined functions. The method is driven by two questions ‘How?’ and ‘Why?’. Movement from left to right explains ‘how’ the work is being done, while movement from right to left explains ‘why’ the work is being done. Model design starts with a diagram. Elements of the diagram are functions and activities. The FAST diagram simply assists in breaking down a large problem. The proper understanding of the problem gives 50 percent of the solution. First step is to define the scope of the problem. The analysis starts with three main questions:

- What is a problem?
- Why is that a problem?
- Why is a solution necessary?

Essential part in this process is separating the problem from its symptoms and effects by analyzing model “functions”. By defining the scope, the objective higher order function is defined. A logical way to define a function is using the set of questions (‘how’, ‘why’ and ‘when’) that are explaining the function itself. Graphically, define within two vertical lines. Left sideline has objective function. This function is higher order function. Right side has lower order function. To be easier to create diagram it is important to state that there are two directions: HOW from left to right and WHY from right to left. For each function in the model, it is necessary to answer on HOW and WHY. Two other directions of functions are WHEN. When represent supporting function (direction up) or activity (direction down). The main point is to pose a question ‘how is this function performed’ while moving from left to right or question ‘why is this performed’ while moving from right to left.

3.2.2 FAST model example

The methodology is applied for assessing flood resilience on the elements of urban systems (individual house). Before starting with defining functions and critical path it is necessary to define a scale for house as urban city function and scales for city services that are necessary to provide the individual house functionality:

- Urban function: *Individual house*
- Scale for urban function: parcel
- Service: energy, water, waste, communication, transport
- Scale service: district and city

The objective function is defined as ‘create flood resilient house’. The procedure is following (Figure 17); Objective higher order function is settled on the left side of the diagram. The basic function is located right next to the objective function. Basic function defines how objective function is accomplished. All the function on the right of basic function describes the approach chosen to achieve the basic function. Those functions are called ‘dependent functions’. Connected functions that follow ‘HOW’ and ‘WHY’ logical path creates critical path. Independent functions are positioned above while activities are positioned below critical path.

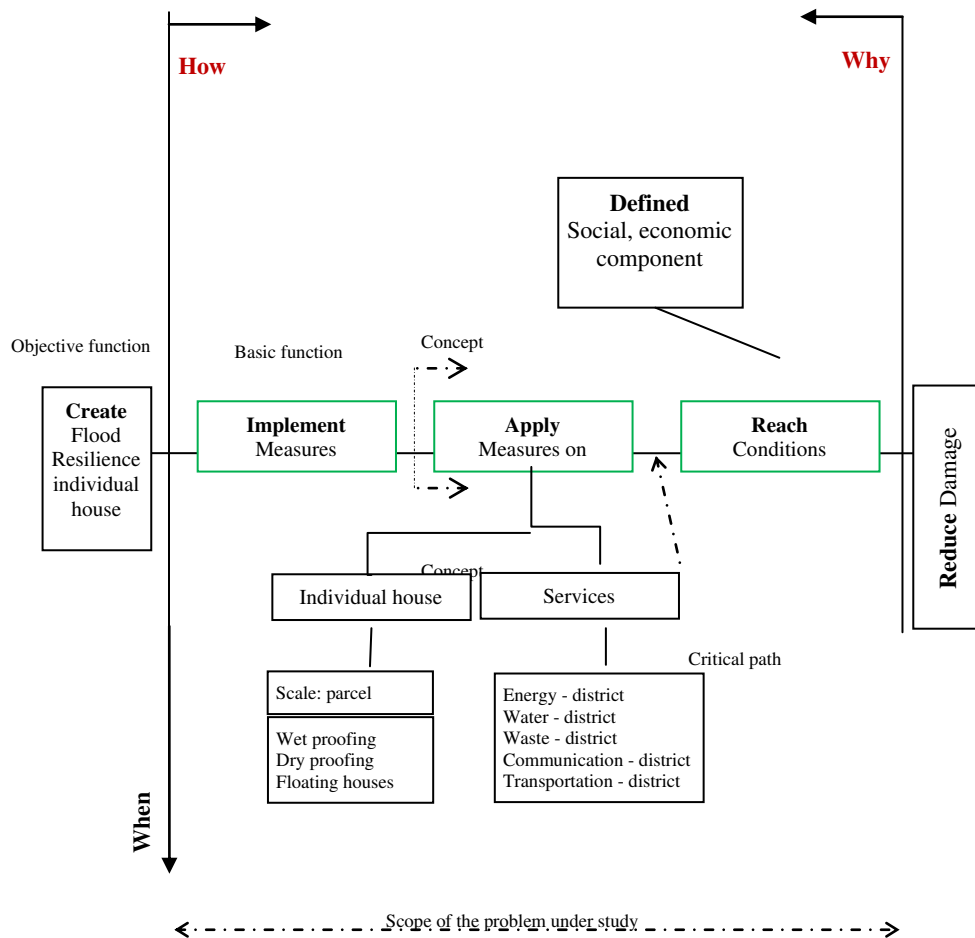


Figure 17: Methodology for assessing flood resilient individual house

The presented concept is useful for the further investigation and application on urban flood resilience assessment. The concept allows function decomposition of the elements within urban systems. Later, the urban system elements mapped to its function will be presented.

3.3 Quantification of urban flood resilience

Following the integrated flood risk management concept the developed method, represent the guidance to urban planners and decision makers to connect with flood risk management. The focus within this method is on the flood disasters particular in urban systems (in cities). The method for flood resilience assessment introduces the concept of scales (already described within paragraphs above) stressing that the existing urban patterns can be better recognized when an urban system is analyzed through scales (Batista et al., 2013). In this way, the resilience assessment at city scale becomes amended with resilience assessment of smaller scales such as districts, blocks and properties. The evaluation of flood resilience is expressed through the value of Flood Resilience Index (FRI).

The method for FRI contains a set of indicators for facilitation. The functional analysis is used to describe the structure of the urban system and the relationship between different components along with their importance for the suitable function of a city. As already, described, urban systems have two categories of vital importance for functioning. The first one are urban functions, the components that are satisfying the needs of inhabitants and the services that are providing connectivity and allow functionality between urban functions. The former components are seen as a spatial extension while the latter ones are seen as fluxes (Figure 15).

3.3.1 FRI at parcel/building level (micro and meso-scale)

The assessment of flood resilience on parcel scale is taking into account implementation of all measures that are protecting a 'house from water' or provide minimized damages and rapid retrieve of floodwater in cases when water is in the house. Adaptation of FRI method to parcel scale concentrates on evaluation of functionality of individual urban function. Evaluation of urban function is in accordance of different types (Figure 15).

Physical components of urban system have a unique building topology. Based on the Figure 15 there are eight different building typologies for analysis that will filter given requirements for urban functions and for city services. Further analysis will bring a set of indicators for flood resilience of urban functions and services.

The characteristic of urban functions is defined with respect to their type. Further, the critical requirements can be divided to one necessary for a building as a construction and requirements

in respect of different function of the building (school, hospital, administrative, police, etc.). Setting the critical requirements for urban functions is done in respect to flooding processes. The main purpose is to investigate “*is the particular function operational during and after flood?*”. Therefore, operational characteristic of urban function is defined with critical requirements.

This indicates that if critical requirements are satisfied the urban function has *a certain level of functioning* during and after flooding processes. Further, the critical requirements provide the down threshold and implies that below are defined threshold urban function is not operational. Different levels of functioning during and after flooding processes indicate a different level of flood resilience. In this context, the critical requirements stand as an adequate instrument to measure flood resilience on building level. The flood resilience is respectively: very low, low, medium and high for a building. The elaboration is necessary regarding the insurance of flood safety for buildings. Within this requirement are all improvements described in the chapter above regarding mitigation measures for buildings.

Table 9: Critical requirements for urban functions

*If requirement is not available the value for evaluation is 0; 1=very poor; 5=best

	Critical requirements	Availability level
1	To ensure suppliers for production	(1,2,3,4,5)
2	Access to site by workers, inhabitants	(1,2,3,4,5)
3	Ensure water and sanitation	(1,2,3,4,5)
4	To ensure energy supply	(1,2,3,4,5)
5	Ensure food supply	(1,2,3,4,5)
6	Ensure flood safety	(1,2,3,4,5)
7	Ensure waste collection and transportation	(1,2,3,4,5)
8	Indoor climate control (temperature)	(1,2,3,4,5)
9	Connection to network essential to deliver critical function	(1,2,3,4,5)

In the context of presented criteria, the *flood resilience index (FRI) for buildings* is an averaged value of evaluated critical requirements.

Evaluation urban flood resilience is done through flood resilience index (FRI). The index is represented as a level of flood resilience assessment in analyzed area and flood characteristics. This is with respect that resilience is a characteristic by definition and represents **ability to accept** a disturbance up to some level. This ability is defined up to the level where the system is able to organize itself and preserve the structure and function. Reflected in urban systems this means that resilience is defined up to the level that urban structure and urban community are able to accept disturbance, preserve the ‘level of functioning’, organize and recover from it.

The proposed method is set to take into account different spatial scales. Analyzed urban systems are scaled following its spatial evolution. Looking at a city through different spatial scales it is more likely to assess present issues regarding urban flooding. The individual parcel represents the smallest “unit” of the urban system. A group of parcels surrounded with streets represent block. Third level of organization is a district (group of blocks or administrative unit) and the final organization ring is the city itself.

The characteristics of urban functions are defined with respect to their type. Additionally the set of requirements can be divided to one necessary for a building as a construction and requirements in respect of different function of the building (school, hospital, administrative, police, etc.). Setting the requirements for urban functions is done in respect to flooding processes. The main purpose is to investigate “*is the particular function operational during and after the flood?*”. Operational characteristic of urban function during and after a flood is defined by two different sets of requirements:

- Services (related to external dependencies);
- Safety of urban function (related to the safety for users).

Under services the set of external dependencies are listed: communication, electricity, water (distribution and waste), transportation, solid waste network. Thus, if a house as urban function is considered this is a logical set of requirements needed for the functioning and for connection with other urban functions within the urban system. The external dependence along with internal provide operability of urban function. With services all external connections for urban function are satisfied. On the other hand the ‘safety of urban function’ is related to the safety of users (people). Following a set of question is raised while evaluating ‘is the UF safe for users’:

- Is there enough food in the house for residents for the period during the flood and if necessary after flood?
- Is the house safe for residents to stay during and if necessary after the flood?
- Is the house secured to be a potential shelter not just for residents (has access to transportation, water, energy, communication....)

In accordance, this indicates that if these two sets of requirements are satisfied (external and internal) with respect to different level of availability the urban function has *a certain level of functioning* during and after flooding processes. Further, the two sets of requirements provide the criteria for operability of urban function. The flood resilience on building level is expressed as a function of external and internal requirements:

$$FRI_{building} = f(r_e, r_i) \quad (1)$$

Where:

r_e – external requirement

r_i – internal requirement

It is important to highlight that evaluation of resilience can be done just looking to a specific flood event with its characteristics. This is in addition to a dynamic nature of resilience and system that is investigated.

Further, the resilience, in our case the *specified resilience* is expressed as a resilience of what (urban system, district, block, parcel/building) to what (flooding). If an analyzed area or system is resilient to fluvial flood that does not mean that system is resilient to coastal flood due to the different flood characteristics.

Different flood events have different characteristics. The flood duration, flood depth and flood velocity are one of the main.

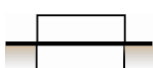


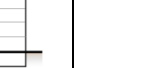
While evaluating floods resilience and considering flood depth for example there will be different resilience levels for different flood depths. With respect to that the different measures will be implemented.

Different levels of functioning during and after flooding processes indicate a different level of flood resilience. In this context, the set of two requirements stands as an adequate instrument to measure a functionality of urban function. Setting up an availability level with respect to

different flooding conditions there are sufficient data to measure flood resilience for urban function.

The first assessment relates to building as a construction. Different building typology has a different requirement. Therefore, the following building types are analyzed: building with ground floor, one or three floors, four, seven and buildings with eight floors and more. The building has to be accessible to people, to have connection with city services, which indicates connections to roads, electricity, drinking water, etc. In the table below the set of critical requirement for different building construction is presented.

Table 10: Critical requirements for building

Type of building					
Floors		Ground floor (G)	G+1 - G+3	G+4 - G+7	G+8 and higher
Critical requirements for building	Access to site by people	*	*	*	*
	Flood safety	*	*	*	*
	Indoor climate control				*
	Connection with city services	*	*	*	*
Structure limitation		- Existence of basement facilities - Vital function hubs on ground level	- Existence of basement facilities - Vital function hubs on ground level	- Existence of basement facilities - Vital function hubs on ground level - High building	Existence of basement facilities - Vital function hubs on ground level - High building
Recommendation for building code (new buildings)	<ul style="list-style-type: none"> - Wet proof building - Dry proof building - Houses raised on piles - Houses with raised thresholds - Buildings with periphery walls (temporary) - Buildings with external doors (permanent) 				
Improvement of existing buildings	<ul style="list-style-type: none"> - Raising thresholds where possible - Allocation of vital service hubs above flood depth - Wet proofing - Dry proofing - Internal and external walls/doors 				

In both, Asian and European case study areas dominant is the collective type of the residential buildings. The individual type of building is rare in this urban case study area. The critical requirements for ‘housing’ urban function defer from other urban functions: education, food, work, safety and governance, health, religion, leisure and tourism. The following critical requirements consider the way to set the threshold for urban functions and services:

- To ensure suppliers;
- Accessible to people;
- Ensure water and sanitation;
- Energy supply;
- Ensure food supply;
- Ensure flood safety;
- Waste management;
- Indoor climate control;
- Connection to network essential to deliver critical function.

The critical requirements for urban functions and services are listed in the table below.

Table 11: A critical requirements at the property level

Urban functions	Housing		Education		Work		Safety		Governance	Health	Food	Religion			Leisure and tourism			
	Individual	Collective	Kindergarten	Primary/high school/higher	Factory/production	Business buildings	Fire stations	Police stations				Administrative buildings and control centres	Medical facilities	Supermarkets	Food storage facilities	Church	Monuments	Cemetery
Suppliers					*					*	*							
Energy	*	*	*	*	*	*	*	*	*	*	*	*						*
Water/Sanitation	*	*	*	*	*		*	*	*	*	*							*
Waste collection	*	*	*	*	*	*	*	*	*	*	*	*					*	*
Communication										*	*							
Transport	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Food supply	*	*	*	*					*	*	*							
Occupation	*	*	*	*	*	*	*	*	*	*	*		*					*
Access	*	*	*	*	*	*	*	*	*	*	*	*	*			*	*	*

The main point is to mark all critical requirements for urban function. They vary with respect to urban function type. The main goal is to target the critical requirements, which will provide functionality during and after flooding. The “ensure flood safety” critical requirement refers to existing routines, organization of installation hubs, secured valves and constructions works taken to protect and secure from flooding. Therefore while evaluating e.g. describing critical

requirement with level of availability (not available (0); very poor (1) to best (5)) this should be taken into account.

The evaluation of FRI for property scale where focus is on urban function and its structure and level of functioning during flooding conditions presents a union of all external and internal requirements presented in table below.

Table 12: FRI evaluation at property scale

Requirements for urban function	Availability level (0-5)	FRI (property scale)
EXTERNAL SERVICES (r_e)	0,1,2,3,4,5	$FRI_{building} = \frac{\sum_{i=1}^5 r_{ei} + \sum_{i=1}^5 r_{ii}}{8} \quad (2)$
Energy	0,1,2,3,4,5	
Water	0,1,2,3,4,5	
Waste	0,1,2,3,4,5	
Communication	0,1,2,3,4,5	
Transport	0,1,2,3,4,5	
INTERNAL SERVICES (r_i)		
Food availability	0,1,2,3,4,5	
Occupation of urban function	0,1,2,3,4,5	
Access to urban function	0,1,2,3,4,5	
Where: r _e is an external service r _i is an internal service		

3.3.2 FRI at block scale

FRI evaluation on a parcel scale focuses on a single building/urban function while the evaluation on block scale follows other direction. By definition, a block represented as a set of buildings (individual structures) surrounded by streets. The set of buildings in the block unit could have the same urban function but it is not the case all the time. In this, case the block represents a single unit for analysis and like that, the dominant urban function represents a typology for the chosen block. The functionality of a block is set with functionality of services (electricity, water, waste, communication and transportation). The set of critical requirements for block scale defines ability to fulfil the conditions for functioning on a block scale during and after flooding process. While on parcel scale, the focus is on single building and its function within urban system the block scale takes into account availability of services. The following critical requirements consider the way to set the threshold for urban functions and services:

- To ensure suppliers;
- Accessible to people;
- Ensure water and sanitation;
- Energy supply;
- Ensure food supply;
- Ensure flood safety;
- Waste management;
- Indoor climate control;
- Connection to network essential to deliver critical function.

The critical requirements for urban functions and services are listed in the table below.

Table 13: Critical requirements of block scale

	Critical requirement	Availability level
1	To ensure safety	(1,2,3,4,5)
2	To ensure access to urban function	(1,2,3,4,5)
3	Ensure water and sanitation	(1,2,3,4,5)
4	To ensure energy supply	(1,2,3,4,5)
5	Ensure food supply (depends on flood duration)	(1,2,3,4,5)
6	Ensure flood availability	(1,2,3,4,5)
7	Ensure waste collection and transportation	(1,2,3,4,5)
8	Ensure communication	(1,2,3,4,5)

*If requirement is not available the value of evaluation is 0; 1=very poor; 5=best

In the context of presenting criteria the *flood resilience index (FRI)* for block scale is an averaged value of evaluating critical requirements.

The FRI assessment on the block scale is important to map the critical points that should be protected and have higher priority of protection during and after flooding. The perfect example is a location of electrical substations and transformer stations. They are providing electrical supply not only for one building but also usually for several blocks and they could even be analyzed on a district scale as well. In addition, these infrastructural elements usually do not occupy just one single building they are usually a set of buildings/parcels. Therefore, physically they could occupy more than one building and in the sense of providing service to a set of buildings depend on their functionality. The critical requirement ‘ensures suppliers for production’ refers to strategic urban functions within the block e.g. water treatment plant, sewage treatment, electrical hubs, train stations, bus stations, airports, etc.

The dysfunction of these strategic functions could trigger dysfunction of much bigger area. Evaluation of FRI for block scale focuses on urban functions and city services and flood impact on them. The block is defined as a set of buildings or parcels surrounded by streets. For the chosen block, the dominant urban function is set. Both, flooded block and block that is not flooded are analyzed. Different urban functions are within one block. The path for calculating Flood Resilience Index on the block scale should follow the path presented in figure below.



Figure 18: FRI for a block scale with two cases: flooded and no flooded block

The example for evaluation for FRI on the block scale is chosen block in the old city of Nice. The block is composed of building with commercial activity on the ground level. Observed block has an absence of any flood protection measures and along with the flat entrances ensures flooding inside the buildings. The evaluation of FRI on the building and parcel level simulate certain flood conditions. The values of the flood resilience index refer to the very low resilience level. The evaluation is set to follow up the same process as for the smaller scale (building parcel) presented in Table 12.

3.3.3 Qualitative parameters - availability levels of urban function for FRI evaluation

Introduction of availability levels in FRI evaluation for micro and meso scale represents a way to describe the level of functionality for the certain flood conditions. In this way the examined set of external and internal critical requirements set for a urban function can assign availability level that correspond to the existing flood conditions. There are six availability levels set for functionality of urban function. The availability levels of urban function are:

- 0 - Not available;
- 1 - Poor availability;
- 2 - Low availability;
- 3 – Medium;
- 4 - Medium to high availability;
- 5 - Requirement fully provided.

Specification of availability levels of urban function for certain flood conditions is further done within the Table 14.

Table 14: Description for the availability levels of each critical requirement (property/block scale)

Value	External requirement
ENERGY	
This requirement is influenced by the availability of electricity and gas	
0	Total service shut down for a given property, block or district
1	Service shut down, but precarious alternative/substitute service available
2	Long intermittent interruptions
3	Intermittent interruptions
4	Minor sporadic interruption of the service
5	No interruptions for the provision of energy in any of this forms
WATER	
It refers to availability of both drinking water provision and waste water collection	
0	Total service shut down for a given property, block or district. No drinking water available and there is flooding through wastewater.
1	Service shut down, but precarious alternative/substitute service available. Drinking water is provided but there is a quality issues due to flooding.
2	Drinking water is provided but there is a quality issues due to flooding.

Value	External requirement
	Wastewater represents additional flood risk for the property.
3	Water service has intermittent interruption. Wastewater is not leaving the property.
4	There is interruption in the drinking water services. Wastewater is able to leave the property.
5	Provision of water with no interruptions. Drinking water is provided and wastewater system is operational.
SOLID WASTE	
This requirement represent availability of solid waste collection services	
0	Total service shut down for a given property, block or district.
1	Service shut down, but precarious alternative/substitute service available.
2	Waste collection is mostly interrupted
3	Waste collection suffers minor delay
4	Waste collection has minor interruption without significant reflection on property
5	Waste collection function is normal
COMMUNICATION	
This requirement represent cell phone reception, internet connectivity, fix-line prone networks	
0	No communication service available for a given property, block or district.
1	Precarious conditions of communication
2	Long intermittent interruptions
3	Intermittent interruptions
4	Minor sporadic interruption of the communication service
5	Communication service is fully operational
TRANSPORT	
This requirement represent the availability of different transportation networks in urban system (rail, bus, car, bicycles and ferries/boats)	
0	Transportation services fully interrupted
1	Road transportation is blocked but precarious alternative routes exist. Public transportation has major interruptions.
2	Major delays in transportation network occur due to use of long alternative routes. Not all public service is available.
3	Roads are impaired and usable with major delays
4	Roads are impaired and usable with minor delays
5	Transportation network function normally without interruptions
FOOD	
This requirement represent the availability food during flood event	
0	No food available during flooding
1	Food is highly scarce in the property or it is located in inaccessible place
2	Food might spoil or be insufficient during an event, not enough storage
3	Food must be rationed during flood, not enough storage available

Value	External requirement
4	Enough food is available during flood event in a safe, accessible place
5	Plenty of food is available during flooding and its storage is in the flood-free safe, accessible place.

3.3.4Weights

Weights are introduced with proposed method for FRI on property and block scale. This is done in order to give a priority to certain critical requirement based on the type of flooding, duration and flood depth and its influence on the urban function (dominant urban function)

Table 15: Weights for FRI (parcel scale)

Weight w_i	Description
1,2	Very low to low importance
3	Medium importance
4,5	Medium high to high importance

In this case weights have a value between 0 and 5 and they are assigned to each critical requirement. The FRI value is then obtained with the following formulas.

$$FRI_{building/block} = \frac{\sum_{i=1}^5 r_{ei} \times w_i + \sum_{i=1}^3 r_{ii} \times w_i}{\sum_1^8 w_i} \quad (3)$$

Where:

w_i - assigned weight;

r_e - external requirement;

r_i - internal requirement.

Weights allow the FRI to be tailor-fitted for the special case study areas and provide usability in different countries where level of importance for critical requirements varies. The variation can be due to the specific flood characteristic. As example the flood duration can have a big influence on the weight for internal critical requirement such as food. For the long flood

duration the weight of this requirement is 5 but for the flood duration of few hours this internal requirement does not have big weight.

3.3.5 Example

Property/ building scale - Nice

The FRI assessment on property/building scale is performed for the whole case study area. The results obtained within this analysis are transformed in map using GIS. As described within introduction of methodology the assessment is done based on critical requirements for each urban function mapped in the case study area. Total number of objects classed in urban functions is approximately 55000. The table with evaluation of critical requirement is presented i below.



Figure 19: Case study boundary, Nice, FRANCE

Table 16: Evaluation of critical requirements for 'housing' urban function (example)

The three considered return periods are included in evaluation of FRI. The main idea was to adapt

Critical requirement		Description	re, ri	wi
EXTERNAL DEPENDENCES	Energy	Electric network is water-proof and the fuse box is found above a flood depth. Just minor interruptions could be expected.	4	3
	Water	No, no-return valve for waste water. A drinking water provision might be interrupted. Sewerage system is separated.	4	3
	Waste	Almost no waste collection can be supported during flooding. Garbage trucks cannot access the premises.	3	3
	Communication	Internet services might be interrupted. Mobile phone reception remains operable.	4	4
	Transport	There is one road connecting the building but it is blocked by a flood depth of around 20 cm. If passed, connection to rail, car, and bus transportation is available in all directions but with a delay.	4	4
INTERNAL DEPENDENCES	Food	The building has possibility for food storage, but it does not provide room for long durations of flooding.	3	3
	Occupation	The property is a residential. It does not have special flood proof features, making it easy for water to flow into the building, thus hindering its level of occupancy greatly.	4	4
	Access	There is street connecting the buildings to the city and it is blocked by a flood depth of around 20 cm. The building might be access through the water sheet with a motorized vehicle or by walking provided low water velocity.	4	4
FRI			3,85	

the method and to be able to map results in GIS. In this way, the flood resilience through index is comparable with other outputs such as flood maps, land use, risk maps, vulnerability maps, etc. The evaluation of FRI for property/building scale is preformed for each urban function. Evaluation of FRI deepens on the flood depth so for this evaluation the four different flood depth were considered: 0.1, 0.1, 0.5, 1 and flood depth above 1m.

Table 17: FRI values for different flooded urban functions considering different flood depths in Nice case study area

URBAN FUNCTION	FRI for different flood depths			
	0.2m	0.5m	1m	>1m
housing	3.85	3.59	2.81	2.41
working	3.88	3.46	3.19	2.12
safety & administration	3.90	3.60	3.00	2.13
health	3.88	3.63	2.88	2.63
food	3.86	3.62	3.00	2.29
leisure & tourism	4.00	3.82	3.35	3.12
religion & cemetery	4.00	3.88	3.59	3.59
education	3.42	3.08	2.71	2.71
transportation	4.00	3.60	2.87	2.13

This table shows the dynamic character of flood resilience and its change with respect to different flood depths. The evaluation is also done for un-flooded urban functions. The internal critical requirements in this case have high values while the focus is on the external critical requirements. The criteria during evaluation were also the location of particular urban function. The influences of flood on areas outside of flood extend are visible within this evaluation. The results are presented in table below.

Table 18: FRI values for different un-flooded urban functions considering different flood depths in Nice case study area

URBAN FUNCTION	FRI			
	0.2m	0.5m	1m	>1m
Housing	4.30	4.15	4.07	3.30
Working	4.31	4.15	4.04	3.31
safety & administration	4.33	4.20	4.03	3.37
health	4.25	4.13	3.63	3.25
food	4.18	3.76	3.24	2.86
leisure & tourism	4.24	4.06	3.88	3.76
religion & cemetery	4.24	4.24	4.06	3.94
education	4.38	4.04	3.96	3.88
TRANSPORTATION	4.47	3.60	3.30	3.03

Comparing the urban functions and the number of direct affected in the case study area based on the previous evaluation it is possible to have a presentation of FRI dynamics. In figure below the FRI dynamics is presented for all urban functions with respect to different flood depth.

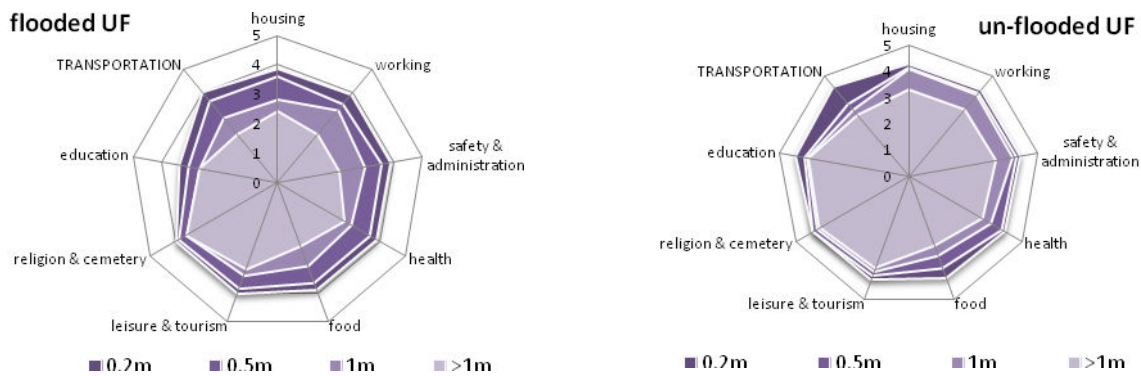


Figure 20: Comparison of different FRI values for flooded and non-flooded urban functions

The influence on FRI values flooded and un-flooded urban functions is significant. This is represented in figure below. Both, flooded and un-flooded urban functions are a part of assessment of FRI. The evaluation of FRI for un-flooded urban function is done on the spatial extension of flood. Then, for each urban function the FRI value is calculated for different flood depth (0.2m, 0.5m, 1m, and >1m). The presentation of differences of FRI values between flooded and un-flooded is done in percentage in the form of pie chart diagram.

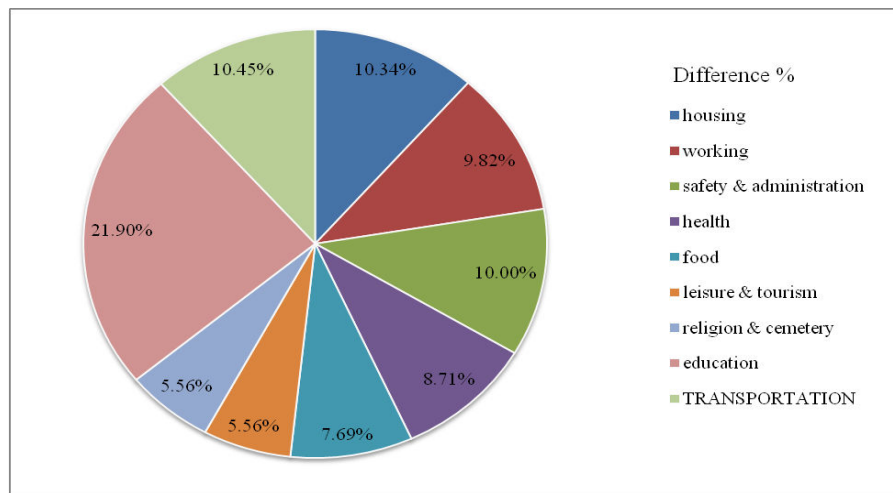


Figure 21: Difference in FRI of flooded and non-flooded urban functions

Urban function 'education' has the highest difference in percentage. For health, housing, working, safety and administration and food the difference shows importance of both external and internal requirements for the FRI.

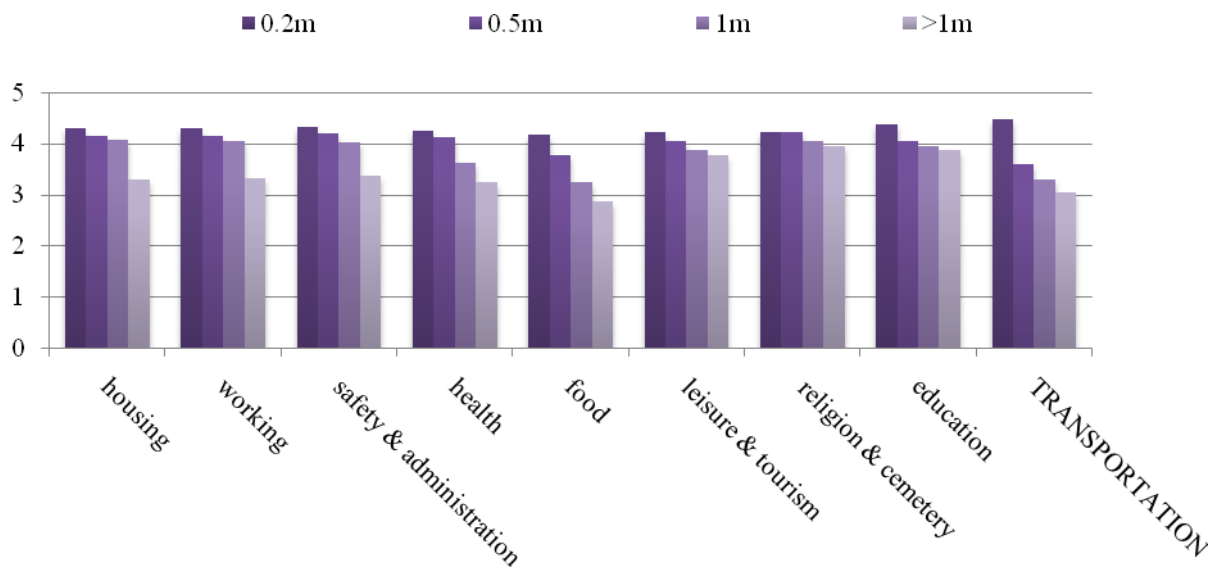


Figure 22: FRI dynamics with respect to different flood depth for Nice case study

Further, the GIS presentation of preformed evaluation is presented below. The presentation consist three different return periods taking into account results from FRI evaluation for property/building scale. The spatial presentation of FRI values is presented on figures 23 and 24. The two scenarios are chosen: (i) BAU scenario for the current state with the three different return periods (10, 50 and 100 year) and (ii) scenario S1 that correspond to the case with applied and implemented measure of door barrier. This comparison is crucial because it is presented on the building scale level, and then there is an ability to have clear presentation of results of different FRI values.

FRI for parcel scale
Location: Nice, France



Figure 23: FRI evaluated for BAU on property/building scale, Nice case study

Beside the normal scenario, the evaluation of FRI is tested for the chosen set of measures. As a result, the change in value of FRI is presented on Figure 24.

FRI for parcel scale
Location: Nice, France

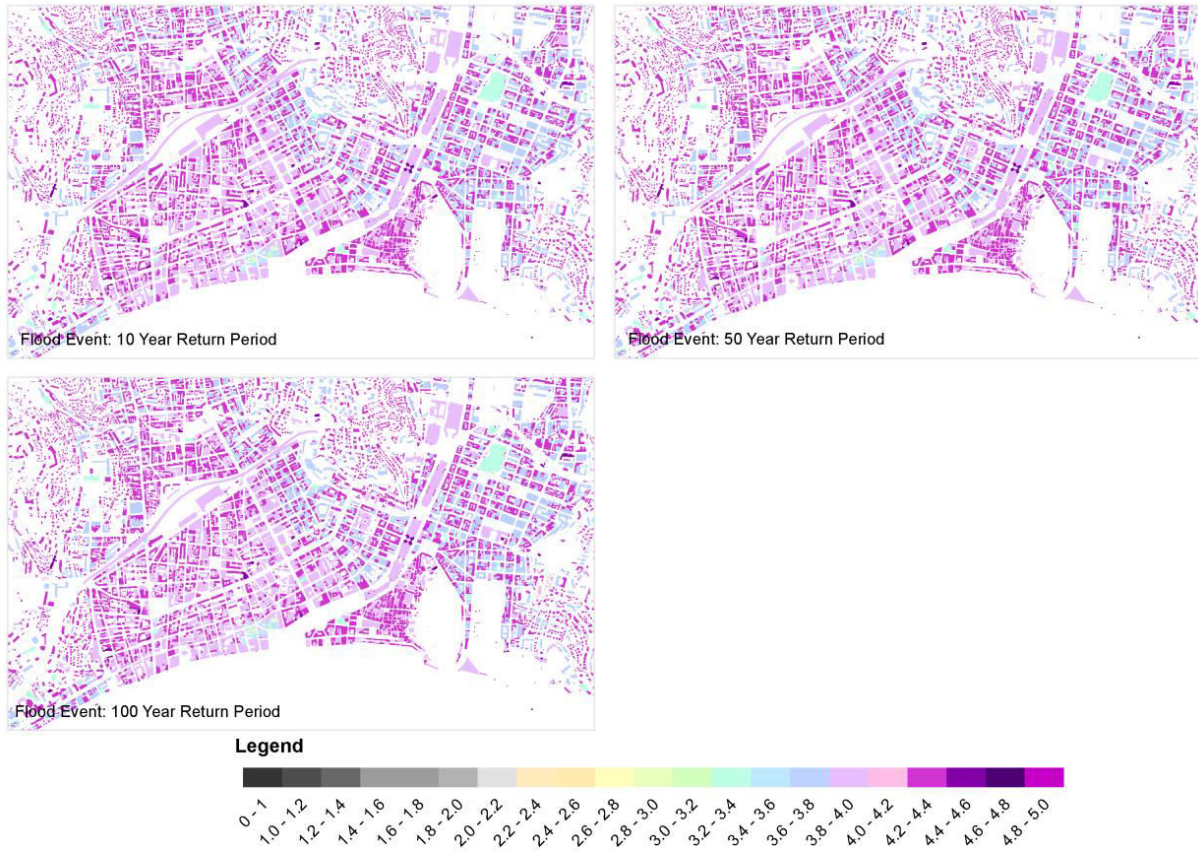


Figure 24: FRI evaluated for S1 scenario on building scale, Nice case study

From
FRI for parcel scale
Location: Nice, France



Figure 23 and Figure 24 the change in value of FRI shows that with use of particular measure is possible to increase index value for all three return periods. The particular measure has following characteristics: (i) first function is to prevent water to enter the property (ii) provides the possibility for occupation of urban function. In this example, the door barrier as a flood preparedness measure is used. As mentioned the GIS application is used to map all urban functions and to assign different values of FRI.

3.3.6 FRI for city/district scale

The evaluation of FRI for big scale such as district or a city the CDRI's five dimensions are included. Here the aggregation is done since the scale is big. The movement for individual entity (building/urban function) is now moved to the whole system. Consequently, the focus is bigger and the urban system with its dynamic character is analyzed through five dimensions: natural, physical, social, economic and institutional. Within each dimension, the set of indicators is set for better characterization. The approach brings resilience into flood risk management through 5R concept. The connection is done with the inclusion of flood resilience in flood risk management and 5R (reflect, resist, respond, recovery and relief) are included as well (Batista et al. 2013). This is an overall analysis of urban system (usually city and district scale) looking at its natural, physical, economical, social and institutional dimensions. Each dimension contributes to the evaluation of the flood resilience index for the particular urban system. Dimensions are composed with different variables.

The Flood Resilience Index represents overall flood resilience for different scales of urban systems. The assessment of Flood Resilience Index on the parcel and block scale is focused on the building (urban function) while for the bigger scale (city/district) the evaluation of Flood Resilience Index is done through five dimensions (natural, physical, economical, social and institutional). These five dimensions describe the physical and social attributes of urban systems. One of the main objective criteria to evaluate is the urban community able to accept certain disturbance and recover from it. This is done after reassessment of FRI after implementation of the measure.

- **Natural dimension** – Describes the space where urban area is located with different ranges for variables: available water bodies, percentage of existing slope or flat areas, drainage density, rainfall duration, existing watershed;
- **Physical dimension** – For each sub variable the variable available is evaluated according to structural measures protection, communication network (telephone, internet, transport...), human safety (ex. emergency shelter), equipment for service and available networks in building location;
- **Economic dimension** – Increase of households is in line with population growth rates. Employment is a direct link to economic growth of the area and triggers urban growth. This implies that that long term benefits of planning policies,

disaster management and mitigation plans are important tools for increasing resilience and reducing losses;

- **Social dimension** – Also, explore available resources, health status, knowledge and flexibility as well as connections within the community;
- **Institutional dimension** – Existence of flood management plans, policies, regulations, evacuation plans.. Is the population in this area taken into account for existing migration plans for the emergency, etc.

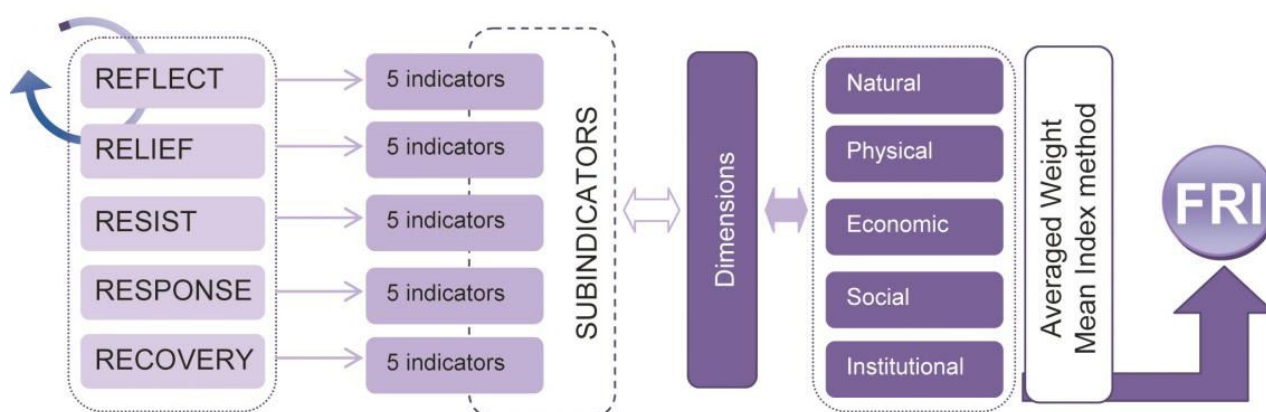


Figure 25: Schematic presentation of FRI evaluation of city/district scale

Ninety-one different indicators describe each dimension within urban system. The condition of each dimension is depended on the actions taken at the city level for the correct functioning during and after flood event. Figure bellow shows the number of indicators according to their dimension. A full list of indicators is presented under Annex A.

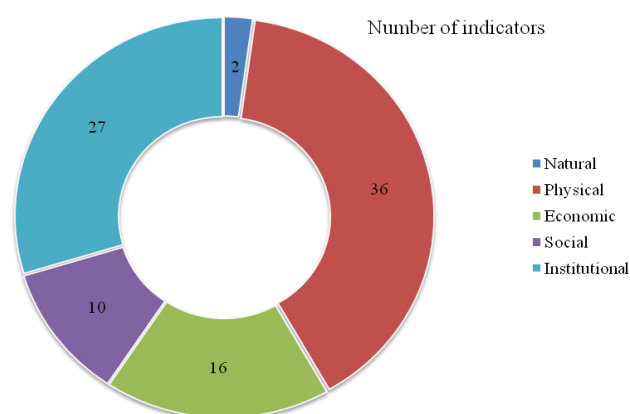


Figure 26: Number of indicators per dimension for large scales

The construction of a rating scale with weights for all variables needs to be done using weighted indexes. Aggregate Weighted Mean Index or AWTMI (for each dimension) will be calculated using Weighted Mean Index (WTMI) method (Rajib Shaw and IEDM Team (2009).

The calculated averaged WTMI of one dimension is the Flood Resilience Index (FRI) for that dimension. Rating scales have assigned numbers 1, 2, 3, 4, 5 corresponding to *very low, low, medium, and high* respectively. The scale is presented in the table below.

Table 19: Scales for Flood Resilience Index

Very low 0-2	The activities are not clear and coherent in an overall flood risk management (5R). Awareness is very low on the issues and motivation to address them. Interventions have a short-term character. Actions limited to crisis response.
Low 2-3	Awareness of the issues and motivation to address them exist. Capacity building of human resources remains limited. Capacity to act is improved and substantial. Interventions are more numerous and long-term. Development and implementation of solutions.
Medium 3-4	Integration and implementation of solutions is higher. Interventions are extensive, covering all main aspects of the ‘problem’, and they are linked within a coherent long-term strategy.
High 4-5	A “culture of safety” exists among all stakeholders, where the resilience concept is embedded in all relevant policies, planning, practice, attitudes and behaviour.

As for the building and block scale, the weights introduced here with purpose to have better presentation on indicators for the analyzed area and with respect to different flooding conditions. Following that FRI value is obtained following the formula below.

Table 20: FRI evaluation for macro scale

Dimension (d)	FRI
Natural	$FRI_{city/district} = \frac{\sum_{i=1}^n I_i \times w_i}{\sum_1^n w_i} \quad (4)$
Physical	
Social	
Economic	
Institutional	
Where:	<p>n is a total number of indicators for the given dimension I is an indicator's value within each dimension d is dimension</p>

The set of different indicators is presented in the table below while the complete list with explanation is within ANNEX B.

Table 21: Dimensions within the urban system with the area of influence

Dimension	Area of influence
institutional	Flood prevention management and urban planning -regulations
	Land use restriction (flood-prone area)
	Climate change plan
	Capacity building of human resources
	Crisis management
natural	River network
	River watershed management (infiltration and retention)
Physical	Transportation network
	Adaptation for living with floods
	Cascading flood compartment system (Structure)
	Crisis management
	Evacuation of exceeding floodwater (Structure)
	Evacuation system
	Flood protection
	Floodwater storage (Structure)
	Infiltration and reduce run-off (existing structure)
	Reconstruction system
	Rescue system (strategic functions: control center, hospitals, fire and police stations and emergency shelter)
	River network
	River watershed management (infiltration and retention)
	Solid waste management
	Urban drainage (Structure)
Weather forecast	
economic	Financial management
	Financial resources
	Lesson learned from past events
social	Capacity building of human resources
	Community

The reflection on the 5R concept is also in the developed matrix in ANNEX A. The table below summarizes the main element for each "R" in the FRM cycle.

Table 22: FRM elements in the FRI evaluation at city scale

Reflect	
1	Flood prevention management and urban planning -regulations
2	Crisis management
3	Land use restriction (flood-prone area)
4	Capacity building of human resources
5	Climate change plan
Relief	
1	Floodwater storage (Structure)
2	Evacuation of exceeding floodwater (Structure)
3	Cascading flood compartment system (Structure)
4	Infiltration and reduce run-off (existing structure)
5	River watershed management (infiltration and retention)
Resist	
1	Flood protection
2	Urban drainage (Structure)
3	Financial resources
4	River network
5	Weather forecast
Response	
1	Crisis management
2	Rescue system (strategic functions: control center, hospitals, fire and police stations and emergency shelter)
3	Evacuation system
4	Community
5	Adaptation for living with floods
Recovery	
1	Reconstruction system
2	Solid waste management
3	Transportation network
4	Financial management
5	Leson learned

The application of FRI evaluation on city scale is presented within chapter 5 with examples on five different European and Asian cities.

3.4 The roadmap for FRI assessment

Based on presented methodology the following step is application. For the purpose of clarity there is a necessity to write a roadmap for the application on real cases. First step focuses on definition of scenarios chosen area. The pathway for scenarios and the climate future for case study contain a main narrative description and qualitative as well as quantitative socioeconomic parameters. Scenarios are covering main trends in urbanization and population of a case study area. The defined scenarios identify the environment for case study. The scenario with the trend for urbanization, urban growth, economy and adaptation gives the input parameters for FRI evaluation.

Second step in FRI assessment focuses on flood map production. The production of flood maps is guided with scenarios. Flood maps do have influence on spatial scale for FRI evaluation. In this sense, the scale for implementation of measures for higher flood depths is on the district and city scale, while the scale for measures against lower flood depths are based on building and parcel scale mostly.

Further, the outputs from flood modelling are influencing outputs from damage assessment. This refers to step 3 of the roadmap. The flood risk assessment and inputs from previous two steps are shown in the figure below. The presented path from Step 1 to Step 3 reflects the complexity of resilience assessment. Starting from scenario definition and taking into account the simulation of flooding, calculating the flood damages the last part under the Step 4 consider a lot of different factors that influence the process of assessment of flood risk management. The flood resilience assessment has an integrative character. An integrative approach combines different elements into whole.

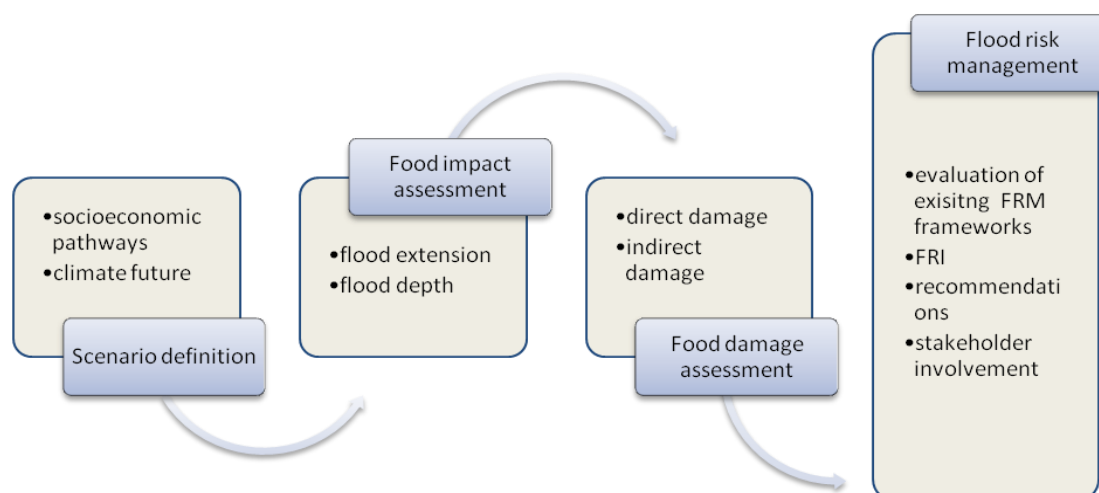


Figure 27: The roadmap for FRI assessment

3.5 Conclusion

Urban systems nowadays have many challenges. Flooding processes driven by various factors such as high urbanization along with tremendous change of land use, development of urban infrastructures consequently increases the vulnerability of urban systems. Priorities that are usually on the table during crisis relate to saving lives and assets. The acceptable risk level varies from world region, level of economic development, urbanization level, etc. Choosing the right resilience strategy and method on already defined priorities is crucial. Importance in introducing resilience to flood risk management is significant. The role of the insurance industry, government agencies and flood warning systems becomes fundamental. It is clear that a coordinated approach to the utilization of such products is vital crossways the industry and relevant stakeholders. Assessing flood resilience involves in equation flood damage, risk perception and vulnerability analysis. A role of resilience in sustainable development becomes significant. Methodology analyses urban system through different scales and elements (urban city functions and services). The purpose is to minimize the flood damages if possible. In most of the causes damages driven by floods can be minimized if urban system: already have implemented some of the existing active and passive protection measures, a community within the system is able to organize itself and to prevent more damages, the shape of a system is adapted to receive some disturbance, being able to learn from past events.

The methodological framework is potentially applicable to any urban system on any geographic scale. Connections and dependences between main city elements and natural hazards (in this case urban flooding process) have to be defined. With its implementation, social, economical, political and cultural relations between cities will be more visible and better established. The approach should uncover the role of physical components of urban system and population in relation to urban flooding processes. A further strategy focuses on simulation of community losses and recovery measures. As a major challenge that faces urban systems nowadays, the research on resilience prioritizes in following years. A key recommendation proposes: improving resilience determines urban patterns, which are matching with optimal water distribution, waste collection, energy distribution etc.

4 Measures for increasing flood resilience of urban systems

Parts of this chapter have been published as:

Batica, Jelena, Philippe, Gourbesville. "A resilience measures towards assessed urban flood management – CORFU project" Proceedings of 9th Urban Drainage Modeling conference, September 4-6, Belgrade, Serbia, 2012

4.1 Introduction

Within this chapter, the focus is on the measures and their classification in the FRM cycle. Following the different scales within urban system as well as mapping of systems components, the importance of existing measures and their classification brings a new perspective.

A strategy is defined as a combination of long term goals aims, specific targets, technical measures, policy instruments, and processes which are continuously aligned with the societal context (Gouldby B. et al, 2005).

Historically, most settlements have developed near water and rivers, for a number of reasons including food, transport and water supplies. Most urban communities have experienced flooding. The bases of the first strategies were on relocation during the flood and moving back after the flood event (Kersting, 2010). This was under the condition when higher terrain was available. For the places where this was not possible, the adaptation of houses took place and one of the examples was house built on pillars. This first flood management strategy was based on the acceptance of living with floods in a quasi-natural environment. This is also a first adaptation strategy (Kersting, 2010).

Strategies become more sophisticated over time due to the growing complexity of human activities. This is due to recognition that the desired level of safety in the urban environment and communities need upgrade. With time, strategies have been institutionalized and incorporated within the legal framework operating at different spatial scales.

The ultimate expression of this is formulated within the European directives produced by the European Parliament. These directives are establishing a common framework for major catchments in Europe and all the member states. The directives represent a holistic approach committed to water and flood management. They are considered to be a major step for the development of strategies and as an objective for many countries outside the EU.

All frameworks regarding flood risk management on the level of the European Union are gathered under EU Water Framework Directive and the sister directives including the Floods Directive. As a result, the adaptation actions must be consistent with mitigation actions. One of the main requirements is that for each river basin, an integrated management plan has to be developed. This promotes the mitigation of the adverse effects of floods.

4.1.1 Flood mitigation and adaptation capacity development

Flood mitigation measures aim to reduce flood damages. A combination of long-term goals, aims, specific targets, technical measures, policy instruments continuously aligned with the societal context is defined as a strategy (Gouldby B. at all, (2005)). The societal context comprises economic, social, and political conditions, formal and informal institutions, resources and capabilities.

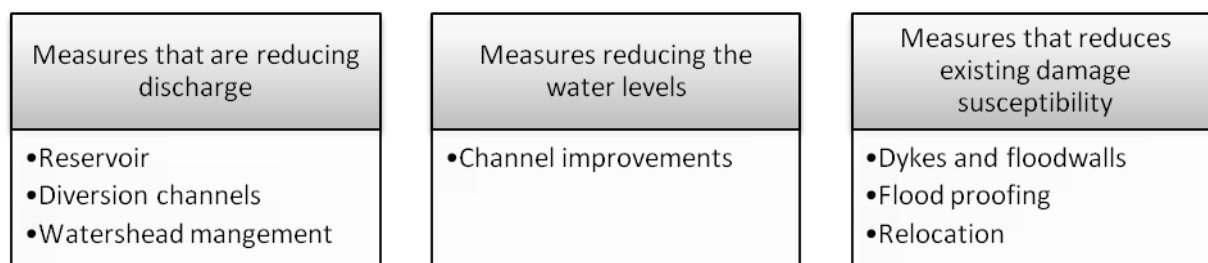
The set of strategies for flood mitigation has to be developed. In addition to that, the following consideration took place in investigation:

- There are differences in existing flood risk management frameworks in Europe and Asia;
- Some cities are in more developed countries than others;
- There are different levels of flood risk acceptability in Europe and Asia.

There are different maturity levels according to the results from the analysis obtained within chapter 2 where different FRM frameworks were evaluated. This is in addition to different levels of integration of FRM frameworks. The analysis showed that the basis of FRM frameworks is more on protection strategies where the focus is on flood prevention for the events smaller than a certain threshold (usually designed discharge).

Regarding the strategic schemes there are two approaches. The first one is based on structural measures and the other one is based on non-structural measures.

Figure 28: Strategic scheme – structural measures



The schemes based on structural measures involve construction projects that are providing protection to the physical environment and the urban community. The most common

constructions are seawalls, channels, levees and revetments. This scheme considers high investments, long-term frame for realization and has significant impact on the environment. The structural measures can be with the purpose to reduce discharge, reduce water level or reduce existing damage susceptibility.

Table 23: Strategic scheme – resilience measures

Capacity building of human resources	Flood maps (Inundation and Risk) Info material (brochures, public presentations, internet portals etc.) Education - Communication	Face-to-face learning Web-based learning Training Collaborative platforms
Land use control	Spatial Planning Flood risk adapted land use Building regulations	Building codes Zoning ordinances
Flood preparedness	Flood Resistant buildings Wet-proofing Dry-proofing	Infrastructure maintenance
Contingency measures	Financial Preparedness Insurance of residual risk Reserve funds Emergency Response: Evacuation and rescue plans Forecasting and warning services Control Emergency Operations Providence of emergency response staff	Emergency infrastructure Allocation of temporary containment structures Telecommunications network Transportation and evacuation facilities Recovery disaster recovery plans, pecuniary provisions of government

The measures listed in Table 23 represent resilience measures. In general, resilience measures provide better organization of inhabitants, adapted built environment and planned emergency actions during and after the flood.

Capacity building of human resources refers to increasing awareness of flood risk among key stakeholders. One of the ways to raise awareness among population can be raised by presenting brochures, short public presentations, creating internet portals that contain useful information. Regular communication with the population and education are also one of elements for capacity building of human resources. In present urban systems (Europe and Asia), these measures are in developing stage since they were not considered under traditional flood risk management.

Land use management refers to spatial planning and building regulations in order to create more space for water. The new buildings come up with improved shapes that are able to accept a certain amount of floodwater and have minimal flood damage. The land use management contributes prevention to flood where possible.

Adapting to flooding by floatable building and buildings on piles, dry and wet proofing of buildings contributes to increased flood preparedness and contributes to mitigate the effects of flooding.

The measures that refer to preparation for flooding processes are financial preparedness, volunteers, shelter management, improving flood insurance schemes, evacuation and rescue plans, etc. These measures are to be tested during the flood event.

The strategic schemes based on the non-structural measures have policies that promote development towards less vulnerable areas. This measure includes regulatory and incentive-based policies. With these policies, the development patterns are facilitated and they are more resilient comparing to long term strategies. Strategies based on non-structural measures are more recent and maybe more effective than those strategies based on only structural measures. The non-structural measures include land use planning, policies, trainings, education and many others. In the table below the non-structural measures are presented. These measures provide a higher resilience level in certain areas and the urban community and they are usually called flood resilience measures.

The third strategic scheme includes both structural and non-structural measures. With the mixture of two described strategic schemes for mitigation, this third option brings the possibility of combining the investment into levees and capacity building of human resources through education, training, also the orientation can be to different construction types of the buildings that can accept the certain flood impact and so on.

In order to have a solution for different case studies the following division for mitigation strategies is done (Table 25). The proposed strategies cover the city scale.

4.1.2 Components of resilience and timing frame for resilience measures

Components of urban flood resilience defined within Chapter 2 as 5R (reflect, resist, response, recovery, relief) are set to highlight main components of resilience within FRM cycle. Here, the

analysis goes further and focuses on the timeframe regarding measures implementation. The basic delineation as mentioned in the paragraphs above set the division on structural and non-structural measures. In figure below the system state in the form of graph, present the level of disturbance before, during and after the flood event or a shock.

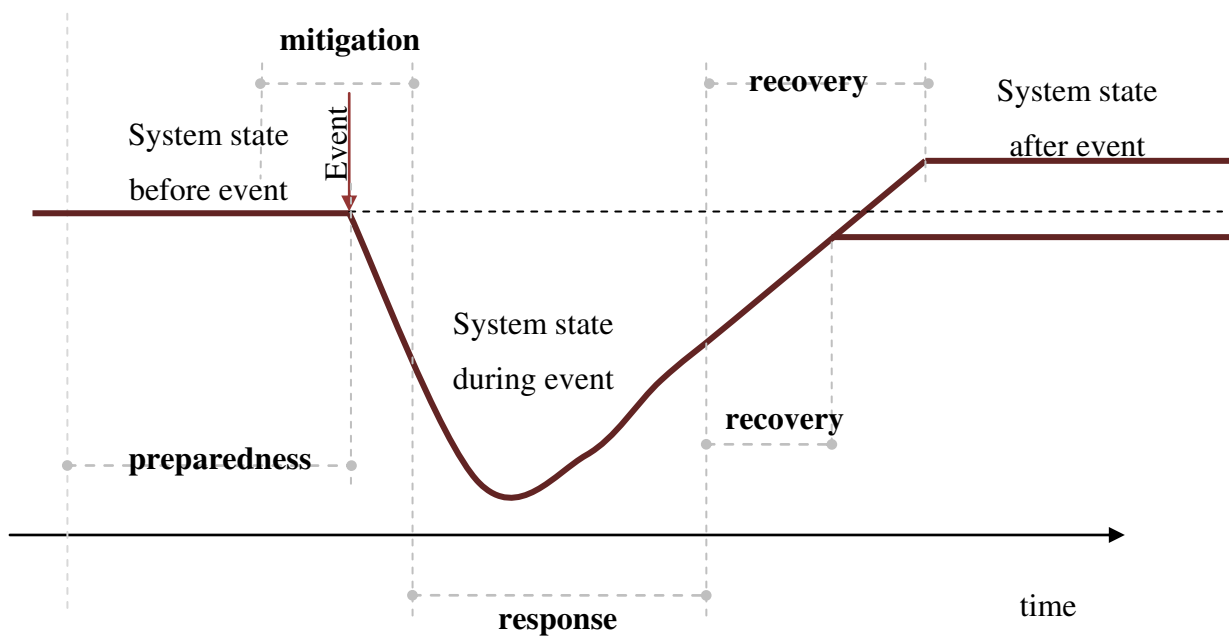


Figure 29: The system state before, during and after flood event

4.1.3 Elaboration on flood resilience measures

Flood resilience measures (Table 23) improve the ability of a system exposed to preserve the structure and functionality during and after flood event and the measures provide ability to learn from past event and improve better preparation. As a result, the urban system increases its flood resilience in all segments (physical, social, economic, institutional and natural).

4.1.3.1 Capacity building of human resources

The knowledge-based measures consider providing *information* and *education of society*. Under providing *information*, the focus is on the availability of flood maps. Flood risk mapping is the process of establishing the spatial extent of flood, corresponding flood depth and velocities.

Combining information regarding probability and consequences the flood maps can be extended into risk maps. Risk mapping requires combining maps of hazard, vulnerability and exposure. More commonly the inundation and risk maps should be created and presented to indicate vulnerable urban areas. Information is spread through brochures, public presentations and internet portals with the purpose of increasing awareness.

These maps are based on hydraulic models and known flood extents and observed flood depths for past flood events where there is no available hydraulic model result. This measure usually represents the first one on the way of defining the strategy. The main technical requisite for this measure is existence of data related to topography, soil, rainfall, etc.

A non-structural measures increases flood awareness and the ability to respond to flooding among stakeholders. The resilience potential of this measure is in the possibility to have maps that include resistance measures, restorative measures, raising the awareness of stakeholders and the public, enhancing adaptation potential.

The responsibility for implementation of this measure is at the institutional level mainly, including national, regional, city and local governments, then Universities, research centres and similar institutions.

The implications of this measure on the stakeholders are as follows:

- For inhabitants who are affected by flood, they provide a source of information and raise awareness, decreasing vulnerability
- For Water related engineers, they provide context to further design strategies.
- For decision makers, they provide valuable information.

Flood maps are a common practice in flood management. Examples or implementation are wide, especially among developed countries.

Flood Event: 10 Year Return Period
Location: NICE, France

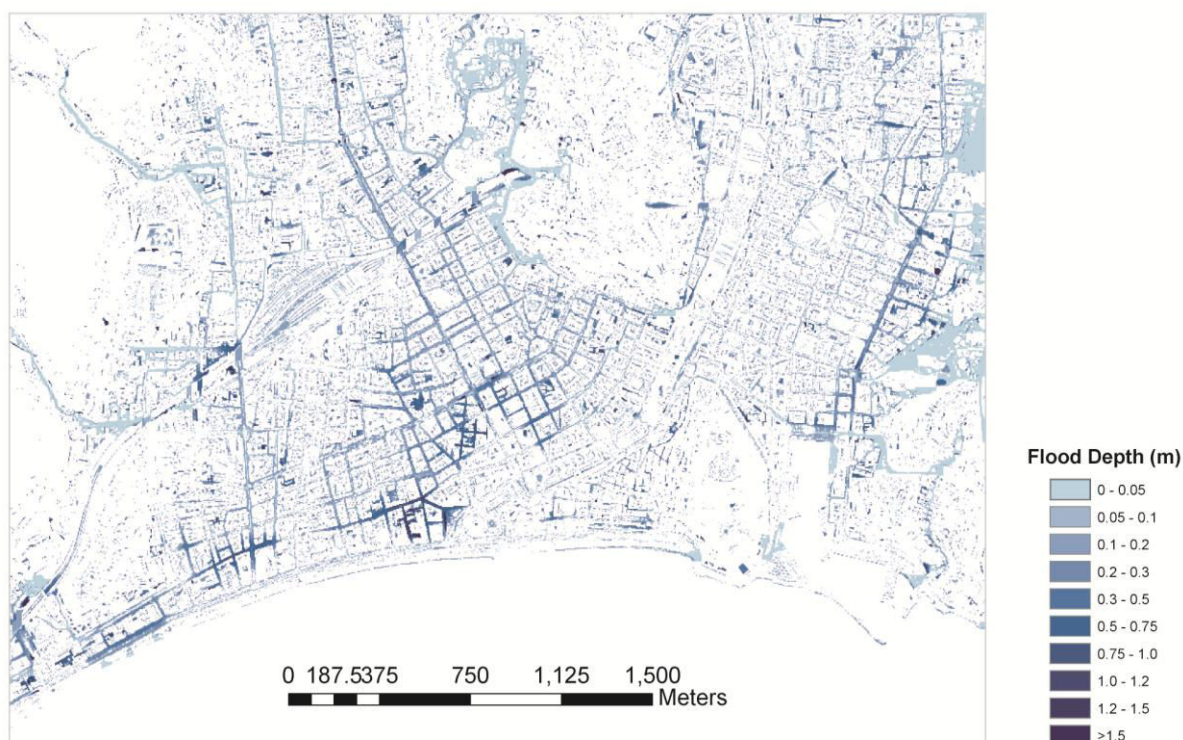


Figure 30: Example of flood map, case study Nice, France

Education on the subject of flooding focuses on four elements:

- Face to face learning – where courses are made directly with communities and proprietors
- Web-based learning – where courses made remotely with communities and proprietors
- Training – organization of workshops for communities and proprietors
- Collaborative platforms – that create spaces for collaboration between different types of stakeholders

Education as a measure is based on the type of interactions sought by stakeholders, the reach and type of target audience, the scale of interaction required the specific themes to discuss about or the defined objectives. As a non-structural measure, this is already practiced and this measure usually accompanies other measures for capacity building. It is also highly dependent on the specific goals of the designed platform.

Adaptive characteristics of this measure include raised awareness among stakeholders and the general public increasing adaptation potential and capacity response. It also connects the institutional level with the social level providing tools for the betterment of the stakeholder's situation at working scale.

Some of the examples of capacity building of human resources through education platforms are the web-based advisory tool at property level 'Floreto' (figure 5).



Figure 31: Example of web-based platform for capacity building of human resources¹

4.1.3.2 Land use control

Land use planning defines the development of land use strategies to best meet people's current and future needs, according to the land's capabilities. Urban, city, or town planning, deals with

¹ <http://floreto.wb.tu-harburg.de/>

design of the built environment from the municipal and metropolitan perspective. Regional planning deals with a still larger environment, at a less detailed level

Land use planning should integrate flood aspects in spatial planning and definition of land use concepts for areas prone to flood. The designing criteria for this measure considers flood risk adapted land use where the runoff coefficient is included, then building codes and regulations for the built environment and zone ordinances. As a non-structural measure land use control is not that much in practice. It can be stated that land use control is emerging as a measure. Hydraulic modelling results are needed to determine areas where land use control is urgent and also the proper government guidelines to encourage local authorities to apply it. Spatial planning and building regulations considered under this non structural measure. The measure has adaptive character because it is providing needed guidelines for integrating flood protection into land use.

Benefits that this measure brings are in betterment of public spaces, reduction of flood damages, increased environmental awareness, encouragement of green development and increased land values for the areas that are in the land use plan.

The responsibility for implementation of this measure is on the institutional level mainly, national, regional, city and local governments. Very important is social level where developers have to follow the guidelines imposed by authorities.

Implication of this measure on the stakeholders is following:

- For Water related engineers, they provide context to further design strategies.
- For authorities, it allows a better planning of the city and a flood sensitive development that relieves funds into other sectors of the government like health or education.
- For developers it provides guidelines and codes that need to be followed in order to abide the law. They must provide then projects that comply with the predetermined land use control.

A popular example of land use control is the “Water sensitive urban design” implemented in several developed countries such as USA, UK, and Germany.

Below is an example of flood control in Germany:

The German Statutory Code on Construction and Building (Baugesetzbuch = BauGB), from 25.06.2005 introduced:

- Consideration of flood prone areas when defining urban development plans (KERN 2005).
- Flood prone areas have to be clearly indicated in the land use plans. (§ 5 IV a BauGB).
- It also implies the areas that are not defined yet but their designation is expected (§ 9 VI a Bau GB).

4.1.3.3 Flood preparedness

As a part of flood resilience measure the flood preparedness deals with all actions that bring increased protection for flooding processes in advance. The main characteristics are on resistance and adaptation mainly of the built environment. It focuses on upgrading of an existing building to increase safety by adding or replacing items. This could be done by any combination of changes or adjustments incorporated in: design, construction and alternation of individual buildings or property. The scale for these measures resides in the property level.

Flood preparedness can be mainly influenced by increasing the resilience of the people and the built environment. It can be achieved by local scale measures taken at the property (building) level. Using these measures, the resilience of the buildings can be improved either by:

- Preventing floodwater entering the building (dry proofing)
- By applying waterproof materials and elevating the services and inventory above the expected flood level (wet proofing).

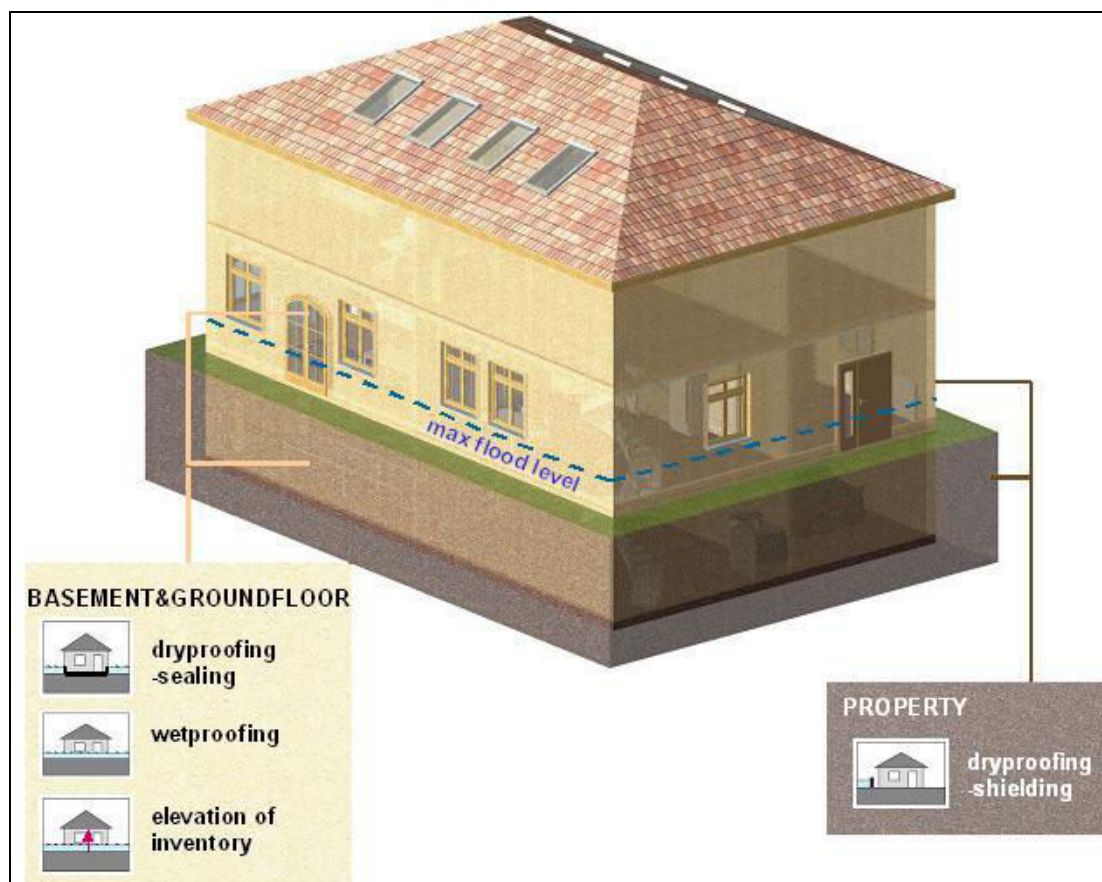


Figure 32: Dry proofing and wet proofing for building (example)²

Necessary elements for this measure is known depth of flooding, availability of economic resources for implementation, design and layout of property, type of land use and activities undergone within the property. In combination with other measures a flood preparedness is mainly combined with education measures (part of knowledge based measures) in order to instruct proprietors on how to operate certain technologies regarding flooding processes. Flood preparedness has resistance and adaptive character since resistant buildings provide resistance and coping ability with different climate scenarios. Benefits of this measure are in reduction of economic loses where traditional insurance companies will not cover. The largest costs are present in flood proofing materials and stable barriers that hold up water.

² <http://daad.wb.tu-harburg.de/knowledge-base/entry-points-of-the-knowledge-base-from-a-to-z/flood-risk-management/flood-management>

The responsibility for the implementation of this measure is on the social level mainly; as such, measures strongly depend on the residents' behaviour and their capacity to apply them. They are only effective if residents are aware of the imminent hazard.

Implication of this measure on the stakeholders is following:

- For inhabitants who are affected by flood, these measures represent a safety factor protecting their homes against flooding.
- Proper encouragement of the authorities must be sought in order to induce the upgrade of properties into flood resistant properties, this can be done via incentives

4.1.3.4 Contingency measures

Contingency measures are measures employed during the flood by their preparation and scope is defined much earlier. The scope of measures is financial preparedness, emergency response, and emergency infrastructure and recovery actions. All of them are under defined flood action plan.

Financial preparedness can be managed through reserve funds and insurance of residual risk. The latter consists of insuring properties in terms of flood hazards. Normally, a zoning system is developed depending on the potential risks due to overflow and storm events, then properties fall into an insurance category. Still many insurance companies rely on arbitrary parameters to define zones.

Within emergency response, four mayor categories can be determined:

- Evacuation and rescue plans;
- Forecasting and warning services;
- Control emergency operations;
- Provision of emergency response staff.

Emergency infrastructure can be classified as:

- Allocation of temporary containment structures;
- Telecommunications network;
- Transportation and evacuation facilities.

Recovery is consisted of disaster recovery plans and pecuniary provisions of government. Both allow the recuperation of normal activities in the affected area.

The scales for implementation of this measure are:

- Financial preparedness: property level, but based on district/neighborhood scales;
- Emergency response: city-wide but actions usually take place at the district/neighborhood scales;
- Emergency infrastructure: city-wide;
- Recovery: city-wide.

This measure is already practiced and emergent. Flood maps are needed in order to develop contingency measures accordingly to each zone's need. A set of clear indicators is needed to define triggers of contingency plans. They rely on quality of monitoring systems, speed in transferring recorded data to flood control centres. As a non-structural this measure has a restorative character because contingency measures provide specific plans to restore conditions prior to the event of flooding. The responsibility of implementation for this measure lies on the institutional and social level. Institutional level the responsible for flood warnings: Fire departments, storm water utilities and districts' local administrations and for financial preparedness: local governments and insurance companies. Social level responsibility is on the property owners who must be aware of the benefits of insuring their assets.

There are the following Implications of this measure on the stakeholders:

- City and local administrations: action plans must be well defined and operational in order to be prepared when a disaster occurs.
- Insurance companies: must rely on flood related data instead of arbitrary conditions for the implementation of premiums.
- Property owners: need of awareness of evacuation plans and payment of premiums in order to be insured. They must have confidence in the contingency plans in order to follow them.

Some of the examples for implementation flood contingency measures are:

Weather forecasting in Europe:

- Germany: German weather Service (DWD), which is a state authority with regional agencies.
- France: they work at the national level through the National Hydrometeorological Service for Flood Forecast Assistance («Service Central d'Hydrométéorologie et d'Appui à la Prévision des Inondations») which provide since 2002, a bi-daily flood vigilance map (www.vigicrues.ecologie.gouv.fr) and Météo France (former France National Service) which provides a daily meteorological vigilance map (www.meteofrance.com/vigilance/index.jsp)
- England: meteorological office in combination with the Environment Agency and local authorities.

Insurance:

- In Germany, the „Zonierungssystem für Überschwemmung, Rückstau und Starkregen“ (ZÜRS) is a zoning system of the German insurers for estimation of potential risk due to overflow and storm events, which is unique for the whole Germany. The areas prone to flooding are categorised from 1 (probability of hazard event is less than once in 200 years) to 4 (probability of hazard event is once in 10 years). Experience shows that the people are ready to pay for the flood insurance about 100€ per year (Feuerkasse).
- The role of flood insurance schemes is to compensate the damages caused by flood. Flood insurance is an important non-structural measure and it is usually gathered under natural hazard events. In developing countries the insurance sector is often fragmented and not well established. Flood insurance may provide: an effective mechanism for providing support for families affected by flooding, mechanisms of spreading flood loss over a large area and a large number of individuals, extremely limited possibility for poor households who live in the highest risk conditions to obtain an insurance policy and the huge difficulty to determine the risk of flood damage and to build up a flood insurance portfolio.
- In Barcelona, the Insurance Compensations Consortium is a governmental society which deals with flood damage coverage. In legal terms, this insurance is a public corporate entity attached to the Ministry of Economy through the Directorate General of Insurance and Pension Funds, but is a legal entity in its

own right with full operational capabilities. This trend is explained by the increase of insured assets, together with the increased vulnerability due to the construction in exposed areas.

- Flood insurance in China has flooded disaster compensating strategy which is based on government compensation, supplemented by insurance compensation, public donations, and international aid. Therefore, the flood insurance clause has never been set individually while it is leached on to property insurance for family and enterprise and hence be categorized as the scope of basic liability of the property insurance clause, of which the premium rate is defined according to fire hazard rating without considering flood risk factors. Until now, the country remains unified insurance rates instead of specifying separate flood insurance rates.
- There are a number of insurance companies that exists in Bangladesh. They mainly provide insurance on life, personal health, accident, fire, burglary, industrial risks, machinery breakdown, vehicle, aviation, marine cargo etc. Natural disaster related insurance is still in the planning stage. Micro-flood insurance is thought as a viable insurance scheme in flood prone areas.
- Insurance against flood is included in building insurance in Mumbai. Building insurance covers the structure of the home. It is insured as per the reconstruction value and not for market value. Re-construction value means the cost of rebuilding the property, including architect and surveyors fees, and the cost of clearing away the debris and meeting any new building regulations or bylaws.
- In France, the law is dealing with major a natural risk (droughts, floods, landslides, etc.) that threatens lives with important domain to protect the lives of people. Law has two major objectives, the expeditious compensation for losses suffered by victims and the prevention or reduction of future damages. Coverage for damages to the property caused by flooding, landslide, drought, earthquakes is for everyone who has vehicle, home and business insurance that covers damages, such as fire, water damages or loss by theft, etc. (Parisi, 1997). Though, this increased coverage is available only if the disaster is declared by the inter-ministerial declaration. A commission, formed of representatives of central government, decides whether a given occurrence is deemed a natural

disaster and hence makes claimants eligible for reimbursement. A tool for nationally legalized natural disaster insurance system is "*Cat Nat*". The *CatNat* "catastrophe naturelle" system in France shows the state involvement only for reinsurance and/or catastrophe situations. Application is developed for dissemination and it's used by insurance companies. The content is regarding natural zoning data, by organization dedicated to natural risk knowledge and prevention, for the whole French insurance market.

- The Korean government has long-term disaster preparedness plans and one of the following programs is the Flood Insurance Program. This national flood insurance program aims to produce flood insurance map production and floodplain management. The new national flood insurance program will enable the government to provide flood insurance to regional entities across the nation. The Korean government will develop a community rating system to encourage regional entities to adopt floodplain management standards set by a national flood insurance program.

A comparison of flood resilience measures is presented in table below with represented scales for analyzed measure and its influence on the system dimension (ie natural, physical, economic, social and institutional).

Table 24: Comparison table for the flood resilience measures with respect to different system dimensions and spatial scales

Flood Resilience measures	Dimensions					Scale
	Natural	Physical	Social	Economic	Institutional	
Flood maps	*	*				3,4
Info material			*			,2,3,4
Face to face learning			*		*	3,4
Web-based learning			*			3,4
Training			*			3,4
Collaborative platforms			*			3,4
Flood-risk adapted land use		*				4
Building codes					*	4
Zoning ordinances					*	4
Wet proofing		*				1,2
Dry proofing		*				1,2
Infrastructure maintenance		*			*	1,2
Insurance of residual risk				*		1
Reserve funds				*	*	4
Evacuation and rescue plans			*		*	4
Forecasting and warning services		*	*		*	1,2,3,4
Control emergency operations						4
Provision of emergency response staff			*		*	
Allocation of temporary containment structures		*			*	3,4
Telecommunications network		*			*	4
Transportation and evacuation facilities		*			*	3,4
Disaster recovery plans, pecuniary provisions of government				*	*	4
Legend:						
1 – parcel scale; 2 - block scale; 3 – district scale; 4 – city scale; / - depends on type; □ - yes						

Table 25: Proposed flood mitigation strategies for analyzed case study areas in Europe and Asia (city scale)

Type of a strategy	Description	Measures included	
PREVENTION	Development of flood prone areas is limited throughout planning policies. Government actions have influenced the way land and buildings are developed and built Public activities to reduce hazard losses	Planning and zoning Building Code Development and Enforcement Open Space Preservation	Storm Water Management Regulations Drainage System Maintenance Beach Maintenance
PROTECTION	Modification of existing buildings / infrastructure to protect them from a hazard. Relocation from the hazard area Provided information and technical or financial assistance to stakeholders how to elevate, insure or protect the property.	Flood Resistant buildings Wet-proofing Dry-proofing Acquisition	Elevation Relocation Structural Retrofits Storm Shutters Insurance
CAPACITY BUILDING OF HUMAN RESOURCES	Actions aiming to inform, educate all stakeholders about potential risk from hazard and potential way to mitigate them	Flood/Hazard information centres School-age and adult education programs Library resources Technical assistance Flood maps (Inundation and Risk) Info material (brochures, public presentations, internet portals etc	Education – Communication Face-to-face learning Web-based learning Training Collaborative platforms
EMERGENCY SERVICES	Actions taken during the flood in order to minimize impact	Warning Emergency response planning Evacuation	Critical facilities protection Health and safety maintenance
FLOOD CONTROL	Based on structural measures Actions based on the structure that is reducing the impact of floods	Seawalls Diversions Storm Sewers Storm water controls Floodwalls	Levees / Channel Modifications Retaining walls Safe rooms Reservoirs

4.1.4 Flood resilience and resistance measures for city services

City services often called a critical infrastructure. They represent as a set of networks that are providing connections to Urban Functions (UF) and give them with operational structure. There are five elements of city services:

- Transportation network;
- Energy network;
- Water (drinking and waste) networks;
- Communication network;
- Solid waste network.

City services present crucial components in the city. One of the most important characteristic of city services is their **interdependency**. This is with respect to their interconnectivity. For example, the failure of one service can have a direct damage on other services (a fail of electricity can have a direct impact on water supply networks). Two different types of failure can occur: cascading and single point failure. Cascading failure of a city service is a failure when a single component failure propagates and triggers other services. Single point failure presents a situation when single asset provides dependency to a number of other components. For cascading failure the chain of connection is not known while for single point failure the connections are well known. A hierarchy exists between the city services. Commonly the energy, water, communication and solid waste network follow the form of the transportation network. The transportation network provides the essential connectivity between urban functions.

There are the following steps for the flood risk management regarding city services:

- Map the flooded services;
- Development planning control – related to production of planning policies;
- Developed flood forecasting and flood warning systems;
- Incident management and emergency response;
- Raising level of threatening city services – raising thresholds.

The strategies for city services rely on planning activities. The planning system provides a framework that can ensure new infrastructure and manage modification on existing infrastructure. During the process of planning of new infrastructure and modifying existing one the importance is on the adoption of the principles on the national spatial scale.

4.2 Mitigation measures (block and parcel/building level)

Following flooding processes in Europe and Asia particularly in chosen cities Nice, Barcelona, Hamburg, Beijing and Taipei. These variations are marked within economic, social, physical and institutional differences as well as different flood types. With respect to different flooring types, there is a criterion for measures implementations. These criteria focus on flood characteristic, flood depth. Different flood depth is therefore one of the main criteria for choosing a proper measure. The flood depth up to 0.6m is the depth where structural characteristic of the building is not jeopardized. The flood depth above the 0.9m can cause structural instability of buildings. With this, it is possible to make a decision whether or not to implement a measure and what measure. The duration of the flood also presents criteria for implementation of measures.

In accordance to the different flood source there is a different duration for each flood type. In Figure 33, below there is a presentation of different flood source with respect to the different flood duration.

Table 26: Flood types in case study areas

Country	City	Inhabitants	Type of flooding				
			Low infrastructure capacity	River	Coastal	Flash Flood	Pluvial
Spain	Barcelona	1 622 000	*	*		High possibility	*
China	Beijing	16 950 000					*
Germany	Hamburg	1 784 000		*			*
France	Nice	343 123	*	*	*	High possibility	*
Taiwan	Taipei	2 619 000	*	*		*	*

* Recognized flood type

There two different types of measures that are to be implemented on the local/property level; resistance and resilience measures. These two concepts go together.

The resistance measures focus on prevention of water to enter the building. Resilience measures on the other side are gathering all the measures that are implemented when floodwater is inside the building. Resistance measures have two characteristics, permanent and temporary. In addition, resistance measures are deployed away from the parcel/building or they part of building construction. Both resistance and resilience measures provide to affected people some degree of protection and reduction of damages. Resilience measures provide damage reduction, the fast recovery and reducing the time that is spent out of the building.

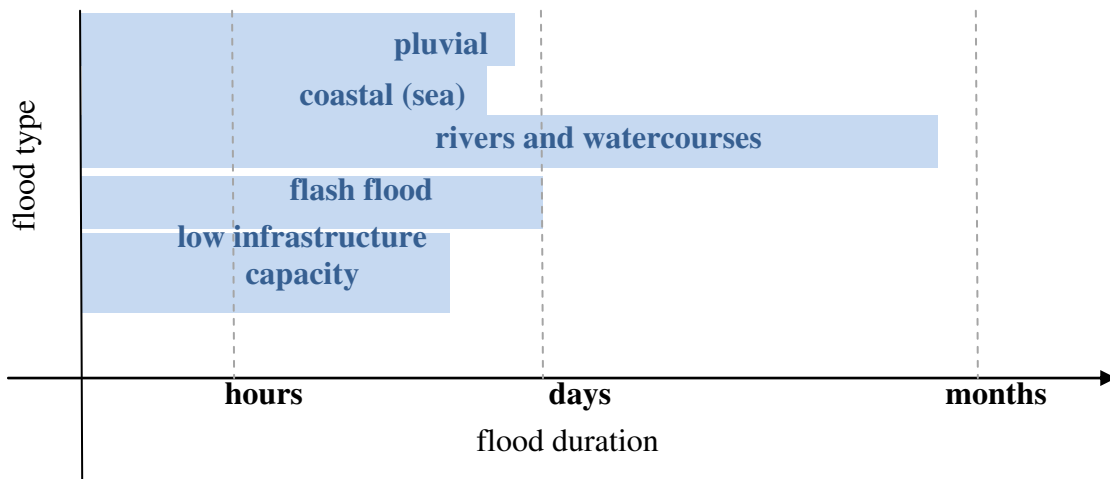


Figure 33: Different flood types with respect to flood duration

Measures at the parcel / building scale can be separated into three different groups (table below):

- Measures rises the thresholds above flood water level
- Measures that are not allowing flood water to enter the property
- Measures that are employed within the building and provide fast water evacuation
- and faster recovery

Table 27: Three main groups of measures at parcel/building scale

I group	II group	III group
Raising thresholds	Hold flood water outside of building/block	Fast water evacuation and property recovery
Raise building level (floor level in the house) SUDS Re-routing flood water with channels	Free standing barriers Periphery walls, gates Door guards and ventilation opening covers Flood skirts External doors	Cellar tanking Concrete floors Ceramic tile floors Internal doors and walls Raised electrics, tv and communication devices Raised kitchen appliances Stainless steel kitchen Double check valves for water distribution points

With respect to different flood depths the presented the set of available measures presented on table below focuses on the type of measure (temporary/permanent), proper flood depth and flood type.

Table 28: Measures listed with respect to different flood depth

Measure	Flood depth	Temporary/permanent	Flood type
Raise building level (floor level in the house)	<0.3 m	permanent	Flash floods, river floods, low infrastructure capacity
SUDS		permanent	Flash floods, river floods, low infrastructure capacity
Re-routing flood water with channel		permanent	Flash floods, river floods, low infrastructure capacity
Free standing barriers	<1 m	temporary	Flash floods, river floods, low infrastructure capacity
Periphery walls, gates		temporary	
Door guards and ventilation opening covers	<1 m	temporary	Flash floods, river floods
Flood skirts	<1 m	temporary	Flash floods, river floods, low infrastructure capacity
External doors	<0.6m	permanent	Flash floods, river floods, low infrastructure capacity
Cellar tanking	<0.6m	permanent	Flash floods, river floods, low infrastructure capacity

Concrete floors		permanent	All flood types
Ceramic tile floors		permanent	All flood types
Internal doors and walls		permanent	All flood types
Raised electrics, tv and communication devices		permanent	All flood types
Raised kitchen appliances		permanent	All flood types
Stainless steel kitchen		permanent	All flood types
Double check valves for water distribution points		permanent	All flood types

Measures implemented before, during and after flood present one of the main tool in flood resilience assessment. The resilience assessment covers evaluation FRI on current state, then measures implementation and re-evaluation of FRI. The procedure provides the possibility to see the effectiveness of measures implemented, decrease in flood damages and fast recovery after the flood. For the events where floodwater is higher than the 1m shift analysis to block scale. This is with respect to the structural safety of urban function and to avoid structural damage. The water depth above 1m can threaten the construction of the building and therefore the measures should be applied on the block scale.

Table 29: Flood resilience and resistance measures on block scale

Resistant	Resilient
Free standing barriers Re-routing flood water with channels Sandbag Periphery walls, gates SUDS	Floating pedestrian platforms

A set of buildings surrounded by streets represent a block. The measures on the block scale have an influence on the set of building. The function of these measures is to keep away floodwater from entering the property (in this case, it is a parcel). As mentioned above the floodwater is higher than 1m and it is threatening to the construction of a building.

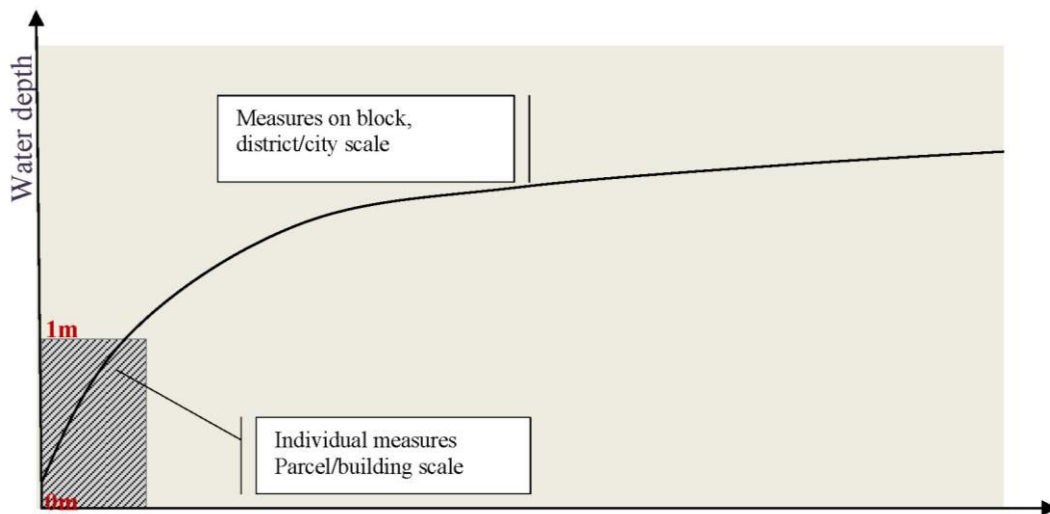


Figure 34: Implementation of measures with respect to flood depth

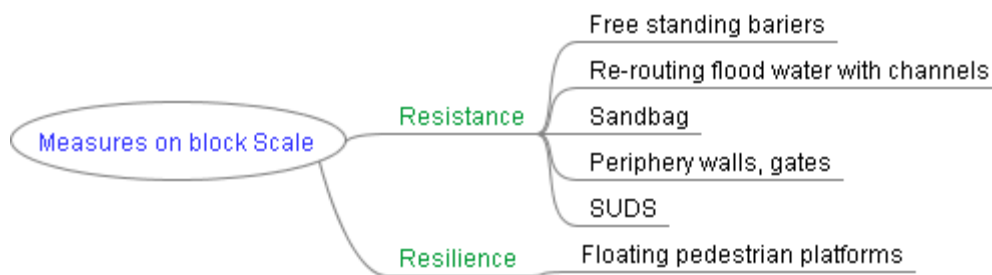


Figure 35: Measures on block scale

The imperative in flood resilience assessment is on different scales. Therefore, the list of measures for building scale presented at table below.

The measures are divided on resistance and resilience measures. measures for urban functions (building scale) are for the flood depth of 0.3m and up to 1m and for the flood duration from a few hours up to a few days.

Table 30: Flood resilience and resistance measures on parcel/building scale (urban function)

Resistance	Permanent	Prevent water entering doors/windows	Raised porch/threshold Auto-barriers Water-resisting external doors/windows Sealant around external doors/windows
		Prevent water penetrating walls	Re-pointing Repair cracks in walls Seal service outlets Covering weep holes Wall sealant/Permanent Wall
		Prevent water entering service pipes	Non-return valves for wastewater pipes and washing machine outlets
	Temporary	Prevent water entering doors/windows	Entrance door/patio door/garage door/window barriers Sandbags/adsorbent bags Freestanding barriers Flood Skirts Perimeter flood wall with gates
		Prevent water penetrating walls	Airbrick covers Sealing the opening in the walls
		Prevent water entering service pipes	Toilet plugging Covers Appliance vent covers Pipe bungs
		Flood warning devices	Flood alarm
Resilience	Limit water damage	Water compatible internal walls Water compatible floors Water compatible kitchen/bathroom appliances and fixtures Water compatible Woodwork Water compatible stairs	
	Remove vulnerable items from flood risk	Raised utilities Raised kitchen appliances Removable fixtures and fittings Relocate valuables Watertight covers for values	
	Expel water	Pump	

4.3 Conclusion

In order to sum up the measures available for implementation can be divided on many categories. Within this chapter, the first division recognizes structural and non-structural as a main. Further, the focus is to divide the resilience measures on main categories and set the main categories at the city scale. The focus is to divide the measures, both resistance and resilience, on different scale and state why their implementation correspond to the chosen scale. Next, the detailed division is done for parcel and block scale.

5 Application and results

5.1 Implementation

Developed method for quantification of FRI is applied in detail on Nice case study in France where example of FRI application on property scale is presented within chapter 3. The testing of method in cities of Barcelona, Hamburg, Beijing and Taipei case study is included within this chapter for the city scale applying the matrix within Annex B. The engineering teams located in the cities using the developed method presented within this thesis with local data and knowledge regarding urban flooding gave the results for Barcelona, Hamburg, Beijing and Taipei.

The research for these five cities was four years long and within this thesis, the results are presented with steps defined and taken during the analysis.

Firstly, amount of data used in this research is significant. In order to evaluate FRI for a city scale and taking into account five dimensions: (i) natural, (ii) social, (iii) economic, (iv) physical and (v) institutional. Second very important fact is that political systems in chosen case study areas differ and because of that, there was some data restriction due to the security issues. Based on that, the following assumptions are made:

- When no availability can be assessed for an indicator, it can be left out of the integration of the overall FRI if its weight value is not higher than 3.

For the calculation of the FRI, weights were assigned to each indicator having the following considerations:

- Natural indicators are assigned a weight of five;
- Emergency evacuation & warning, and accessibility are given an importance of four;
- Land use and urban expansion have a weight of 4, as well as protected critical facilities;
- Volunteers and solid waste management are assigned a weight of two;
- Every other indicator is assigned a weight with the importance level of three.

Following the method described in chapter 3, the three characteristics are taken into account in the evaluation of FRI (i) environment, (ii) estimated risk and (iii) price. The weights are assigned after consultations with researchers within each case study teams (Barcelona, Hamburg, Nice, Beijing and Taipei).

The process of FRI evaluation requires following procedures:

(i) Selection of socioeconomic scenarios - This imply the selection of economic, social, climate change and adaptation conditions for evaluation in the chosen case study.

(ii) Flood risk assessment (flood map) - Hydraulic analysis for chosen flood event and as a result the flood map is used for further analysis.

(iii) Availability of GIS software with available layers case study area, existing and future land use, existing buildings in the form of polygons, drainage system, transportation network.

(iv) Process of resilience flood performance with and without measures expressed through the flood resilience index.

The Figure 36 present a scheme how process of FRI evaluation looks like. In the following part of this chapter, the results of hydraulic modelling and damage assessment are presented as they are the necessary part of FRI assessment methodology.

For the purpose of clarity and comparison, the CORFU flood damage assessment tool³ is used. The tool is a part of CORFU project and it is developed for building content damage. Tool is integrated within GIS and uses the following input data: land use, buildings (in polygon form), depth damage curves corresponding to different land use type (or building type) and flood map. As a result, the damage per building is presented spatially and in the form of tables. This tool is very useful because it is allowing for this analysis a comparison of damage and FRI and its sensitivity with respect to different measures applied.

³ <http://www.corfu7.eu/media/universityofexeter/research/microsites/corfu/1publicdocs/publicresults/D3.3.pdf>

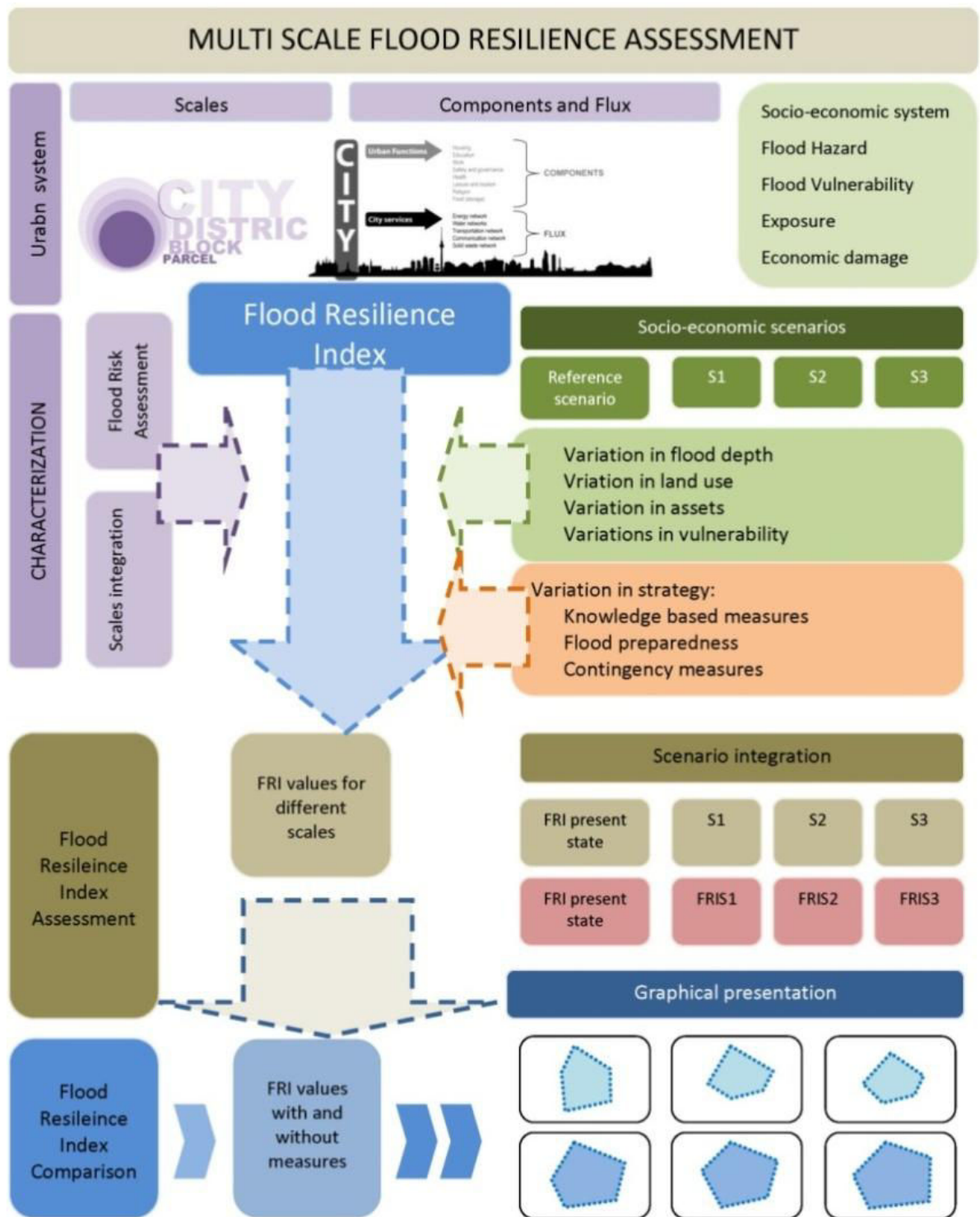


Figure 36: General scheme for FRI assessment

5.2 Nice case study

The Urban Community of Nice Cote d'Azur is the inter-communal structure gathering the City of Nice and its suburbs. The Urban community of Nice has four main directions of competences:

- Development – through support of new business and driving economic development
- Spatial planning – based on urban planning and transportation monitoring and improvement (car parks, roads, equipment, etc.)
- City management – managing among waste management, energy management, water management etc.
- Housing – public housing sector

The 27 communities belong to Nice cote d'Azur urban community with 530 000 inhabitants covering area of 450 km². The city of Nice is spread on over 72 km² hectares with hills, flat parts including the seafront, the central basin and the valleys. Diversity of Nice terrain comes through: plane parts in about 18 km². They are occupied by the dense urban patterns. The hilly areas (about 47 km²) are occupied by medium density areas mostly residential (individual and collective), agricultural activities and forested areas.



Figure 37: The city of Nice in France.

The rain patterns in Nice are characterized with two main periods, during the autumn and early spring. The dry period is during the hot weather from June to October. The average annual temperature of 15° and a mean annual rainfall of 826mm (with recorded maximum rainfall is in November) conceal an uneven distribution of temperature and precipitation during the seasonal cycle.

(i) Scenarios

The main storyline regarding the Nice case study focuses on land use change, different flood depth through increased precipitation, transportation change and regarding key stakeholders and their activities on adaptation and mitigation measures and strategies beneficial for increased flood resilience.

(ii) Characterization

Within a characterization of flood risk management three main components of flood risk are considered (i) flood hazard, (ii) flood exposure and (iii) flood vulnerability.

The developed methodology, however, consider city/urban scale the analysis of urban system.

The system analysis for the Nice case study considers the flooding, its character and spatial distribution for the analyzed event. In addition to this case study the scales chosen for flood resilience assessment are (i) city/urban and (ii) property/building scale (example presented in chapter 3).

5.2.1 Hydraulic modelling

The main objective for hydraulic modeling was to simulate surface runoff and estimate flood impact of selected area. One of the main obstacles was terrain configuration. This Mediterranean area is characterized by flat and very steep areas. In addition, the two types of mesh are applied: regular and flexible. This was done in order to test both approaches and estimate accuracy of results. Also, the two different mesh types were used to examine the model stability and behavior on very steep areas. Both meshes are created with buildings included. The urban bathymetry is created using regular mesh. For the regular mesh the buildings are included into the topography. Using this approach the accuracy of results with respect to buildings is a bit reduced. Available data for building hydraulic model is accurate topographic data. Since the model focuses on surface runoff the different return periods were used (T10, T50 and T100). Here presentation is done just for the 100 year return period. In addition, for verification the

mapped places with water levels are available. The modeling data are explained in detail in the paragraphs below. Additional data are provided from historical event (river flooding).

The runoff generation is modeled for the whole 72 km² of case study area. The impact of existing mitigation measures was not tested because the dikes are embedded into existing DSM. Testing in this case involved removing the whole dike system located in the west part of the city from the DSM and then running the hydraulic model.

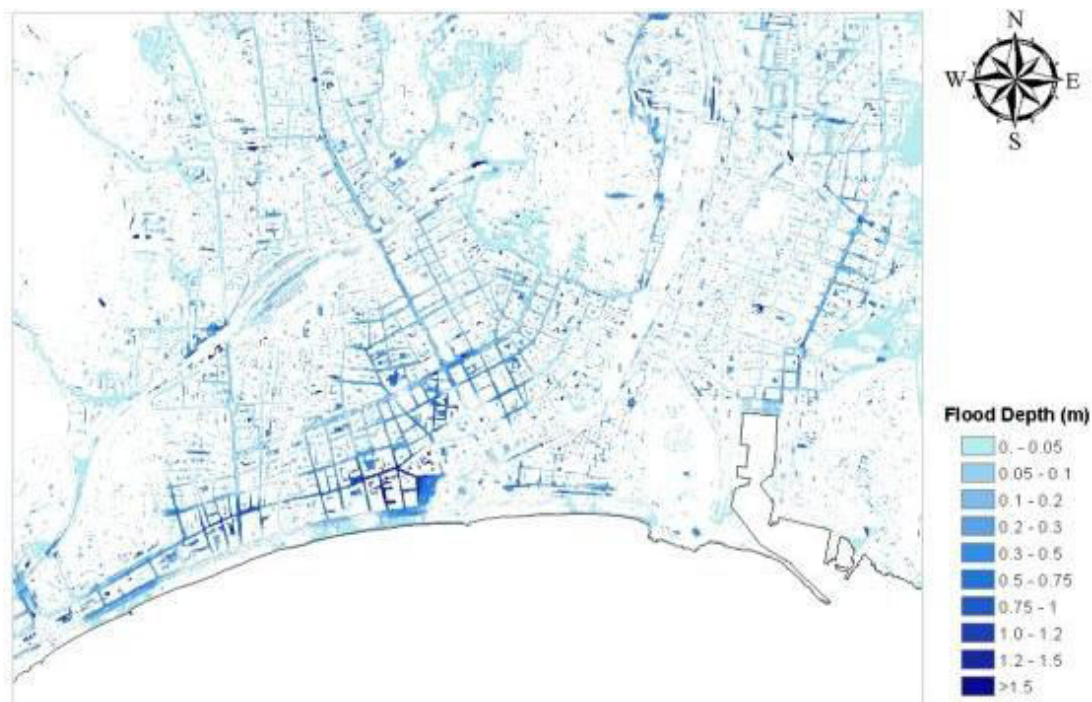


Figure 38: Flood map for 100 year return period, Nice, France.

5.2.2 Damage assessment

The vulnerability assessment of direct damages demands depth/damage curves and corresponding land use maps. Following the development methodology for mapping the urban systems (Batica et al., 2012) the land use is presented with urban functions. Depth damage curves (Figure 39) are also adapted to the rearranged land use. As mentioned the land use is represented through different urban functions, therefore the created depth-damage functions are following the same procedure.

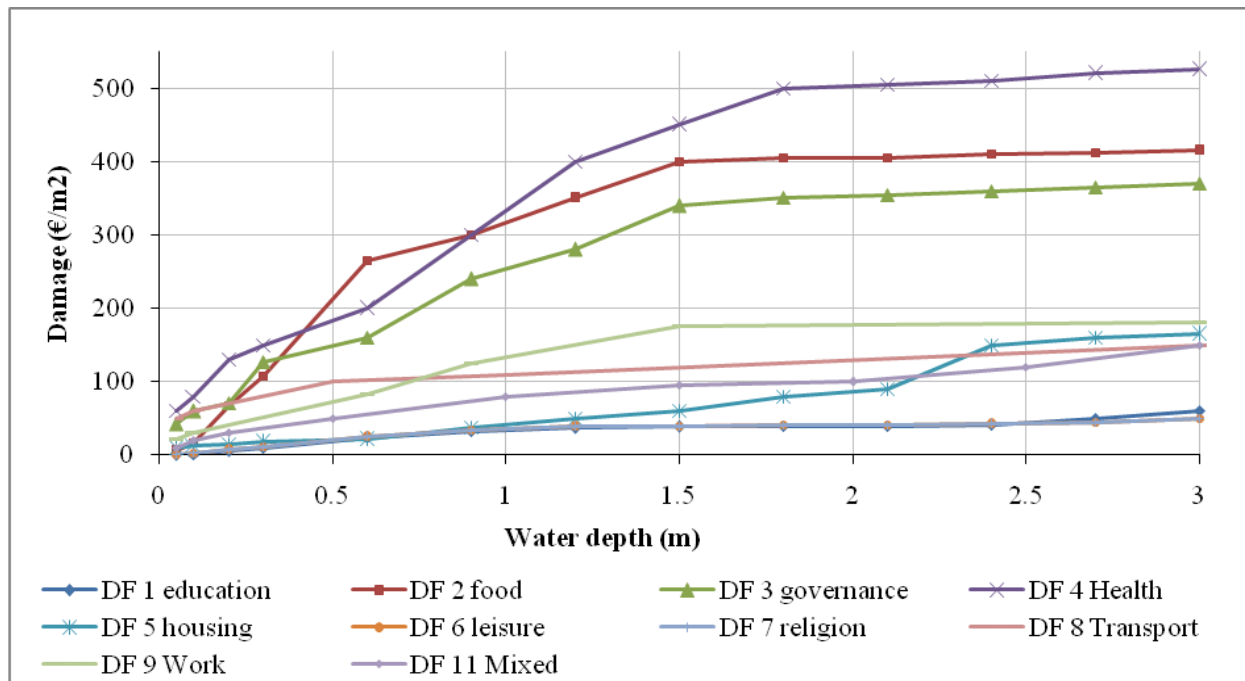


Figure 39: Depth damage curves for buildings, Nice, France

The depth damage curves created and adapted to fit the primary mapping of urban system on different urban functions. Adaptation is done with the data obtained from the report on flood damage functions in EU member states (Huizinga, 2007). The damage functions from France and Germany are from (i) building, (ii) commerce, (iii) industry and (iv) roads. The damage functions for transportation do not applied to buildings that are located on railway and bus stations and buildings located on airport.

The analysis of flood damages for Nice case study is presented with a total number of flooded urban functions in analyzed area and the amount of damage calculated using CORFU damage tool. The results are presented in the table below.

Table 31: Statistics of flood damages

Urban Function (UF)	Number of flooded buildings
	100year return period
Education	44
Food	29
Governance	76
Health	35
Housing	3920
Leisure	60
Religion	55
Transport	66
Working	492
Mixed	1131
Sum	5908

Flood damage expressed in monetary terms per urban function is presented graphically (Figure 40). Figure presents the averaged damage value per urban function. As presented the transportation and health facilities mapped in the Nice case study have the highest damage for the modeled flood event.

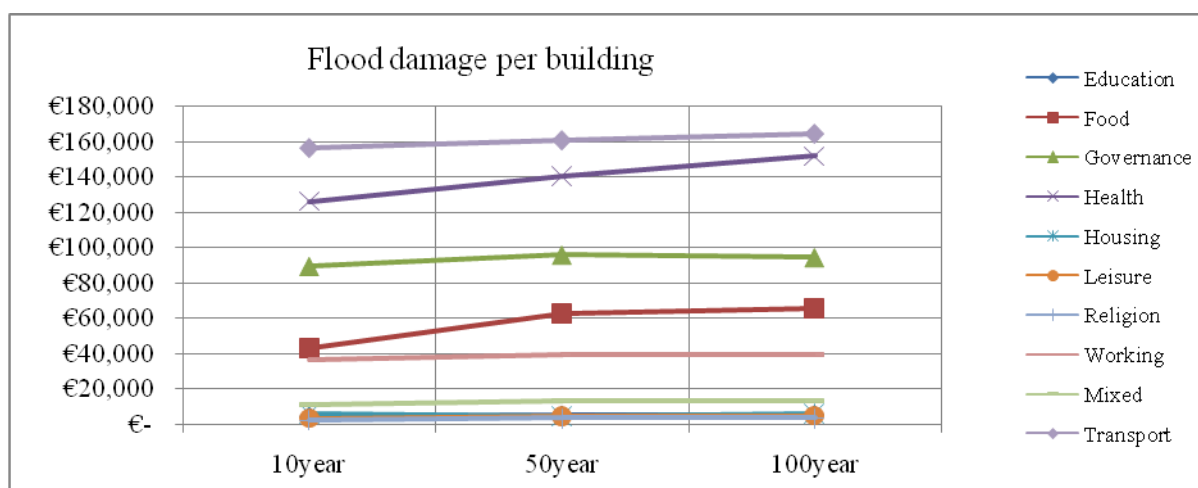


Figure 40: Direct flood damages per urban function

In total for different urban functions, the damages are presented for the flood event of 100 year return period with grouped amounts in the table below. The presentation is done spatially using GIS (Figure 41).

Table 32: Flood damage in Euro (€)

Urban Function (UF)	Total Damage (Euro)
	100year
Education	€ 239,062.05
Food	€ 1,907,129.24
Governance	€ 7,165,916.19
Health	€ 5,310,768.04
Housing	€ 23,688,683.71
Leisure	€ 278,538.64
Religion	€ 193,483.25
Transport	€ 10,851,473.78
Working	€ 19,300,765.83
Mixed	€ 14,853,539.31
Sum	€ 83,789,360.04



Figure 41: Calculated flood damage for Nice case study for 100 year return period

5.2.3 FRI evaluation process

Adaptation measures for the Nice case study were considered following: (ii) flood preparedness and (iii) contingency measures. These measures reduce vulnerabilities of people and property, and correspond to the second established principle of the existing PAPI (Programme d'Actions de Prévention des Inondations) plan for Nice.

The proposed measures do not have impacts on flood maps. Their impact is shown within the developed (i) CORFU damage assessment tool and (ii) Flood Resilience Index (FRI) assessment tool. Within this report the analysis of flood resilience index for chosen measures is performed. The summarized scenarios are presented in Table 33.

Table 33: Summarized scenarios and measures for the Nice case study.

Scenario	Time Horizon	Adaptation Measures	Scale	Land use	Socio-economic pathway	Climate change
Current state	Present	Existing status – no adaptation	District , city	Existing land use	Existing economy	No change
Scenario 1	Present	Adaptation at the building level	District , city	Existing land use	Existing economy	No change
Scenario 2	Present	Adaptation at the building level and focus on knowledge based measures	District , city	Existing land use	Existing economy	No change
Scenario 3	Present	Adaptation at the building level and focus on contingency measures	District , city	Existing land use	Existing economy	No change
Scenario 4	2050	Existing status with increased rain intensity	District , city	Land use in 2050	1% inflation rate per year	Increased precipitation episodes for 10%

Within scenarios for Nice case study area considers variations in flood depths, land use, assets, flood vulnerability.

(i) Three different return periods are considered for the analysis. The rain event of 10, 50 and 100 year return period are analyzed. The focus was on runoff generation over the case study area. As a result the flood maps are obtained. For the time horizon at year 2050 then there are also flood maps for the same return period with intensity increased by shifting factor.

(ii) Variation in land use is expressed with significant change in the west part of the city. The new development area will be situated on the left bank of the Var river with the new education, business and transportation hubs. The changed land use will change the flood damages and the flood resilience level.

(iii) Variation in assets is expressed with the new extent of the transportation network in the city. The extended tram line will spread along the coastline and end at the west part of the city. The flood damages of this city service will be changed.

(iv) Flood vulnerability also varies considering the effect of implementing measures on different scales.

The FRI assessment for Nice case study considers scenarios with and without flood resilience measures presented in

Table 33 with respect to different scales.

5.2.4 FRI evaluation for City/urban scale - Nice

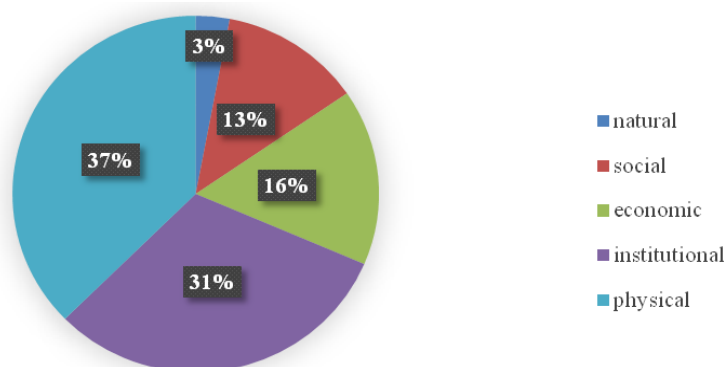


Figure 42: Weight percentage in each dimension (city/urban scale), Nice case study, France

As presented in Figure 42 the importance of each dimension varies from 3% for natural to 37% for institutional dimension.

The evaluation of overall FRI followed by values assigned to each indicator with their respective weights. For the present conditions, the FRI for the Nice case study was The result of the FRI under present conditions was 3.45.

Table 34: Overall FRI for the city/urban scale, Nice case study – current state scenario

	Indicators	Dimension index $\sum((x_i * w_i) / \sum w_i)$	"Importance" $\sum w_i / \sum w$	Overall index
Natural	2	3.50	2.97%	3.45
Social	10	3.17	12.46%	
Economic	16	3.65	16.02%	
Institutional	24	3.70	31.16%	
Physical	30	3.25	37.39%	

Table 35: Overall FRI for scenarios, Nice case study

Scenario	FRI	Δ
Current state	3.45	-
S1	3.71	7.53%
S2	3.73	8.11%
S3	4.10	18.84%
S4 (2050)	3.42	-0.87%

The presented values of FRI for the defined scenarios give following conclusions:

The number of the indicators change for scenario S1 is 12, S2 is 18, S3 is 17 and S4 is 3.

For the current state baseline scenario the 82 are used from 91 total indicators

Scenario S1 considers adaptation measures related to flood preparedness and focuses on protecting the property from floodwater. The focus is on the physical dimension and better protection of urban functions

Scenario S2 considers knowledge based measures in the case study area. These measures take into account education on risk and availability of existing information related to flood risk. This scenario influence social dimension at most and an institutional focusing on the legal framework for improving existing flood risk in the case study area.

The contingency measures within S3 scenario are focused on response and relief stage in 5R framework. The measures taken during and after flood are mostly included within economic, institutional and social dimensions.

Scenario S3 where contingency measures are taken into account have the best results of FRI. The increase is significant within physical and institutional dimension with 21.71% and 22.47% respectively. This is in addition of considered improvement in this dimension regarding crisis management, available physical assets that are employed during and after flood.

The S4 scenario considers no measures but has increase in rain intensity. The increased flood depth is not influencing a spatial extent of flood but the influence on damages is noticed. Regarding FRI evaluation the values are lower compared to current state scenario for 0.87%. The values specially differ in the institutional and physical dimension. This is in addition of new land use projected for the 2050 year.

Table 36: Scenarios FRI breakdown per dimension and change (Δ) with respect to current state, Nice case study

	Current state	S1	Δ (%)	S2	Δ (%)	S3	Δ (%)	S4	Δ (%)
natural	3.50	3.50	0.00	3.50	0.00	3.50	0.00	3.50	0.00
social	3.17	3.17	0.00	4.22	33.33	3.17	0.00	3.17	0.00
economic	3.65	3.80	4.06	3.72	2.03	4.35	19.24	3.65	0.00
institutional	3.70	3.72	0.33	4.11	10.94	4.51	21.71	3.63	1.99
physical	3.25	3.87	18.78	3.25	0.00	3.99	22.47	3.23	-0.83

5.2.5 Summary of the results

A summary of the results for all scenarios and taking into account different scales is presented in table below.

Table 37: FRI values for different scenarios and different scales, Nice case study

FRI Urban, city scale					
	Current state	S1	S2	S3	S4
Without measures	3.45	3.45	3.45	3.45	3.42
With measures	No measures	3.71	3.73	4.10	No measures

There is a significant increase in FRI value for the implementation of flood preparedness measures on property/building level. The direct connection with influence of internal requirement for urban function is noticed. With proposed measure the floodwater is not entering house and the character of the urban function remain the same. The focus is on the external requirement. The social component of this is important, since, the urban function can be used during flood event and it is safe for occupants. The FRI level is therefore fully deepens on external requirements.

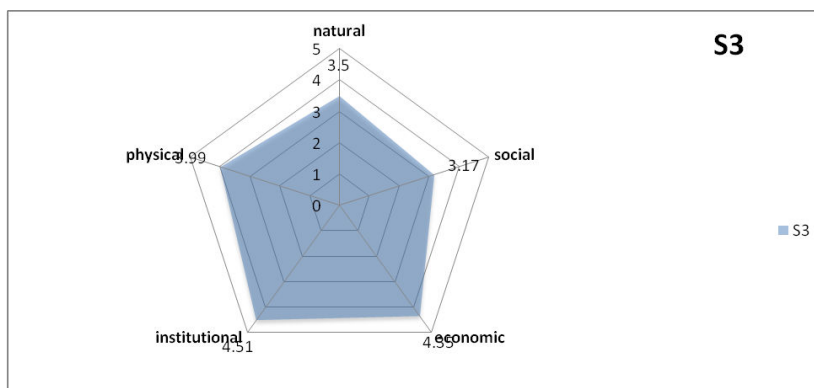
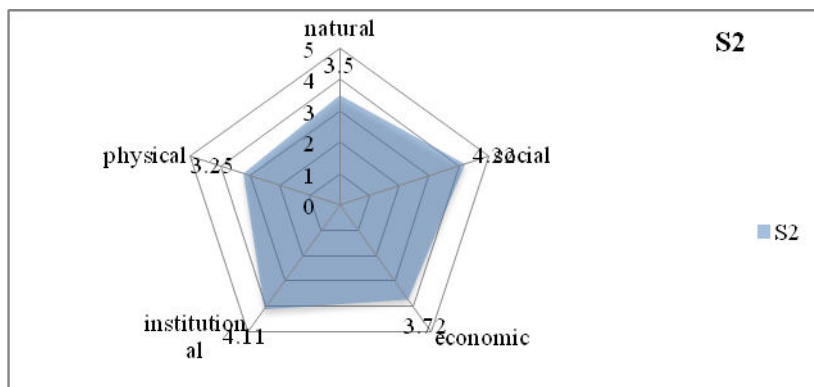
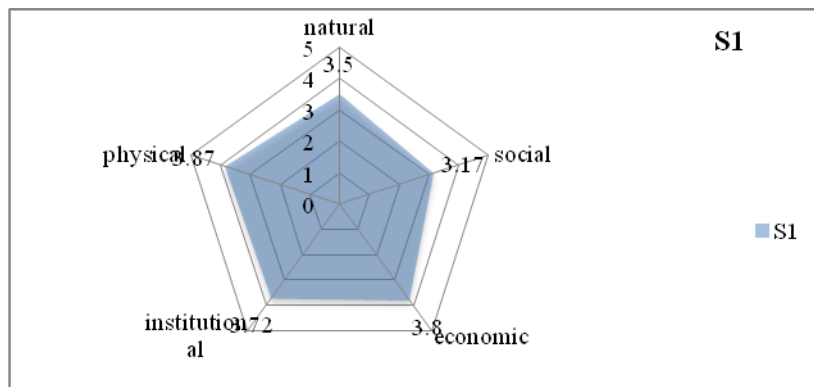
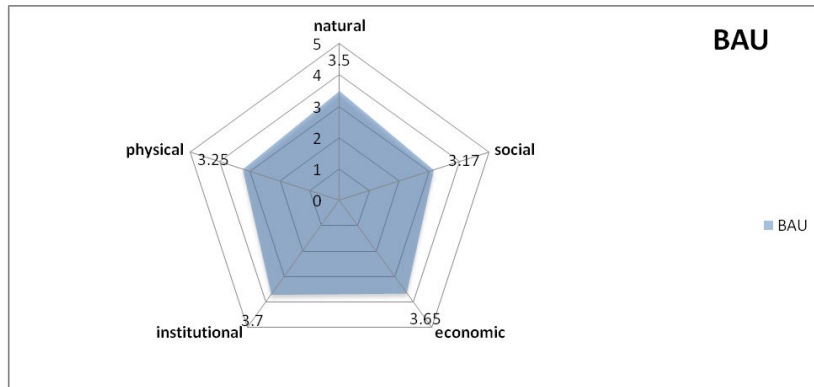


Figure 43: FRI presentation for different scenarios - city scale, Nice case study, France

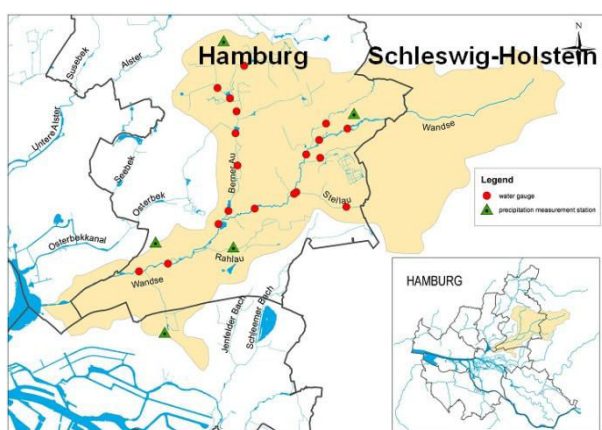
Figure above presents the FRI evaluation results for Nice case study. The evaluation is done for city scale using FRI matrix with 91 indicators. Graph on the left side presents the FRI for current state and scenario S4. For these scenarios, the measures are not considered. The graph on the right includes the FRI for S1, S2 and S3 scenarios. The measures considered for these two scenarios are flood preparedness, knowledge based and contingency measures respectively.

It can be concluded that implemented measures in S, S2 and S3 scenarios have an influence on FRI. A sharp increase of FRI is for the S3 scenario where the focus is on contingency measures. The increase compared to current state as a baseline scenario is 18.84%. This high increase is due to improvement of crisis management for considered events, people mobility and rescue services.

In general, the implementation of measures improves the FRI for considered case study. The level of improvement is in this case measured with developed method for FRI.

5.3 Hamburg

Wandse is a small urban catchment of about 87 km², whereby 60 km² is located in the Hamburg area. In terms of its topographic characteristics it is considered as a low-lying area (0-80 m asl), spreading from the NW to SE. The upper catchment is close to the natural state dominated by farmland and nature protection area. Main urban area, located in the mid and lower catchment, is a high density residential area, dominated by detached buildings (23,85% out of all landuse types in the Wandse catchment). Industrial area is mostly located in the mid and lower catchment area, partly directly at the river (e.g. Yeast factory at the Km 4.500 or a commercial centre encroaching the river Wandse at the Km 12.162). 66,6 % of the catchment drains in the separate system, the lower catchment part to the combined sewerage system. The main characteristics of the Wandse catchment are summarised in **Error! Reference source not found.**



Topography:

- predominantly lowland
- 6-48 m a s l

Soil type:

- dominated by medium to light clayey sand

Urbanization type:

- differentiated; upstream and middle part areas are closer to the natural state

Sewerage system:

- partly combined, two third of sewer system is of separate nature

Figure 44: Summary of the main parameters characterizing the Wandse catchment area

In the flood risk assessment step, the flood risk is assessed based on the data and information describing the hazard, exposure and vulnerability of the urban system (including flood maps, vulnerability maps, and drainage and infrastructure networks) for the present state and future

scenarios (climate and socio economic). This provides the spatial context that will allow selecting the proper scales for the evaluation of flood resilience.

Table 38: Scenarios considered for Hamburg case study

Scenario	Time Horizon	Adaptation Measures	Scale	Land use	Socio-economic pathway	Climate change
Current state	Present	Existing status – no adaptation	Catchment	Existing land use	Existing economy	No change
Scenario 1	2021	Retention areas	Catchment	Existing land use	Existing economy	No change
Scenario 2	2121	Improvement of ecological status of river system, optimisation of weirs, SUDS, flood resilience measures, moderate implementation	Catchment	Existing land use	Existing economy	No change
Scenario 2'	Present	Full implementation	Catchment	Existing land use	Existing economy	Discharge increase: AB1 + 20%

5.3.1 Hydraulic modelling

The A1B scenario has been adopted for the modelling purposes in the Wandse catchment. 8 different realizations of the IPCC A1B scenario have been simulated in the regional climate model for central Europe (REMO). As the results showed a significant disparity both between climate model runs and flood return periods, we have decided to use the worst case of +20% discharge for all flood events and at all stations along the river Wandse.

For the model set-up a digital terrain model (DTM) was generated based on the combination of laser scanning point data, breaklines and polygons of the channel beds describing the waterways.

On this basis the DTM contains the sufficient accuracy for a realistically representation of the modelled environment and the simulated inundation of the water within the area. Roughness modelling was considered based on landuse categories and breaklines were derived from the datasets. The combination of breaklines from both the roughness polygons and the DTM is the basis for the mesh generation using GAJA3D, a MATLAB based library for flexible mesh creation (Rath, 2007).

In order to assess the hydrologic and hydrodynamic conditions in the Wandse catchment for the defined scenario (Scenario 1), the open source modelling platform Kalypso (<http://sourceforge.net/projects/kalypso/>) has been deployed.

KALYPSO is based on a set of generic functions for managing spatial data called KalypsoBASE. It handles and stores all model data in the OGC Geography Markup Language (GML), a well-known structured text format, and implements a number of OGC web service standards. Five advanced modules for specific simulation purposes are founded upon KalypsoBASE (Kalypso Hydrology, Kalypso WSPM, Kalypso 1D2D, Kalypso Flood and Kalypso Risk).

Based on peak discharges resulting from the KalypsoHydrology, the river hydraulics were computed for an urban area, an urban-suburban area and a suburban area with the one-dimensional water surface profile model KalypsoWSPM. The inundated areas and flow depth were calculated on the basis of digital terrain data with the module KalypsoFlood. The computed inundated areas and water flow depths are illustrated in **Error! Reference source not found.** As introduced in section **Error! Reference source not found.**, a maximum increase of 20% in flood peak discharge due to climate change is projected for 2050 (Hellmers & Hüffmeyer, 2014).

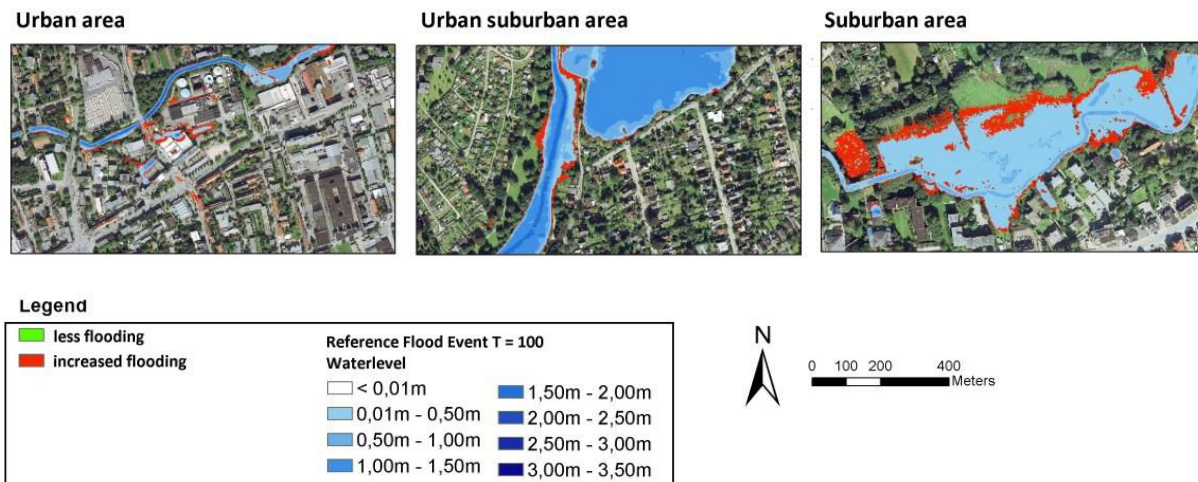


Figure 45: Change in flow depth and inundated areas of a 100 year flood event The results are illustrated for a highly urbanised (Wandsbecker Chausse), an urban-suburban (Ostend pond) and a suburban area (Rahlstedt)

5.3.2 Damage assessment

For the assessment, direct damages are classified into damages to residential buildings, commercial objects, infrastructure and agriculture. In the present study, the focus is on the first two categories. Basically, the spatial distribution of elements at risk is carried out for the determination of direct damages in the site under investigation. Furthermore, a classification is required in order to assess the inventory for the development of depth-damage functions.

Based on the storm surge event XR2010A the damages are calculated with respect to the maximum water stages occurring at each location over the time span of propagation. The damages are calculated separately for the residential buildings and the commercial objects and in each case separately for the buildings and the inventory.

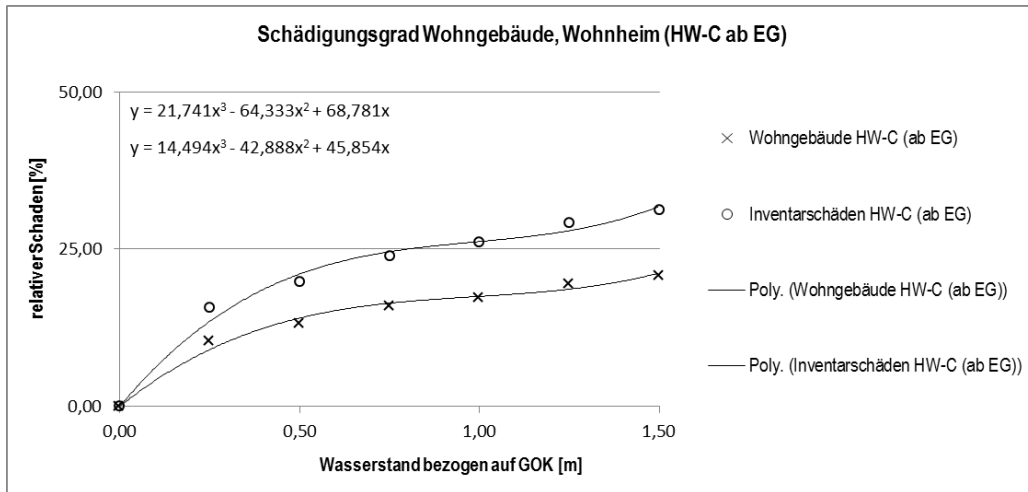


Figure 46: An example of a damage curve: multi-, duplex-, detached, medium resistance (1948) from the ground floor (residential, and public buildings)

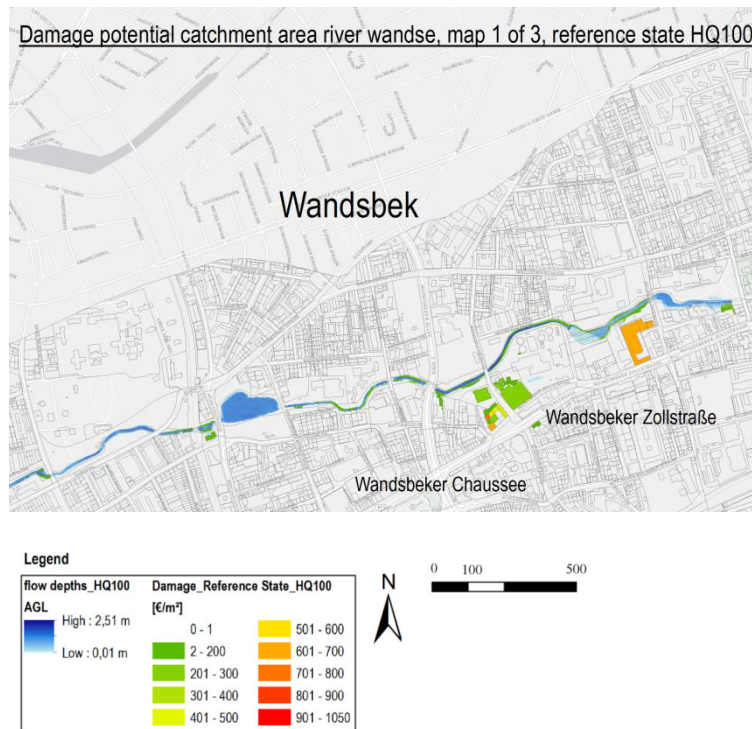


Figure 47: Spatial distribution of specific damage (€/m²) for a 100 year flood event on the basis of the present scenario (year 2010); The results are illustrated for the focus areas: a highly urbanised (1-3), an urban-suburban (4-6) and a suburban area (7-9)

The calculated damages for the chosen return period are presented in the table below.

Table 39: Damage at a flood event of a certain probability p and annual expected damage (AED) for the Wandse catchment based on the reference land use- present state

		(Present state)
Return Period T_i	Probability p_i	S (Damage at flood event p_i)
[a]	[1/a]	[1000€/a]
100	0,01	1.787,7

5.3.3 FRI Evaluation process utilizing the Flood Resilience Index (FRI)

Under the conditions stated above, the importance of each dimension varies from 41% for the physical to 4% for the natural.

Several indicators were not considered because of the lack of information. These indicators were: 7 indicators from the physical dimension considering mainly real-time monitoring systems; 5 indicators from the institutional dimension, mostly related to efficiency and effectiveness of rescue crews and plans; and 3 indicators from the economic dimension about solid waste treatment, drainage time, and productivity of rescue services.

For the assessment of the FRI, all measures have been analysed in isolation and their potential to add to the performance of the overall strategy has been analysed (i.e. no coupling of measures has been performed). The reason is to have an analysis of their resilience performance irrespectively of the priorities given by the stakeholders. In the final step, the suggested portfolio of measures are to be revisited and if needed revised.

The fact that the institutional and physical dimensions have the largest weights within the overall FRI is reflected in its change in value, which is not significantly enhanced by the implementation of the measures.

After assigning values to each indicator with their respective weights, the overall FRI was calculated. The result of the FRI under present conditions was of **4.27**.

Table 40 provides an overview of the FRI for each dimension and overall FRI.

Table 40: Overall FRI for the catchment scale of the Wandse, Hamburg case study

	Indicators	$\sum w_i$	$\sum(x_i*w_i)$	Dimension index $\sum((x_i*w_i)/ \sum w_i)$	Weight	Overall FRI
Natural	2	10.00	35.00	3.50	4.20%	4.27
Social	10	28.00	118.00	4.21	11.76%	
Economic	13	37.00	159.00	4.30	15.55%	
Institutional	22	66.00	283.00	4.29	27.73%	
Physical	29	97.00	417.00	4.34	40.76%	

Results of the FRI for the different scenarios are given in Table 41, where the percentage of change with respect to the present state is also calculated.

Table 41: FRI for all scenarios and their respective percentage of change in comparison to present state, Hamburg case study

Scenario	Overall FRI	% of change
Present state	4.27	-
S1	3.79	-11.32%
S2'	4.19	-5.22%
S2	4.63	5.51%

Scenario S1 affects 37 indicators of the 76 indicators used in the baseline scenario (present state), S2' affects 16, and S2 19 indicators. There is noticeable lower FRI value for S1 mostly because of the lack of awareness and weak regulation towards the inclusion of flood management as part of the city policies. For S2', the changes are not as pronounced as for S1, because a certain level of measures has already been considered as implemented (e.g. there is better regulation and because transportation is not as vulnerable as in S1). S2 obtained the best value in terms of FRI performance because there is improvement in all social indicators due to the adoption of FVR & IMM. The current state has already high levels of flood resilience in its social aspect (4.21), so the S2s policies bring that value to 5.

In general, the physical dimension of the FRI remains the same for all scenarios, with only minor changes between scenarios, oscillating in their value from -2% to +3% of change from the current state. The most pronounced change is found in the social dimension, with both scenarios S1 and S2' having a change of -24%, while the change in S2 is of +19%, followed by the natural dimension which fluctuates from -29% for S1 to +28% for S2. Fluctuations in the natural dimension are high because it consists of only two indicators, where each increase or decrease of one point in the availability level has an effect of 15% change on the dimension's FRI value. These fluctuations however, do not have a meaningful influence on the overall FRI as the natural dimension overall importance is only 4%.

S1 has notable decreases in both the natural and institutional dimensions with -29% and -23% in reference to the present state. This performance is influenced by the loss of one point in both natural indicators and the loss of one point in all social indicators (which measure awareness, relationships, and livelihood). For an overview of these changes, refer to Table 42.

Table 42: Scenarios FRI breakdown per dimension and change (Δ) with respect to present state, Hamburg cases tudy

	Present state		S1		S2 (with measures-moderate)		S2 (with full implementation of measures)	
	FRI		FRI	Δ	FRI	Δ	FRI	Δ
Natural	3.50		2.50	-29%	4.00	14%	4.50	28%
Social	4.21		3.21	-24%	3.21	-24%	5.00	19%
Economic	4.30		4.24	-1%	4.30	0%	4.46	4%
Institutional	4.29		3.29	-23%	4.18	-6%	4.71	9%
Physical	4.34		4.25	-2%	4.46	3%	4.54	5%

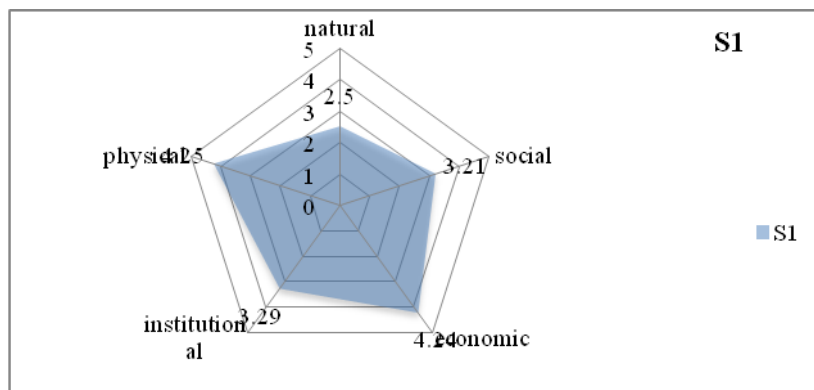
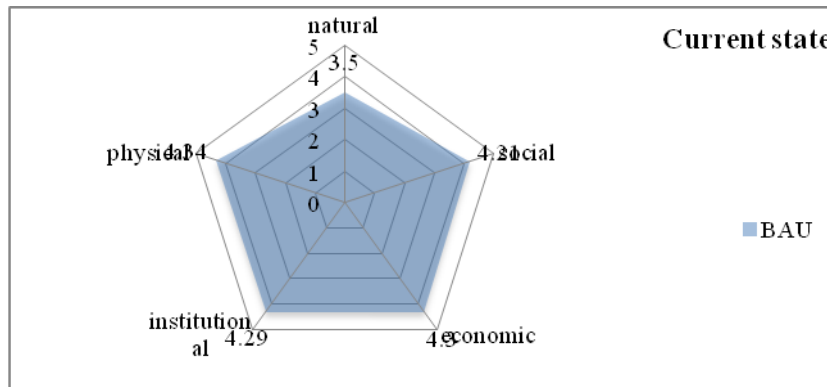
5.3.4 Summary of Results

In general, the implementation of the measures on the scenarios improves the FRI value. However, it is difficult to observe the influence of the measures at the borough- and property scales' calculated FRIs. This issue rises from the lack of indicators that integrate the catchment-scale with the borough- and property scales.

In the case of the overall FRI, the inclusion of a set of the measures provides the best flood resilience performance for the natural dimension. S3 presents the best value for the social dimension, thus the implementation of a set of measures does not provide any change to it. Physical and economic dimensions remain stable from one scenario to another so the focus can be directed to the other three dimensions of the FRI (see Figure 48).

Table 43: General results for all scales

Catchment	Scenario			
	Present	S1	S2'	S2



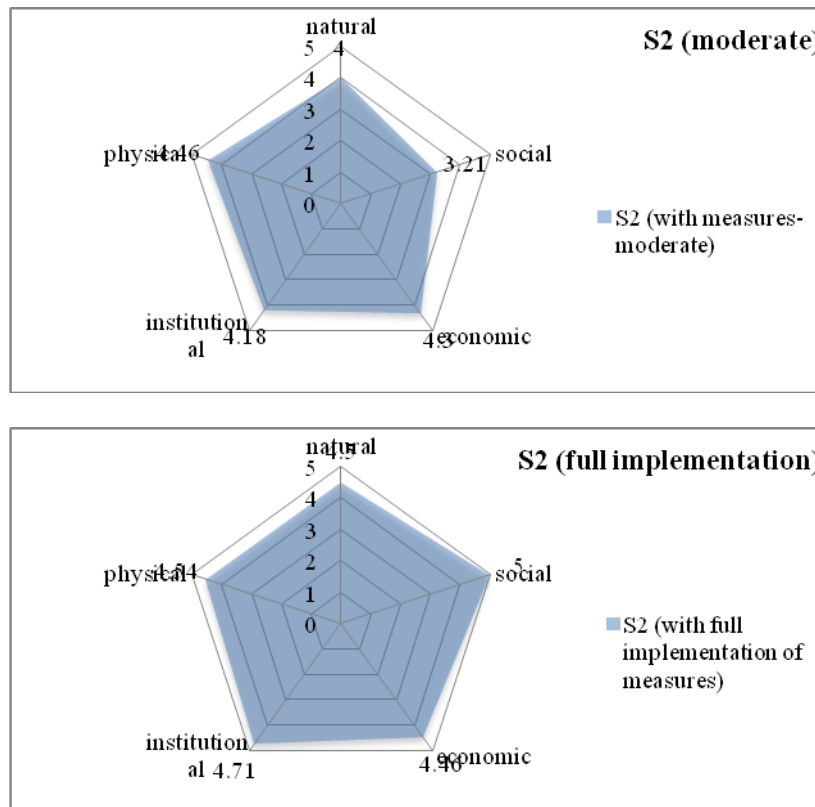


Figure 48: Comparison of all scenarios' overall FRIs per dimension

The FRI method went beyond the mere cost benefit analysis and pointed out a few additional features a property/borough or the whole system are to consider or improve (e.g. the accessibility of the properties during floods, access to resources in the post disaster recovery etc..) in order to cope better with floods. For the consistency of the assessment, the same group of experts or stakeholders should perform the analysis for the situation with and without adaptive strategies. In that way, it is possible to mitigate the subjectivity error by adding the same level of the subjective thinking to both scenarios.

5.4 Beijing

Beijing is located in the mid-latitudes and has a temperate continental monsoon climate. In Beijing the average annual rainfall is 572 mm which is unevenly distributed over a year. The rainfall during the flood season (from June to September) in an average year accounts for about 85% of the total in a year, and in high flow years the rainfall in this season can amount to more than 90% of the total. The largest three-day rainfall may account for 30% of the amount for the whole year. With city expansion and climate change, urban local flooding has occurred frequently in Beijing in recent years. For instance, large areas were inundated during the storm events on June 23, 2011 and July 21, 2012, which caused road inundation, vehicle damage and even personal injury and death.

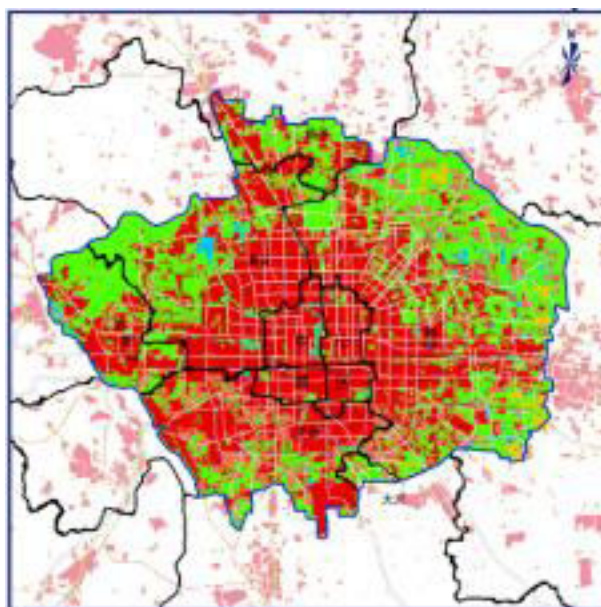


Figure 49: Beijing city planning area map.

5.4.1 Hydraulic modelling

Most of the data used for the Beijing case study are considered highly confidential. The terrain model and the land use information are only accessible within the Beijing city services office. Hence, limited information of the modeling results is allowed for publication. In general, the digital terrain model (DTM) of Greater Beijing with 5 m horizontal resolution was used for

hydraulic modeling. Land use information from urban planning data last updated in 2008 was used, as well as building polygons data issued in 2004. Most of the drainage system modeling data came from pipeline planning documents, and a minor part was from surveying. We used MIKE 21 to build a simple hydraulic model for the city area, MIKE Flood for Yizhuang district. Yizhuang has a flat terrain with an average altitude between 26 and 34 m. The overall topography is sloping down from the northwest to the southeast with gradual slope between 1/1000 and 1/2500, which is defined as piedmont plain type.

Pipe network data, ground elevation data and rainfall information are three essential components for hydraulic modelling. The drainage network data includes topology structure of pipe, pump station, relevant hydraulic facilities and other hydrology and hydraulic parameters. The surface information contains catchment processing parameters and ground digital elevation model, for which 10 m x 10 m regular grid was used for the following case study. Separate drainage system has been constructed in Yizhuang region with a total length of 183 km and designed for rainfall return periods of 0.5 and 1 years.

A flood model for the Yizhuang area was built using MIKE Urban which couples the 1D drainage network model and the 2D overland flow model to simulate flooding for different return periods in the area. Hydraulic modeling results for 2020 and 2050 with 50-year return period rainfall are demonstrated in figure below.

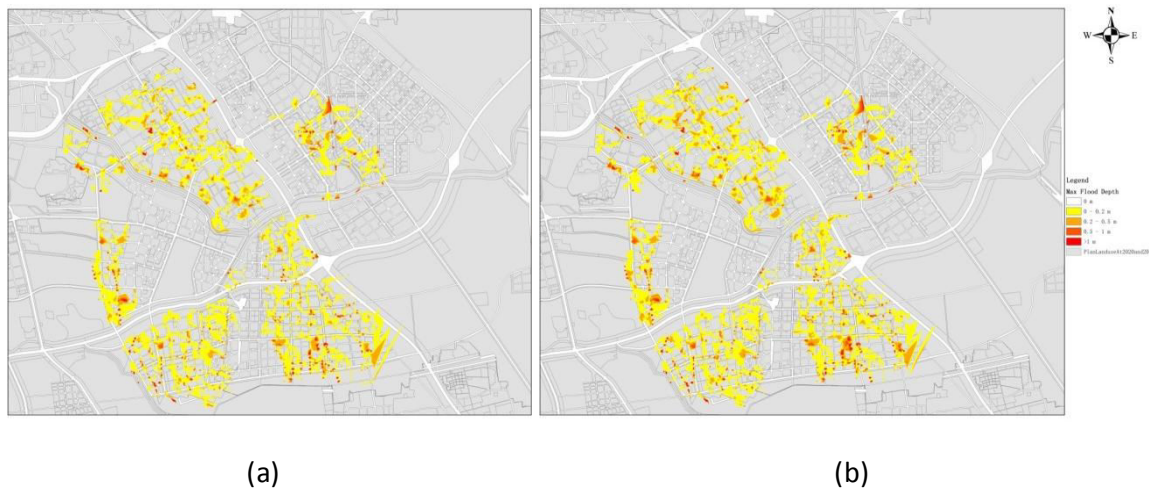


Figure 50: Spatial distribution of inundation for (a) 10-, (b) 20-, (c) 50-, and (d) 100-year return period events with current rainfall intensity

5.4.2 Damage assessment

Building vector data were collected for the case study. Each building has a unique index value is introduced to distinguish building vector data, which could be overlain with land use maps to generate the building land use spatial distribution (figure below).

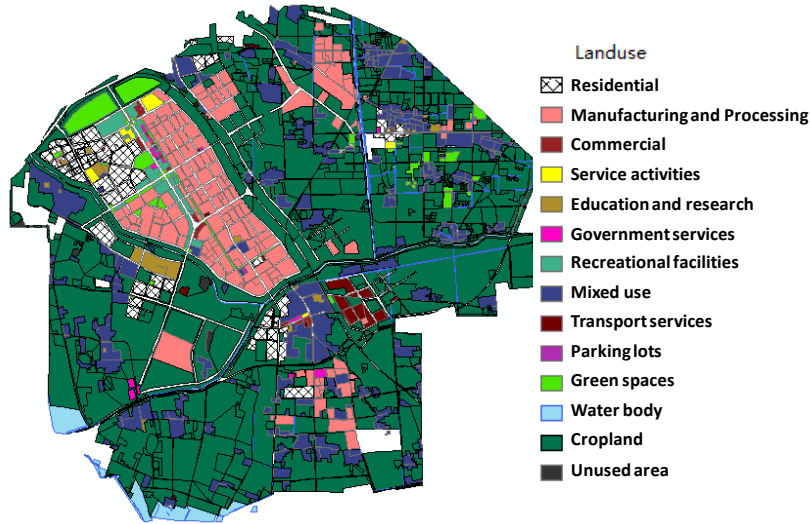


Figure 51: Building land use spatial distribution

Used depth damage curves are presented in the figure below. Due to the lack of data and inability to adapt existing depth damage curves to the spatial land use distribution the UK depth-damage curves are adopted.

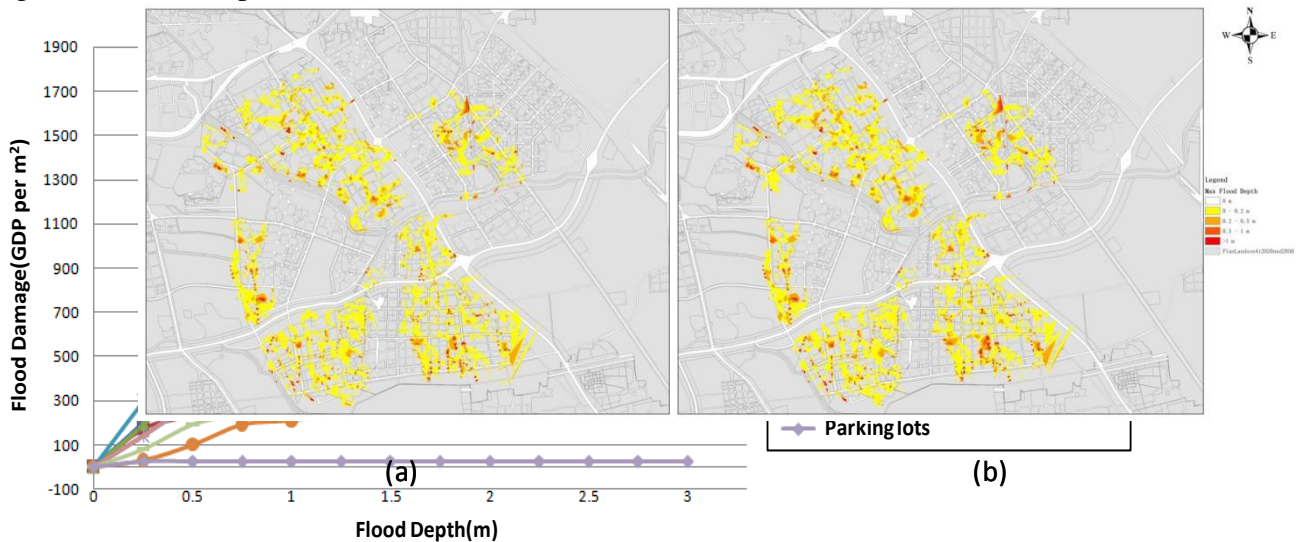


Figure 5-52 UK Depth-damage curves

(Figure 53: Building damage results of (a)10, (b)20, (c)50, and (d)100 year return period of rainfall event). The flood damage statistics is summarized in table below.

Table 44: Flood damage and rainfall statistics for different return periods

Return period (year)	10	20	50	100
Rainfall(mm)	172	197	229	254
Total Loss(hundred million RMB)	2.01	3.23	4.97	5.90

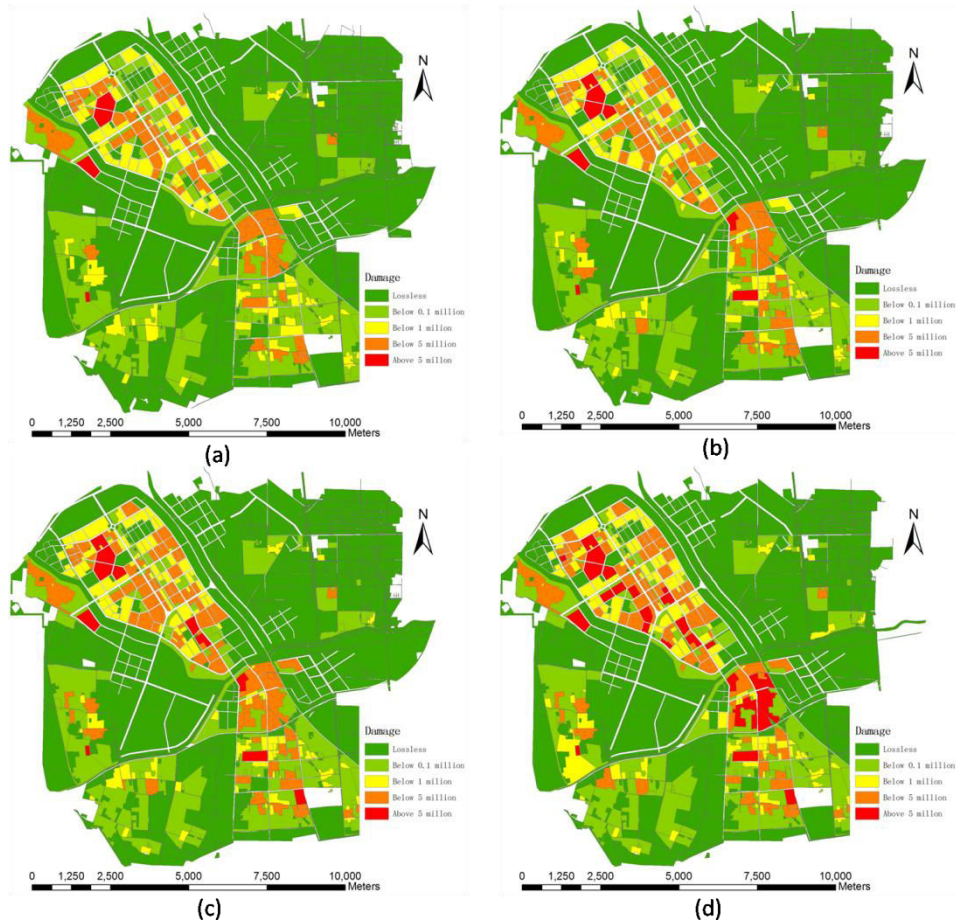


Figure 53: Building damage results of (a)10, (b)20, (c)50, and (d)100 year return period of rainfall events

The relationship of flood damage versus design storm frequency is shown in figure below.

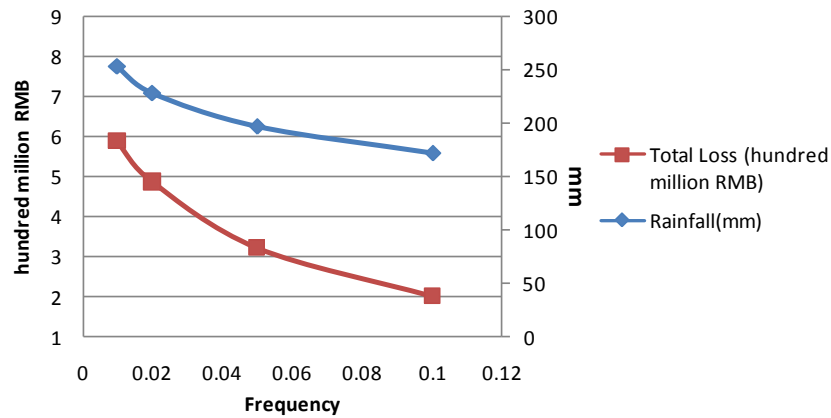


Figure 54: Relationship of flood damage versus design storm frequency Indirect tangible impacts

5.4.3 FRI Evaluation process utilizing the Flood Resilience Index (FRI)

For the calculation of the FRI, weights were assigned to each indicator having the following considerations:

- Natural indicators are assigned a weight of four.
- Volunteers and solid waste management are assigned a weight of three.

The weights are assigned after consultations with researchers at CAUPD in Beijing.

Two different states are considered: (i) the present state with present land use and (ii) future state at 2050 with projected land use and rainfall.

The results are presented in tables bellow with calculated values of FRI for each dimension.

Table 45: Scenarios for Beijing case study

Scenario	Time Horizon	Adaptation Measures	Scale	Land use	Socio-economic pathway	Climate change
Current state	Present	Existing status – no adaptation	District	Existing land use	Existing economy	Existing precipitation with 50 year return period
Scenario 1	2050	Retention areas	District	Projected land use in 2050	Existing economy	Projected precipitation for 2050 with 50 year return period

Table 46: FRI for present state, Yizhuang, Beijing China

	Indicators	Dimension index $\sum((x_i * w_i) / \sum w_i)$	"Importance" $\sum w_i / \sum w$	Overall index
natural	2	2.50	2.34%	2.48
social	10	2.55	11.11%	
economic	16	3.00	16.67%	
institutional	27	1.83	29.53%	
physical	36	2.72	40.35%	

Table 47: FRI for 2050 state, Yizhuang, Beijing China

	Indicators	Dimension index $\sum((x_i * w_i) / \sum w_i)$	"Importance" $\sum w_i / \sum w$	Overall index
natural	2	2.57	2.34%	2.46
social	10	2.72	10.70%	
economic	16	2.90	16.39%	
institutional	27	1.80	31.44%	
physical	36	2.73	39.13%	

5.4.4 Summary of results

The FRI evaluation for Beijing case study focuses on Yizhuang area. The FRI assessment is conducted for property, block and district scale.

The FRI values on building scale where urban functions are considered have a range of value from 0.71 to 4.95. A very low value of FRI is due to missing availability of evaluated requirement at certain flood depth. On the other side the value of 4.95 correspond to very small flood depths and high availability level of requirement.

For FRI calculation at district scale the developed matrix is used with 91 indicators. The calculation is done for two different states: (i) present and (ii) future 2050. The values presented in Table 46 and Table 47 shows two different values of FRI respectively 2.46 and 2.48. Very small difference is due to the fact that no measures included in evaluation. The considered change in land use is contributing to the increase of FRI for 2050 year. The conclusion can be that the land use planning which is a part of flood preparedness measures is contributing to increase of FRI for chosen area.

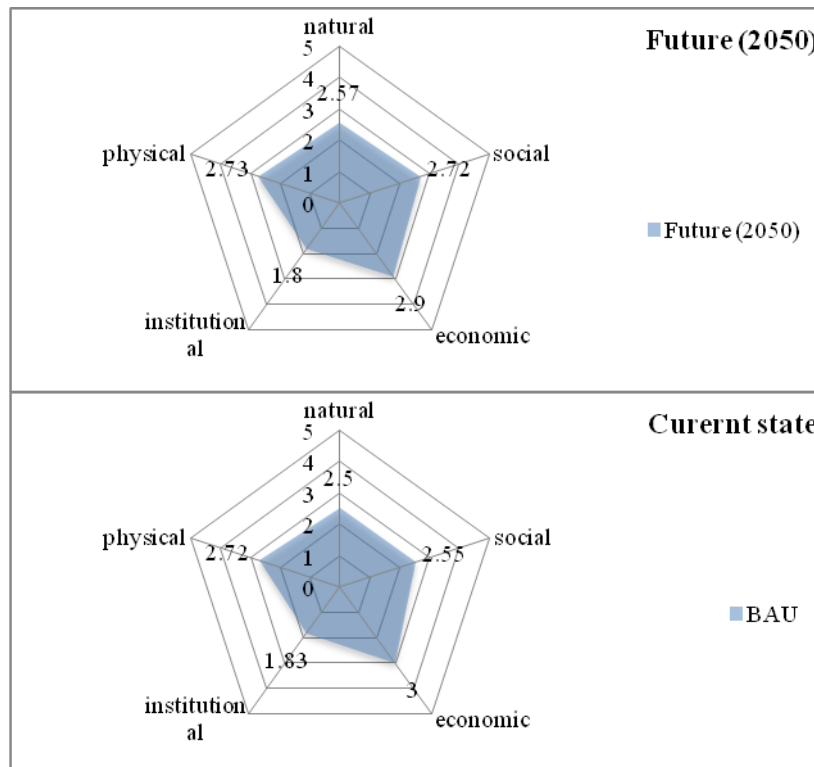


Figure 55: Comparison of all scenarios' overall FRI's per dimension

5.5 Barcelona

Barcelona has a population of 1,621,537 and a land area of 101.4 km² (15 980 inhabitants/km²). It is located in the northeast coast of Spain facing the Mediterranean Sea on a plateau bounded by the mountain range of Collserola, the Llobregat River to the southwest and the Besòs River to the northeast. The city benefits from a classic Mediterranean climate and occasionally suffers from heavy rainfall of great intensities, which cause flash floods. The yearly average rainfall in Barcelona is 600 mm, but the maximum intensity in 5 min, corresponding to a return period of 10 years, reaches 204.7 mm/h. Consequently, it is not rare that 50% of the annual precipitation occurs over two or three rainfall events. The morphology of Barcelona is characterized by high gradients (with an average of 4%) in areas close to the Collserola Mountain and flat areas near the Mediterranean Sea (with average slopes of 1%) (**Error! Reference source not found.**). This morphology produces flash floods in the bottom part of the city during heavy storm events. The city is subdivided into 31 catchments.



Figure 56: The location of Raval District in downtown Barcelona.

5.5.1 Hydraulic modelling

In order to represent adequately urban flooding generated by sewer overflows and to carry out a realistic flood risk assessment, it is clear the need of coupled approaches (modelling of the surface and sewer flows at the same time) (Phillips et al., 2005; Lipeme Kouuyi et al., 2008; Obermayer et al., 2010; Leandro et al., 2009).

a 1D/2D coupled model (2D for the analysis of the hydraulic behaviour of the ‘major system’ formed by streets, sidewalks, squares, etc. and 1D for the analysis of the ‘minor system’ formed by the sewer network), represents a powerful tool to describe, in a very realistic way, the hydraulic behavior of urban areas suffering flooding problems due to the excess of runoff not conveyed by the drainage networks.

In order to ensure good and detailed results, it is not sufficient to have a technologically advanced tool for the calculation concerning hydrological and hydraulic processes, but several other aspects must also be carefully considered, such as:

1. Detailed topographic data able to reproduce complex urban morphologies
2. Methodologies able to take into account flow interchanges between the two layers of drainage (surface and underground layers)
3. Rainfall and flow/flow-depths records for the adjustment of the model parameters in the calibration phase and for the results verification
4. Time series of the operations carried out by the sewer devices (variable sluices, pumps, etc.)

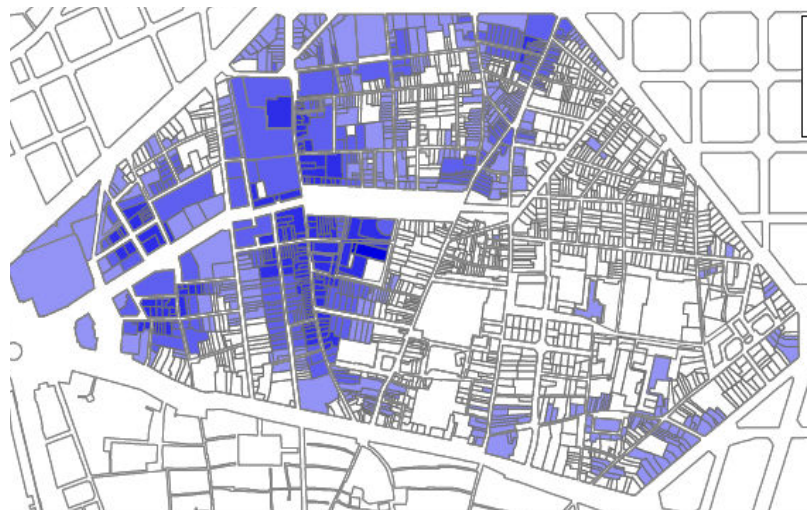


Figure 57: Flood depths inside the parcels of the Raval District for rain events with return period of 1 year (left), 10 years (center) and 100 years (right) for the Baseline scenario

5.5.2 Damage assessment

A good quality and precision of data is crucial when carrying out a micro-scale study. Consequently, regarding land-use, a GIS map has been developed using data from the local land registry at block level. As the flood typology in the case study area consists in flash floods producing low water depths and high speeds, only land-uses of the ground floor and basements have been added to the dataset.

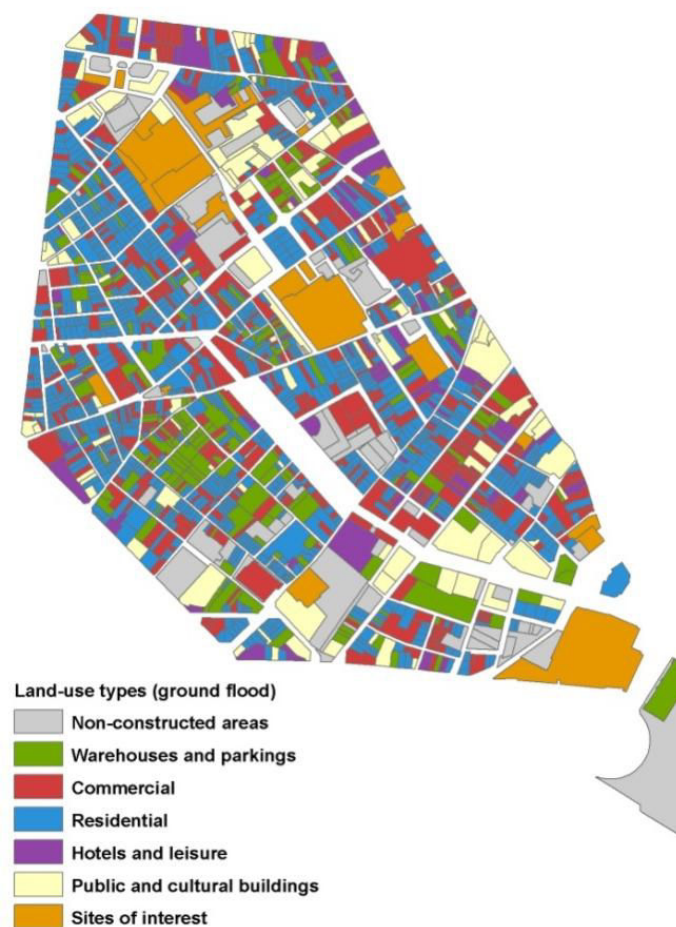


Figure 58: Land-use classes in the Raval district, the main land-use class of the ground floor is shown at a block scale

Depending on the information available and the goals of the assessment, there are several types of depth-damage curves (Merz et al. 2010). As in Barcelona there is a lack of historical damage data, and the building typology may be remarkably different from other regions previously

studied, following the recommendations of D3.3, it was decided to develop specific synthetic relative depth-damage curves for the city. The curves are used to obtain damage costs for a certain water depth relative to the extent flooded. Then, multiplying the obtained value by the affected area of the building, the damage cost at a block scale is acquired.

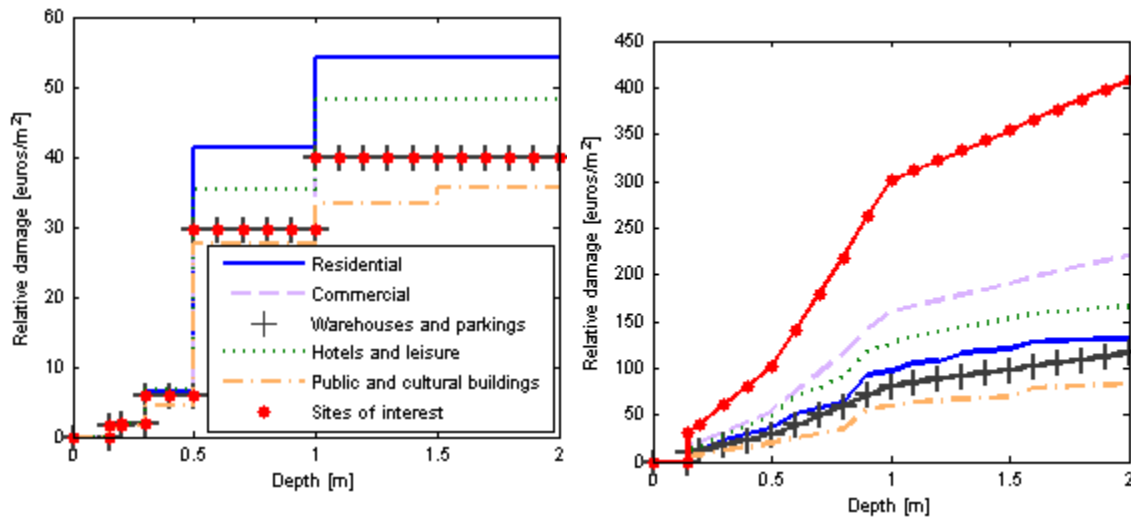


Figure 59: Depth damage curves for the buildings (left) and content (right) taking into account the local conditions of the Raval district.

The relationship between building and contents damages strongly depends on the type of land-use considered. Whereas in households the building damages tend to be higher than the contents' (Thieken et al. 2005), this trend is not so clear in other land-uses. In the case of commercial use, flood losses are highly variable due to the differences depending on the kind of business considered (Gissing & B Long 2004). Since the Raval district mainly has small and simple retail shops with many goods, the curves define the content damages up to five times greater than the building ones.

As damage is represented in each block, larger blocks will accordingly present larger damages (as the area flooded will be multiplied by the relative damage to obtain the total figure). This is something which should always be taken into account, because in general, the blocks presenting the highest damage values are also the ones with the largest areas.

Table 48: Damages and probabilities for the three synthetic rain events simulated.

Return period (years)	1	10	100
Probability	1	0.1	0.01
Damage (€)	78,846	1,615,738	19,156,196



Figure 60: Flood damages in the Raval district for a rain event of return period of 1 year (left), 10 years (centre) and 100 years (right).

5.5.3 FRI Evaluation process utilizing the Flood Resilience Index (FRI)

Three different return periods have been used, of 1, 10 and 100 years, to represent the most plausible flood situations in the area:

Flood hazard, vulnerability and risk concerning pedestrian circulation (the hazard values are calculated in each cell of the unstructured mesh that covers the streets, but the vulnerability and risk are obtained at the level of census areas)

Flood hazard, vulnerability and risk concerning vehicular circulation (the values are calculated in each cell of the unstructured mesh that covers the streets)

Flood hazard and damages concerning goods and properties (the values are calculated in each block).

In the following figures, several examples of the maps that have been created for different scenarios and variables can be seen. They are presented randomly, so an idea of all the things that have been assessed can be obtained.

Table 49: Scenarios for Barcelona case study

Scenario	Socio-economic	Adaptation	Future land use	Climate change
Current state	Increases from 2009 to 2050: GVA 81% Employment -6% Population -11%	No adaptation	Planned land use in 2050	Uplift factors (2009 to 2050): T=100 → 1.15
A1	Increases from 2009 to 2050: GVA 81% Employment -6% Population -11%	Only non-structural adaptation measures are implemented	Planned land use in 2050	Uplift factors (2009 to 2050): T=100 → 1.15
A2	Increases from 2009 to 2050: GVA 81% Employment -6% Population -11%	SUDS are implemented	Planned land use in 2050	Uplift factors (2009 to 2050): T=100 → 1.15
A3	Increases from 2009 to 2050: GVA 81% Employment -6% Population -11%	Structural measures (pipes and one storage tank are implemented)	Planned land use in 2050	Uplift factors (2009 to 2050): T=100 → 1.15

BAU scenario

Table 50 Assessment of the FRI in the Raval district for the current state scenario (2050)

Dimension	Indicators	$\sum w_i$	$\sum(x_i * w_i)$	Dimension index $\frac{\sum((x_i * w_i))}{\sum w_i}$	Weight	Overall FRI
Natural	2	10	35	3.50	4.67%	3.51
Physical	26	86	311.5	3.62	40.19%	
Social	8	24	78	3.25	11.21%	
Economic	11	32	122	3.81	14.95%	
Institutional	20	62	205	3.31	28.97%	

Adaptation scenarios

Table 51 Assessment of the FRI of the adaptation scenarios in the Raval district

Dimension	Adaptation1	Adaptation2	Adaptation3
Natural	4.25	4.00	4.50
Physical	4.09	3.74	4.33
Social	4.38	3.81	3.50
Economic	4.06	3.94	3.98
Institutional	4.19	3.80	3.60
FRI	4.15	3.81	3.98

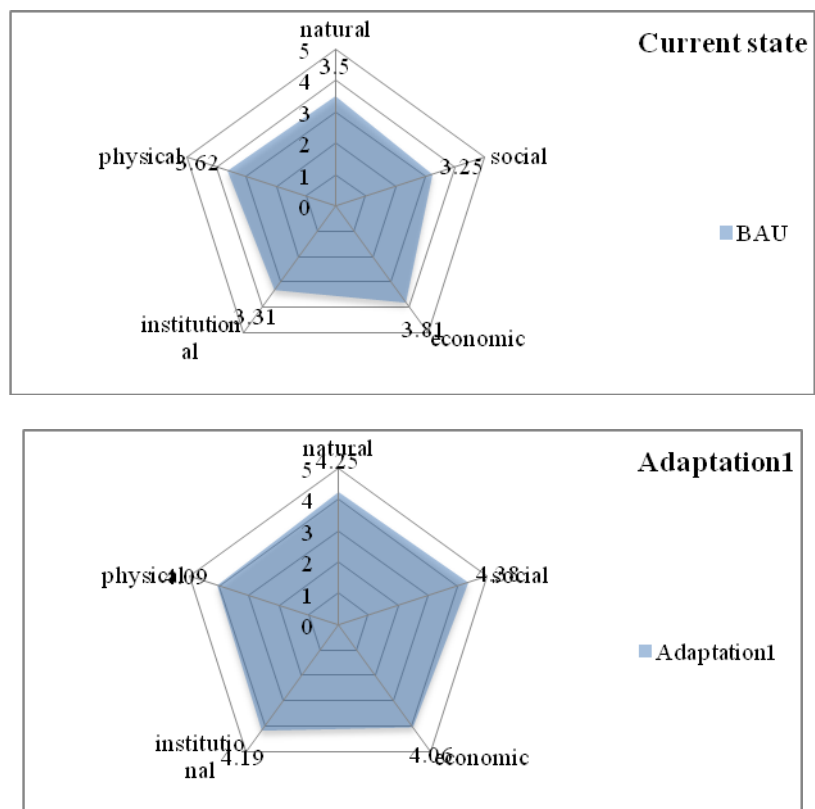
5.5.1 Summary of results

From the values that can be seen in the previous tables, it is clear that the several adaptation scenarios improve the resilience of the studied are with respect to the current state scenarios. The increases of the FRI values for the adaptation scenarios range between 4.5 and 21.4 %.

It is observed that the strategy that provides higher increases of the FRI is the one expressed in scenarios Adaptation 1 and 3. For this strategy, an EWS is implemented, as well as local

protection measures, education and awareness campaigns and the creation of a risk culture. This package of non-structural strategies mainly focuses on reducing the vulnerability. Consequently, although the hazard and hence the natural dimension is not as much affected as it is with other strategies, all the other dimensions are considerably improved, leading to FRI over 4 for all the situations (for the optimistic and pessimistic climate scenarios, and the two evaluations).

The structural strategies implying new pipes and one storage tank are the ones that have the second highest values of the FRI. In this case, the highest increases are shown in the natural and physical dimensions. This is so, because the classical structural strategies applied mainly focus on the hazard reduction. Finally, the SUDS are the strategies that have been considered that present smaller increases of the FRI. However, the FRI increases are around 10%, which means that their performance is still very good. This is explained by the fact that these strategies affect all the dimensions, but in a moderate way.



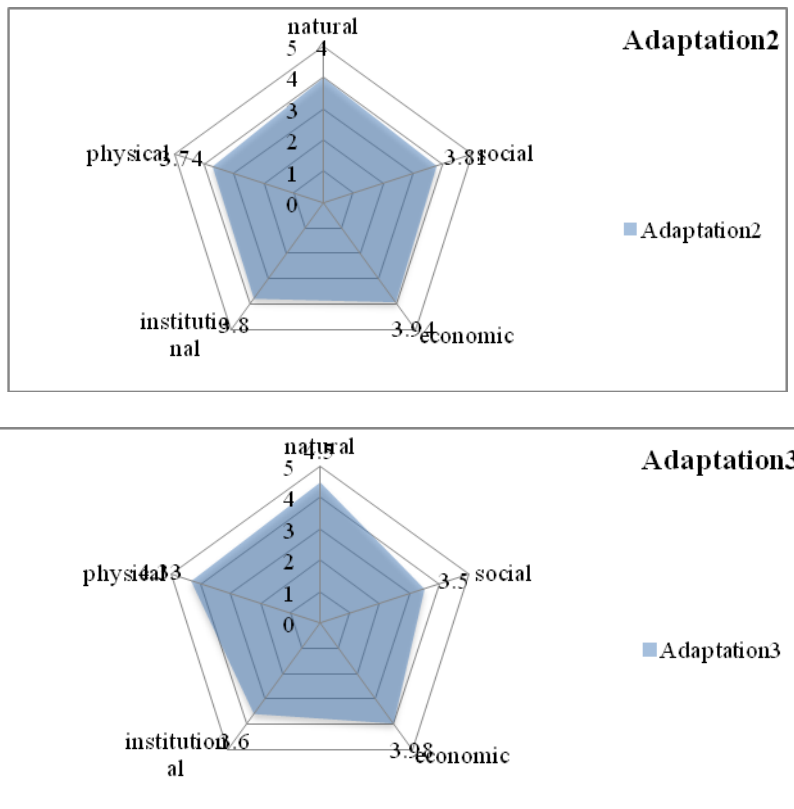


Figure 61 Comparison of the FRI values per dimension

5.6 Taipei case study

Taipei City is located at the downstream floodplain of the Danshuei River Basin. The Digital Elevation Model (DEM) of Taipei City shown in **Error! Reference source not found.** displays that the northeast region is mountainous with elevation above 400m, the southeast and south areas have few hills, and the northwest part is alluvial floodplain with elevation below 5m. The Danshuei River and its tributary, the Sindian River, flow along the west boundary of Taipei City. Another tributary, the Keelung River, passes through Taipei City from east to west and converges into the Danshuei River.

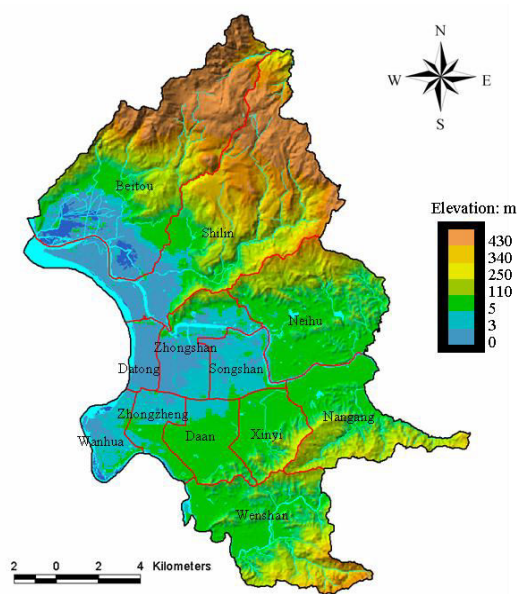


Figure 62: Digital Elevation Model, river system, and administrative districts in Taipei City

5.6.1 Hydraulic modelling

Parameters for model selection are usability, work flow, openness, flexibility and GIS integration as well as physical soundness, efficiency and stability of simulation engines.

The land area was extended from 83.6 km² to 272 km², however, the land zoning area for urban development planning of Taipei City show that only 134 km² is flat land suitable for urban development. The rest areas are covered by hills, slope land and low-lying land, which were not appropriate for evolution.

Figure below shows the hydraulic modeling result of the A1B climate scenario in the CTA for the future. For 10 year return period, the flood area increases from 101 ha (1.47%) of the baseline scenario to 134 ha (1.95%). And the deepest flooding depth rises from 2.2m to 2.7m. For 25 year return period, the flood area changes from 191 ha (2.77%) of the baseline scenario to 266 ha (3.86%). As for 100-year return period event, the flooded area and the maximum flood depth change from 385 ha (5.58%) and 4.1m of the baseline scenario to 548 ha (7.95%) and 4.31m, respectively. For 200-year return period event, the flood area increases from 526 ha (7.63%) of the baseline scenario to 730.9 ha (10.6%) and the maximum flood depth changes 4.3m to 4.5m.

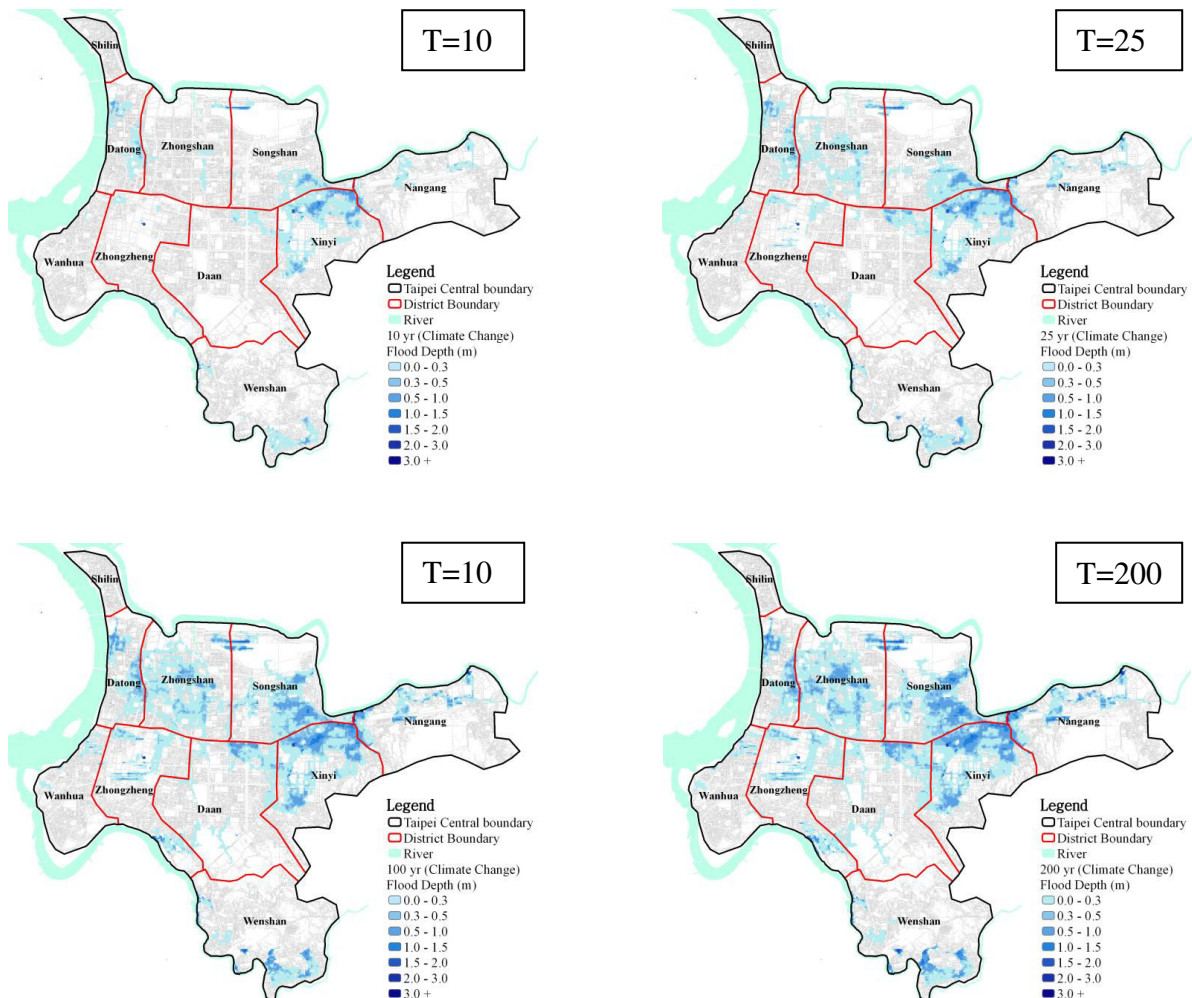


Figure 63: Flood modelling results of the A1B scenario in the CTA

5.6.2 Damage assessment

The hazard information was obtained via hydraulic modeling. The land uses data were obtained from the government database as shown in figure below.

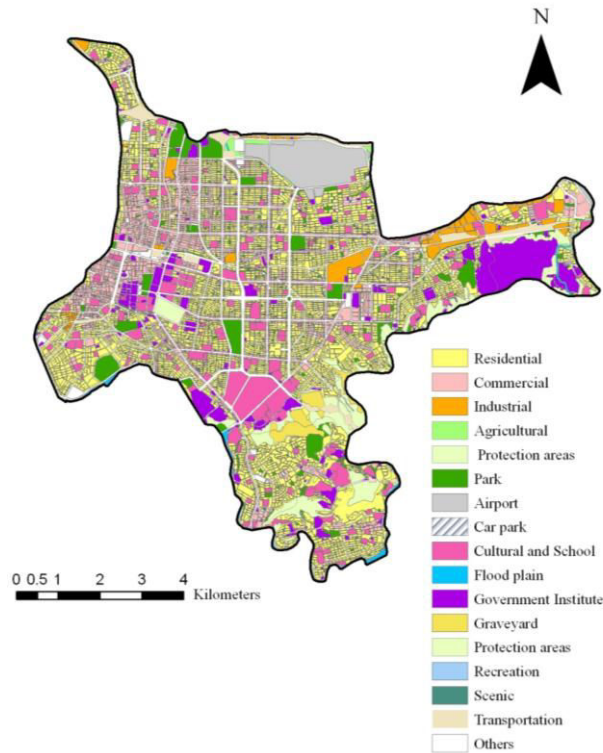


Figure 64: Land zonings in Taipei City.

For the depth damage relationships, we considered that human activities, which are related to the types of land use, are the major factor that affects the level of loss once a flooding is occurring. Wang (2003) collected the data of a field survey from the flooded areas in Taipei city, and of flood loss claims for tax relief from the government revenue office after a major typhoon event in 2001. Wang associated the damage information with the land use types, which were classified into residential, commercial (retailer, service), industrial (manufacturing, wholesaler) and cultural zones, and developed the DDCs as shown in figure below.

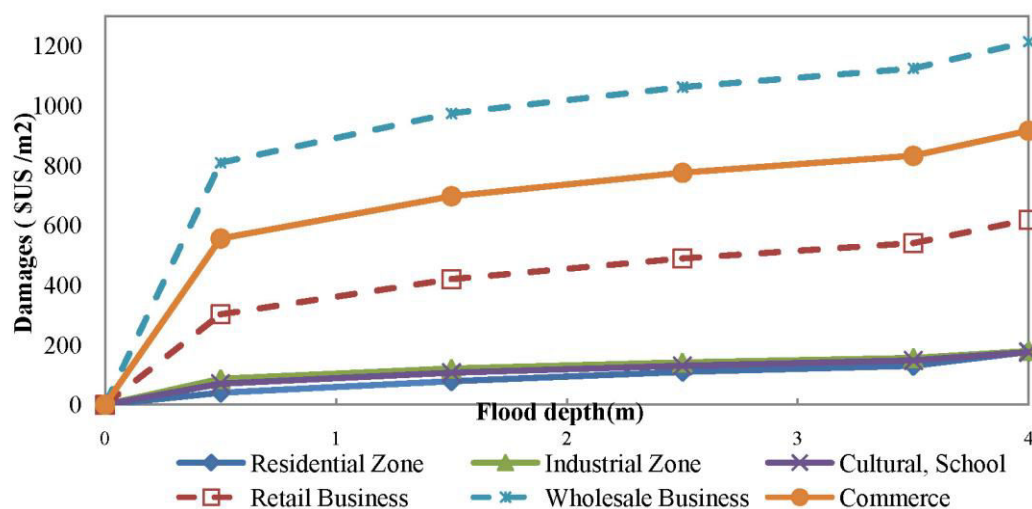


Figure 65: Depth-damage curves for residential, commercial, industrial and cultural zones in Taipei City (Wang 2003).

Result of damage assessment is shown in the figure below. The total flood damage for 10 year event is 21 million USD and most of them occur in Xinyi district. The damage increases to 42 million USD for 25 year event. For 100 year event, more districts including Datong, Zhongshan, Songshan and Xinyi are serious flooded and the total damage in the CTA is 87 million USD. For 200 year event, Datong, Zhongshan, Songshan and Xinyi districts have the worst damage and the total is 114 million euros.

Table 5-52 Average expected annual damage assessment in CTA

Return period (year)	Flood damage (million eur)
100	86.85

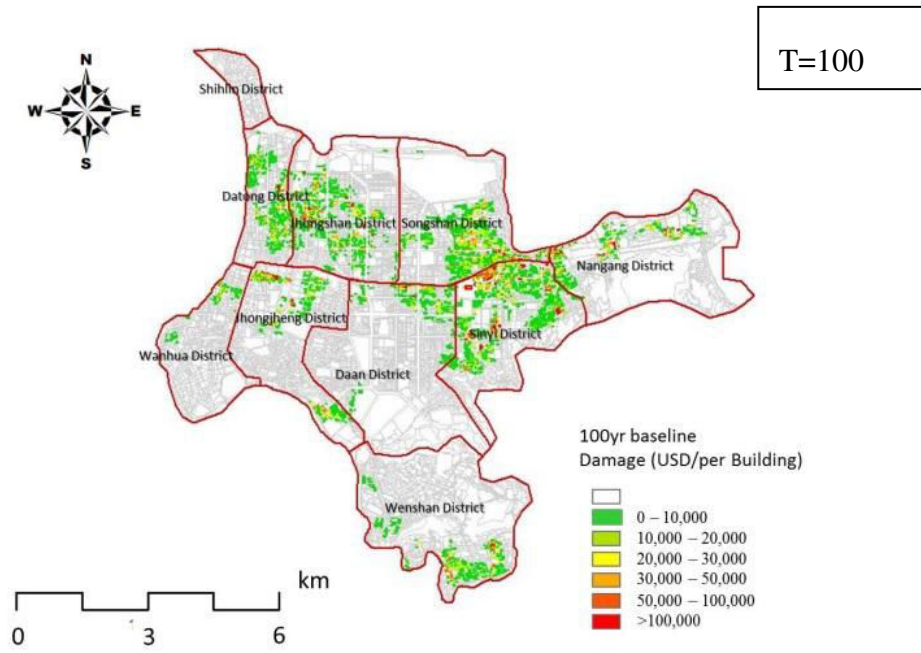


Figure 66: Pluvial flood damage in the CTA of 100 year return period under the baseline scenario.

5.6.3 FRI Evaluation process utilizing the Flood Resilience Index (FRI)

The simple description of scenarios are considered:

- Baseline: is present state, no mitigation measure in this state.
- A1B: future state (2039 year), also no mitigation measure in this state.
- Adaptation 1: future state (2039 year), with mitigation measure (increases water retention) in this state.
- Adaptation 2: future state (2039 year), with mitigation measure (increases water retention and reduction of vulnerability) in this state.

Table 53: Scenarios for Taipei case study

Combined scenario	Climate change scenario	Time horizon	Socioeconomic scenario	Adaptive capacity
Baseline	None	Present	None	None (existing status)
Future	A1B	2039	Medium growth pathway of population	None
Adaptation 1	A1B	2039	Medium growth pathway of population	Increase water retention
Adaptation 2	A1B	2039	Medium growth pathway of population	increase water retention and reduce the social vulnerability

No matter the natural, social, economic, institutional and physical, the data analysis is difficult to collect and insufficient in Taipei city. Hence, here is one scale in this project-city scale.

The data and information (drainage systems, pumping station, flooded maps and vulnerability maps et.) are used to evaluate the different scenarios flood risk in the city. The simulation of 10-, 25-, 100-, 200-yr return period maps is produced.

For the case, the calculation of the FRI is based on the baseline (present state), assuming there is no mitigation measures (including increase water retention and reduction of vulnerability that measures are provided by Taipei case team) being implemented.

Table below shows there are 91 indicators of Flood Resilience Index, several FRI indicators were not considered due to the lack of information. Following indicators from evaluation matrix (Annex B) were not included due lack of information:

- 2 indicators from the social dimension including involvement, support and informal coordination with people;
- 10 indicators from the economic dimension, mostly related to insurance;
- 5 indicators from the institutional dimension, mostly related to rescue equipment and plans that to be implemented; and
- 12 indicators from the physical dimension about mainly real-time monitoring system and adaptation regulations.

Table 54: The indicators of FRI are considered for baseline scenario, Taipei case study

	Natural	Social	Economic	Institutional	Physical
All indicators	2	10	16	27	36
Baseline	2	8	6	22	24

After assigning values to each indicator with respective weights, the Taipei city FRI was calculated. Table 3 provides an overview of the FRI for each dimension and overall FRI for city scale. The result of the FRI under baseline (present state) conditions was of **3.05**. That's means medium flood resilience in urban, integration and implementation of solutions is higher as follow in Table 4, but the mostly problem is low economic dimension in Taipei.

Table 55: FRI for the city/district scale of Taipei case study

	$\sum w_i$	$\sum(x_i * w_i)$	Dimension index $\frac{\sum(x_i * w_i)}{\sum w_i}$	FRI
Natural	10	35	3.50	3.05
Social	28	94	3.36	
Economic	37	63	1.70	
Institutional	66	238	3.61	
Physical	97	297	3.06	

The FRI values for the different scenarios are calculated and the percentage of change with respect to the baseline is also calculated, the results are presented in Table 56.

Scenario A1B affects 2 indicators of the 62 indicators used in the baseline scenario, adaptation 1 scenario affects 6, and scenario adaptation 2 affects 8 indicators. The lower FRI value for baseline scenario, due to no mitigation in this scenario, only consider the present state including land-use, plans, installation et. Some indicators are being implementing in baseline scenario, but will be completed in future (2039). For A1B scenario (2039 year), the difference is the heavy rainfall higher than sufficient capacity for rainwater drainage, also no mitigation in this scenario. In Adaptation 1 scenario, increase any physical dimension including water retention to reduce flood hazard. For Adaptation 2, obtained the best value (**3.40**) in terms of FRI due to there is not only improvement in increases water retention, but also evacuation, increase the flood safety (social shelters) to reduce the vulnerability. Hence, the FRI value in Adaptation 1 and 2 are higher than other scenarios. The scales for FRI are presented in the table below:

Table 56: FRI values for all scenarios and the percentage of change with respect to baseline scenario in comparison.

Scenarios	Baseline	A1B	Adaptation 1	Adaptation 2
FRI	3.05	3.02	3.32	3.40
Δ FRI (%)	-	-0.81%	9.11%	11.62%

In A1B (future, 2039 year), assuming the natural, social, economic and institutional as the same as current state (Baseline), only considering the capacity for rainwater drainage is insufficient. Adaptation 1 and 2 are having mitigations in future, 2039. Hence, the FRI value oscillating from -0.81% to 11.62% of the change from the baseline scenario. The mostly change are social, institutional and physical dimensions. In social dimension, Adaptation 1 and Adaptation 2 having a change of 12.77%, due to the all social indicators are considered. In institutional dimension, Adaptation 1 and Adaptation 2 are having the same change of 6.30%. Followed by the physical dimension which fluctuates from -4.04% to 36.36% (A1B to Adaptation 2 scenarios).

In general, the main difference is some indicators of physical dimension are considered they will be completed in future (except A1B). Adaptation 1 was compared with Adaptation 2, the different points are Adaptation 2 having emergency evacuation routes, availability and implement ability of adaptation regulations of adaptation regulations, although only two indicators to impact, the weight of them are high importance. Each dimensions for FRI are given in the table below, and the Figure 67 presented the graphical of FRI.

Table 57: FRI for the city/district scale of Taipei case study

	Baseline	A1B		Adaptation 1		Adaptation 2	
	FRI	FRI	Δ FRI (%)	FRI	Δ FRI (%)	FRI	Δ FRI (%)
Natural	3.50	3.50	0.00%	3.50	0.00%	3.50	0.00%
Social	3.36	3.36	0.00%	3.79	12.77%	3.79	12.77%
Economic	1.70	1.70	0.00%	1.70	0.00%	1.70	0.00%
Institutional	3.61	3.61	0.00%	3.83	6.30%	3.83	6.30%
Physical	3.06	2.94	-4.04%	3.79	23.91%	4.18	36.36%

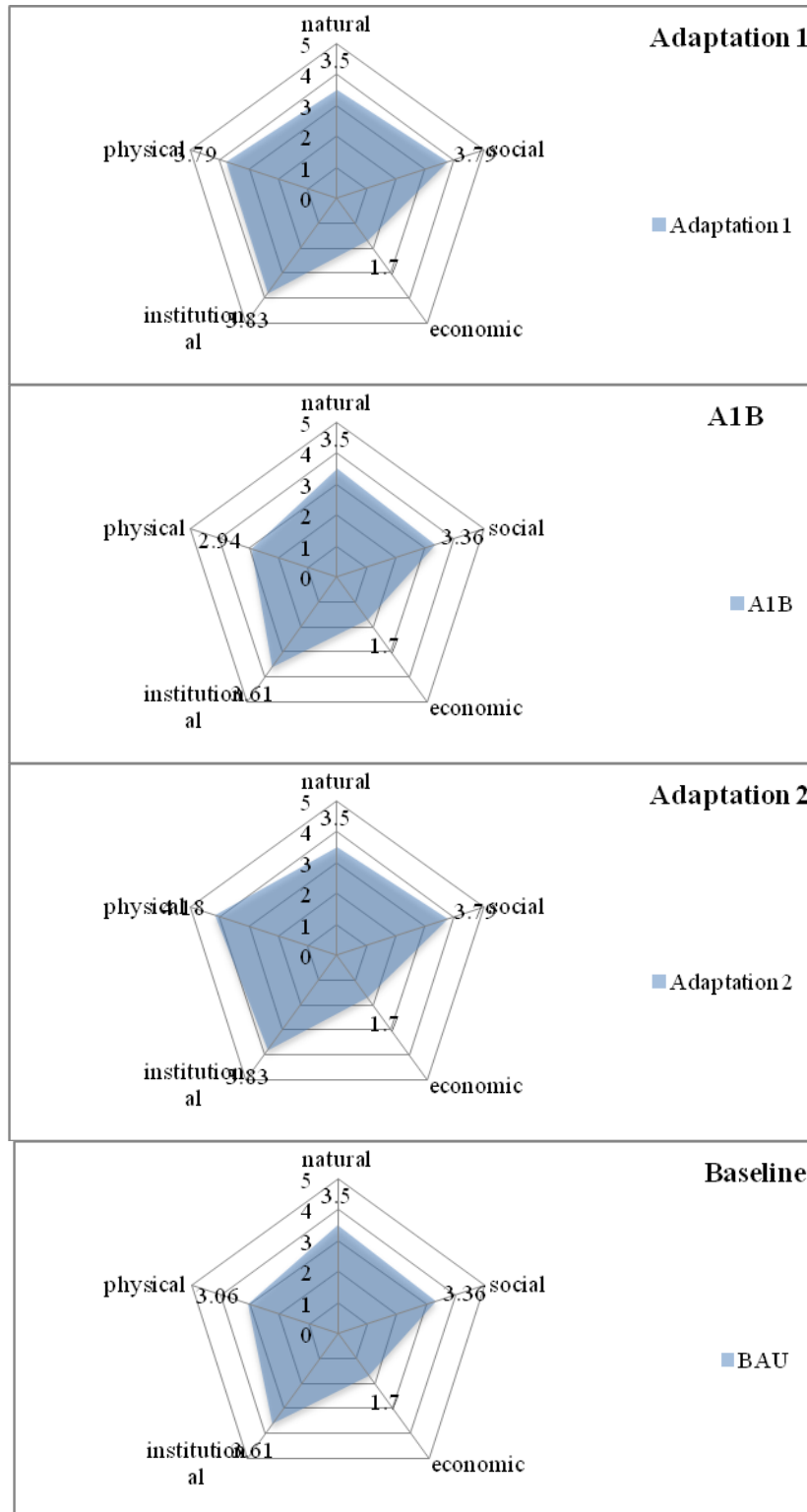


Figure 67: Graphical FRI presentation for Taipei case study

5.6.4 Summary of Results

Because of there have lack of information to be analyzed in Taipei case, only apply the FRI on city scale and not compared with other scales. It is difficult to know how the effect of result in other scales. The four scenarios were chosen and analysed for the city scale, Baseline and A1B have no measures; Adaptation 1 and Adaptation 2 have mitigation measures. In general, the implementation of the mitigation measures on the scenarios improves the FRI value.

Overall, of the FRI's for each scenario on city scale is medium and has subtle change. The results for overall FRI have the value of 3.02; the FRI of Baseline is 3.05; Adaptation is 3.32; and Adaptation 2's FRI value is 3.40. However, the Baseline also has not considered measures either, but the flood hazard of A1B is seriously, than Baseline. It should be noted if no measures to reduce or adapt the flood happened that scenario might not be as flood resilient, should more pay attention to them.

From the dimensions point of view, the economic dimension is the lowest under all scenario because the insurance is difficult to performed and the lack of information in Taiwan. The FRI values for other dimensions are higher than 3. Adaptation 2 scenario presents the best value (4.18) for the physical dimension (Baseline, A1B and Adaptation 1 got the value of 3.06, 2.94 and 3.79 respectively), thus the shelters and retention are considered to be increased and other indicators of measures will reduce vulnerability in this scenario.

This is depend on the management select different plans, scenario even return period to determine the effect by flood since the FRI at a different scale can significantly reflect the flood resilience in urban area. If the implementation of a set of measures, this is important to improve economic dimension in Taipei case.

5.7 Conclusion

Based on presented evaluation of five cities in Europe and Asia the following conclusions can be drawn:

- Urban systems in the case studies differ significantly. The differences are marked within different areas, climate, flood type, land use development, priority highlighted for FRM.
- The indicator values from case study areas differ and can be explained with the different level of risk awareness, risk culture and risk perception.

- the different measures chosen for evaluation of FRI depend on flooding type used in analysis and in the foundation of existing and projected (future) FRM frameworks in case study areas.

6 Discussion, conclusions and recommendations

6.1 Assessment

The synthesis of research on flood resilience in urban systems and interaction with FRM presented in this thesis takes a qualitative approach. The benefit of methodologies developed the previous chapters and application on different cities in Europe and Asia give a possibility to make critical assessment and suggest further research and implementations.

At the beginning of thesis following objectives were made:

- Is there a method that can evaluate existing flood risk management taking into account different level of content within FRM and different implementation status?
- How flood resilience of urban systems can be evaluated taking into account its characteristics?
- What are differences in resilience between different urban systems?

6.1.1 Specific objective 1

The concept of evaluation of maturity of different FRM frameworks is developed and presented in chapter 2. The maturity method for FRM requires specific view on with segregation of main elements in flood risk: (i) hazard, (ii) vulnerability and (iii) exposure. In this context the FRM evaluation becomes more tangible with possibility to evaluate, compare and decide the future development of FRM.

- The criteria provide a possibility to explore flood risk management frameworks, their integration, implementation and readiness level.
- The readiness level then gives a possibility to go towards achievement of resiliency.
- Results provide identification of weak points in existing flood risk management frameworks. The evaluation that is taking into account elements of risk (hazard, exposure and vulnerability) segregated into separate components gives possibility to map the weak points in existing frameworks. This is important in many ways:
- It is providing better understanding of a concept
- Becomes more visible what strategies and measures should be part of FRM. This is important in a way that no decision for example on the local level regarding flood protection cannot be made if it is not in line with the current FRM

6.1.2 Specific objective 2

The developed method for FRI demonstrates that flood resilience of urban systems can be evaluated. Within developed method the system approach is used where urban system is analyzed through its elements (urban functions and services) and by its evaluation the level of functioning is expressed through resilience level. Again the evaluation of resilience becomes more tangible and by describing the state of the system before and after event it is possible to determine the level of change (adaptation or not) in system functions. The developed methodology follows different spatial scales and by that there are two different evaluation methods. For the micro and meso scale the focus is on the single system element. Here, the focus is on the element functions during and after event. The FRI evaluation for macro scale and here its district and city scale looks at the urban system through five dimensions and evaluate through set of indicator level of functioning of a whole system.

6.1.3 Specific objective 3

Differences between urban systems analyzed in this thesis differ in many ways. Differences in case study areas start form different institutional organization. The priority made in the existing FRM frameworks differs in Europe and Asia. The level of urbanization and level of available assets in the analyzed cities is not the same. This contributes to different level of disturbances made during and after flood and make reflection on flood resilience in urban systems. A very important thing is existing risk culture among analyzed areas. The level of economic preparedness differs and it is noticeable that even there are available financial resources for example in Beijing the social level of community is not high. This is not the case in Taipei.

6.2 Recommendations

As mentioned the developed method for maturity and FRI should contribute to increased involvement of key stakeholders in the decision making process. The current situation regarding a place of stakeholder in the decision making process focuses on different spatial levels and stages which is good, but there is a still of disconnection among stakeholders. Stakeholders engage process should evolve in response to the government and its decision to achieve better efficiency in flood risk management decision-making process. The rise of community engagement looks for a rethinking of how the view of stakeholder can be much better involved in decision-making. A stakeholder participation process is a complex. The differences between stakeholders and their interest within flood risk management planning do exist. The engagement process of different stakeholders considers participation and consultation. These two terms are describing stakeholder participation process.

There are different ways of stakeholder participation, or a different ways how stakeholders can be involved in decision making process (Foti, et al. 2008).

(i) Information sharing - this type of engagement is defined as a one-way process. This means that information's are flowing from government to public or to public to government. The good example is the measure 'capacity building of hulan resources', where the information sharing considers the information material regarding flood risk is given to the population.

(ii) Consultation - a both way process. This is defined as an interaction between the government for example and the different stakeholders. The feedback exist in the decision making process. This is done throughout meetings, public debates, etc.

(iii) Collaboration - the process where one of collaborator is initiating the meeting but preserves the power of decision making.

(iv) Joint decision making - here the collaborator is sharing the control over decision making.

(v) Empowerment - the opposite direction of decision making where the collaborator is transferring the control over decision making to the stakeholders.



Figure 68: Stakeholder involvement in decision-making process

As mentioned the decision making process is very complex. From the decision makers side the lot of different characteristics of stakeholders have to be considered in the process of stakeholder engagement. Of course, the different stakeholder groups will have different relationship considering the decision a decision maker. There are many engagement challenges in this process. The starting point is to identify the stakeholders. Stakeholders are individuals and groups that have an interest in flood protection, flood safety and development. One of the approaches of grouping stakeholders is:

- Government or public sector - depending of the case study area it is central or federal, state/regional or provincial/ district, and municipal level institutions and dependencies;
- Civil society (not for profit): NGOs, universities, research institutes, civil society, worker/trade unions, community organizations, and organizations that represent women, youth, and other vulnerable groups;
- Private sector (for profit): firms, associations, organizations, cooperatives, and individual proprietors, such as banking, transport, industry, marketing, professional and media services;
- Rights-holders: property owners, communities or individuals in land or resources possession that will be impacted by the decisions being made.

In order to have the proper information shared with stakeholder the proper steps should be made in order to understand the priorities of the stakeholders.

Beside the involvement of key stakeholders the developed methods should be part of safety chain in flood risk management cycle and may signify the link between stakeholders and decision makers.

6.2.1 FRI – limitation, future development and improvement

Limitations of the proposed index

In this study, we developed flood resilience index with ability to objectively assess all indicators. The outcome indicators are developed from actions in flood risk management cycle. The flood resilience index still depends on some assumptions. The proposed measurement of indicators relies on weights (assign for each indicator). Some limitations related to providing a quality measure of the process are possible since weights are used to intensify the scores in the assessment. The use of weights should be done with precaution in order to prevent an essential loss of information. Using weights can hide a relevant characteristics regarding FRI evaluation. This is because they alter the importance of indicators. On the other hand, FRI method is created to be used by decision makers and of course, they should have a different understanding about the importance of indicators.

Future development of FRI

The flood resilience concept brings a new philosophy to urban systems, ‘living with floods’. The approach transforms the existing structure of urban system and creates a system that is accepting the water with minimal damages, system that is able to recover in a minimum period and system that is able to have a certain level of functioning during the flood.

The imperative is to acknowledge the importance of social, institutional and economical component when managing flood risk. The Flood Resilience Index (FRI) represents a tool for stakeholders and decision makers. Different weights in matrix for evaluation FRI on the city / district scale highlights the most important variables that are contributing higher level of resilience for the certain case study area.

Improvement

The resilience of a system could be improved by using diverse regulations such as institutional, urban planning and design, architectural design, public participation, financial stimulation, etc. Most of flood risk management (FRM) strategies are based on historical events by depending on resistance measures. Currently the focus is on minimizing the consequences of flooding where

flood risk management strategies are based on concept ‘living with floods’. Urban communities are moving to the risk culture and accepting the resilience. This trend of development in resilience evolution is graphically presented in Figure 69.

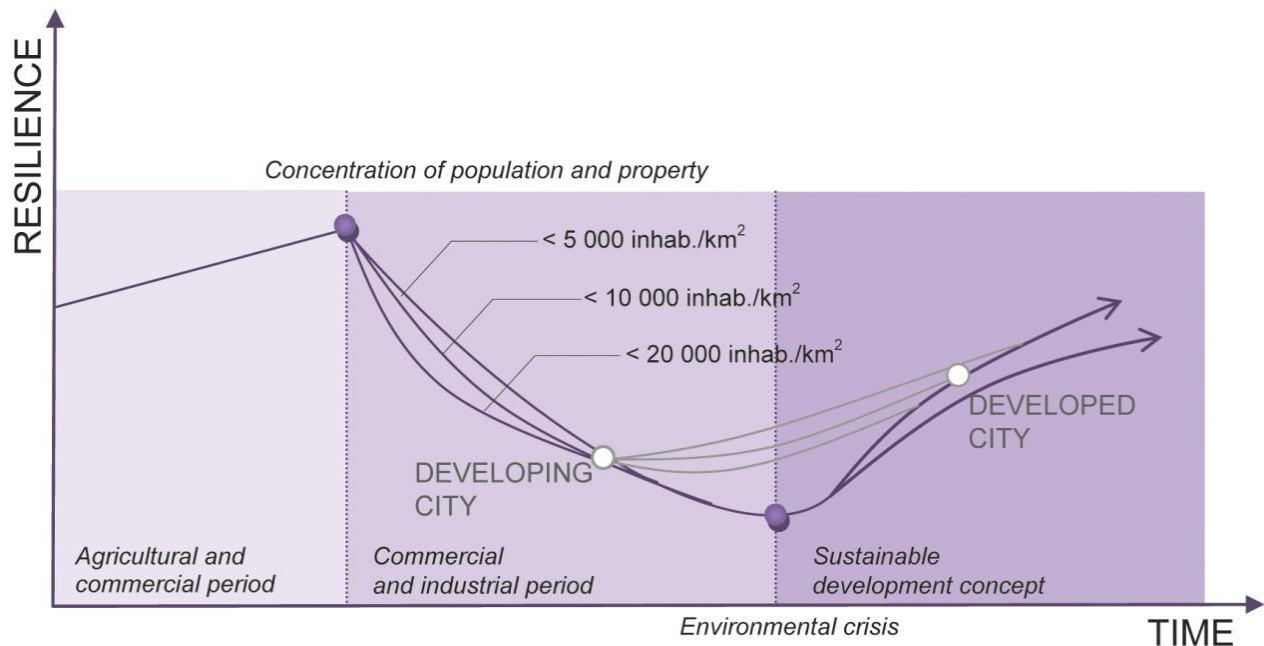


Figure 69: Evolution of flood resilience curve in theory

The presented flood resilience curves for urban system highlight the nonlinear characteristic of the whole resilience concept. This theoretical curve tends to present how development of urban system has influenced flood risk.

It starts with agricultural age where the resilience is constant due to no significant development of assets, landscape and concentration of population. With the beginning of industrial time, the changes in the landscape become significant. The assets become more sophisticated which contributes to higher concentrations of people. The structure of urban system starts to change and big challenges are posed to original landscape. Flood risk starts to increase and strategies were developed to reduce flood frequency and flood hazard. The theoretical curve is presented in Figure 69. The expansion of urban landscapes on behalf of environment started to be more dominant. The flood vulnerability becomes higher and the urban communities realized that the way forward is in increased flood resilience. The risk culture is introduced to urban communities and they move to resilience concept.

6.2.2 Sensitivity analysis

The development of a new tool that should be used by a decision makers without any engineering experience and due to the nature of work in some cases do not have wide picture regarding new flood risks that are posed to urban communities it is a challenge to meet all objective conditions. For the purpose of security in the results, the sensitivity analysis is conducted. The example is done within analysis of Barcelona case study. The evaluation of FRI on case study scale done with the matrix (ANEX B) is given to two different “evaluators”. Both evaluators have different decision making experience and were able to fill up the matrix and get the value for the FRI. The results are presented in the tables below.

Table 58: Assessment of the FRI by “Evaluator #1” in the Raval district, Barcelona

Dimension	Indicators	$\sum w_i$	$\sum(x_i * w_i)$	Dimension index $\frac{\sum((x_i * w_i))}{\sum w_i}$	Weight	Overall FRI
Natural	2	10	35	3.50	4.67%	3.51
Physical	26	86	311.5	3.62	40.19%	
Social	8	24	78	3.25	11.21%	
Economic	11	32	122	3.81	14.95%	
Institutional	20	62	205	3.31	28.97%	

Table 59: Assessment of the FRI by “Evaluator #2” in the Raval district, Barcelona

Dimension	Indicators	$\sum w_i$	$\sum(x_i * w_i)$	Dimension index $\frac{\sum((x_i * w_i))}{\sum w_i}$	Weight	Overall FRI
Natural	2	10	35	3.50	4.41%	3.76
Physical	28	94	357	3.80	41.41%	
Social	8	24	114	4.75	10.57%	
Economic	11	32	128	4.00	14.10%	
Institutional	22	67	220	3.28	29.52%	

According to “Evaluator #1”, scenario affects 11 indicators of the 67 used in the baseline scenario. On the other hand, “Evaluator #2” introduced changes in 22 indicators for scenario. The calculated difference in the estimated values for FRI is 5.76%. With this the general conclusion is that the sensitivity analysis shown that the developed methodology is not very sensitive on different evaluators.

6.2.3 Final conclusion

In conclusion, the importance is in the possibility to use experience from flood resilient urban systems and avoid huge flood damages and dysfunctions. The developing urban systems can find a good practice and good paths towards flood resiliency without reaching a low level of functioning.

The urban flood resilience methodology brings a new light on existing flood related problems that are urban communities face nowadays. Furthermore, this concept brings better analysis of urban flooding processes. As presented, the new analysis of urban systems is developed. The urban systems presented a set of functions and services with addressed outputs. This is critical in mapping of urban areas that are in flood risk.

The traditional flood risk management approaches focuses on implementing existing sets of measures on a city scale while assessment on district, block and individual scale is not dominant. Therefore, the necessity of implementing the spatial scaling of urban systems contributes to allocation of resources to needed areas.

The methodology presented within this thesis shows that flood mapping can be done in respect to urban functions. Flood resilience measures increase the involvement of population in flood management on a city level. Finally, urban communities are slowly leaving the ‘zero myth’ that is bringing a false sense of protection and they are now moving to risk culture and accepting the resilience concept ‘living with floods’.

The resilience assessment is a challenging task and calls for involvement of all key stakeholders. Also, as presented the resilience have five dimensions that have to be evaluated in order to make an evaluation. The dynamic characteristic of resilience challenges the urban flood management and therefore the flood resilience measures should be implemented in order to reach an acceptable level of flood resilience of urban systems.

The traditional flood risk management is based on resistance strategies. Within thesis, the resilience strategies are presented along with resilience measures. Flood resilience measures increase the involvement of population in flood management on a city level.

The urban flood resilience methodology brings a new light on existing flood related problems that are urban communities face nowadays. Furthermore, this concept brings better analysis of urban flooding processes.

The approach presented in this thesis is based on functional analysis and provides a better presentation of urban systems. The urban systems are presented as a set of functions and services with addressed outputs. Based on the developed method that evaluates the specified resilience (flood resilience) the Flood Resilience Index gives specific property of each element. Presented method is critical in mapping of urban areas that are in flood risk.

The imperative is to include stakeholders in the decision making process. The Flood Resilience Index (FRI) is a tool, which is meant to be used by stakeholders. Different weights in the matrix for evaluation of FRI on the city / district scale highlights the most important variables that are contributing higher level of resilience for the certain case study area.

In this perspective, resilience of a system could be improved by using diverse regulations such as institutional, urban planning and design, architectural design, public participation, financial stimulation, etc. Most of flood risk management (FRM) strategies are based on historical events by depending on resistance measures.

Facing on increasing impervious urban surface and irregular climate events, implementation of resistance FRM strategies could not satisfy expectation of urban inhabitants. Those strategies were mainly for the reduction of flood hazard and frequency of flood. The weakness of these strategies is that areas are protected with the same level without knowing which areas will be flooded first.

As a future research FRI could have integration within decision making processes on local level providing the vital information's to stakeholders and assisting them in increasing resilience having in mind dynamic character of flood resilience.

A FRI provides a holistic approach in evaluating resilience, As that, further steps are to implementation of measuers that are contributing increased flood resilience

7 Annexes

Annex A

BARCELONA, SPAIN

Chosen flood event

Type of flood: Flash flood caused by heavy rainfall

Date: 22nd October 2009

Duration: several hours

Highest rainfall intensity recorded: 108 mm/h

Highest water level in urban area: 0.25 m - 1 m (in Raval district)

Flooded area: several underground metro station and streets

Loss of human life: -

Estimated total amount of damage: -

Nonstructural measures

- **INUNCAT**: Plan elaborated to operate in case of strong storms and intense precipitation episodes (flood episodes)
- **PAMs** (Municipal Actuation Plan, in Catalan “*Plans d'actuació d'emergència municipal*” PAEM), disaster crisis management plan.
- Barcelona flood PAM
- The Master Drainage Plan development (following MDP) is composed of the following systems.
- Technological Systems for aid-decision implementation:
- Territorial Information System (SITE)
- Mathematical Modelling System (SIMO) and integrated mathematical modeling system
- Real Time Control System (SITCO)
- Integrated Master Drainage Plan, commonly known as PICBA06 (Pla Integral Clavegueram de Barcelona) (CLABSA, 2006) consists above systems.
- Geographic Information System (following GIS)
- Modeling System (in terms of water quality and quantity), including the sewer network, the WWTP and the receiving waters.
- Remote and Real Time Control System, operating 11 detention tanks, 21 pumping stations and 36 gates, receiving information from next to 200 sensors, including radar information and short term forecasting system.
- CLABSA Control Centre management plan

- Specific tool to forecast and warn of real-time flash floods in urban areas (HIDROMET)

Recorded dysfunctions during chosen flood event

The last flooding event which occurred in the Raval District was produced by the storm event of 22nd October 2009. Pluviograph CL24 is the nearest raingauge to the Raval District and recorded a rainfall intensity of 108 mm/h for of 5 minutes, 95.1 mm/h for a duration of 20 minutes and 45.2 mm/h for a return period of 45.2 mm/h. These values correspond to a return period of 3.9 years for the 20 minute intensity, and to a return period of less than 1 year for the 5 minute intensity.

An internal report on the event was prepared by CLABSA. This event could be used for the validation of the future model used in the CORFU project. The report described flooding problems in the following areas:

- Parallel Avenue (between Aldana Street and Sant Pau Street) with flow concentrated on the left side of the roadway (side close to Raval District);
- Ronda Sant Pau Street (between Aldana Street and Sant Pau Street);
- Road cross among Parallel Avenue, Ronda Sant Pau Street and Sant Pau Street.

According to the descriptions provided by several inhabitants and employees of this area, flow depths reached 75-100 cm in the gutter on the left side of the roadway and approximately the 70% of the total amount of runoff is conveyed through Sant Pau Street.

San Pau Street is subdivided into 3 stretches:

Stretch between Parallel Avenue and A L'Abat Safont Street. According to the descriptions provided by several inhabitants and employees of this area, flow depths reached approximately 25 cm in the gutters.

Stretch between L'Abat Safont Street and Riereta Street. According to the descriptions provided by several inhabitants and employees of this area, flow depths reached approximately 75-100 cm. This stretch does not have sidewalks and present lack of inlets. In this area, storm water in underground car-parks and the garden of Sant Pau Del Camp's Church.

Stretch between Riereta Street and Rambla del Raval Street. According to the descriptions provided by several inhabitants and employees of this area, flow depths reached approximately 25 cm and storm water ponded in a lower part of the Rambla Del Raval Street, at a sag point in the area.

BEIJING, CHINA

General flood information

Type of flood: Flash flood

Date: 27th June 2006; 21st July 2012

Duration: less than 5 hours; 16 hours⁴

Highest total rainfall recorded in urban area: 117 mm/24h (inner city); 190.3 mm/24 h (inner city) and 460 mm/24h⁵ (Fengshan district, Southwest suburbs of Beijing)

Highest peak intensity of rainfall: less than 50 mm/h; 50-100 mm/h¹ (Pinggu quejiayu, Northeast suburbs of Beijing)

Flooded area: 39 sections of the Third, Fourth and Fifth Ring Roads; 63 sections of major roads flooded (inner city of Beijing)

Depth of flood in urban area: 0.3m-1m; 0.3m-4m

Loss of human life: none; 77 people (in the flashfloods and the landslides)

Estimated total amount of damage:

Nonstructural measures

- Water Law of the People's Republic of China 中华人民共和国水法, approved in 2002 by National People's Congress
- Measures of Beijing Municipality for the Implementation of the Water Law of the People's Republic of China, approved in 2004 by Government of Beijing Municipality
- Flood Control Law of the People's Republic of China
- Measures of for the Implementation of Flood Control Law of the People's Republic of China
- Regulations of the People's Republic of China on Flood Risk Management
- Regulations of Beijing Municipality on Administration of Urban Rivers and Lakes
- Measures of Beijing Municipality on Water Conservation
- Measures of Beijing Municipality on Flood Risk Management, approved in 2005 by Government of Beijing Municipality
- Beijing General Urban Planning (2004-2020)
- General Land Use Planning in Beijing (2006-2020)

Recorded dysfunctions during chosen flood event

⁴ Beijing Municipal Institute of City Planning Design (BMICPD)

⁵ China Metrological Administration

The storm, which started on 21st July around 5 pm and continued late into the midnight, flooded 63 sections of major roads and sent torrents of water tumbling down steps into underpasses. The city received about 170 millimeters of rain on average, though a township in Fangshan district to Beijing's west was hit by 460 mm. A serious landslide in Fangshan districts caused several deaths. More than 500 flights were cancelled at Beijing's Capital International Airport. However, the subway system was largely unaffected, aside from being swamped with people desperate to get home and unable to use cars, buses or taxis.

In general, the capacity of SWD system in Beijing is designed to protect against the 1-3 year return period flood. Some recently flooded sunken interchanges of roads and Olympic Park were updated to raise their capacity to 3-5 year return period flood (50-56 mm/h). The torrential rainfall, not recorded in 61 years, resulted in the SWD system being completely paralyzed, especially in the suburbs. Thus, the natural drainage system inside the Second Ring⁶ Road played an important role in keeping the Forbidden City and central areas from being submerged during this event, even if there was only the SWD system built in the Ming (1368-1644) and Qing (1644-1911) dynasties. Nine wells inside the palace collect the rain and link to an underground river which surrounds the palace and flows to the city moat. In addition, the paving was laid in such a way that rainfall could easily find its way into the soil beneath. Many other historic places, including Tian'anmen Square and the Temple of Heaven, have similar systems and were not submerged.

The major deficiencies in SWD system exposed in the Beijing 7.21.2012 floods are as following.

- Inadequate capacity of the SWD system, which could not drain the torrential rainwater.
- High percentage (80%) of impermeable surfaces in the urban area which caused water logging in low-lying areas, such as sunken interchanges of roads, and caused flooding at riverbanks in the suburbs.
- Absence of holding ponds/tanks which could retain storm water.
- Incoherence between urban expansion and installation of SWD system in suburbs occurred in last decades.
- The pumping stations serving 90 overpasses citywide were built in the last century on the basis of the experience of the former Soviet Union, where more than half the country

⁶ Four storm water holding ponds of the natural drainage system inside the Second Ring Road are BeiHai, ZhongHai, NanHai and HouHai Lakes.

received annual rainfall of less than 400 mm, according to the Beijing Drainage Group Co. Ltd.

Besides the outdated drainage work and the above listed reasons, experts also believe the floods are largely the result of urbanization and the elimination of greenbelts decreasing ability to cope with heavy rain in urban area.

HAMBURG, GERMANY

General flood information

Type of flood: Regular flood and coastal flood caused by Cyclone Tilo

Date: 9th November 2007

Duration:

Highest water level in urban area: NN+5.42 m

Wind speed: max. 125 km/h

Flooded area: the Hamburg Fish Market and low lying areas of the port

Depth of flood in urban area:

Loss of human life:

Estimated total amount of damage:

Non-structural measures

- The Water Act to Improve Preventive Flood Control (FCA), approved in 2005 by the German Federal State
- German Water Act (WHG)
- Federal and Regional Planning Act (ROG)
- German Statutory Code on Construction and Building (Baugesetzbuch)
- Contingency plan, defined by Ministry of Internal Affairs
- Hot Spots (flash flood-prone areas' map), defined by Hamburg authority
- Flood management plans, Wilhelmsburg
- Evacuation schemes of Wilhelmsburg
- Means for contingency communication: radio, telephone, hot lines or Storm surge warning service (WADI)

Recorded dysfunctions during chosen flood event

Guided by the flood event in 1962 the new improvement is preformed. After 1962, massive investments in the coastal defenses were made. For example, dikes were raised to NN+7.20 m. A flood that happened in 1976 was not so significant due to the newly enforced costal defense built. On 9th November 2007, the cyclone Tilo swept over the North Sea, causing the highest water levels in Hamburg for eight years. The Hamburg Fish Market and low lying areas of the port were flooded. Wilhelmsburg was not flooded during this event.

NICE, FRANCE

General flood information

Type of field: Flash flood & pluvial flood due to high precipitation

Date: 5th November 1994

Duration: the airport returned to normal one week after the event

Highest total rainfall recorded: 350 mm/72 hours (in the catchment area of Var River)

Highest river discharge: 3000- 3800 m³/s (in the downstream of Var River)

Flooded area: riverbank of Var River, such as airport, Arenas, CADAM, etc.⁷

Depth of flood in urban area: +0.4 m (in the airport)

Loss of human life: 0

Estimated total amount of damage: 23 million €⁸

Non structural measures

- Legislation transposing the Water Framework Directive (WFD), (Loi portant transposition de la directive cadre sur l'eau (WFD))
- Law on Natural Disasters (Loi relative aux catastrophes naturelles)
- Water Policy, (Loi sur l'eau)
- Law on the prevention of natural and technological hazards, (Loi relative à la prévention des risqué naturels et technologiques)
- Legislation transposing the Water Framework Directive (WFD), (Loi portant transposition de la directive cadre sur l'eau (WFD))

⁷ DDTM, Plan de la Prévention des risques d'inondation (PPRI) de la basse vallée du Var, III-2

⁸ Gourbesville P., Le bassin versant du Var et la crue de 1994, HydroEurope, 2009, p.13

- Law on security, protection of forests against fire and prevention of major risks, (Loi relative à la sécurité, à la protection de la forêt contre l'incendie et à la prévention des risques majeurs)
- Master Plan development and Water management SDAGE/SAGE (Schéma Directeur d'Aménagement et de gestion de l'eau SDAGE / SAGE)
- Flood zone Atlas (Atlas des zones inondables)
- Management and Flood prevention Plans (Plan d'Aménagement et de Prévention des Inondations (PAPI))
- Flood Risk Prevention Plan (Plan de la Prévention des Risques d'Inondation, PPRI) of Paillon River, approved in November 1999
- Flood Risk Prevention Plan (Plan de la Prévention des Risques d'Inondation, PPRI) of Var River, approved in April 2011
- River contract (Contrat de rivières)
- Land Use Plan (POS)
- The Local Development Plan (PLU): Plan de Prévention des Risques d'Inondation (flood), Plan de Prévention des Risques Falaises Littorales (coastal cliffs), Plan de Prévention des Risques Zones Basses (low-lying areas)
- Disaster crisis management plan
- Weather forecast

Recorded dysfunctions during chosen flood event

The flood of November 5, 1994 is no doubt the most spectacular event in the lower valley of the Var. The flood was caused by exceptional rainfall not because of its intensity but because of its spatial extent, which affected more than 2/3 of the watershed. The rainfall was generated by a low pressure passing the watershed of Var River since 2nd November. With continuous rainfall until November 5, an accumulated precipitation reached more than 350 mm in less than 72 hours in the catchment area of the river.

During this event, the flood was caused by embankment failure in several places, such as Carros industrial zone on the right bank, one section of the motorway A8, and an area on the left bank in the downstream of the river. Before reaching the coast, the fast flow of floodwater swept the motorway off and it submerged Nice-Côte d'Azur airport facilities in water, which the depths were greater than 0.4 m.

There were no reported fatalities or injuries. However, the inhabitants were frightened and surprised by the fact that the embankment could not anymore protect them against the flood. Many infrastructures, especially national and departmental roads, and several buildings were seriously damaged. The estimated direct damage caused by this event was \$23 million. The airport restarted its regular service one week after the event. It is incredible to believe that the flood management administration centre was located in the basement of CADAM⁹ situated on the left bank of the river. The latter was one of the first buildings flooded¹⁰.

TAIPEI, TAIWAN

General flood information's

Type of flood: Flash flood; pluvial flood
Date: 16th-19th September 2001¹¹, caused by torrential precipitation of typhoon Nari
Duration: 1-4 days
Highest total rainfall recorded in urban area: 787 mm/36 h (Nangang district)
Highest peak intensity of rainfall: 109.5 mm/h (Neihu district)²
River peak discharge: 2050 m³/s (Keelung river)²
Highest winds: 140 km/h ~ 185 km/h¹²
Flooded area: 1,986 hectare (in Taipei)²
Depth of flood in urban area: 0.3-4.6 m (in Taipei)³
Loss of human life: 27 people¹³
Estimated total amount of damage: NT\$ 1.36 billion²

Nonstructural measures

- National Flood Risk Management Plan, approved in 2006 by *Executive Yuan*
- National Flood-prone Areas Information Release Regulations, approved in 2009 by Ministry of Economic Affairs
- National River Management Regulations, approved in 2002 by Ministry of Economic Affairs

⁹ Centre Administratif Des Alpes-Maritimes (CADAM)

¹⁰ Gourbesville P., 2009

¹¹ Water Resources Agency, Ministry of Economic Affairs of Republic of China, <http://ind.ntou.edu.tw/~klee/hydrology/Na-Li.html>, consulted on 18th Sep. 2012

¹² World Environment News, <http://www.planetark.com/dailynewsstory.cfm/newsid/12545/story.htm>, consulted on 18th Sep. 2012

¹³ Qiuo, Can-Tia et al., A study of Taipei instructional disaster prevention system: Typhoon Nari event, Research program: Evaluation of institutional system on disaster prevention and management of Taipei City Government, 2003, 32 p.

- Simplified Administrative Procedure Regulations for Reconstruction of Transportation and Public Facilities in Flooded Area, approved in 2009 by Ministry of Economic Affairs
- National Disaster Prevention and Relief Act, approved in 2000 by Ministry of Interior
- National Flood Disaster Prevention and Relief Regulations for Damaged Gas Utility and Oil Pipeline, approved in 2009 by the Ministry of Economic Affairs
- Taipei Disaster Prevention and Relief Regulations, approved in 2006 by Taipei City Government
- Taipei Disaster Response Center Operating Guidelines, approved in 2002 by Taipei City Government
- Classified 3 levels of municipal disaster management: blue (level 3), yellow (level 2) and red (level 1)
- Operation Norms of Allocation for Buildings Waterproof Gate(board) Setting, approved in 2009 by Ministry of Interior
- Standards of Allocation for Buildings Waterproof Gate(board) Setting, approved in 2004 by Taipei City Government
- Danshui River Flood-prone Plain Control Regulations, approved in 1999 by Ministry of Economic Affairs
- Keelung River Flood-prone Plain Land-use Control Regulations, approved in 2003 by Ministry of Economic Affairs

Recorded dysfunctions during chosen flood event

The torrential rainfall caused the serious damage in several western cities of Taiwan, including Taipei. The flash flood flowed through a floodgate of an unfinished levee work at Dakeng Stream of Keelung River, and poured into Nangang and Neihu districts. The pump stations in these two districts were submerged by flood water and paralyzed progressively since late evening on 16th September. Among these failed pumping stations, the failure of Yu-Cheng station (No. 17), with design capacity of 184m³/s, was the one of principal reasons of serious damage of downtown Taipei. The control room and water cooled motors of Yu-Cheng station were protected by a high wall of 110 centimeters and this measure of protection was used to being sufficient to protect equipment from flood water of heavy precipitation events during last decade. However, torrential rainfall brought on by typhoon Nari, never occurred since last decade, showed weakness of protection measures.

The failure of high walls and pump stations has engendered inundation in 16 underground Mass Rapid Transit (MRT) stations and two train stations; it took 3 months to repair and rework the whole traffic service system¹⁴. The flood water started to pour into the underground metro station of Guenyang, located on the Nangang district, in the early morning on 17th September and progressively deluged the other underground metro stations by transport network, even the MRT Control Center and two train stations. After this event, the installation of automatic floodgates in all the entrances of MRT stations was implemented.

Also, the roads of center city were inundated and water poured into the buildings and basements. **Since the 1990s**, the city of Taipei has started to build underground transportation networks, commercial streets, and parking, but underground spaces protections against flooding had not yet been installed at all entrances. During heavy rainfall, as this event, the assembly of sandbags at the entrances was the only protection against flooding. On the one side, these huge underground spaces were temporarily stored flood water so that affected areas did not spread widely. On the other side, these underground spaces without adaptive measures against flood water significantly increased the amount of damages and aggravated dysfunction of urban activities for several months. According to the Taipei City Government, the lack of structural protection provided for underground spaces would be one of issues to be improved after this event.

¹⁴ Taipei Metro Company (2002), Report of February 2002, <http://www.trtc.com.tw/ct.asp?xItem=1207131&ctNode=24546&mp=122031>

ANNEX B

Table 60: Dimensions and variables of urban flood resilience index

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
NATURAL	resist	River network	Channel conveyance able to accept peak discharge	Passive treatment system (SUDs, BMP, etc., which means in combination green spaces and structural measures) = % of total green spaces
	relief	River watershed management (infiltration and retention)	Capacity to avoid the flood (vulnerability reduction)	Capacity to avoid the flood (vulnerability reduction)
PHYSICAL	recovery	Transportation network	Emergency evacuation routes	Building code (dry and wet flood proofing as well as the other adaptations)
	relief	Cascading flood compartment system (Structure)	Sufficient capacity to accept part (%) of flood water	Building code (dry and wet flood proofing as well as the other adaptations)
	response	Crisis management system	Early warning system for announcement	Building above water logging
	resist	flood protection	Real-time monitoring FP	System implementation
	resist	River network	Real-time monitoring RN	hydraulic structures within flood risk management plans
	relief	River watershed management (infiltration and retention)	Hydraulic structures RWM	Building code (dry and wet flood proofing as well as the other adaptations)

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
	recovery	Solid waste management	Accessibility of roads SWM	Building code (dry and wet flood proofing as well as the other adaptations)
	recovery	Transportation network	Accessibility of roads TN	Building code (dry and wet flood proofing as well as the other adaptations)
	response	Rescue system	Location of rescue services are protected	Building above water logging
	response	Adaptation for living with floods	Adapted flood-proofing construction (for strategic functions)	Building code (dry and wet flood proofing as well as the other adaptations)
	response	Adaptation for living with floods	Adapted construction for transportation network and other services	Building code (dry and wet flood proofing as well as the other adaptations)
	response	Adaptation for living with floods	Availability and implementability of adaptation regulations	Building code (dry and wet flood proofing as well as the other adaptations)
	response	Crisis management system	Crisis management center or location is protected	System implementation
	response	Crisis management system	Coordination with rescue and evacuation system	System implementation
	relief	Evacuation of exceeding floodwater (Structure)	Real-time monitoring EEF	Building code (dry and wet flood proofing as well as the other adaptations)
	relief	Evacuation of exceeding	Sufficient capacity to evacuate	Flood safety (emergency shelter)

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
		floodwater (Structure)	floodwater and avoid the flood	
	response	Evacuation system	Smart (safe) location for evacuation shelter or location is protected	Building above water logging
	resist	flood protection	Hydraulic structures FP	hydraulic structures within flood risk management plans
	resist	flood protection	Sufficient capacity with respect to analyzed event	Waterfront spatial planning : room for the water (fluvial & maritime); rain garden
	relief	Floodwater storage (Structure)	Sufficient capacity for rainwater drainage	Waterfront spatial planning : room for the water (fluvial & maritime); rain garden
	relief	Infiltration and reduce run-off (existing structure)	Infiltration capacity (%)	Building code (dry and wet flood proofing as well as the other adaptations)
	resist	River network	Hydraulic structures RN	hydraulic structures within flood risk management plans
	relief	River watershed management (infiltration and retention)	Real-time monitoring RWM	Building code (dry and wet flood proofing as well as the other adaptations)
	resist	Urban drainage (Structure)	Real-time monitoring DU	Building code (dry and wet flood proofing as well as the other adaptations)
	resist	Urban drainage (Structure)	Sufficient capacity to accept flood water	Waterfront spatial planning : room for the water (fluvial &

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
				maritime); rain garden
	resist	Weather forecast	Communication system with flood control centre	Building code (dry and wet flood proofing as well as the other adaptations)
	resist	Weather forecast	Using real-time monitoring system (watershed)	System implementation
	resist	Weather forecast	Availability of early warning system for FRM	System implementation
	resist	Weather forecast	Sufficient accuracy	System implementation
	response	Adaptation for living with floods	Adapted construction for flood distribution	Building code (dry and wet flood proofing as well as the other adaptations)
	relief	Cascading flood compartment system (Structure)	Real-time monitoring CFCS	System implementation
	response	Crisis management system	Coordination with real-time monitoring of resist and relief measures	Building above water logging
	relief	Floodwater storage (Structure)	Real-time monitoring FS	Waterfront spatial planning : room for the water (fluvial & maritime); rain garden
	relief	Infiltration and reduce run-off (existing structure)	Real-time monitoring I&RR	System implementation

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
	recovery	Reconstruction system	Availability of allocation for reconstruction & renovation	Building code (dry and wet flood proofing as well as the other adaptations)
	resist	Weather forecast	Provides sufficient lead time for rescue and evacuation works	Building above water logging
SOCIAL	response	Community	Active enrolment and support (family)	Livelihood
	reflect	Coordination between stakeholders	Informal coordination within community	Awareness
	reflect	Knowledge exchange	Multidisciplinary knowledge exchange (engineer, architect/urban planner, sociologist, economist, politician - city government, etc.)	Awareness
	reflect	Knowledge exchange	Knowledge exchange between scientific and operational stakeholders	Relationship
	recovery	Lesson learned from past events	Learning and adapting from previous event	Awareness
	reflect	Public participation	Associations of flood-risk related management	Awareness
	reflect	Public participation	Flood risk education	Awareness

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
	reflect	Public participation	Flood risk management communication	Relationship
	response	Community	Volunteers C	Relationship
	recovery	Reconstruction system	Volunteers RS	Awareness
ECONOMIC	response	Crisis management system	availability of financial resources	Building above water logging
	response	Evacuation system	Ability to evacuate people before human loss	FRM in the city
	recovery	Financial management	Allowance for the reconstruction or renovation of buildings adapted to the mitigation of flood risk	Availability of credit/compensation / insurance
	recovery	Financial management	Deduction the taxes of people in flooded areas	Availability of credit/compensation / insurance
	recovery	Financial management	Financial support from the insurance	Availability of credit/compensation / insurance
	resist	financial resources	Accessibility to resources	GDP per capita (% of people on social welfare from general population)
	resist	financial resources	Flexibility / Welfare availability	GDP per capita (% of people on social welfare from general population)
	recovery	Lesson learned from past events	Examination of dysfunctions of previous events	FRM in the city

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
	recovery	Reconstruction system	Availability of insurance & financial services	Availability of credit/compensation / insurance
	response	Rescue system	Accessibility and availability of emergency shelters	FRM in the city
	response	Rescue system	Accessibility and availability of emergency road networks	GDP per capita
	recovery	Solid waste management	Sufficient equipments to treat solid waste	GDP per capita
	recovery	Transportation network	financial recourses for protection of transportation network	FRM in the city
	recovery	Reconstruction system	Flooded areas become dry during xx hours/days.	GDP per capita
	response	Rescue system	According to model results (depth and duration of floodwater), rescue services able to save people before occurrence of human loss. (Productivity)	FRM in the city
	recovery	Solid waste management	Solid waste could be treated within (xx) days	GDP per capita
	INSTITUTIONAL	reflect	Flood resilience urban planning regulations – flood-prone areas	Land use control

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
	reflect	Flood resilience urban planning regulations – flood-prone areas	Urban expansion control	Implementation of disaster management plan
	reflect	Climate change plan	Using flood model result	Cooperation cities ward officials for emergency management
	reflect	Climate change plan	Urban spatial planning adaptations	Extent of community participation in flood risk management plan preparation process
	reflect	Climate change plan	Using climate change scenario prediction model	Extent of community participation in flood risk management plan preparation process
	reflect	Coordination between stakeholders	Committee of flood risk related stakeholders (city)	Use of city-level hazard maps in development activities
	reflect	Coordination between stakeholders	Exchange by GIS tool	Use of city-level hazard maps in development activities
	reflect	Crisis management system	Availability of evacuation plans and maps	Existence of disaster drills
	reflect	Crisis management system	Availability of evacuation trainings	Existence of disaster drills
	reflect	Crisis management system	Crisis management and evacuation plans	Implementation of efficient waste management system
	reflect	Crisis management system	Crisis management plan with maps (availability)	Implementation of disaster management plan
	response	Evacuation system	Evacuation procedure is	

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
			designed based on model results (time and demographic density).	
	reflect	Flood prevention management - regulations	Flood vulnerability maps	Mainstream of FRM in city's development plans
	reflect	Flood prevention management - regulations	Regulations with flood risk maps	Mainstream of FRM in city's development plans
	reflect	Flood resilience urban planning regulations – flood-prone areas	Building code	Implementation of disaster management plan
	reflect	Land use restriction (flood-prone area)	Implemented building code	The extent of environmental conservation regulations reflected in development plans
	reflect	Land use restriction (flood-prone area)	Flood maps	Implementation of mitigation policies to reduce flood risk
	reflect	Land use restriction (flood-prone area)	Wetland/green space preservation	Cities institutional collaboration with NGOs and private organization
	reflect	Land use restriction (flood-prone area)	Urban planning policies	Implementation of mitigation policies to reduce flood risk
	response	Rescue system	Emergency communication system is settled	Climate change plan
	reflect	Crisis management system	Availability of solid waste management plans	Implementation of efficient waste management system

Dimension	FRM element	Area of influence	Indicator	Explanation (example)
	reflect	Flood resilience urban planning regulations – flood-prone areas	Building ban	Implementation of disaster management plan
	reflect	Crisis management system	Structural failure (Evacuation of exceeding floodwater, floodwater storage, cascading flood departments, flood protection, river network, infiltration and reduction of run-off, river watershed)	Existence of disaster drills
	reflect	Crisis management system	Availability of solid waste management maps	Use of city-level hazard maps in development activities
	recovery	Reconstruction system	Duration of reconstruction period is less than x days	Efficiency of trained emergency workers during a flood
	recovery	Reconstruction system	Availability and flexibility of reconstruction codes	Existence and effectiveness of an emergency team and plan during a disaster: leadership
	reflect	Transportation network	Plans for managing and protection of existing road network	Ability (manpower) and capacity (technical and software) to produce a flood risk management plan

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During

List of publications:

Batica, Jelena and Philippe, Gourbesville.,: “Development of Flood Resilience Index”. Journal of Flood Risk Management, 2014 (submitted)

Batica, Jelena, and Gourbesville, Philippe.: “Urban Scale Uncertainty and runoff generation – Nice case study, France”, SIMHYDRO conference, Nice, France 2014

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ABSTRACT

Floods that happen in urban areas are governed by increased frequency. Existing flood defence structures demonstrate its downsides. One of the solutions is moving to risk culture and finding the balance between the shape of land use and urbanization through adaptation, mitigation, prevention, and response and recovery strategies. The new holistic approach is based on resilience concept give a place for new development and implementation of new approaches under existing flood risk management (FRM) frameworks. Adding resilience to flood risk management is a first step. The Flood Resilience Index (FRI) is developed in this thesis is a unique approach for evaluation of flood resilience in urban systems with the main priority on system structure when evaluation is done on micro and meso scale and on system dimension when flood resilience is evaluated on macro scale. The main reflection is on the development of method by evaluation of existing flood risk management (FRM) frameworks. Through evaluation, there is a possibility to notice the level of integration and implementation of crucial element of flood risk. The developed method for evaluation of flood resilience is potentially applicable to any urban system on any geographic scale. Connections and dependences between main city elements and natural hazards (in this case urban flooding process) are defined. With its implementation, social, economical, political and cultural relations between cities will be more visible and better established and flood risk management well implemented.