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Preparing for Extreme And Rare events in coastaL regions

Development of a framework for strenghtening resilience and coping capacities in coastal areas

Flood Resilience Index (FRI)

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Abstract (for dissemination, 100 words)	*Groundwork of the report is a holistic risk assessment and risk cascading approach that takes into account different indicators for assessing flood resilience. The report has two main parts; the first part has theoretical explanation with description of methodology developed. The first part also includes the description of web based tool PEARL FRI TOOL adapted and created for stakeholders and their better understanding how some of indicators contribute to better flood resilience. The second part of this report gathers five case study areas where FRI methodology is applied. Each case study has short description of extreme event, general description of area and presentation of results after application of FRI methodology. This is a part of ANNEX B.*
Keywords	Flood resilience, urban systems, flood risk

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Summary

Report on development of a framework for strengthening resilience and coping capacities in coastal areas based on a holistic risk assessment and risk cascading approach takes into account different indicators for assessing flood resilience.

The first part of the report focuses on the setting the scene for the framework development. The explanation is done for the definition of flood risk, protection strategies and measures.

Defining the framework for resilience involves definition of vulnerability, carrying capacity and defining resilience. The method developed in this report concerns specified resilience and its quantification through Flood resilience Index (FRI).

The new approach in system analysis is presented: scaling and mapping of urban systems. The new flow paths are presented regarding mapping system to its components and fluxes.

This holistic approach brought a new tool for evaluating flood resilience, a FRI. The index is providing a good communication tool with the stakeholders in the sense that there is a possibility to map the area with respect to different index values.

A developed framework is applied on three case studies from PEARL project: Rethymno (Greece), Genoa (Italy), Les Boucholeurs (France), Hamburg (Germany) and Ayuthaya (Thailand).

The report has two main parts; the first part has theoretical explanation with description of methodology developed. The first part also includes the description of web based tool PEARL FRI TOOL adapted and created for stakeholders and their better understanding how some of indicators contribute to better flood resilience. The second part of this report gathers five case study areas where FRI methodology is applied. Each case study has short description of extreme event, general description of area and presentation of results after application of FRI methodology. This is a part of ANNEX B.

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Abbreviations and Acronyms

FRM - flood risk management

EU - European Union

WFD - Water Framework Directive

FD - Flood Directive

FRI - Flood Resilience Index

BRGM - Bureau de Recherches Géologiques et Minières

NGF - General Levelling of France (Nivellement Général de la France)

CORFU - FP7 project (COllaborative Research on Flood resilience in Urban areas)

1 INTRODUCTION

Flooding is one of the most frequent natural hazards, and more people than ever are affected by flooding (Kreimer et al 2003, Munich Re 2000). Floods that happen in urban areas are governed by increased frequency (Ouarda et al., 200;, 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 flooding processes 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 the world vary from levels of economic development, infrastructure age, social systems and decision-making processes, established drainage methods, seasonality of rainfall patterns and climate change trends.

There is a need for sensitivity analysis of urban systems. It implies a deeper investigation of urban flooding, condition of the built environment, way of mapping of built environment, its interaction with nature and vulnerability evaluation. Further to that, what is needed is a resilience approach that is solving and assessing sensitivity of urban systems in respect to flooding.

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. A many drivers contribute to this fact: existing shape of urban environment, its structure, existing institutional frameworks, 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 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. Moreover, the produced runoff is not 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 flooding processes that is measured with time. Assessment of resilience where focus is on population follows a bottom-up approach. It starts 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.

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 causalities report, damage assessment facilitating claim procession, reconstruction, charity funds, social therapeutic measures, disaster recovery plans and financial assistance after a flood.

Flood management cycle incorporates these "soft measures". They differ 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 report 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 stands as a system property to cope with disturbances up to the level where the functionality of complete urban system stays undisturbed by the level that. In order to make the concept more tangible the resilience concept needs quantification. In these light, defined indicators brings possibility to evaluate flood resilience of urban system.

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 is not reachable. This comes from the fact the protection structures are limited with the design period.

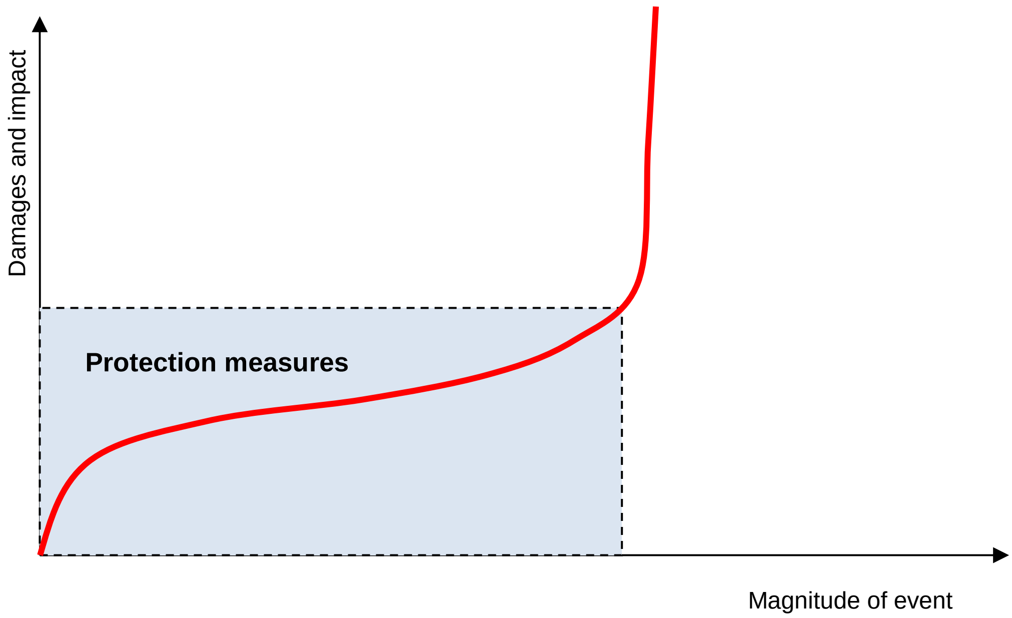


Figure 1: Presentation of Flood Risk Management - FRM concept

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 measures that can increase adaptation and carrying capacity are located in this area (

Figure 2)

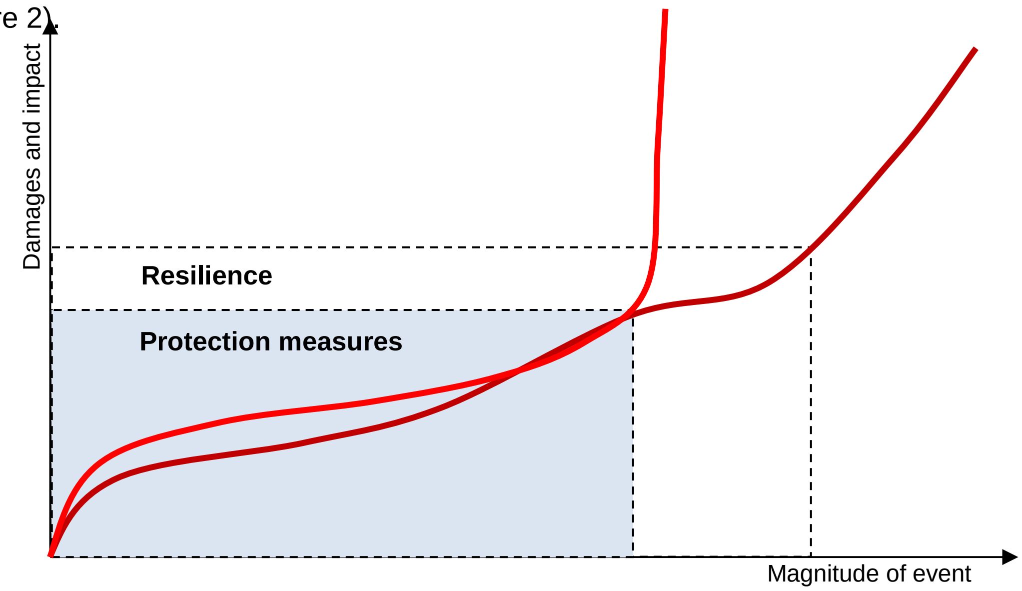


Figure 2: Resilience concept

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. In addition, 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.

1.1 Position of this report in WP5

Following the objective where focus is on developing the metrics for evaluation of different resilient strategies. After identification of key stakeholders and before mapping of resilient strategies defining the framework for evaluating flood resilience is developed. This framework will support future selection of resilient strategies, ensure the connection between results and stakeholders and contribute to development of roadmaps for flood risk management.

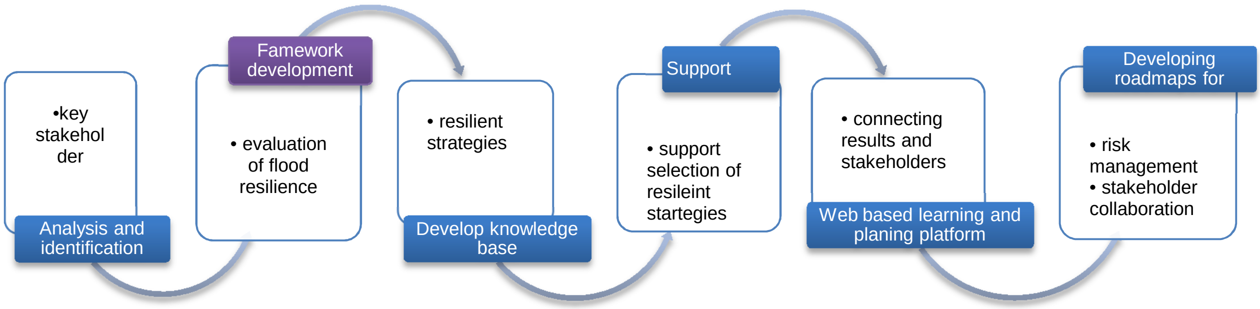


Figure 3: The pathway of reports within WP5 of PEARL project

1.2 What is this framework doing?

Defining resilience takes into account both physical and social characteristics of case study area. Here, the specified resilience, in our case flood resilience is defined as ability of urban system exposed to flooding process is able to function during and after flood. This is explained in a synthetic way.

The term resilience is very broad and in order to evaluate resilience for case study area following characteristics should be known:

Particular flood event - It is not enough to say let's evaluate flood resilience. The flood characteristics such as spatial extension, flood depths and flood velocities are needed.

Physical character of case study such as: different building materials used type of transportation network, existing structural measures, etc.

Economic and institutional framework is also important in order to evaluate the institutional capacity of a case study and include is in overall resilience evaluation on macro scale.

1.3 Mapping of resilient strategies

The variety of resilience strategies exist. In order to be in line with the subject of this report and regarding mapping of strategies here the basic division will be considered with structural and non structural.

By definition the structural measures present any physical construction that reduces or avoid possible impacts of hazards, or application of engineering techniques applied to achieve hazard-resistance and resilience in structures or systems. On the other side the non-structural measures is any measure not involving physical construction and uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education.

Flood resilience assessment developed in this report and creation of Flood Resilience Index (FRI) can be used for mapping of resilient strategies.

Application of FRI assessment and mapping of resilient strategies is done using GIS. This is done in the test case study with 72km^2 area. The assessment of whole area with existing build environment includes 56 000 objects, historical flood mapping and necessary data regarding economic, social and institutional dimension.

In order to map resilient measure the two scenarios are considered, one without any measure and another with included flood protection measure. In particular, this measure is door barrier that is preventing flood water to enter the building. The figure below presents FRI assessment without any measure while the Figure 5 presents FRI values for each building in the case study area with applied measure (door barrier).

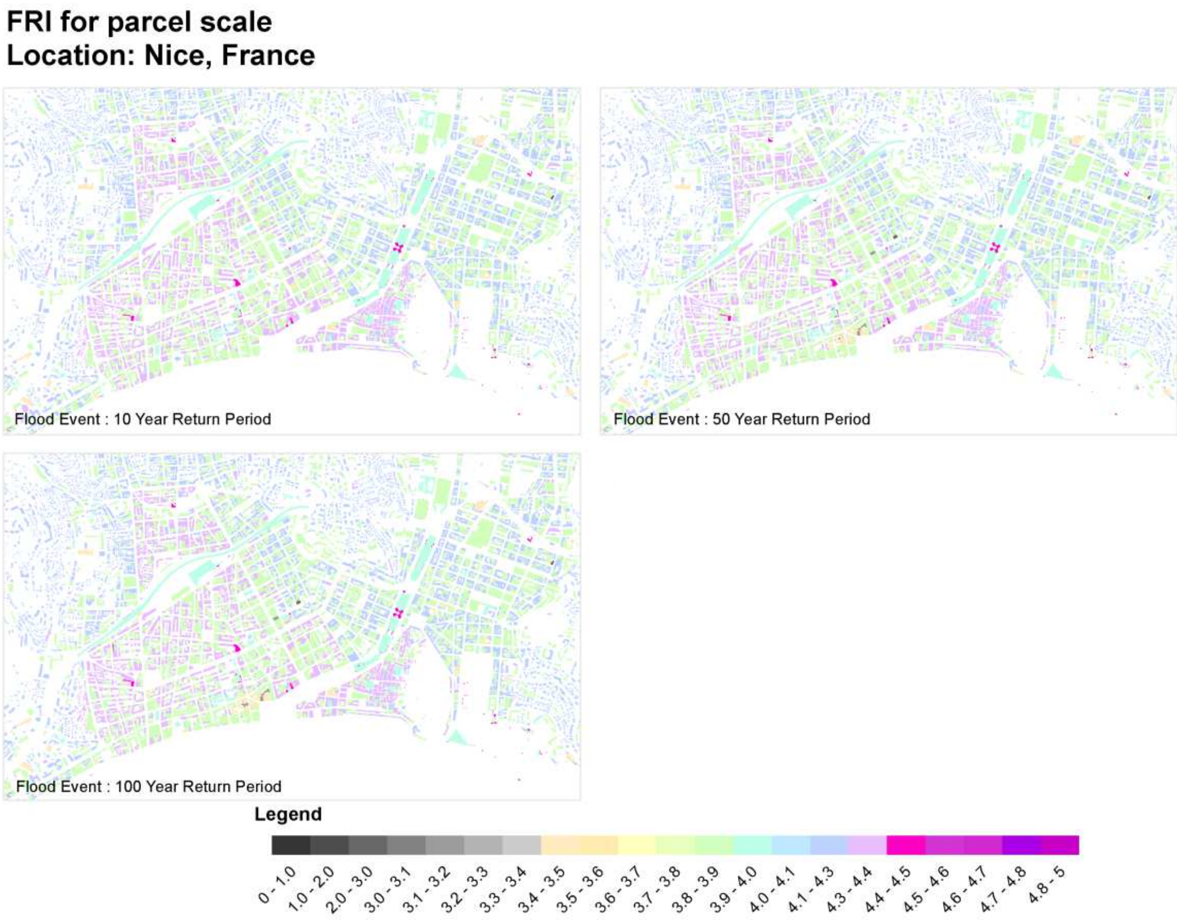


Figure 4: Mapping of FRI evaluated for case study area without applied measure

Figure 5: FRI evaluated for S1 scenario on building scale, Nice case study

From Figure 4 and Figure 5 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.

Mapping of resilient measures provides better communication with stakeholders. It also enables better understanding the effect of applied measure and contributes to overall risk understanding.

1.4 FRI and vulnerability with connection to WP3

Under the holist risk assessment the resilience takes important place. Underlying both soft and hard measures and strategies in risk reduction resilience brings a new way of thinking and connecting. The extreme events we are analysing have hydro meteorological nature. Mainly flooding processes are main or a part of extreme events. The flooding processes in urban areas pose significant damages; therefore flood risk is the main pillar of the holistic risk assessment.

Connectivity with WP3 lay in in-depth analysis of carrying capacity, vulnerability and resilience as main components of flood risk.

Flood risk assessment in urban systems rests on the evaluation the interaction of three characteristics: **carrying capacity, vulnerability and resilience** (Burton, 1983). *Carrying capacity* identifies the maximum tolerable damage that a community or a city can bear. The concepts of vulnerability and resilience serve to measure and to assess the **carrying capacity** of a community or a city. Vulnerability expresses the impact of disturbance to a system while resilience describes the capacity of a system to absorb the shock.

Urban development and an increase of vulnerability lead urban communities to adopt a culture of risk and to develop the ability to accept a certain level of flooding.

There is a need to distinguish vulnerability and resilience. Vulnerability is a pre-event characteristic of a social system and describes its potential to be harmed. Vulnerability is a function of exposure or sensitivity of a system to disturbance. This is explained by identifying who or what is at risk?

Vulnerability defines 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 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). From an ecological perspective, resilience is defined as the ability of a system to absorb changes of variables and parameters, and still persevere (Holling, 1973). Holling was one the first scientists to introduce the concept of ecological resilience. Ecological resilience is focused 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 have defined conditions which will provide some functionality. Urban systems need to have in advance defined 'conditions' in order to have the proper level of functioning.

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 make it 'difficult' to implement in 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. A broader view of some resilience approaches is described in Table 1 (Carpenter et al, 2001).

Table 1: 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 at 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. 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. Disturbance in the system depends on system reorganization possibilities. These processes have spatial and temporal scales. The resilience concept includes adaptation, learning and self organization in addition to the general ability to resist interruption.

Specified resilience deals with asking the question: "what is resilient to what" (Carpenter *et al.*, 2001). 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). A suitable definition for resilience which is adopted in this research is proposed by the United Nations' International Strategy for Disaster Reduction (UNISDR). In the context of urban flooding, resilience can be defined as follows:

"*Resilience is the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures*".

From this wide sense the concept provides a perhaps more suitable background framework to develop and assess integrated approaches to flood risk 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, so as to enable it to function normally. The resilience approach aims to prevent the urban system as a whole to move to an undesirable state from which is not possible to recover from flood impact. 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 the 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 resilience thinking, a different point of view for guiding and organizing urban systems. Vulnerability and resilience are important elements in the analysis of urban areas and

their existing flood risks but there should be a distinction between the vulnerability and resilience of people on one side, and the urban structure on the other.

1.4.1 Adding resilience to flood risk management

The resilient urban systems and urban communities have the ability to accept, resist, recover and learn from the events. This ability is measured with resilience. In this interpretation resilience represent a property. Adding resilience to flood risk management bring new elements in the cycle. The new elements also cover actions related to preparedness, response and recovery. Within this research the five new elements of flood risk management are defined as: **reflect, relief, resist, response, and recovery**.

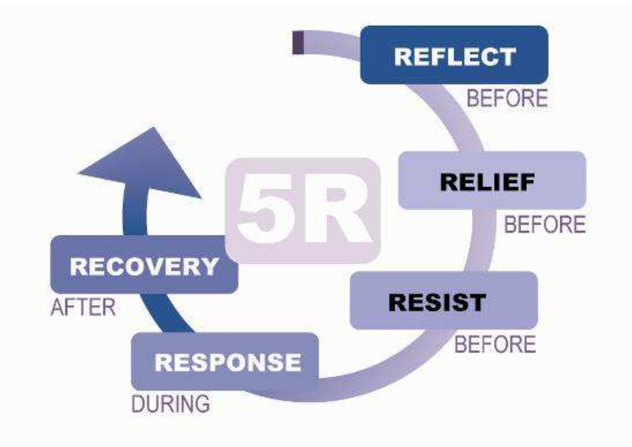


Figure 6: Defined elements for flood risk management cycle – CORFU project

- Reflect – Focusing 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" where existing structures and urban functions are employed for the collection of flood water (green areas, different playgrounds, etc). Implementation of physical, technical, non-structural and procedural measures relates to the concept “living with floods”.
- Resist– Reduction of flood risk if possible. This is in direct connection with existing threshold capacity. Limiting flood damage and easing recovery by planning and building adaptation, infrastructure, surfaces and economic activity relate to the concept of resistance.
- Response– Focusing on measures taken during the flood on crisis management. Flood impact is reduced by implementation of physical, technical, non-structural and procedural measures relates to the concept “living with floods”.
- Recovery– Providing support by developing capacity building in communities enable to cope with the impacts after flooding events.

Actions and measures are directly connected with flood resilience. They are related to the strong intention to increase the building of human resources capacity, better land use management, increased flood preparedness and emergency measures.

The proposed approach is based on the development of assessment tools with indicators able to provide a comprehensive overview of resilience of a city and community. For that reason the evaluation considers different spatial scales for analysis and highlighting the components and flux of an urban system. The main research question is how to evaluate flood resilience of urban systems taking into account its characteristics?

The approach under this methodology is systematic. This is done in order to map all components of urban system and all variables relevant for flood risk. The urban environment has two linked components, the (i) physical and (ii) social systems. We analyze both components and define what is needed to obtain a stable state within the urban system. A stable state is related to the functionality of its components.

The need for this approach comes from the fact that urban systems nowadays are more vulnerable to flooding then before due to urbanization. Urban systems need to change to create the ability to accept flooding with limited damages. The change means reshaping, adapting and preparing the urban environment. In this light the spatial development of the urban system is in focus. Spatial analysis is significant in focusing on the physical characteristics of the components of urban system.

The methodology is developed through different scales looking at the system components at the micro scale. The interaction between different system components and their interconnectivity and different levels of functioning during flood events provide essential information on flood resilience. Also, the methodology brings fundamental recommendation to help transform the urban spatial organization.

The relationship between the nature of interaction and the organization of an urban system is fundamental. City systems - urban systems - are very complex. They provide different services for the residents. This complexity of urban systems can be analysed using functional analysis that provides a description of the city organization. The main interest is to provide indicators that could be used to characterize urban resilience to flooding.

2 Defining the framework

With developed framework, we are representing the means for evaluating flood resilience. As we speak about specific resilience, the notation and flow path is following certain steps. There are four main steps in evaluating flood resilience of an urban system.

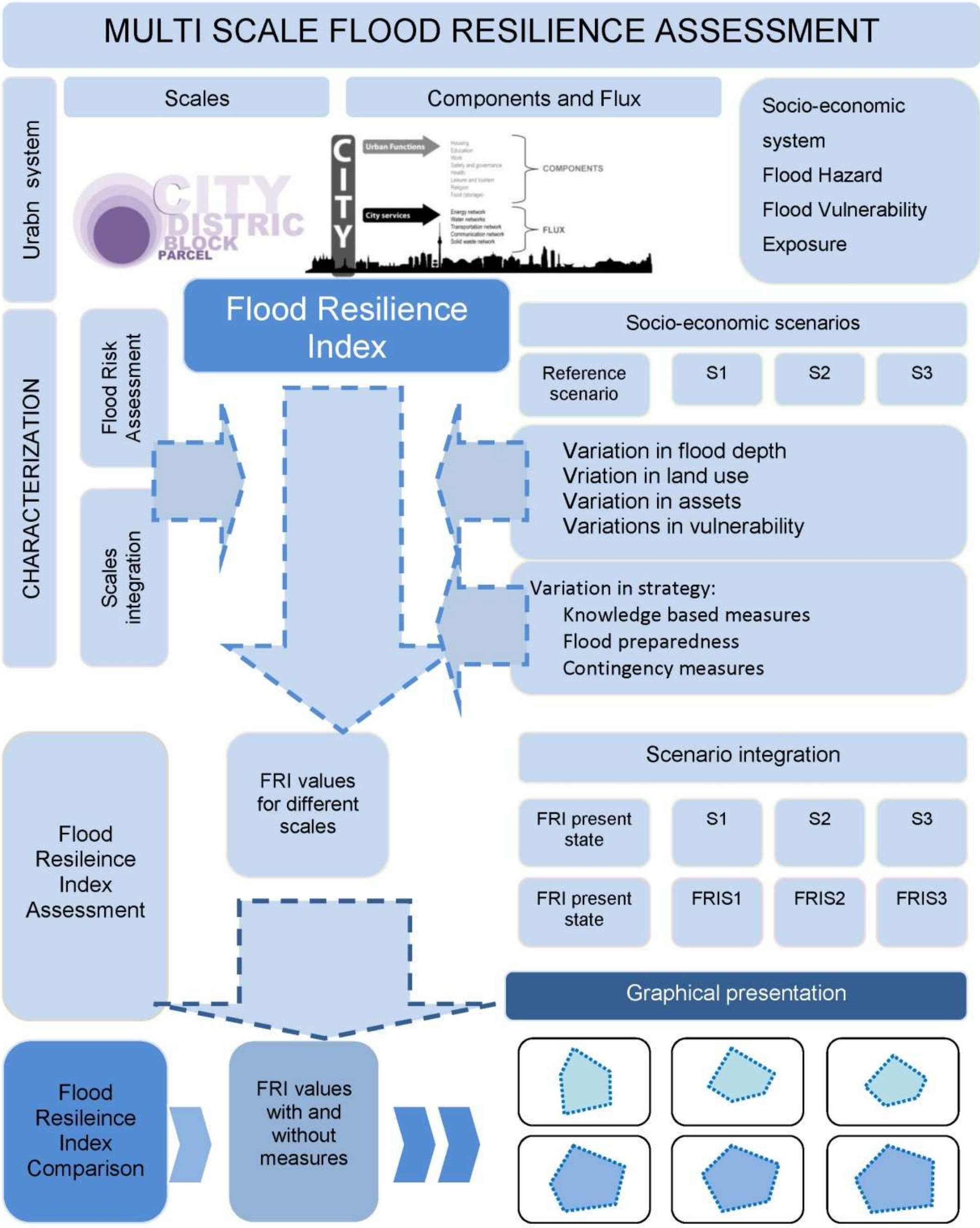


Figure 7: Proposed framework for multi scale flood resilience assessment

Framework presented on Figure 7 explains evaluation of flood resilience within different steps. Steps needed for evaluation are as follows:

– defining the urban system

- characterisation of risk
- evaluation of FRI
- comparison of different values of FRI

Definition of urban system takes into account the physical boundaries, system division on different scales, mapping the urban system and defining socio-economic aspects and risks. System division on different scales depends on the level of data. Four scales re available: city, district, block and parcel scale. The scales are explained in the text within section 2.5 of this report. Mapping of urban system takes into account all components e.g. different buildings (residential, administration, military, etc). Setting the urban system based on different building topologies the new map is created with elements highlighted for the flood resilience evaluation. The social condition as well as particular event (flood event) is described. This is in addition to the specified resilience where resilience is evaluated "**from what to what**". This means that for resilience evaluation it has to be known up to what level is system resilient to what risk.

Characterisation of risk takes into account already finished risk assessment and selection of scales for evaluation.

Evaluation of FRI follows the steps and procedure described within section 2.8 of this report. As noted there two evaluation schemes for: (i) micro and (ii) macro scales.

The final step takes into account comparison of different values of FRI obtained from different scenarios. Within different scenarios (S1, S2 ...Sn), the different measures are included.

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 complexion. 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 broth 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. It is 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.

2.2 Methods and metrics for evalaution of resilience

Exisitng methods for flood resilinece use indicators. They are widespread as a mean for comparison, contract and evaluation performance of certain system state. In this sense, they are proven handy in areas related to the environmental and risk management in form of indexes (e.g. Environmental Performance Index -EPI-, Risk Management Index -RMI-).

Along these lines, evaluating the resilience of systems of complex nature such as urban flood management must rely in the application of resilience metrics (Scherzer in SMARTeST, 2013).

As example three exisitng methods are analysed. Table 2 provides a general overview of the indicators used in each of those works. It can be concluded that researchers have intention to include more aspects of flood resilience into the metrics. Wth the inclusion of more variables and indicators the concept of resilience becomes more complex and detailed.

Table 2: Comparison of existing methods for resilience evaluation

Name	Criterion	Variables & (Indicators)	Type of variables
Resilience indicators	Resilience to flooding	Amplitude (2), “Graduality” (1), Recovery (9).	Quantitative for Amplitude and “Graduality”. Qualitative for Recovery. Thresholds for the qualitative

			variables based on interpretations
CDRI	Resilience to climate disasters	Indicators for natural (2), physical (8), social (3), economic (6), and institutional (4) dimensions.	Qualitative. Thresholds based on interpretations
UNISDR Score card	Resilience to disasters	Indicators for organization (10), budget (9), risk assessment (4), infrastructure (26), health & education (6), building regulations (5), education programs (4), ecosystems (3), emergency management (13), recovery (2)	Qualitative and quantitative. Thresholds mostly based on percentages

The measuring methods of urban resilience evolved from hard and quantitative indicators, to more broad and qualitative ones. In this light, the CDRI is seen as an extended and more integral continuation of the indicator “Recovery” presented by de Bruijn (De Bruijn, 2004) where already three different dimensions were taken into account (physical, economic, and social).

In the case of the UNISDR Scorecard, the focus is mainly given to the institutional dimension of resilience but includes variables for all other dimensions and pursues a straightforward approach to facilitate city officers to assess resilience in their communities in qualitative terms. In this sense, its approach is similar to the CDRI who is also aimed to city officers but provides a wider range of indicators that the CDRI does not.

The three metrics have in common certain indicators, especially in the economic and social dimensions.

2.3 Resilience strategies

The resilience strategies in detail are presented within report 5.3 (Development of knowledge base of resilient strategies). Within this report, the small focus is on the socio-economic and institutional strategies.

2.3.1 Socio-economic and Institutional strategies

Socio-economic and institutional strategies nowadays become more dominant element in flood risk management. As a part of soft measures in the past, they were not considered as important as they are today. Starting from the notation of risk and moving to the risk minimizing measures the social and institutional measures are placed in both (i) horizontal and (ii) vertical 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.

Table 3: Vertical scale for risk minimizing, France flood risk management as example

LEVEL	FLOOD MANAGEMENT
European	POLICY Flood risk management: Flood prevention, protection and mitigation Trans European Networks (TEN) (http://www.unece.org/) LAW Water Framework Directive (WFD) (http://ec.europa.eu) OTHER PLANNING INSTRUMENTS ICPR (IKSR) (http://www.iksr.org)
National	LAW Law on Natural Disasters (Loi relative aux catastrophes naturelles), (http://www.legifrance.gouv.fr) 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 prevention des risques majeurs), (http://www.legifrance.gouv.fr) Water Policy, (Loi sur l'eau), (http://legifrance.gouv.fr) Law on the prevention of natural and technological hazards, (Loi relative à la prévention des risqué naturels et technologiques), (http://www.legifrance.gouv.fr) Legislation transposing the Water Framework Directive (WFD), (Loi portant transposition de la directive cadre sur l'eau (WFD)), (http://www.legifrance.gouv.fr)
Regional	POLICY Master Plan development and Water management SDAGE/SAGE (Schéma Directeur d'Aménagement et de gestion de l'eau SDAGE / SAGE), (http://www.eaufrance.fr) Flood zone Atlas (Atlas des zones inondables), (http://www.rdbrmc-travaux.com) Management and Flood prevention Plans (Plan d'Aménagement et de Prévention des Inondations (PAPI)), (http://www.driee.ile-de-france.developpement-durable.gouv.fr)
Department	POLICY 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)
Inter-municipal	POLICY River contract (Contrat de rivières), (http://www.eaufrance.fr)
Municipal	POLICY Local Development Plan (Plan local d'urbanisme, PLU), (http://www.chatelaillonplage.fr/)

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.

2.4 Urban systems – Scaling and mapping

A city exists to expedite transactions – production processes, consumption activities, social interaction, economic and political decision-making processes. 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 paper 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 (Batica, Gourbesville 2011)**Error! Reference source not found.**

Figure 8: 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.

2.5 Mapping of urban system - urban functions and city services

Mapping of urban system is needed in order to achieve a balanced study of flood resilience. In addition, 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 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 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:

- houses (individual or collective),
- educational areas (for local and non-local education services),
- food (area for food storage),
- work 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 10.

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. This provides connection with dynamic character of urbanisation. 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. The water pattern that existed in the past are interrupted with the urbanisation trends and this represents main problem in urban systems from flood risk management point of view.

Because of that, 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 (Batica, Gourbesville 2011) (Figure 8).

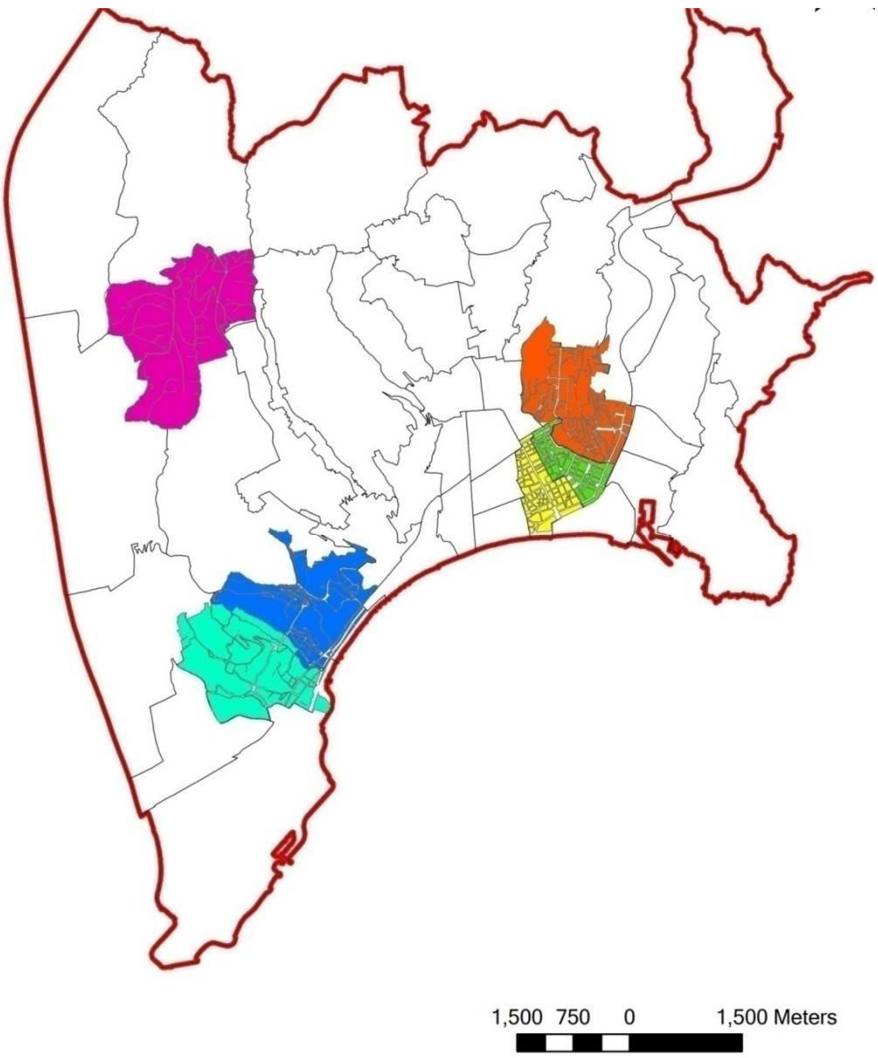


Figure 9: City system represented through scales (city, district, block and parcel), example for the city of Nice, France

Above presented is scaled urban system with four entities: *city, district, block and parcel* (Batica, Gourbesville 2011). Scaling of urban system allows recognition of main urban patterns. Scales are set in order to have different spatial approach when improving flood resilience of urban system.

Components of urban systems are also important because there is a requirement to investigate connections and dependencies of system elements with flooding processes.

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 fulfil 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 below.

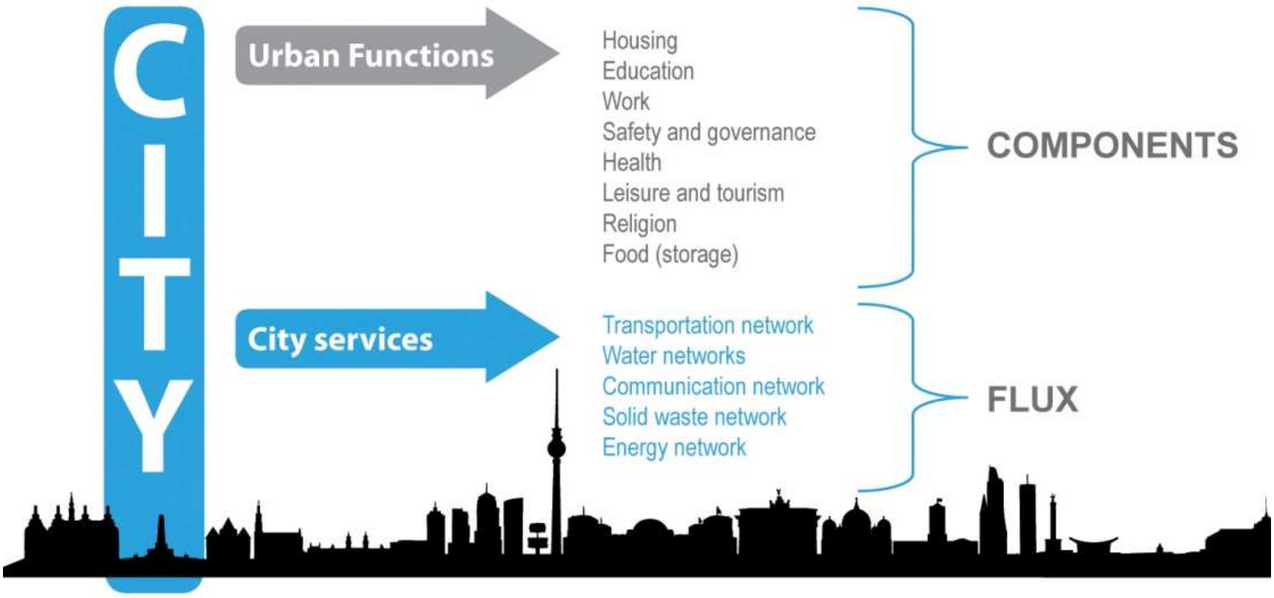


Figure 10: Mapping of the city according to urban functions and services

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 all, 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 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.

The urban functions have spatial extension and they are expressed through units (m^2). There are eight main urban functions that urban system needs to have in order to fulfil 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 of industry and areas for non-industrial activities), safety (police, fire brigade and rescue services at local level) and governance, health (hospitals on local and non-local level), 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. City services in urban system give functionality and interconnectivity to urban functions (e.g. the function of a house is to provide space for living). They can be analyzed as a flux of urban system.

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 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 cause a direct damages to 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 bellow the main dependences are created with respect to dysfunction of different networks.

Table 4: 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	-

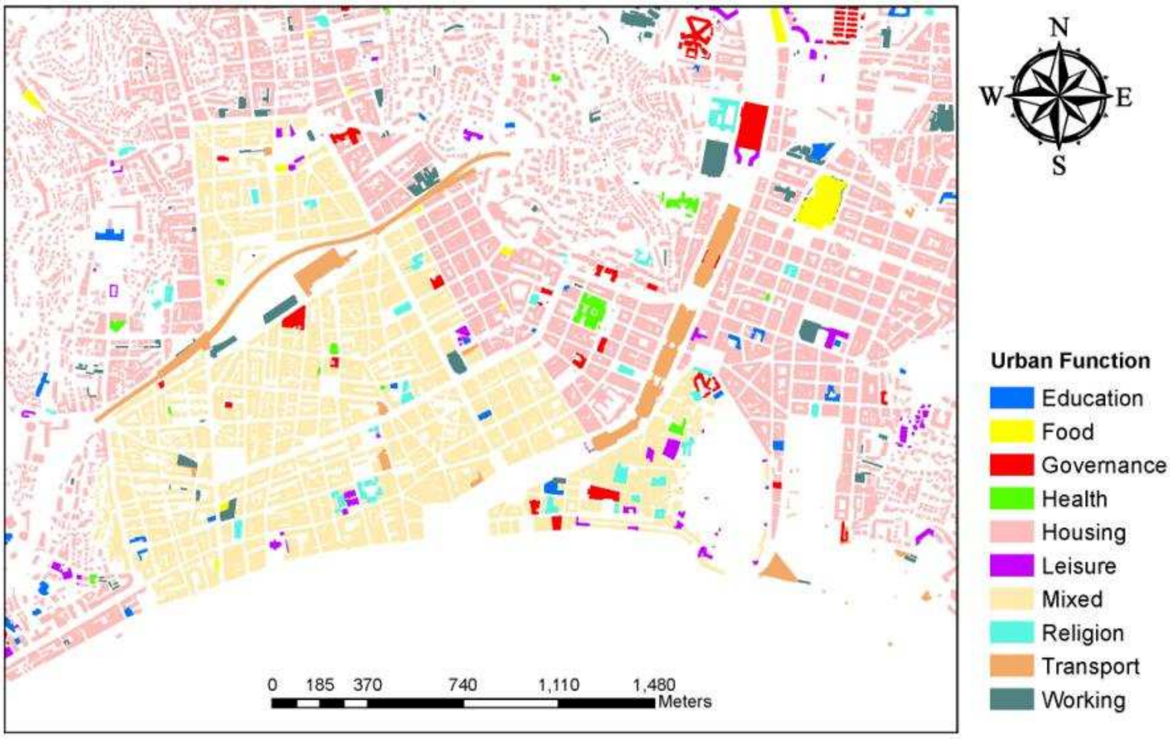


Figure 11: Mapping the urban system - Urban functions and city services, example city of Nice, France

2.6 Quantification of urban flood resilience

Quantification of urban flood resilience in this report is done with developed method for evaluation of Flood Resilience Index. A FRI is developed in order to evaluate the level of flood

resilience for the particular event. The notation for FRI is given as a value for analysed area. The level of resilience can have values from 0 (not resilient) to 5 (resilient). In the text below the method is presented with the example on city area of 72km^2 with 55000 different buildings. This area is taken for demonstration due to availability of data.

2.6.1 Flood Resilience Index (FRI)

The objective of this index is to valuate an urban system's flood resilience depending on the scale of work. To measure flood resilience in urban spaces, the index takes into account several indicators based on the notions of the five R's of resilience regarding flood management: Reflect, Relief, Resist, Response, and Recovery. In the process of calculating the FRI, five different dimensions are analyzed (Physical, Natural, Social, Economic, and Institutional) in order to reflect the overarching nature of flood resilience. In the case of small scales within the urban fabric, the urban functions of the different properties are defined and the availability of critical requirements is assessed.

There is a different process of index evaluation based on scale dependency. For the small scales: (i) parcel/building and (ii) block scale, index evaluation focuses on the urban function. The method for macro scale: (i) district and (ii) city scale takes into account whole system through five dimensions.

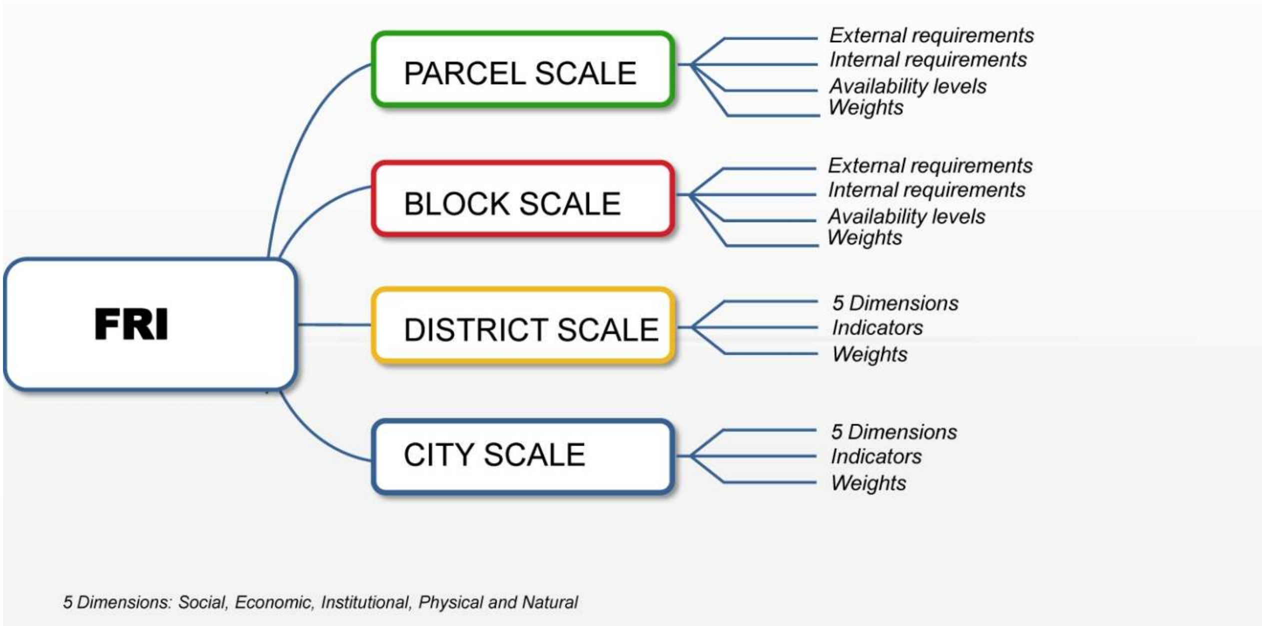


Figure 12: FRI diagram assessment for the different scales

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 natural disasters (floods) 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 (Batica 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 10).

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 10).

Physical components of urban system have a unique building topology. Based on the Figure 10, 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 5: Critical requirements for urban functions

	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)

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

In the context of presented criteria, the *flood resilience index (FRI) for buildings* is an averaged value of evaluated critical requirements. This represents the evaluation of urban flood resilience using Flood Resilience Index (FRI). The index is represented as a level of flood resilience assessment in analyzed area for the existing 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 operationality 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 operationality of urban function. The flood resilience on building level is expressed as a function of external and internal requirements:

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

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.

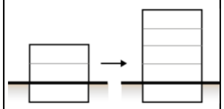
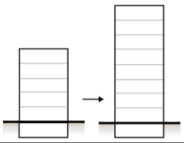
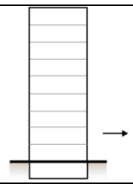
Different flood events have different characteristics. The flood duration, flood depth and flood velocity are one of the main.

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 6: 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)		- 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		-Raising thresholds where possible - Allocation of vital service hubs above flood depth - Wet proofing - Dry proofing - Internal and external walls/doors			

The individual type of building is rare. 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 7: A critical requirements at the property level

Urban functions	Housing		Education		Work		Safety		Governance	Health	Food		Religion			Leisure and tourism		
Critical requirements	Individual	Collective	Kindergarten	Primary/high school/higher education	Factory/production	Business buildings	Fire stations	Police stations	Administrative buildings and control centres	Medical facilities	Supermarkets	Food storage facilities	Church	Monuments	Cemetery	Green area	Pedestrian zone	Museum
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 8: 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	
Energy	0,1,2,3,4,5	
Water	0,1,2,3,4,5	

Waste	0,1,2,3,4,5	$FRI_{building} = \frac{\sum_{i=1}^{5} r_{ei} + \sum_{i=1}^{3} r_{ii}}{8}$
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		

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 9: Critical requirements of block scale

	Critical requirement	Availability level
1	To ensure	(1,2,3,4,5)
2	Access	(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 safety	(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.

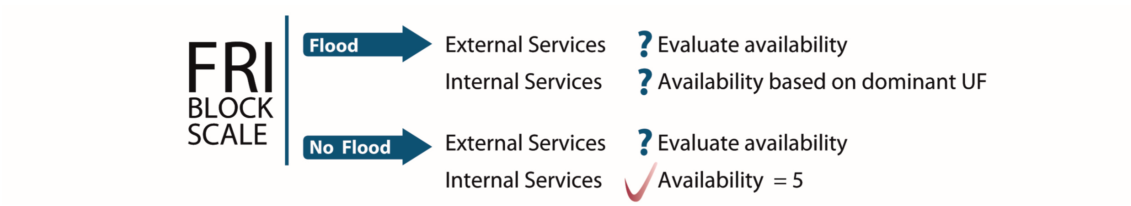


Figure 13: FRI for a block scale with two cases: flooded and not flooded block

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 8.

2.6.2 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 10.

Table 10: 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. 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

Value	External requirement
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
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.
OCCUPATION Refers to the capacity of the property of serving a shelter during a flooding event	
0	The property is not safe for occupation
1	The property might be occupied but the health risks may occur
2	Important areas of the property are completely inaccessible
3	Occupation is possible but areas important but access to important networks of the property are distributed
4	Occupation is possible with minor disturbances to the typical conditions
5	The occupation of the property is fully available
ACCESS Refers to the possibility of accessing a property during flood event	
0	There is no access to the premises during a flooding event
1	Alternative access exist but is highly inconvenient
2	Convenient alternative access exist
3	Access is impaired but possible
4	Access is possible with minor inconveniences
5	Normal access possible

Weights

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 11: Weights for FRI (parcel scale)

Weight wi	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 than obtained with the following formulas.

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

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.

2.6.3 Example

Definition

The FRI assessment on property/building scale is preformed 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.

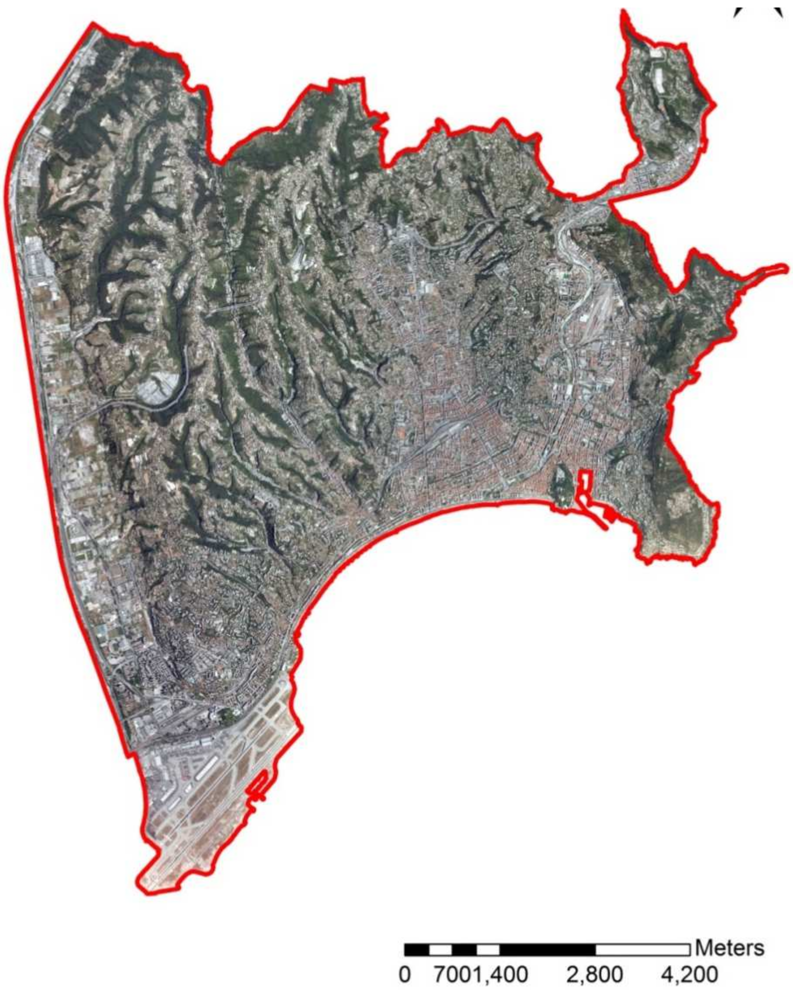


Figure 14: Shape of case study area (Nice, FRANCE)

Characterisation

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.

Performing flood resilience assessment and its multiscale character require a definition of working scales. The general scale division considers (i) macro, (ii) mezzo and (iii) micro scale. The developed methodology, however, consider four scales in the analysis of urban system: (i) city/urban scale, district, block and property/building scale (Batica et al., 2013).

The system analysis for the Nice case study considers the type of flooding, its character and spatial distribution of 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.

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.. The summarized scenarios are presented in Table 12.

Table 12: Summarized scenarios and measures for the Nice case study.

Scenario	Time Horizon	Adaptation Measures	Scale
BAU	Present	Existing status – no adaptation	Property/building, district, city
Scenario 1	Present	Adaptation at the building level	Property/building
Scenario 2	Present	Adaptation at the building level and focus on knowledge based measures	District, city
Scenario 3	Present	Adaptation at the building level and focus on contingency measures	District, city
Scenario 4	2050	Existing status with increased rain intensity	District, city

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 considered measures are presented in the Table 12.

The FRI assessment for Nice case study considers scenarios with and without flood resilience measures presented in Table 12 with respect to different scales.

Two scales are analyzed for flood resilience assessment, the *city or urban scale* takes into account the whole case study area, 72km^2 and the *property/ building scale*. The critical areas for analysis define the coastal zone of the city. This area was marked because of the terrain configuration, where area is flat and possible risk of flash flood driven from the upstream terrain

characterized with high slopes. Hence, the analysis will take into account the whole case study area chosen for both scales, not only coastal zone.

The FRI is calculated using the defined matrix. The matrix has a set of indicators and parameters. The flood resilience index is evaluated through different availability and importance levels (weight) assigned to the defined indicators. The following assumptions are made during the evaluation process.

- When no data are available for an indicator or no availability can be assigned, it is left out of the integration of the overall FRI provided that its weight value in not higher than 3. If the weight is higher, than an availability value must be assumed depending on the context provided and peer analysis.
- A building with all requirements, internal and external, represents an urban cell. Further the urban system is mapped to its functions and services provided to the inhabitants. In addition the eight different urban functions are defined and five city services. They form an urban system together with urban community (inhabitants). A list of **urban functions** is as follows:

- Housing
- Working
- Education
- Food (storage)
- Health
- Safety and governance
- Leisure and tourism
- Reiligion ad cementary
- And city services:
- Energy
- Water
- Communication
- Transportation
- Solid waste

- Food availability is assigned 5 for analyzed flood event. This is done with respect to the characteristics of flood event related to the duration particularly.
- Food availability decreases accordingly to the flood duration.
- "Housing" urban function located in the city centre is considered to have a collective character during analysis
- "Mixed" urban function is a generic one. This urban function is a "housing" but in the ground level, it has a shop, store or an office. The mixed type of urban function dominates in the city centre.

Feedback between scales

The feedback loops between different scales exists. This is in addition to prevent incompatibility of results. The two roads of feedback exist in the analysis. The first one is "top-down" approach where the general characteristic of larger scale is transferred on smaller scales. This means that for assessed FRI of different dimensions (natural, physical, social, economic and institutional) transfer its 'availability' and 'important' to the smaller scales (district, block). This is based on the principle that utilities, social, institutional, and economic conditions in a district bear a similarity to the urban scale they belong to.

Second road regarding the feedback has a 'bottom-up' approach. Here, the characteristics of the specific urban function at the property scale let the credentials of trends that have influenced the FRI values of larger scales. In some situations it is considered that a certain requirement (internal or external) is available on a block scale due to analyzed conditions. If, several urban functions show a different pattern from originally assumed requirement, then this feedback is sent to upper scale to adjust FRI value.

For example, the city is considered to have good access to energy supply. This characteristic is carried on to block scale in which several properties have a non protected electrical network regarding analyzed flood event. In this case the reassessment is made on block or district scale with adjustment of availability of selected requirement or indicator (if its a district or urban scale).

<u>Property/ building scale</u>

The FRI assessment on property/building scale is preformed 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 56 000. The table with evaluation of critical requirement is presented i below.

Table 13: Evaluation of critical requirements for 'housing' urban function (example)

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 three considered return periods are included in evaluation of FRI. The main idea was to adapt 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 14: FRI values for different flooded urban functions considering different flood depths in Nice case study area

	FRI for different flood depths			
URBAN FUNCTION	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 15: FRI values for different un-flooded urban functions considering different flood depths in Nice case study area

	FRI			
URBAN FUNCTION	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.

The influence on FRI values flooded and non-flooded urban functions is significant. This is represented in figure below. Both, flooded and non-folded urban functions are a part of assessment of FRI.

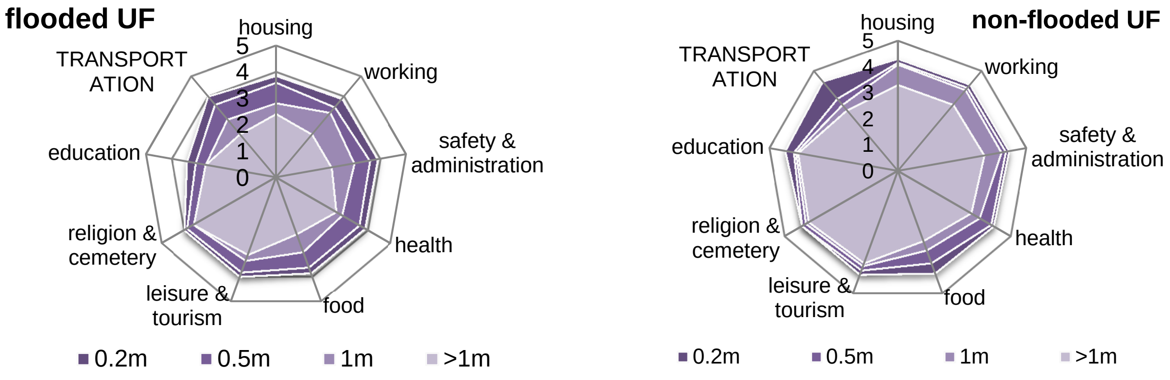


Figure 15: Comparison of different FRI values for flooded and non-flooded urban functions

The difference in FRI values of flooded and non-flooded urban functions shows that the high influence on flooding has

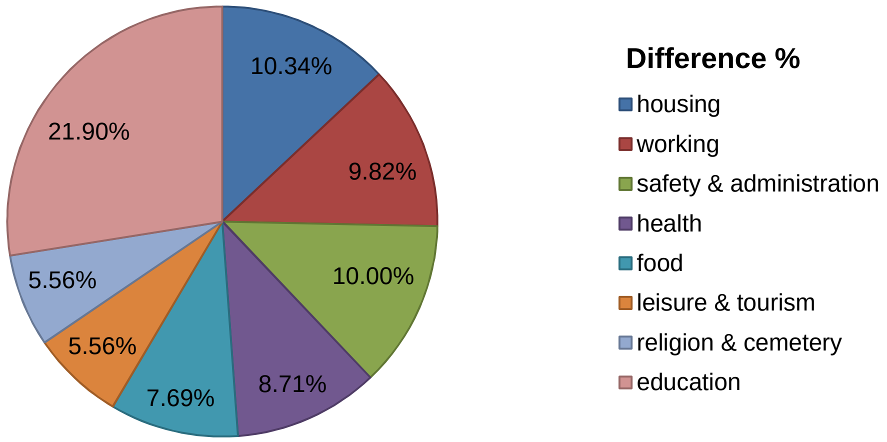


Figure 16: Difference in FRI of flooded and non-flooded urban functions

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.

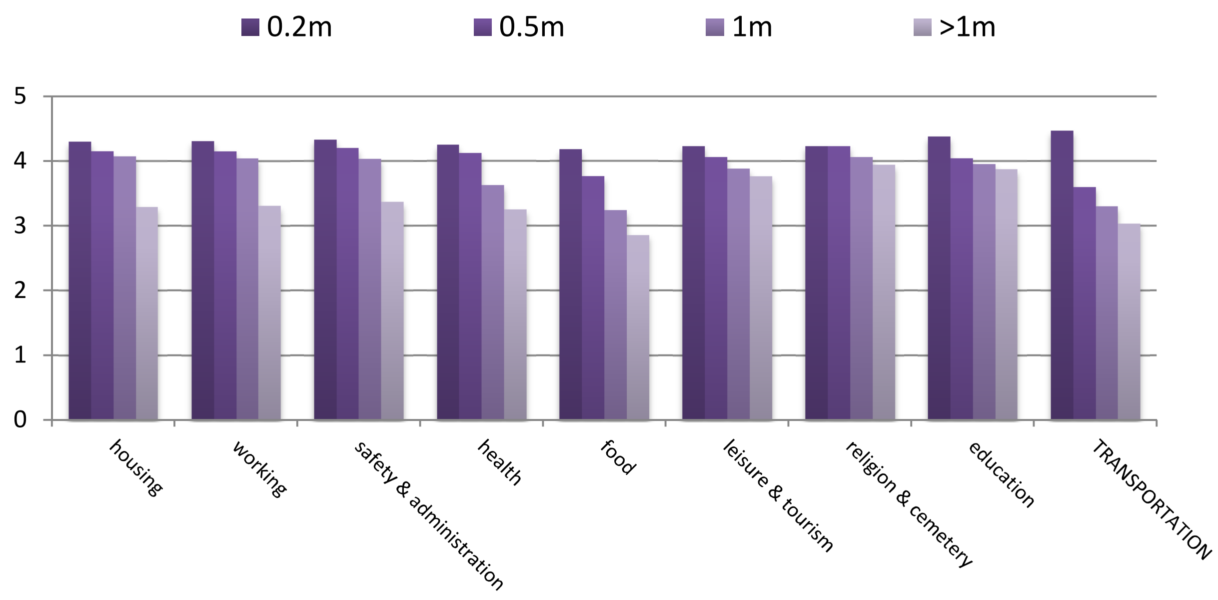


Figure 17: FRI dynamics with respect to different flood depth for Nice case study

FRI for city/district scale

The evaluation of FRI for big scale like district or larger urban scale in this case the whole city area includes five dimensions (natural, physical, social, economic and institutional). Here, the aggregation of all characteristic is translated on bigger scale. 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 (Batica et al. 2103). 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 was 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 availably 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.

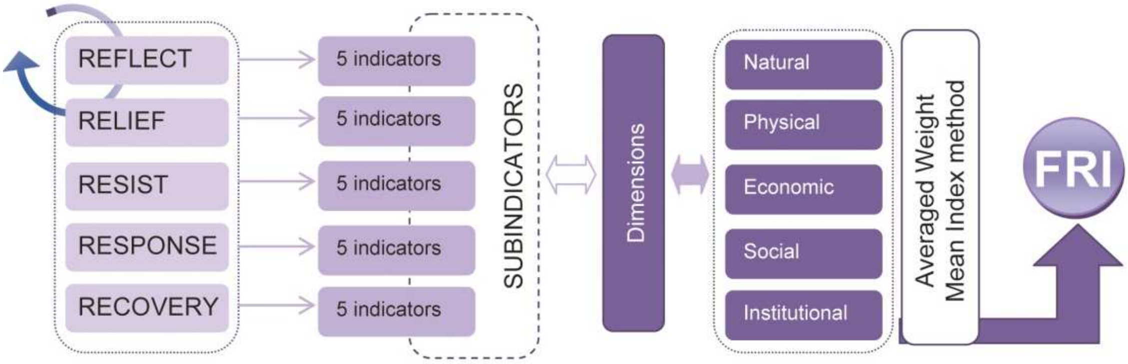


Figure 18: Schematic presentation of FRI evaluation of city/district scale

Assumption for presented example: *When no availability can be assessed for an indicator, it can be left out of the integration of the overall FRI provided that its weight value in 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 defined by Batica et al., 2013, 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 at UNS and employees within the risk management department at municipality Nice Cote d'Azur (NCA).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.

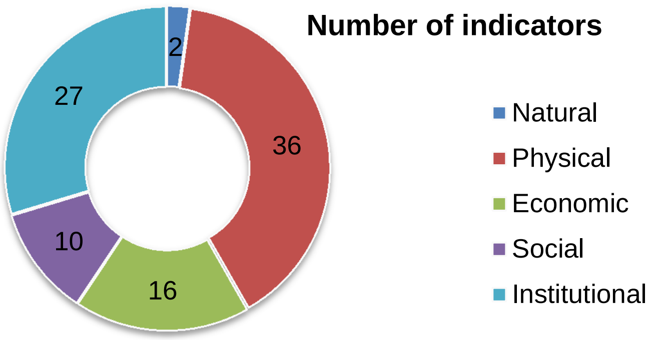


Figure 19: Number of indicators per dimension for large scales

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

The calculated averaged WMI 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 16: 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 17: FRI evaluation for macro scale

Dimension (d)	FRI
Natural	$$FRI_{city/district} = \frac{\sum_{i=1}^{n} I_i \times w_i}{\sum_{1}^{n} w_i}$$
Physical	
Social	
Economic	
Institutional	

Where:
n is a total number of indicators for the given dimension
I is an indicator's value within each dimension
d is dimension

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

The evaluation of overall FRI is followed by assigning values to each indicator with their respective weights. From the present conditions, the FRI for the Nice case study was The result of the FRI under present conditions was 3.45. Table 18 provides an overview of the FRI for each dimension and overall FRI.

Table 18: Overall FRI for the city/urban scale, Nice case study - BAU scenario

	Indicators	Dimension index ∑((xi*wi)/ ∑wi)	"Importance" ∑wi/ ∑w	Overall index
Natural	2	3.50	20%	3.45
Social	10	3.17	20%	
Economic	16	3.65	20%	
Institutional	24	3.70	20%	
Physical	30	3.25	20%	

The overall FRI calculated for different scenarios is presented in the table below.

Table 19: FRI for scenarios

Scenario	FRI	Δ
Present (BAU)	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 3.
– For the BAU 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 are not influencing a spatial extent of flood but the influence on damages is noticed. Regarding FRI evaluation, the values are lower compared to BAU 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 20: Scenarios FRI breakdown per dimension and change (Δ) with respect to current state

	BAU	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

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

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

Further the presentation from available matrix in ANNEX A can be done with summarized 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 ANNEX B with examples on Genoa, Rethymno and Les Boucholeurs.

2.7 What is different?

The evaluation of FRI and its development is a part of research project CORFU. The research continued with this project (PEARL) too. The limitation of the proposed approach is based on the ability to objectively assess all defined indicators. The outcome indicators were 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 (assigned for each indicator) that can't be defined in absolute values. However, the possibility to implement the approach under a participative process which allows choosing representative values, can integrate the dynamic vision which is needed for the urban planning actions. Some limitations related to providing a quality measure of the process are possible since weights are used to intensify the scores in the assessment.

In addition, for the FRI evaluation on macro scale the same importance is given to each dimension. This means that every dimension is giving 20% for the FRI evaluation. Further corrections will be made during the process of FRI implementation to the knowledge base platform (deliverable 5.5).

During development of the knowledge base platform indicators will be reassessed and is possible the correction will be made within this report or they will be included as a part of other reports.

The presented method is a simplification of reality. The method is addressing the flooding processes in urban systems. The focus is on specified resilience, the flood resilience at the city scale. Interconnection between natural, physical, economic, social and institutional system exist and their separation is arbitrary.

2.8 Developing the PEAL FRI Tool (web-based)

Given the initial research activities on the FRI framework, the PEARL project team has planned and implemented the integration of the FRI methodology into an a software application (PEARL FRI Tool) that would support stakeholders in their aim to identify vulnerabilities at city scale and

guide them to specific measures that could improve the resilience of their region. The idea was to integrate the PEARL FRI Tool into the PEARL Knowledge Base and the PEARL web-based learning and planning platform, which were under development in Tasks 5.3 and 5.5 respectively. This way, stakeholders would not only identify in which dimension their city is most vulnerable, but they would be provided with additional functionality to explore different strategies for adaptation in response to flood risk.

During the preparations for the implementation of the tool, the development team organised different activities in Rethymnon city as part of workshops with the stakeholders. These activities focused on the user friendliness and intuitiveness of the FRI methodology. The stakeholders provided useful feedback, which led to an adjustment of the methodology for the PEARL project. The most significant changes refer to the following:

a) The questionnaire for assessing the city performance has been simplified, by reducing the overall number of indicators to 58, keeping the most important ones per dimension.
b) Some additional indicators have been included in order to balance the selected set of indicators per dimension. The full list of indicators per dimension used in the PEARL FRI tool is listed in Table 23.
c) The PEARL FRI is now calculated per dimension fist. After that the overall FRI is calculated using independent weightings per dimension.

The overall FRI score is calculated by applying the following equations:

$$FRI = \frac{\sum_{j=1}^{5} WD_i \times FRID_j}{\sum_{j=1}^{5} WD_j}, \quad (1)$$

$$FRID_j = \frac{\sum_{i=1}^{n_i} W_i \times s_i}{\sum_{i=1}^{n_i} W_i}, \quad (2)$$

Where *FRID*$_j$ is the calculated Flood Resilience Index for a dimension, *WD*$_j$ and *W*$_i$ the weights for dimension *j* and indicator *i* respectively and *s*$_i$the score indicating how well a city performs in the field covered by a specific indicator.

Error! Reference source not found. shows the main page of the PEARL FRI Tool. On the upper part of the page information is provided regarding the purpose of this application and its functionality. On the right side of the screen, a list of indicators per dimension is shown (**Error! Reference source not found.**). The font size of each indicator title is proportional to its weight. Using sliders, users are able to influence the score of the indicators and thus the FRI of the respective dimension and the overall FRI.

On the left side of the screen a spider diagram visualizes the FRI scores of the stored cities per dimension. From the main menu one can show and hide any one of the plotted graphs or switch to another city. Provided that the user has sufficient rights, he can assess the FRI of a new city and save the results to the server.

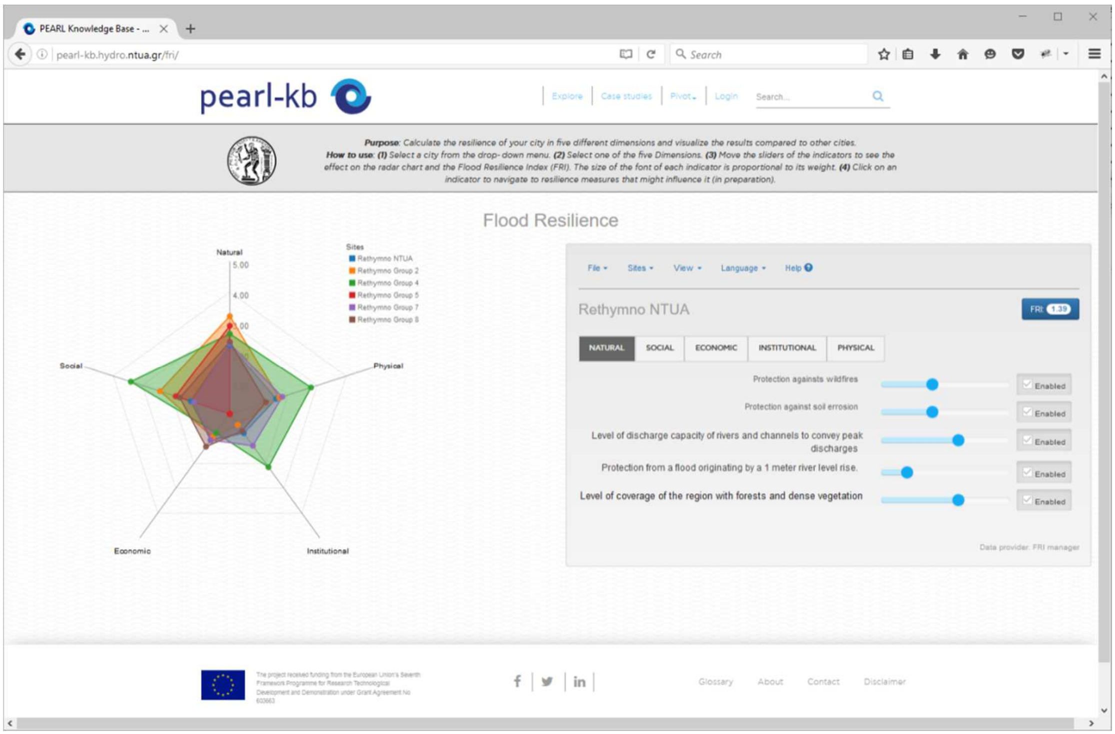


Figure 20: Main page of the PEARL FRI Tool

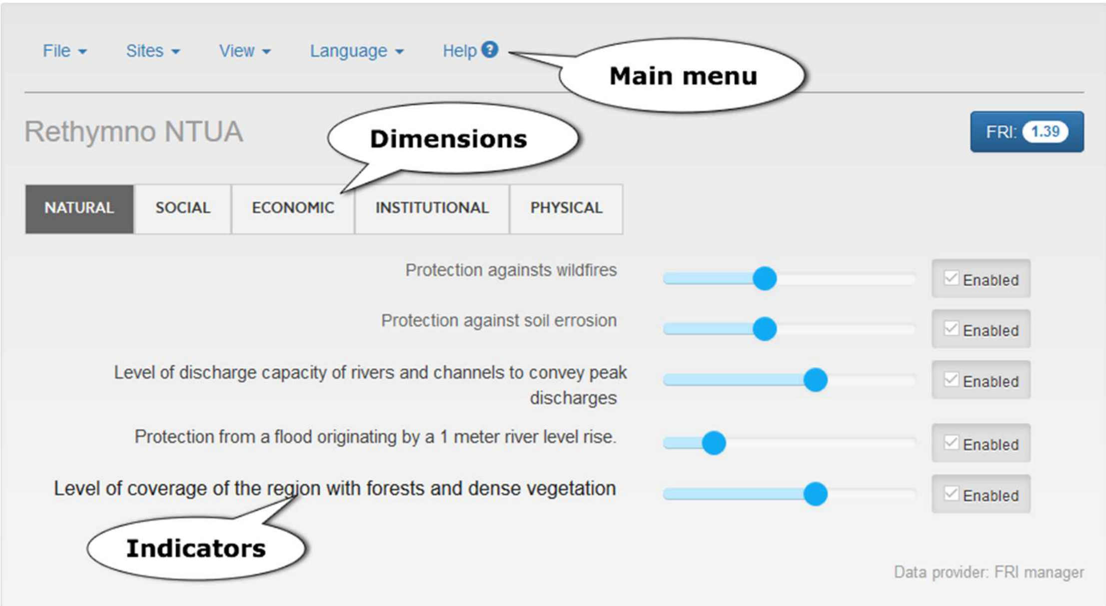


Figure 21: Aspect of the PEARL FRI Tool main page

During the project, the PEARL FRI Tool has been tested in the city of Rethymnon. A number of stakeholders have been asked to assess the resilience of their city in each dimension consisting the FRI by assessing the value of the indicators one-by-one. The stakeholders have been divided into groups, each of them giving its own independent assessment online. The results were visible immediately as a spider diagram shown in Figure 22. One can easily recognize that by giving lower marks to the economic indicators, all stakeholders agree that the city's resilience against floods is low with respect to economic aspects. There is also a common view on the

preparedness of the city of Rethymnon with respect to the Natural dimension, while for the other three dimensions there is no clear estimation.

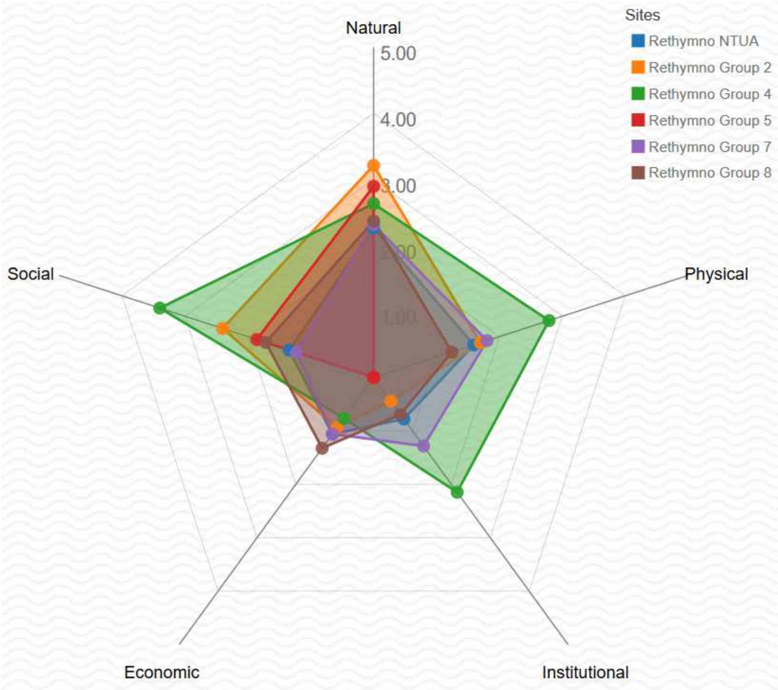


Figure 22: Spider diagram depicting assessments of stakeholders regarding the resilience of the city of Rethymnon per dimension.

By clicking on an indicator title, the user is navigated to the list of measures that might influence the specific indicator, as show in Figure 23. One can then continue his research by navigating to the detail page of a specific measure.

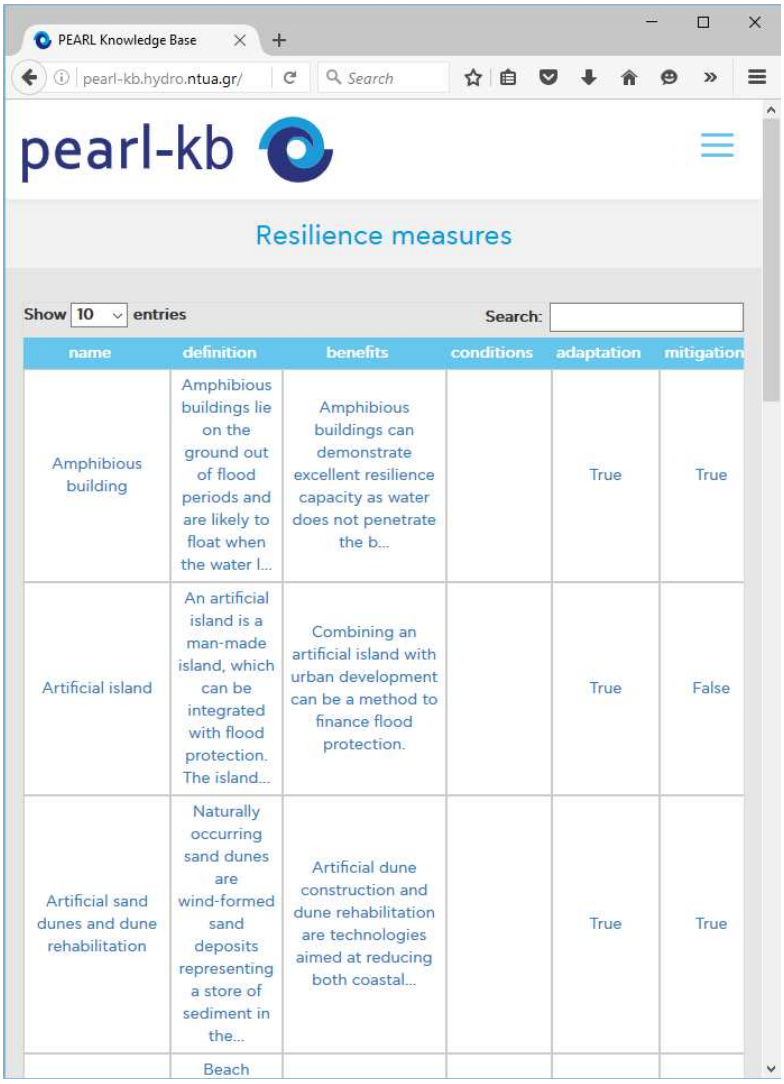


Figure 23: Web page showing a list of measures influencing the protection from floods originating by a 1 meter river level rise

Table below presents a list of indicators used in the PEARL FRI Tool per dimension adapter from initial FRI assessment. The adapted indicators are incorporated in the tool that provides online evaluation of FRI for given area.

Table 23: Indicators of PEARL FRI Tool (web based tool)

Dimension	Indicator
ECONOMIC	Availability and accessibility of financial resources
ECONOMIC	Availability of financial resources for protection of transportation network
ECONOMIC	Assessment of financial resources management and allocation in relation to past flood events
ECONOMIC	Availability of financial resources enabling the development and implementation of evacuation plans before human loss
ECONOMIC	Availability of financial resources supporting rescue services
ECONOMIC	Availability of resources assisting in quicker and more efficient drainage of flooded areas
ECONOMIC	Availability of resources for solid waste removal and management

ECONOMIC	Availability of insurance & financial services
ECONOMIC	Deduction of taxes of people in flooded areas
ECONOMIC	Legal building reconstruction/renovation for flood risk mitigation/adaptation purposes
INSTITUTIONAL	Embodying flood risk in urban planning
INSTITUTIONAL	Embodying climate change predictions in spatial urban planning
INSTITUTIONAL	Land use control
INSTITUTIONAL	Preservation of wetlands and green spaces
INSTITUTIONAL	Availability of flood vulnerability maps
INSTITUTIONAL	Development and availability of regulations and specifications depending zones of flood risk
INSTITUTIONAL	Availability of crisis management plan with maps
INSTITUTIONAL	Availability of plans for management of existing road network and protection from flood risk
INSTITUTIONAL	Availability of evacuation plans with maps
INSTITUTIONAL	Development and design of evacuation procedures based on flood risk simulations and assessment of results
INSTITUTIONAL	Conduction of evacuation training
INSTITUTIONAL	Availability and implementation of regulations enhancing adaptation/mitigation
INSTITUTIONAL	Establishment of Stakeholders Committee on flood risk
INSTITUTIONAL	Embodying flood risk in Building code
INSTITUTIONAL	Level of implementation of Building Code
INSTITUTIONAL	Possibility and capability of modifying Building Code on reconstruction procedures
INSTITUTIONAL	Level of implementation of Flood Directive in Local level
INSTITUTIONAL	Availability of regulations defining reconstruction/renovation procedures after flood events
INSTITUTIONAL	Expected efficiency of the reconstruction works
NATURAL	Level of discharge capacity of rivers and channels to convey peak discharges
NATURAL	Level of area coverage unaffected by flood in case of 1 m river level rise above banks
NATURAL	Level of area coverage with forests and dense vegetation
NATURAL	Level of area coverage unaffected from wildfires the last 2 decades
NATURAL	Level of area coverage unaffected by flood in case of 1 m sea level rise
PHYSICAL	Use of real-time monitoring system for hydraulic structures and urban drainage system
PHYSICAL	Use of real-time monitoring system in the river network
PHYSICAL	Use of an Early Warning System (EWS)
PHYSICAL	Support of announcements (e.g. via email, SMS) to target groups by the EWS
PHYSICAL	Level of accessibility of roads which are important for solid waste management and transportation network
PHYSICAL	Availability and level of accessibility of emergency road network
PHYSICAL	Availability and level of accessibility of emergency shelters
PHYSICAL	Infiltration capacity of paved areas to reduce runoff
PHYSICAL	Sufficient storage capacity of the urban drainage system to accept flood water
PHYSICAL	Level of floodwater retention and detention
PHYSICAL	Availability of flood-proofing constructions of strategic infrastructures
PHYSICAL	Level of protection of crisis management center and rescue services
PHYSICAL	Availability of hydraulic structures within urban system capable to reduce peak discharges
PHYSICAL	Availability of hydraulic structures for river watershed management capable to reduce peak discharges

PHYSICAL	Availability of emergency evacuation routes
PHYSICAL	Availability and level of spatial coverage of emergency communication systems
PHYSICAL	Availability of GIS based information system for stakeholders
SOCIAL	Flood risk education
SOCIAL	Active involvement and support of citizens in flood risk related activities
SOCIAL	Informal coordination of citizens' actions within community
SOCIAL	Multidisciplinary knowledge exchange (engineer, architect/urban planner, sociologist, economist, politician - city government, etc.)
SOCIAL	Responsible authorities learning and adapting from previous events
SOCIAL	Citizens learning and adapting from previous events
SOCIAL	Availability of trained volunteers

3 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.

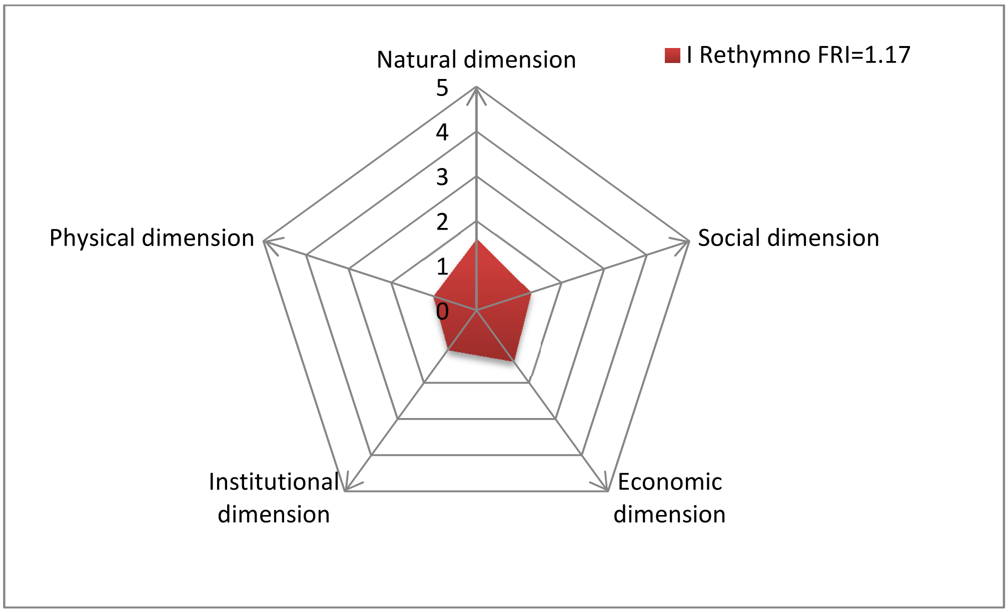
Importance in introducing resilience to flood risk management is significant. The role of the insurance industry, government agencies and flood warning systems becomes fundamental. It is clear that a coordinated approach to the utilization of such products is vital crossways the industry and relevant stakeholders. Assessing flood resilience involves in equation flood damage, risk perception and vulnerability analysis. A role of resilience therefore in sustainable development becomes significant.

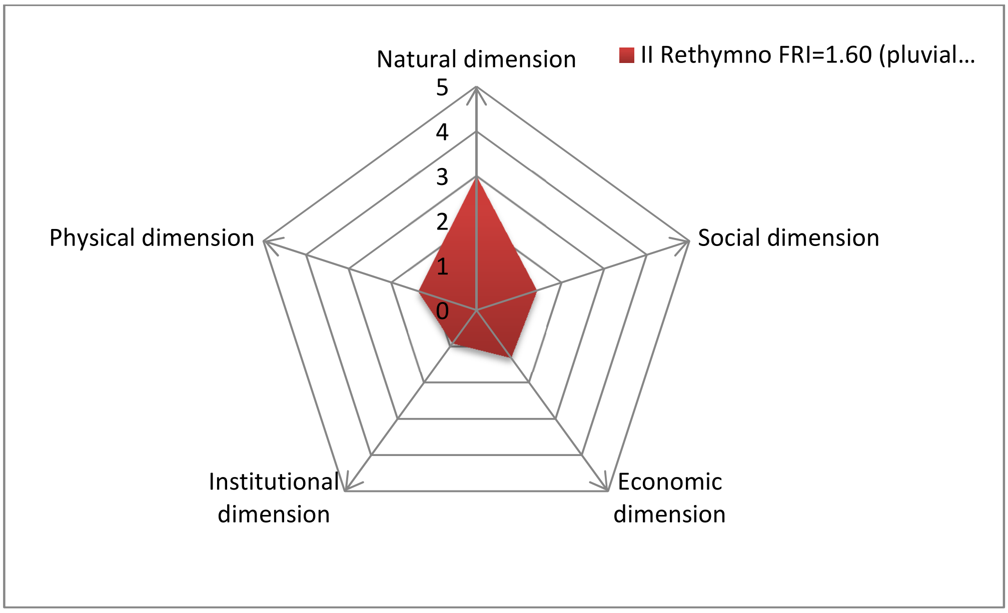
The purpose of presented methodology is to minimize the flood damages if possible. In most of the causes damages driven by floods can be minimized if urban system: already have implemented some of the existing active and passive protection measures, a community within the system is able to organize itself and to prevent more damages, the shape of a system is adapted to receive some disturbance, being able to learn from past events.

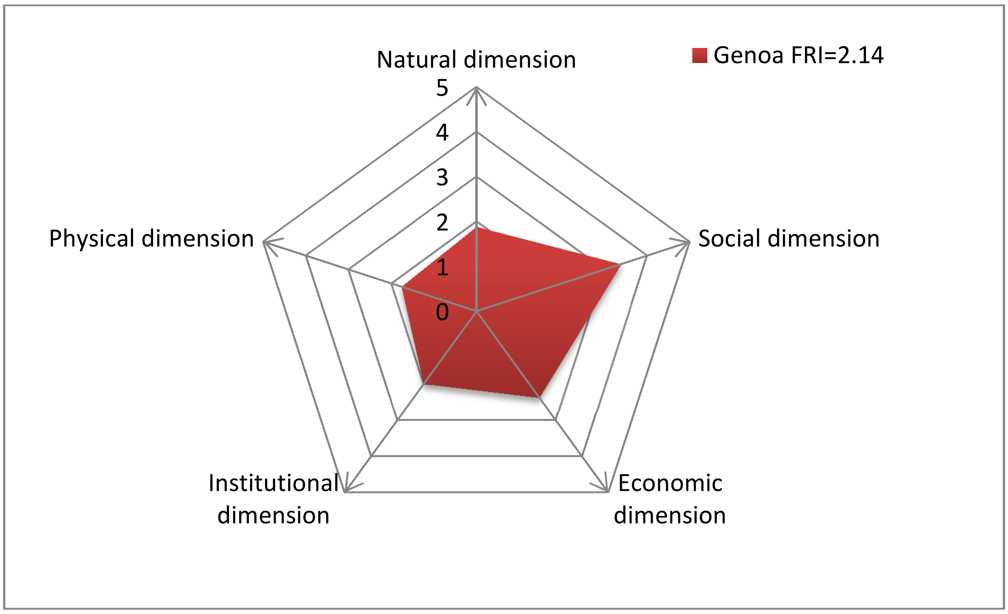
The framework is potentially applicable to any urban system on any geographic scale. Connections and dependences between main city elements and natural hazards (in this case urban flooding process) have to be defined. With its implementation, social, economical, political and cultural relations between 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.

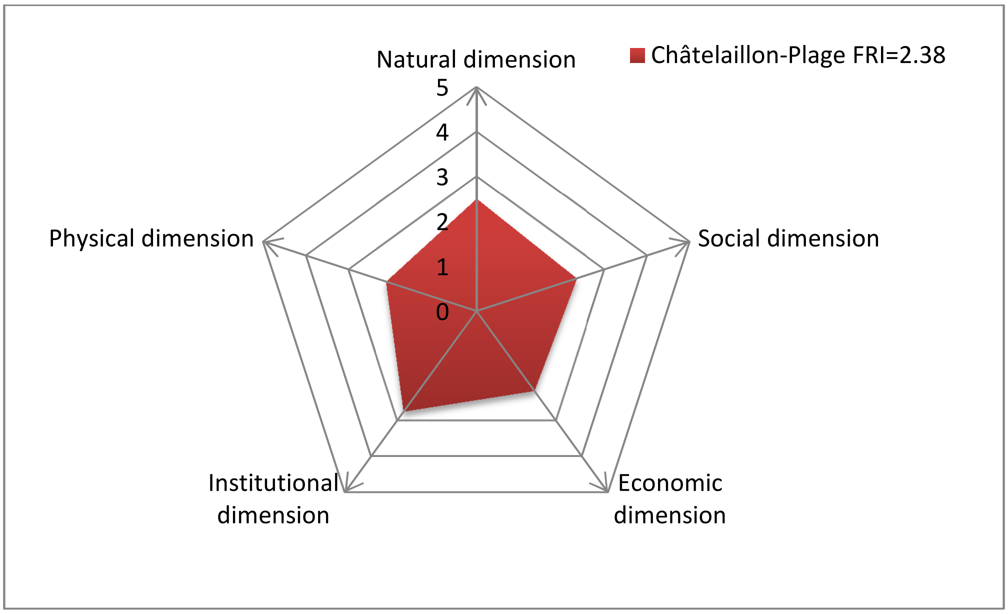
A key recommendation proposes: improving resilience determines urban patterns, which are matching with optimal water distribution, waste collection, energy distribution etc.

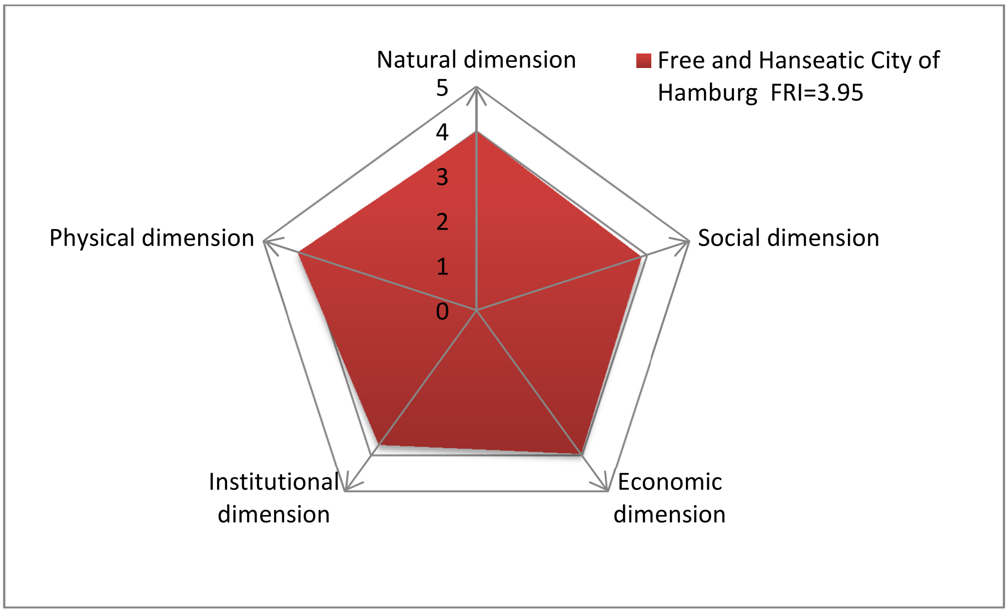
Described approach for flood resilience assessment is applied on five case studies, four European and one international. The spatial scale used for all five case studies is city scale while for French case study the scales for analysis are both building and city scale. In the figures bellow the results of applied analysis are presented in the form of spider chart. Values presented in the diagram are calculated dimension indexes and overall flood resilience index.


Natural dimension
I Rethymno FRI=1.17
5
4
3
2
1
0
Physical dimension
Social dimension
Institutional dimension
Economic dimension


Natural dimension
II Rethymno FRI=1.60 (pluvial...
5
4
3
2
1
0
Physical dimension
Social dimension
Institutional dimension
Economic dimension


Natural dimension
Genoa FRI=2.14
5
4
3
2
1
0
Physical dimension
Social dimension
Institutional dimension
Economic dimension


Natural dimension
Châtelaillon-Plage FRI=2.38
5
4
3
2
1
0
Physical dimension
Social dimension
Institutional dimension
Economic dimension



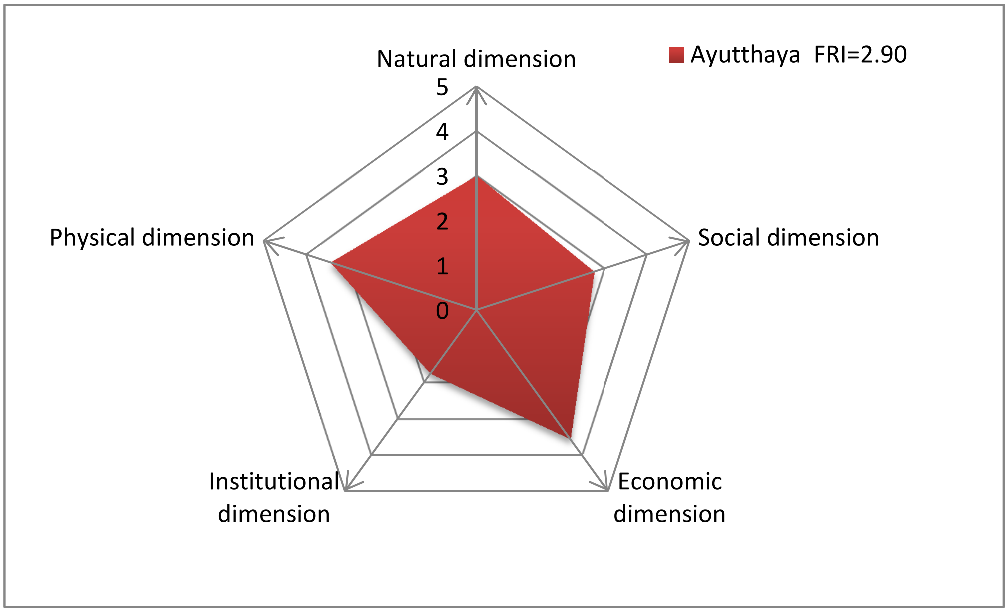


Figure 24: FRI evaluation for all five case study areas: Rethymnon (2 scenarios) - Greece, Genoa - Italy, Châtelaillon-Plage - France, Free and Hanseatic City of Hamburg - Germany and Ayutthaya - Thailand

4 References

Accompanying book of the exhebition in the Hamburg Town Hall (50. Anniversaryofthestormsurge 1962), Landeszentrale für politische Bildung, ISBN: 978-3-929728-72-9

Archontakis D. (1999). Report on the flood events of Rethymno occurred on October 28th, 1991 and on November 10th, 1999

Archontakis D. (2006). Rethymno of the future. Rethymno, Kalaitzakis.

Archontakis D. (2013) The Old Town of Rethymno: from a run down gheto to growth leverage of Rethymno. Rethymno

Ashley R., Blanksby J., Maguire T., Leahy T. (2010). Frameworks for adapting to flood risk: experiences from the EU's flood resilient city project, International Association for Hydro-Environment Engineering and Research (IAHR). http://www.sustainable-environment.brad.ac.uk (accessed 29 November 2012)

Ashley R.M., Blanksby J., Cashman A. and Newman R. (2007): An adaptable approach to flood risk management for local urban drainage. Defra Flood and Coastal Erosion Conference, York, 2007.

Batica, Gourbesville – Methodology for Flood Resilience Index Development – IAHR congress – June 2011, Brisbane, Australia

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

Binnenentwässerung an Nord- und Ostsee, Verlag Konrad Wittwer, 1992, In: Philipp, J.: Summary of the development of coastal and flood protection measures of the Elbe estuary, Project work, 79 pages, 2015 (In German)

Braaker, H; Ollroge, D.: Der SturmflutschutzimHafen Hamburg nach der Sturmflutvom 3.

Burton Ian (1983), "Vulnerability and resilience in the evolution of cities: a methodological framework and research plan", Toronto: Institute for Environmental Studies, University of Toronto

Carpenter S., Walker B., Anderies J.M. and Abel N. (2001). From metaphor to measurement: Resilience of what to what? Ecosystems, 4, 765-781.

Daniell, K.A. et all (2005) – Integrated urban system modelling: methodology and case study using multi-agent systems

De Bruijn, K.M. 2004a. Resilience and flood risk management. Water Policy. 2004 (6) pp. 53-66.

den anderenSturmflutennach 1962, In: Mitteilungen des Franzius-InstitutsfürWasserbau und Küsteningenieurwesen der TechnischenUniversität Hannover, Vol. 45, pp. 222-324, In-house publishing of the Franzius-InstitutfürWasserbau und Küsteningenieurwesen der TechnischenUniversität Hannover, 1977 (In German)

Flood Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the Assessment and Management of Flood Risks

FRD, in press FRD. EC FRD 2007/60/EC Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the Assessment and Management of Flood Risks (Text with EEA Relevance)

Free and Hanseatic City of Hamburg: Die großeFlut in Hamburg – EineChronik der Katastrophe

Ganoulis I. et al. (2000) Research on the Water Supply, Sewerage and Flood Defence System of Rethymno city: Project on the inlet of the diversion conduit "Kamaraki" and the sewerage network. Aristotle University of Thessaloniki, Thessaloniki

Gaume, E., Gaal, L., Viglione, A., Szolgay, J., Kohnova, S., Bloschl G., 2010, Bayesian MCMC approach to regional flood frequency analyses involving extraordinary flood events at ungauged sites Journal of Hydrology, Volume 394, Issues 1-2, 17 November 2010, Pages 101-117

Greenbaum, N., Schwartz, U., Bergman, N., 2010, Extreme floods and short-term hydroclimatological fluctuations in the hyper-arid Dead Sea region, Israel Global and Planetary Change, Volume 70, Issues 1-4, February 2010, Pages 125-137

Heerten, G.; Partenscky, H.-W.: EinVergleich der Sturmflutvom 3. Januar 1976 auf der Elbe mit

Holling C. S. (1973). Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 4, 1-23.

Hötte, H., et.al.: Die Große Flut – Katastrophe Herausforderungen Perspektiven, edt.: Hötte, H.

IPCC - Pacharui et al. (Eds) (2008), Fourth Assessment Report: Climate Change 2007: Sythesis Report, 104 p.

Jahrbuch der Hafentechnischen Gesellschaft, Vol. 36, pp. 157-171, Springer-Verlag, 1977/1978

Januar 1976 – III. Konstruktion und Ausführungsbeispiele des privatenHochwasserschutzes, In: Jahrbuch der HafentechnischenGesellschaft, Vol. 37, pp. 235-255, Springer-Verlag, 1980, In: Philipp, J.: Summary of the development of coastal and flood protection measures of the Elbe estuary, Project work, 79 pages, 2015 (In German)

Klein R.J.T., Smit M.J., Goosen H. and Hulsbergen C.H. (1998). Resilience and Vulnerability: Coastal Dynamics or Dutch Dikes? The Geographical Journal, 164(3), 259-268.

Klein, R.J.T., R.J. Nicholls, and N. Mimura (1999). Coastal adaptation to climate change: Can the IPCC Technical Guidelines be applied? Mitigation and Adaptation Strategies for Global Change, vol. 4, pg 51-64.

Kramer, J.; Rohde, H.: HistorischerKüstenschutz, Deichbau, Inselschutz und

Kreimer, A., Arnold, M., & Carlin, A. (2003). Building safer cities: the future of disaster risk. World Bank Publications

Kusumastuti, D. I., Sivapalan, M., Struthers, I., Reynolds, D. A., 2008, Thresholds in the storm response of a lake chain system and the occurrence and magnitude of lake overflows: Implications for flood frequency Advances in Water Resources, Volume 31, Issue 12, December 2008, Pages 1651-1661

Laucht, H.: Der Sturmflutschutz im Hafen Hamburg nach der Sturmflut vom 3. Januar 1976, In:

Makropoulos C., Tsoukala V., Belibbasakis K., Lykou A., Chondros M., Gourgoura P., Nikolopoulos D. (2015) Managing flood risk in coastal cities through an integrated modelling framework supporting stakeholders' involvement: the case of Rethymno, Crete (abstract submitted and accepted). Paper presented at the 36th IAHR World Congrees 2015, Hague,Netherlands, 28 June -3 July 2015

Makropoulos, C., Tsoukala, V., Lykou, A., Chodros, M., Manojlovic, N. and Vojinovic, Z. (2014) Improving resilience against extreme and rare events in coastal regions: an initial methodological proposal - The case study of the city of Rethymno. International Conference ADAPTtoCLIMATE, 27-28 March 2014, Nicosia, Cyprus

Munich Reinsurance Company (2000). Annual Review of Natural Catastrophes 1999. Munich

Ouarda, T.B.M.J., Cunderlik, J.M., St-Hilaire, A., Barbet, M., Bruneau, P., Bobee, B., 2006, Data-based comparison of seasonality-based regional flood frequency methods Journal of Hydrology, Volume 330, Issues 1-2, 30 October 2006, Pages 329-339

Prudhomme, C., Jakob, D., Svensson, C., 2003, Uncertainty and climate change impact on the flood regime of small UK catchments Journal of Hydrology, Volume 277, Issues 1-2, 1 June 2003, Pages 1-23

RAJIB SHAW and IEDM Team (2009) – Climate Disaster Resilience: Focus on Coastal Urban Cities in Asia (Downloadable at http://www.unescap.org/idd/events/2009_EGM-DRR/Japan-Rajib-Shaw-CLIMATE-DISASTER-RESILIENCE.pdf)

Sayers P., Gouldby B.P., Simm J.D., Meadowcroft I. and Hall J. (2003). Risk, Performance and uncertainty in flood and coastal defence – A review. R&D Technical report FD2302/TR1.

Schmocker-Fackel, P., Naef F., 2010, More frequent flooding? Changes in flood frequency in Switzerland since 1850 Journal of Hydrology, Volume 381, Issues 1-2, 5 February 2010, Pages 1-8

Sendzimir J., Magnuszewski P., Flachner Z., Balogh P., Molnar G., Sarvari A. and Nagy Z. (2007). Assessing the resilience of a river management regime: informal learning in a shadow network in the Tisza River Basin. Ecology and Society, 13(1): 11. [online] URL: http://www.ecologyandsociety.org/vol13/iss1/art11/

SMARTeST team (2013). D3.1:Existing FRe System Design and present use of FRe Technology in FRe Systems. Report of the SMARTeST project, Glasgow, UK: BRE Scotland. [in press]

Tsoukala, V., M. Chondros, Z. Kapelonis, K. Belibassakis, C. Makropoulos (Submitted). An Integrated Wave Modelling Framework For Extreme And Rare Events For Climate Change In Coastal Areas: The Case Of Rethymno, Crete, Oceanologi

UN/ISDR, 2004 : United Nations, International Strategy for Disaster Reduction, http://www.unisdr.org/we/inform/terminology

Villarini, G., Smith, J.A., Serinaldi, F., Bales, J., Bates, P.D., Krajewski, W. F.,2009, Flood frequency analysis for nonstationary annual peak records in an urban drainage basin Advances in Water Resources, Volume 32, Issue 8, August 2009, Pages 1255-1266

Vis M., Klijn F., and Van Buuren M. (eds.) (2001). Living with Floods, Resilience Strategies for Flood Risk Management and Multiple Land Use in The Lower Rhine River Basin. Executive Summary. NCR-report 10-2001. NCR, Delft.

Vis M., Klijn F., de Bruijn K.M. and Buuren M. van (2003). Resilience strategies for flood risk management in the Netherlands. International journal of river basin management, 2003/1, 33-40.

vomFebruar 1962, School authority, 1962(In German)

Walker B., Holling C.S., Carpenter S.R. and Kinzig A. (2004). Resilience, adaptability and transformability in social–ecological systems. Ecology and Society, 9(2): 5. [online] URL: http://www.ecologyandsociety.org/vol9/iss2/art5/

WFD, in press WFD. EC WFD 2000/60/EC Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy

5 Annex A

Table 24: Matrix for FRI evaluation for macro scale

Dimension	FRM element	Area of influence	Indicator
NATURAL	resist	River network	Channel conveyance able to accept peak discharge
	relief	River watershed management (infiltration and retention)	Capacity to avoid the flood (vulnerability reduction)
PHYSICAL	recovery	Transportation network	Emergency evacuation routes
	relief	Cascading flood compartment system (Structure)	Sufficient capacity to accept part (%) of flood water
	response	Crisis management system	Early warning system for announcement
	resist	flood protection	Real-time monitoring FP
	resist	River network	Real-time monitoring RN
	relief	River watershed management (infiltration and retention)	Hydraulic structures RWM
	recovery	Solid waste management	Accessibility of roads SWM
	recovery	Transportation network	Accessibility of roads TN
	response	Rescue system	Location of rescue services are protected
	response	Adaptation for living with floods	Adapted flood-proofing construction (for strategic functions)
	response	Adaptation for living with floods	Adapted construction for transportation network and other services
	response	Adaptation for living with floods	Availability and implementability of adaptation regulations
	response	Crisis management system	Crisis management canter or location is protected
	response	Crisis management system	Coordination with rescue and evacuation system

Dimension	FRM element	Area of influence	Indicator
	relief	Evacuation of exceeding floodwater (Structure)	Real-time monitoring EEF
	relief	Evacuation of exceeding floodwater (Structure)	Sufficient capacity to evacuate floodwater and avoid the flood
	response	Evacuation system	Smart (safe) location for evacuation shelter or location is protected
	resist	flood protection	Hydraulic structures FP
	resist	flood protection	Sufficient capacity with respect to analyzed event
	relief	Floodwater storage (Structure)	Sufficient capacity for rainwater drainage
	relief	Infiltration and reduce run-off (existing structure)	Infiltration capacity (%)
	resist	River network	Hydraulic structures RN
	relief	River watershed management (infiltration and retention)	Real-time monitoring RWM
	resist	Urban drainage (Structure)	Real-time monitoring DU
	resist	Urban drainage (Structure)	Sufficient capacity to accept flood water
	resist	Weather forecast	Communication system with flood control centre
	resist	Weather forecast	Using real-time monitoring system (watershed)
	resist	Weather forecast	Availability of early warning system for FRM
	resist	Weather forecast	Sufficient accuracy
	response	Adaptation for living with floods	Adapted construction for food distribution
	relief	Cascading flood compartment system (Structure)	Real-time monitoring CFCS

Dimension	FRM element	Area of influence	Indicator
	response	Crisis management system	Coordination with real-time monitoring of resist and relief measures
	relief	Floodwater storage (Structure)	Real-time monitoring FS
	relief	Infiltration and reduce run-off (existing structure)	Real-time monitoring I&RR
	recovery	Reconstruction system	Availability of allocation for reconstruction & renovation
	resist	Weather forecast	Provides sufficient lead time for rescue and evacuation works
SOCIAL	response	Community	Active enrolment and support (family)
	reflect	Coordination between stakeholders	Informal coordination within community
	reflect	Knowledge exchange	Multidisciplinary knowledge exchange (engineer, architect/urban planner, sociologist, economist, politician - city government, etc.)
	reflect	Knowledge exchange	Knowledge exchange between scientific and operational stakeholders
	recovery	Lesson learned from past events	Learning and adapting from previous event
	reflect	Public participation	Associations of flood-risk related management
	reflect	Public participation	Flood risk education
	reflect	Public participation	Flood risk management communication
	response	Community	Volunteers C
	recovery	Reconstruction system	Volunteers RS
ECONOMIC	response	Crisis management system	availability of financial resources
	response	Evacuation system	Ability to evacuate people before human loss
	recovery	Financial management	Allowance for the reconstruction or renovation of buildings adapted to the mitigation of flood risk
	recovery	Financial management	Deduction the taxes of people in flooded areas
	recovery	Financial management	Financial support from the insurance
	resist	financial resources	Accessibility to resources

Dimension	FRM element	Area of influence	Indicator
	resist	financial resources	Flexibility / Welfare availability
	recovery	Lesson learned from past events	Examination of dysfunctions of previous events
	recovery	Reconstruction system	Availability of insurance & financial services
	response	Rescue system	Accessibility and availability of emergency shelters
	response	Rescue system	Accessibility and availability of emergency road networks
	recovery	Solid waste management	Sufficient equipments to treat solid waste
	recovery	Transportation network	financial recourses for protection of transportation network
	recovery	Reconstruction system	Flooded areas become dry during xx hours/days.
	response	Rescue system	According to model results (depth and duration of floodwater), rescue services able to save people before occurrence of human loss. (Productivity)
	recovery	Solid waste management	Solid waste could be treated within (xx) days
INSTITUTIONAL	reflect	Flood resilience urban planning regulations – flood-prone areas	Land use control
	reflect	Flood resilience urban planning regulations – flood-prone areas	Urban expansion control
	reflect	Climate change plan	Using flood model result
	reflect	Climate change plan	Urban spatial planning adaptations
	reflect	Climate change plan	Using climate change scenario prediction model
	reflect	Coordination between stakeholders	Committee of flood risk related stakeholders (city)
	reflect	Coordination between stakeholders	Exchange by GIS tool
	reflect	Crisis management system	Availability of evacuation plans and maps
	reflect	Crisis management system	Availability of evacuation trainings
	reflect	Crisis management system	Crisis management and evacuation plans
	reflect	Crisis management system	Crisis management plan with maps (availability)

Dimension	FRM element	Area of influence	Indicator
	response	Evacuation system	Evacuation procedure is designed based on model results (time and demographic density).
	reflect	Flood prevention management - regulations	Flood vulnerability maps
	reflect	Flood prevention management - regulations	Regulations with flood risk maps
	reflect	Flood resilience urban planning regulations – flood-prone areas	Building code
	reflect	Land use restriction (flood-prone area)	Implemented building code
	reflect	Land use restriction (flood-prone area)	Flood maps
	reflect	Land use restriction (flood-prone area)	Wetland/green space preservation
	reflect	Land use restriction (flood-prone area)	Urban planning policies
	response	Rescue system	Emergency communication system is settled
	reflect	Crisis management system	Availability of solid waste management plans
	reflect	Flood resilience urban planning regulations – flood-prone areas	Building ban
	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)
	reflect	Crisis management system	Availability of solid waste management maps
	recovery	Reconstruction system	Duration of reconstruction period is less than x days
	recovery	Reconstruction system	Availability and flexibility of reconstruction codes
	reflect	Transportation network	Plans for managing and protection of existing road network

6 ANNEX B

Three case study analyses are within this annex. The analysed case studies are:

- Rethymno, Greece
- Genoa, Italy
- Chantelaillon Plage, Les Boucholeurs, France
- Free and Hanseatic City of Hamburg, Germany
- Ayutthaya, Thailand

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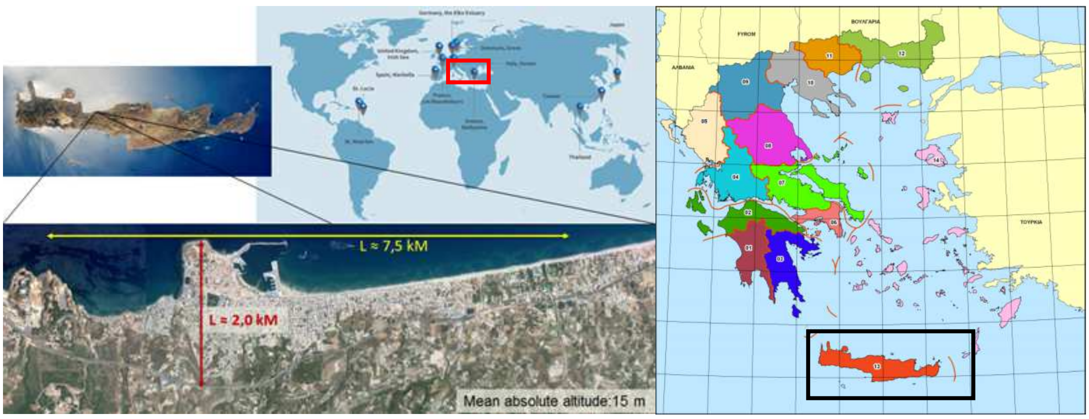
6.1 Rethymno case study, Greece - cases tudy description

Having as primary aim the development of adaptive risk management strategies for coastal communities against extreme hydro-meteorological events while minimising social, economic and environmental impacts and increasing the resilience of Coastal Regions in Europe, PEARL examines six case studies from across Europe and five case studies from the Caribbean and Asia one of which is Rethymno case study in Crete, the largest island of Greece.

Rethymno city is sited at the Region of Crete in Greece and its population stands at 32,468 inhabitants (Census 2011) with a density 140.12 population/km^2. As the 3rd most populous urban area in the island of Crete, commercial, administrative, cultural and tourist activities are being developed along the north coast where the city is located (Makropoulos et. al., 2014) Population growth during the last ten years is high since it is estimated around 12.1% (permanent population according to Census 2001 is 28,959 inhabitants and 32,468 according to Census 2011). A rough estimate of the floating population would be between 20%–30% of resident population especially during summer month due to tourism.

Although Rethymno is not a provincial capital where a large number of decision makers live the city is a major centre of economic activity in the Region of Crete. Tourism is the sector concentrating major economic activity since according to the Municipality of Rethymno 19% of the economically active population is employed in activities directly related to tourism. Public services of the Regional unit of Rethymno are also located in the city.

The mean absolute altitude is 15 m and the length along the coastline of the area under study is 8 km (Figure 25, a).At the coastal area in a zone of approximately 500 m, the area consists of flat terrains i.e. value of area slope 0 – 5% which is gradually increased around 10 - 20% (moderate slope) while moving towards the inland area.Apart from the low-lying coastal area, 13 ephemeral streams cross the city of Rethymno before reaching the sea making it more vulnerable to multiple stressors. Within PEARL project, the urban area under study where the flood risk is being assessed is about 16 km^{2}but for hydrologic analysis purposes a total area of 145 km^{2}is being examined covering the river basins from the origins while trying to estimate the total amount of stormwater that flows through the city of Rethymno (Figure 26).



(a) (b)

Figure 25: Rethymno city, Crete, Greece, sited in the 13th water district of Greece

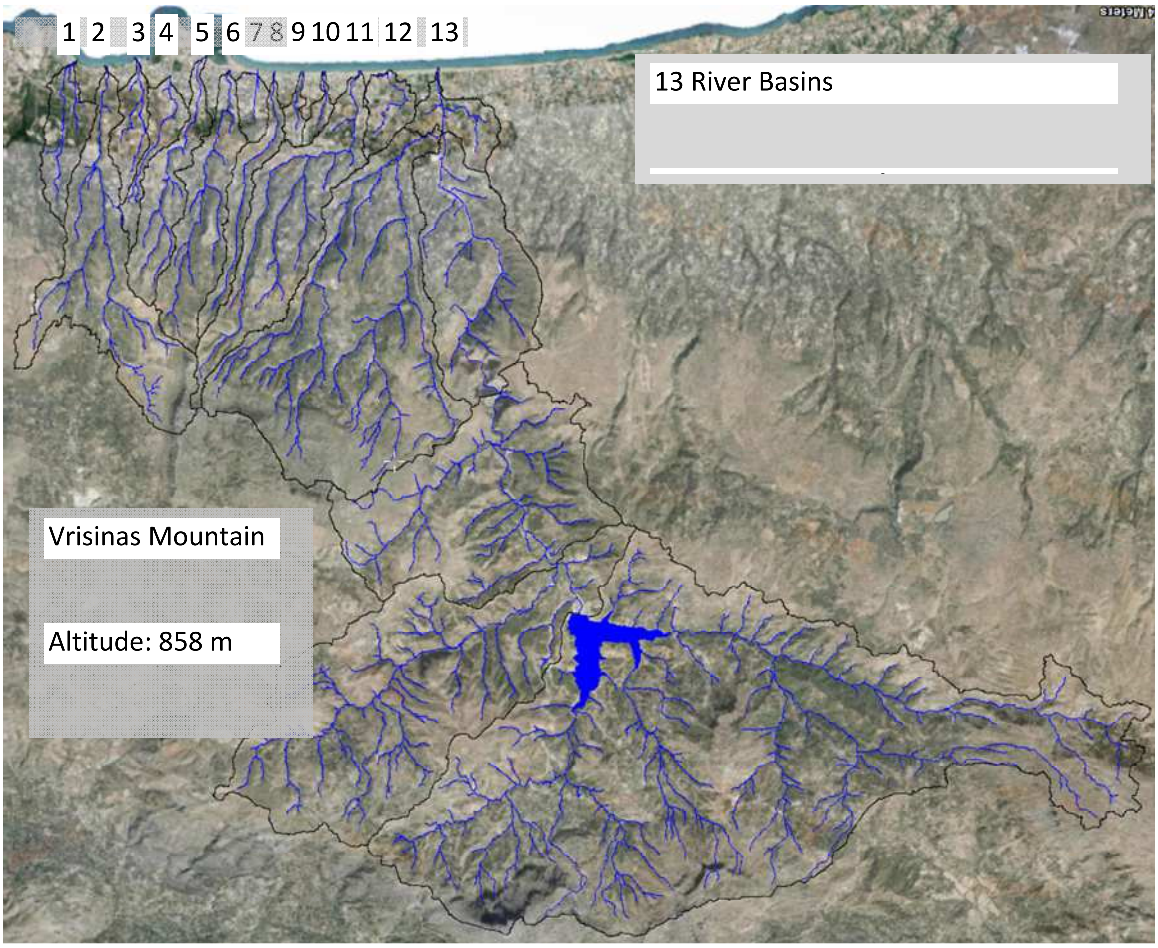


Figure 26: River basins and river network of Rethymno case study

In terms of governance structures related to flood risk management, the Ministry of Reconstruction of Production, Environment and Energy and especially the Special Secretariat for Water are responsible at National level. The term of assignment is not fixed but on the contrary Special Secretaries are appointed by each government, whereas the General Secretariat for Civil Protection under the Ministry of Interior and Administrative Reconstruction is the second structure dealing with flood risk management at a National Level, mostly engaged in issues related during the occurrence of flood events. At a local level, even though there is no authority being responsible for flood risk management, several authorities from the civil sector are being engaged in flood related issues such as the Municipality, the Water Supply and Sewerage Company and the Regional Unit of Rethymno. Jurisdictions have been proven to be unclear and flow of information is difficult especially prior a flood event and while preparedness phase. During a flood event, first responsible is the Fire Department who organise the rest of the authorities and defines the action plan.Rethymno does not have Flood Management Plans specifically derived for the city but currently the Flood Directive is being implemented in Greece. Spatial scale of Flood Directive's implementation is water districts with Rethymno belonging to the 13th one which is Crete (Figure 25, b). Apart from the preparation of flood risk maps within the Flood Directive, focus will be given on prevention, protection and preparedness. The target areas of the Directive are inland and coastal waters by giving emphasis to areas at flood risk which have been identified during preliminary assessment stage.

Financial resources allocated to flood risk management and protection are difficult to estimate but they mostly come from EU funds and specifically Regional Operational Programmes and National Strategic Reference Frameworks.

The built environment is highly susceptible to flood risk since multiple stressors from coastal and inland zone pose flood threat to the city of Rethymno. Nevertheless, the urban growth master plans have not taken into consideration flood prone areas even though they were last established on 2013, nor provided city growth prediction. Additionally, there are no city specific building regulations for Rethymno. The New Building Code of Greece is relatively newsince it was established on 2012 and replaced the previous Building Regulations which were established on 1985.

Climate adaptation is not part of city management, nor has it been known to the city. Since no local studies have been made addressing the impact of climate adaptation, its consequences and the vulnerability of different sectors are unknown.

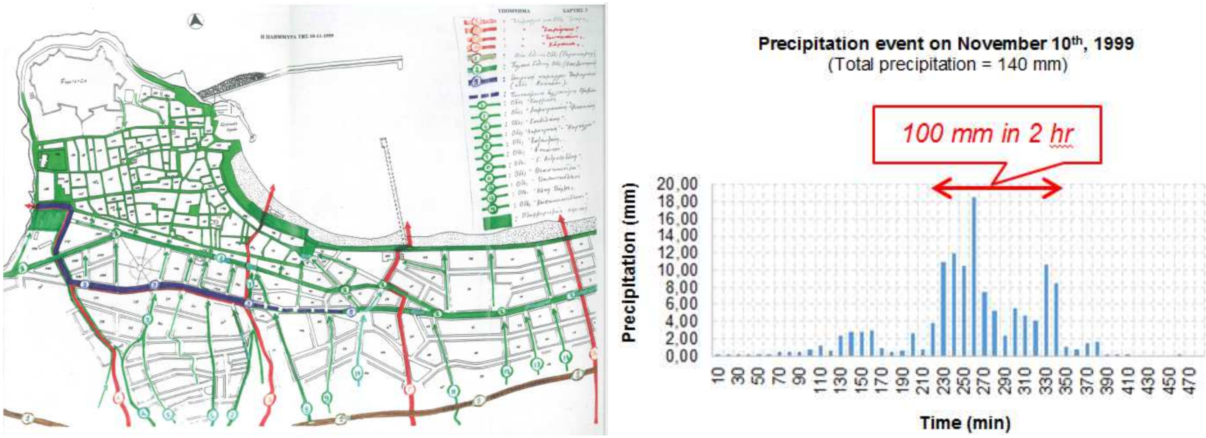
Considering the natural hazards which might threat the city of Rethymno, floods due to multiple stressors e.g. coastal, fluvial, pluvial, storm surges, etc. are first in the list, as well as earthquakes. Tsunamis lately seem to concentrate the interest of researches in the island of Crete. The level of preparedness and response to different natural hazards and urban sectors is low and seems to be concentrated more on earthquakes since several studies have been implemented for Rethymno city, standard operational procedures are more familiar to the citizens and awareness is being raised. The Fire Department is the first responsible authority for all hazards during the event occurrence organising the rest such as the Civil Protection authorities and the Volunteer Teams of Rethymno. Storm surges, strong winds and wave overtopping of port facilities are the last events during of which the disaster response system was tested as described in the below paragraphs.

6.1.1 Scenario description

Multiple stressors have always posed flood threats for the city of Rethymno causing an ongoing risk to its residents, homes, business and public infrastructure. The flow of storm water through the city, the large number of streams that cross it and the rapid transition from the steep slopes at the upstream rural areas to the flat urban zone imposed significant pressure to flood defences throughout the years(Makropoulos et. al., 2015). Major historical floods mainly related to heavy precipitation, exceedance of river's and drainage systems' capacity or inability of flow routing due to lack of maintenance, recorded on February 29th 1968, February 6th 1984, October 28th 1991 and November 10th 1999 (Archontakis D. 2006; Archontakis D. 2013), but others of less importance and destructiveness are encountered every year. Having collected such information for the city of Rethymno, one of the scenarios examined for the estimation of Flood Resilience Index (FRI) is heavy precipitation leading to pluvial and/or fluvial flooding. Apart from the fact that the 13 river basins described within paragraph 6.1.1 drain through the city and perhaps the lower discharge capacity that might be occurred during an extreme event e.g. due to blockage of conduits, lack of maintenance, etc., the inhabitants of Rethymno also affect the evolution of flood risk. There were multiple times when drain grades were covered with plastic in order malodour to be avoided in the Old Town of Rethymno, especially during summer months, which are neglected to be removed when the first precipitation events come on autumn.

While trying to visualise the described event, photographs taken during the last severe flood event on 1999 are listed below (Figure 28) with a map depicting areas of Rethymno which were

flooded according to the mayor who had been elected at that time(Figure 27, a), as well as the recorded hyetograph (Figure 27, b).



(b)

Figure 27: Flood event of November 10th, 1999, (a) inundated areas according to mayor's perception (Archontakis D. 1999) (b) recorded precipitation event (provided by the HNMS)

Figure 28: Inundated areas of Rethymno on November 10th, 1999 (Archontakis D., 1999)

However, pluvial, fluvial and flash floods are only part of the problem. Rethymno is exposed to strong North and North-West winds with great fetches resulting in extreme violent overtopping of the port facilities due to the development of great waves, which eventually cause severe damages. Changes in wind conditions had resulted in causing storm events more frequently than in the past (Tsoukala et. al., 2015). The recently occurred extreme weather conditions of strong winds resulted in the creation of storm waves. More recent flood events related to coastal flooding occurred on January 1st, January 13th and February 10th, 2015. Dire consequences of the extreme waves' formulation were the violent wave overtopping along the windward breakwaters of the harbour, threatening the stability of breakwaters and port facilities. Additional

severe result of wave overtopping is the flood inundation of the harbour's surface area and the surrounding roads. The huge quantities of seawater penetrating the west parking area during those storm events, overflow the harbour's surface area, as well as the wider coastal area (Figure 29, a), inundate parts of the Old Town of Rethymno and pressurise the city's drainage systems. Successive severe damages of the windward wave breakwater (Figure 29, b) have been caused as well as interruption in loading and uploading operations, damages to the port facilities and the cargo, traffic disruption, damages to public infrastructures, local business facilities and citizen's property (Figure 29, c). Having described the coastal forces leading to flooding for the city of Rethymno, the second scenario on which the FRI index is being estimated is related to extreme storm surge events.

(b) (c)

Figure 29: Violent wave overtopping during storm surges events (a) sea water penetration and inundation of adjacent roads, (b) damages of windward wave breakwater, (c) debris from damages spread

Table 25: Scenarios considered for FRI evaluation - Rethymno, Greece

Event	Economic	Urbanization	Measures/actions	Climate change
S2 - Pluvial flooding - November 1999	current	current	no added measures	not considered
S1 - Storm surge - winter 2015	current	current	no added measures	not considered

6.1.2 Implemantation of measures prior and/or after the event

The flood events occurred throughout the years led to adverse human, material, economic and environmental effects and eventually to the selection of engineering/structural measures. After the last severe flood event of 1999, responsible authorities proceed with the development and the implementation of a study related to the flood protection of the city since the existing infrastructure could not protect Rethymno's citizens and properties. The engineering measures that were selected and afterwards constructed were arrangement and diversion of streams and torrents, construction of circular storm water drainage collectors and internal-primary drainage network, as well as three flood control dams (Ganoulis I. et al. 2000) in order to retain peak discharges (Figure 30). The above measures seem to have a very positive effect and to contribute in the flood protection of the city even though it is unsure if the implemented infrastructure has been tested against extreme precipitation events.

In terms of the flood protection against coastal hazards, multiple reconstruction activities in the windward wave breakwater seemed incapable to solve flood problems even though the repair cost was high. The successive damages concern the Port Authority persons in charge who in

collaboration with the Municipality are looking for more permanent solutions and the necessary funding in order to implement them.

Currently, major flaw in the flood protection of the city is assumed to be the lack of flood risk management and the absence of an authority having as major aim the flood protection of the city, the low funding and most importantly the awareness related to flood risk encountered in Rethymno's citizens, authorities and civil engineers. The shift from engineering to operational measures assisting in flood management and not flood defence is indisputable for Rethymno's stakeholders.

(a) (b) (c)

Figure 30: Selected mitigation measures (a) flood control dam, (b) diversion works of Kamaraki stream (c) stormwater collector (Archontakis D., 2013)

6.1.3 FRI for a city scale - Rethymno, Greece

Some assumptions are made before completing matrix presented in Annex A: *When no availability can be assessed for an indicator, it can be left out of the integration of the overall FRI provided that its weight value in 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 3 and 5.
- Emergency evacuation & warning, and accessibility are given an importance of 4 and 5
- Land use and urban expansion have a weight of 5, as well as protected critical facilities
- Volunteers and solid waste management are assigned a weight of 5 and 3.

Following the method defined by Batica et al., 2013 and presented in this report, 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 at our organisation and stakeholders from case study and literature review related to the analyzed event.

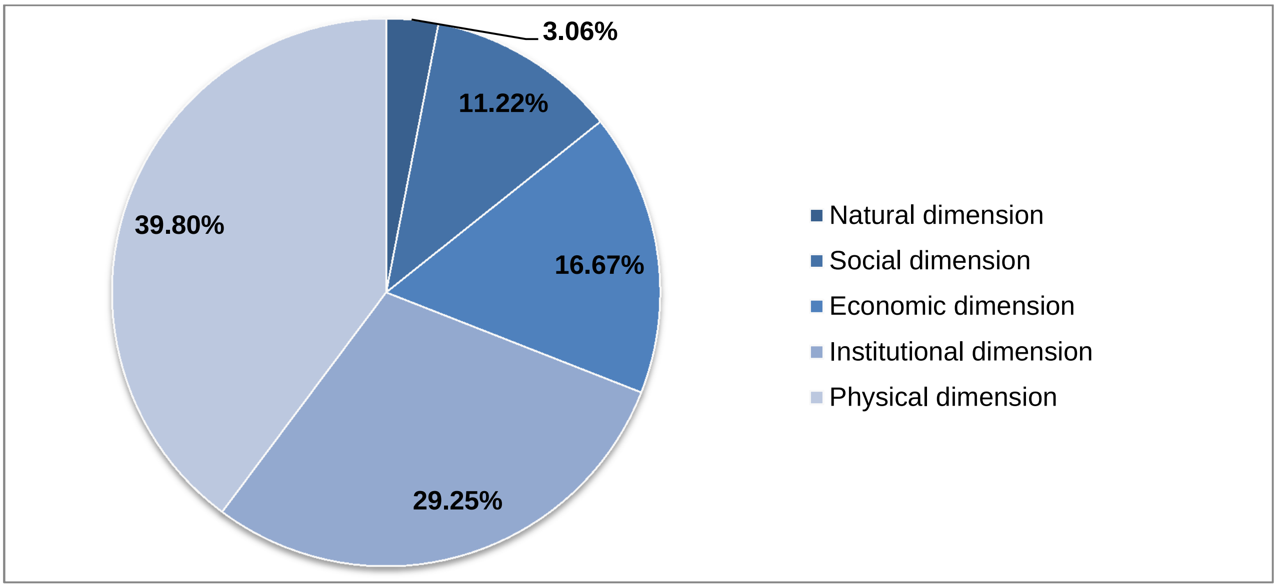


Figure 31: Weight of each dimension on the overall FRI

As presented in figure 31 the importance of each dimension varies from 3.06% for natural to 39.8% for physical dimension.

Evaluation of overall FRI is followed by assigning values to each indicator with their respective weights. For Rethymnom the FRI is evaluated for two scenarios: pluvial flooding (S1) and storm surge (S2). For the given conditions, regarding S1 the FRI for Rethymno is 1.28. The result in the form of table shows separate FRI for each dimension and the overall index.

Results obtained in this analysis demand an interpretation in order to address all the current issues regarding flood resilience

Table 26: Overall FRI for the city/urban scale, Rethymno, Greece for coastal surge scenario

Rethymno-S1	Indicators	not used categories	Dimension index ∑((xi*wi)/ ∑wi)	Overall index
Natural dimension	2	0.00	1.60	1.28
Social dimension	10	0.00	1.28	
Economic dimension	16	0.00	1.41	
Institutional dimension	26	1.00	1.09	
Physical dimension	34	2.00	1.02	

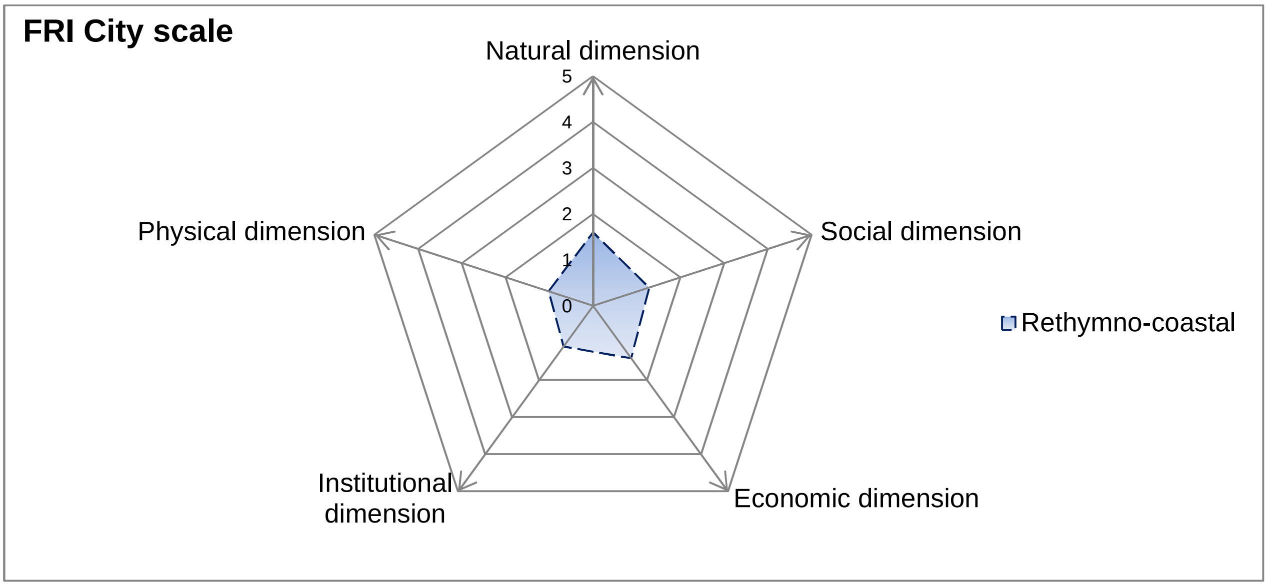


Figure 32: Radar chart presentation of FRI on city scale, for case study Rethymno, Greece - coastal surge scenario

Results obtained using Matrix with 91 indicators give good interpretation about existing and needed assets and policies (laws, binding documents, etc) that will contribute to increase flood resilience of analyzed case study. The 88 indicators is used out of 91.

The value for S2 scenario where pluvial flooding is taken into account gives 1.28 for FRI. The table below presents the values of each dimension.

Natural dimension with index value 1.60 shows that channel vulnerability of coastal part of the city is not enough adapted to avoid effect of a storm surge. Measures that will contribute better adaptation of this riparian part of the case study area is recommended.

Social dimension with index value 1.28 raising awareness among key stakeholders is needed. The ey stakeholders have to be included in the decision making process. Also, their understanding regarding flood risk is valuable in this process.

Economic dimension with index value 1.41 shows low availability in include finance as a support for flooded and to also low availability to invest in preparedness.

Institutional dimension with index value 1.09 shows absence of flood risk management framework that supports actions that will lead to increased flood resilience of case study area. The improved FRM plans, cooperation and collaboration on creation of overall framework that will enhance existing institutional environment is recommended.

Physical dimension with index value 1.02 shows that there is an absence of any dry and wet proofing in the existing buildings. Here the set of hydraulic structures that have ability to reduce the impact of waves.

With the improvement in these segments, the flood resilience of this community can be on higher level.

Table 27: Overall FRI for the city/urban scale, Rethymno, Greece for pluvial scenario

Rethymno-S2	Indicators	not used categories	Dimension index ∑((xi*wi)/∑wi)	Overall index
Natural dimension	2	0.00	3.00	1.60
Social dimension	10	0.00	1.42	
Economic dimension	16	0.00	1.31	
Institutional dimension	27	0.00	0.91	
Physical dimension	36	0.00	1.37	

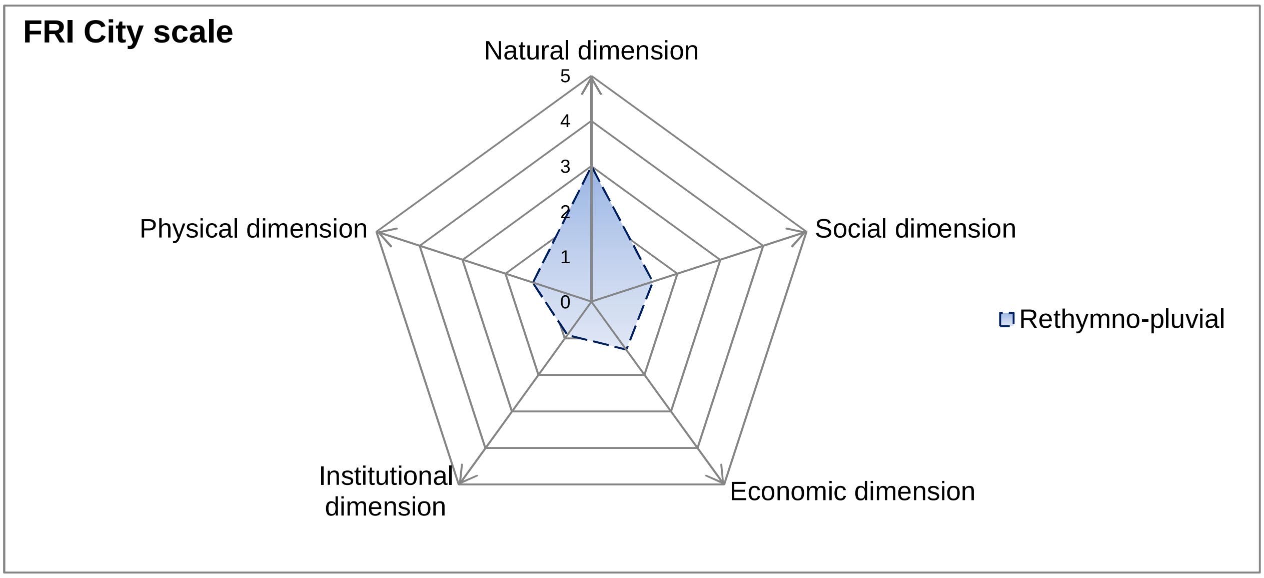


Figure 33: Radar chart presentation of FRI on city scale, for case study Rethymno, Greece - pluvial scenario

Results obtained using Matrix with 91 indicators give good interpretation about existing and needed assets and policies (laws, binding documents, etc) that will contribute to increase flood resilience of analyzed case study. The 91 indicators are used out of 91.

The value for S2 scenario where pluvial flooding is taken into account gives 1.60 for FRI. The table below presents the values of each dimension.

Natural dimension with index value 3.00 shows that existing channel (natural and artificial) is too small to accept floodwater. Measures that will contribute increasing the capacity of natural environment in accepting flood waves are recommended.

Social dimension with index value 1.42 shows that even with the big weights the knowledge exchange is missing or it is not on the proper level. Flood awareness in comparisson to S1 is a bit higher but still not on the level that will create solid knowledge oamong stakeholders regarding flood risk.

Economic dimension with index value 1.31 shows low availability of financial resources for people affected in flood. In addition, the compensation after flood in the form of tax reduction is missing or it is on very low level.

Institutional dimension with index value 0.91 shows that there is an absence of FRM plans in city urban planning. In addition, the participation of community in the flood risk management plans is on the low level.

Physical dimension with index value 1.37 shows that there is an considerable amount of actions that should be included in the protection of the buildings with high chance of flooding.

With the improvement in these segments, the flood resilience of this community can be on higher level.

6.2 Liguria case study (Italy) - Case study description

The case study is located in Genoa, the third largest city in the northern Italy in Tyrrhenian Liguria and crossed by Bisagno River, the biggest basin of the city of approximately 98 km^2. The land use is predominantly residential with some commercial and industrial areas.

As most of the Italian rivers also Bisagno are not able to carry the Q_{200} flow discharge without flooding their flood plains. Most of the Italian rivers and torrents are not able to carry the Q_{200} flow discharge without flooding their flood plains. Actually, both the Bisagno and its small tributary Fereggiano are not able to safely drain the Q_{50}, producing inundations in the urban area of the city. This is well recognised and described in the flood prone areas maps attached to the Basin Plan of the Bisagno river.

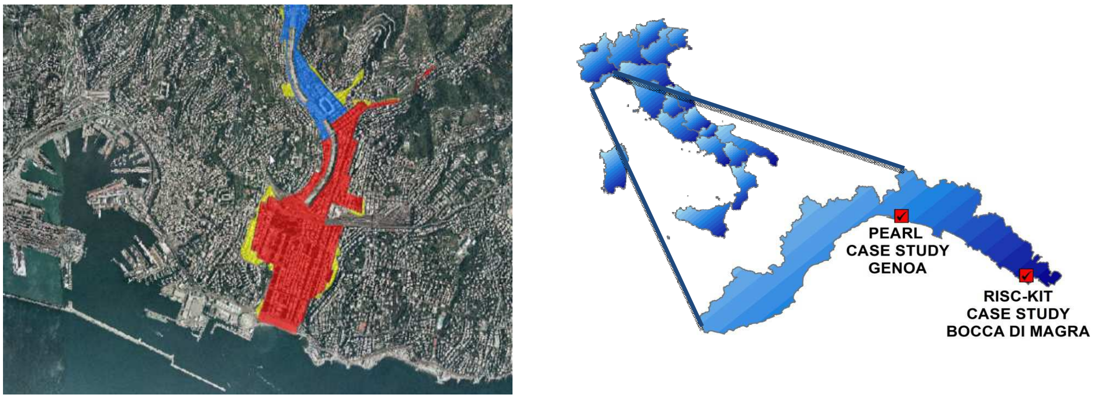


Figure 34: Bisagno torrent. Basin Authority predictions and location of Genova pilot

The Bisagno Basin Plan identifies a number of hydraulic structures and maintenance works to be performed. In first place among the major structures, we will find a diversion channel for the Bisagno, which will collect also part of the Fereggiano discharges. In first place among the maintenance works, we find the Fereggiano. While those works are still waiting for a possible funding, works have been initiated for the complete re-building of the Bisagno cover in its final reach and for a new cover of the Fereggiano in its medium part. Even the completion of this work will not provide full safety against the Q_{200} flood, and the upstream flow diversion is still needed.

In the last century occurred 7 extreme flood events. The extreme event of 1970 was the biggest flood recorded and killing 25 people. It was characterized by high intensity of precipitation of long duration affect especially the Bisagno stream. On the other hand the extreme event of November 2011 was characterized by high intensity of precipitation of short duration affect especially the small basins as the Fereggiano stream of drainage area 5 km^2. The last extreme event was inOctober 2014 and it was less severe than 2011 event and especially interested the final stream of the Bisagnoriver.

In this case study, we investigate the October 2014 event of Bisagno River in terms of hydrologic an hydraulic modelling using free tools. We study the evolution of the event, estimating the return period of rainfall using IDF curves built with GEV distribution, than we find the hydrograph of the event in some sections making a comparison with result of Bisagno Basin Plan, finally we produce depth maps to describe the evolution of the event. We study also the Brugnato event of 2011.

6.2.1 Scenario description

The meteorological event of Genoa on October 9th, 2014 is due to a frontal system able to generate a number of rainfall cells starting on the sea and rapidly moving from south-east to north-west, hitting the natural barrier formed by the mountainous arch of Liguria. The high amount of rainfall released by these sequences of thunderstorms is to be associated to an anomalously (for the season) high temperature of the Mediterranean, to the orographic lifting due to the mountains, and, for this specific event, to the “V-shaped” aspect of winds converging toward the city of Genoa. The centre of the storm was located on the Bisagno and Sturla basins.

Figure 35: Bisagno torrent. Basin Authority predictions and the 2014 flood.

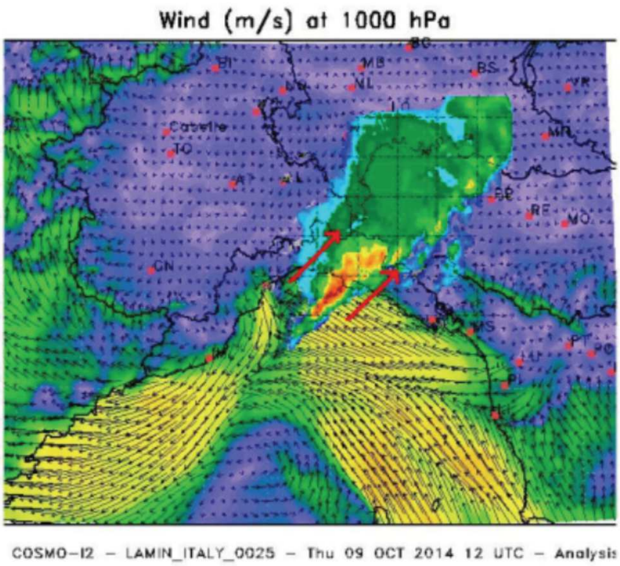


Figure 36: October 9th, 2014: rainfall radar reflectivity, 1000 and 700 hPa winds.

The collection of rainfall measurements for the area is available from the professional (CMIRL) network. Stations are subject to regular maintenance, their location is decided following international standards and quite long time series are available.

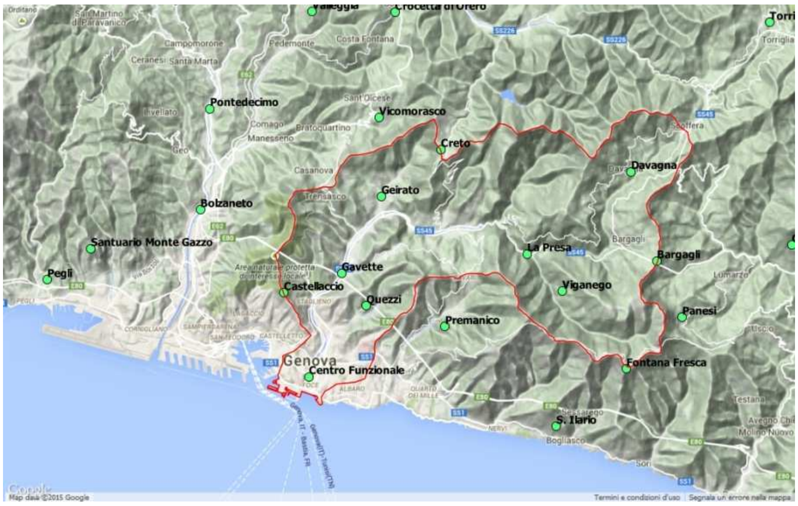


Figure 37: CMIRL network and Bisagno basin in red.

The CMIRL network recorded a maximum of 400 mm for a 24 hours duration cumulated rainfall and 135 mm for 1-hour duration (Geirato station). These values can be quickly compared to the maximum recorded for the November 4, 2011 event: 605 mm for the 48 hours duration, 411 mm/12 hrs, and 181 mm/hr (Vicomorasso station).

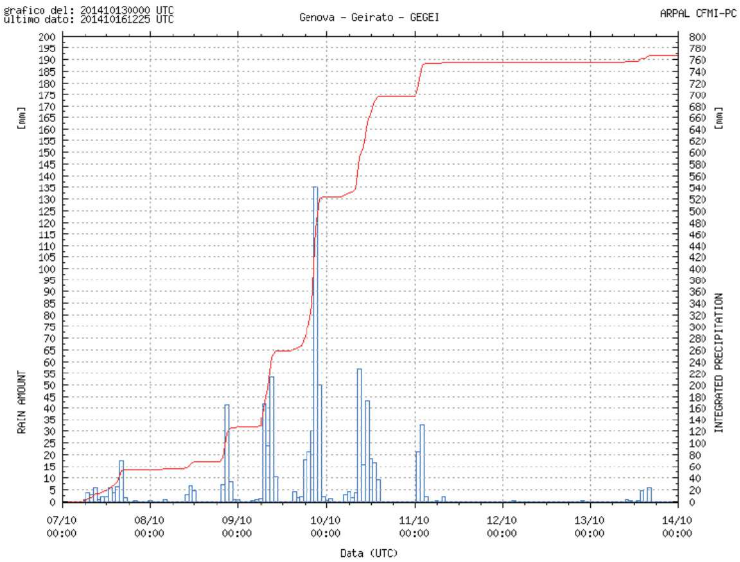


Figure 38: October 9, 2014: rainfall record at Geiratoraingauge station, CMIRL network.

For many other information we suggest to read the scientific paper named “The flash flood of the Bisagno Creek on 9th October 2014: An “unfortunate” combination of spatial and temporal scales” written by Silvestro et al. published in the Journal of Hydrology (doi:10.1016/j.jhydrol.2015.08.004).

Table 28: Scenarios considered for FRI evaluation - Rethymno, Greece

Event	Economic	Urbanization	Measures/actions	Climate change
Rain ev ent - October 9th, 2014	current	current	no added measures	not considered

6.2.2 Measures that existed before the event and measures added after the event

Work for re-building the coverage and enlarging the hydraulic section in the last part of Bisagno torrent: the first part of the coverage (the one closest to the mouth) was already finished when the flood of October 2014 occurred. The work for the second part is now ongoing, whilst the Italian government recently assigned the funding for the work to the third and last part of the coverage. By 2017, the work for rebuilding and enlarging the whole coverage of the Bisagno river should be finished.

By 2016 the work for the Bisagno by-pass (a channel that brings water for the river directly to the sea, in order to decrease the discharge during extreme rainfall events) should be started, and finished by 2020. Following the severe flood that hit Genova downtown in October 2014, the work for the by-pass turned into a priority at regional and national level. Within the initiative Italia Sicura (a plan for funding work to protect national territory against hydro-geological disasters) 275 milion of Euro out of the 670 were assigned to Genova.

Work for the by-pass of Fereggiano torrent (tributary of the Bisagno): The former Italian government funded it and they are still ongoing.

In October 2015, a new warning system based on colours (yellow, orange and red) entered into force at regional level, as well as a new Municipal Plan for Civil Protection.

6.2.3 FRI for a city scale - Genoa, Italy

Some assumptions are made before completing matrix presented in Annex A: *When no availability can be assessed for an indicator, it can be left out of the integration of the overall FRI provided that its weight value in 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 3 and 5.
- Emergency evacuation & warning, and accessibility are given an importance of 4 and 5
- Land use and urban expansion have a weight of 5, as well as protected critical facilities
- Volunteers and solid waste management are assigned a weight of 5 and 3.

Following the method defined by Batica et al., 2013 and presented in this report, 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 at our organisation and stakeholders from case study and literature review related to the analyzed event.

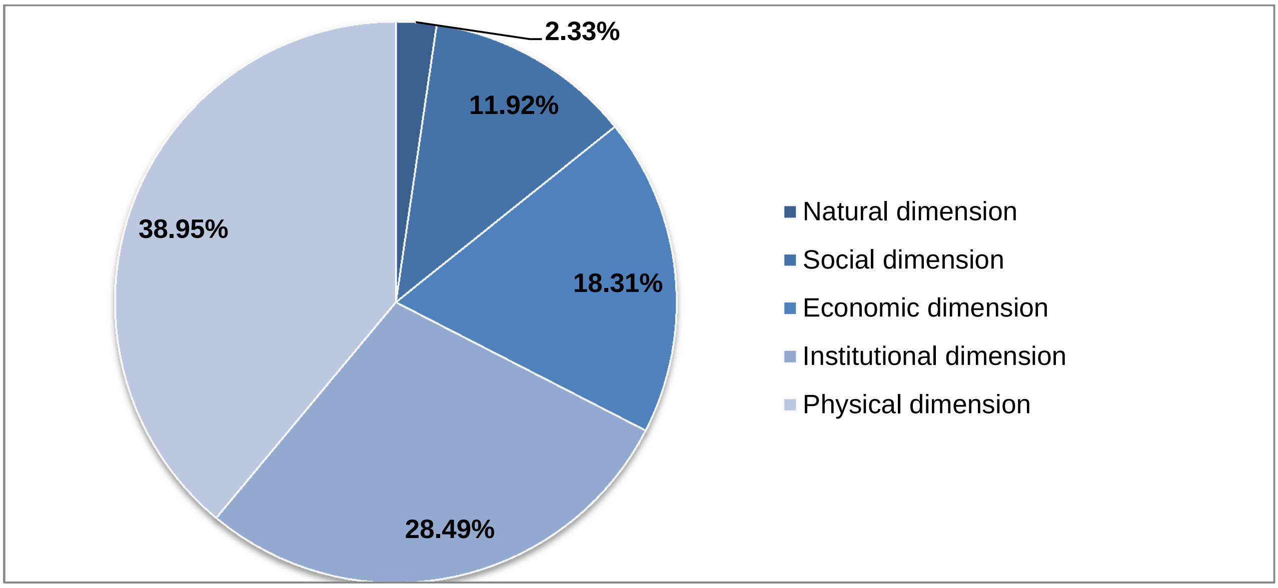


Figure 39: Weight of each dimension on the overall FRI

As presented in figure 31 the importance of each dimension varies from 2.33% for natural to 38.95% for physical dimension.

Evaluation of overall FRI followed by assigning values to each indicator with their respective weights. For the given conditions, the FRI for Genoa is 2.14. The result in the form of table shows separate FRI for each dimension and the overall index.

Results obtained in this analysis demand an interpretation in order to address all the current issues regarding flood resilience

Table 29: Overall FRI for the city/urban scale, Genoa, Italy

Genoa	Indicators	not used categories	Dimension index ∑((xi*wi)/∑wi)	Overall index
Natural dimension	2	0.00	1.88	2.14
Social dimension	10	0.00	3.39	
Economic dimension	16	0.00	2.38	
Institutional dimension	27	0.00	2.00	
Physical dimension	35	1.00	1.76	

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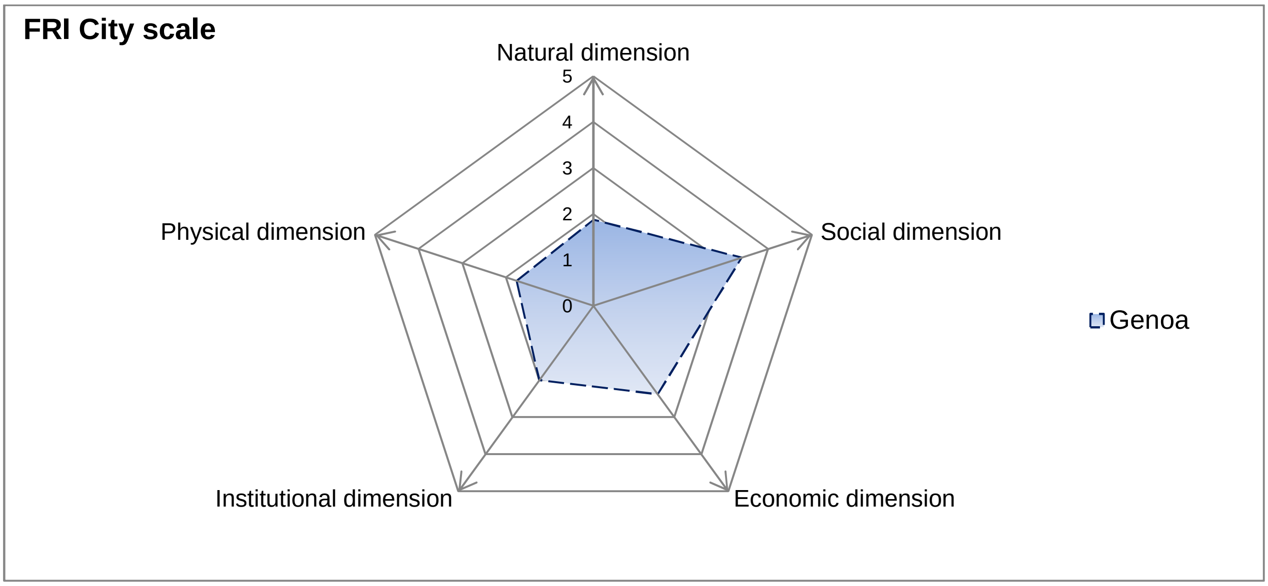


Figure 40: Radar chart presentation of FRI on city scale, for case study Genoa, Italy

Results obtained using Matrix with 91 indicators give good interpretation about existing and needed assets and policies (laws, binding documents, etc) that will contribute to increase flood resilience of analyzed case study. The 90 indicators is used out of 91.

Natural dimension with index value 1.88 shows that channel conveyance is too small to accept floodwater. Measures that will contribute increasing the capacity of natural environment in accepting flood waves are recommended.

Social dimension with index value 3.39 shows that even with the big weights the knowledge exchange is missing or it is not on the proper level. Regarding flood awareness, some additional measures should include flood risk education, flood risk communication management and in multilevel knowledge exchange between engineer, architect/urban planner, sociologist, economist, politician - city government, etc.

Economic dimension with index value 2.38 shows that availability of financial resources for people affected in flood. In addition, the compensation after flood in the form of tax reduction is missing or it is on very low level.

Institutional dimension with index value 2.00 shows that there is an absence of FRM plans in city urban planning. In addition, the participation of community in the flood risk management plans is on the low level.

Physical dimension with index value 1.76 shows that there is an absence of any dry and wet proofing in the existing buildings. There is also absence of hydraulic structures within flood risk management plans

With the improvement in these segments, the flood resilience of this community can be on higher level.

6.3 Les Boucholeurs case study, France - case study description

The area Les Boucholeurs is a fishing district located in the south part of Chatelaillon-Plage, a commune of Charente-Maritime department located in the south west of France. After presentation of PEARL project to the commune of Chatelaillon-Plage the case study area is expanded overall commune.

Figure 41: Case study area, Châtelaillon-Plage (Les Boucholeurs), France (Source: Google map)

The significance of this case study area is the extreme event Xynthia and its effect on the social, economic, natural, institutional and physical dimensions.

This coastal case study has area of 6.9km^2 and 6049 residents (based on the 2008. census). Known by the mussel and oyster farms the district Les Bouchelours is located on the south part of the commune Châtelaillon-Plage and on the north part of commune Yves. Originally, the district was a port located on the mouth of the Port Punay channel. Over the time (in the 20th century), this area becomes the tourist point of interest. The existing waterfront has been converted into paved promenade. The dense urbanization started on the former site of embankment system combined with marchland (existing system of retention areas). This area was in a way a natural buffer boundary with the Atlantic coast. Its primary function was to compensate swells from the north and storms coming from the west,

6.3.1 Scenario description

The rare extreme event Xynthia occurred in early morning of 28th February 2010 as a result of atmospheric depression created on 27th February morning. This storm hint west coast of France causing large-scale floods with huge damages. Beside France, the storm hint Germany and the Benelux countries. In total 65 people died.

Described as an explosive storm with the depression of 20hpa in more than 24h, Xynthia went through the country very fast. Based on the meteorological parameters (atmospheric pressure Xynthia has not reached the exceptional storms Lothar and Martin in December 1999, neither

Klaus in January 2009. Even so, the effect of Xynthia on flooding and erosion is significant, especially in the departement Vandee and Charente-Maritime.

Meteorological characteristics of the storm show that the wind gust speed of Xynthia was 242 km/h at the Pic du Midi d'Ossau in the Pyrenees and in the Charente Maritime at 140 km/h.

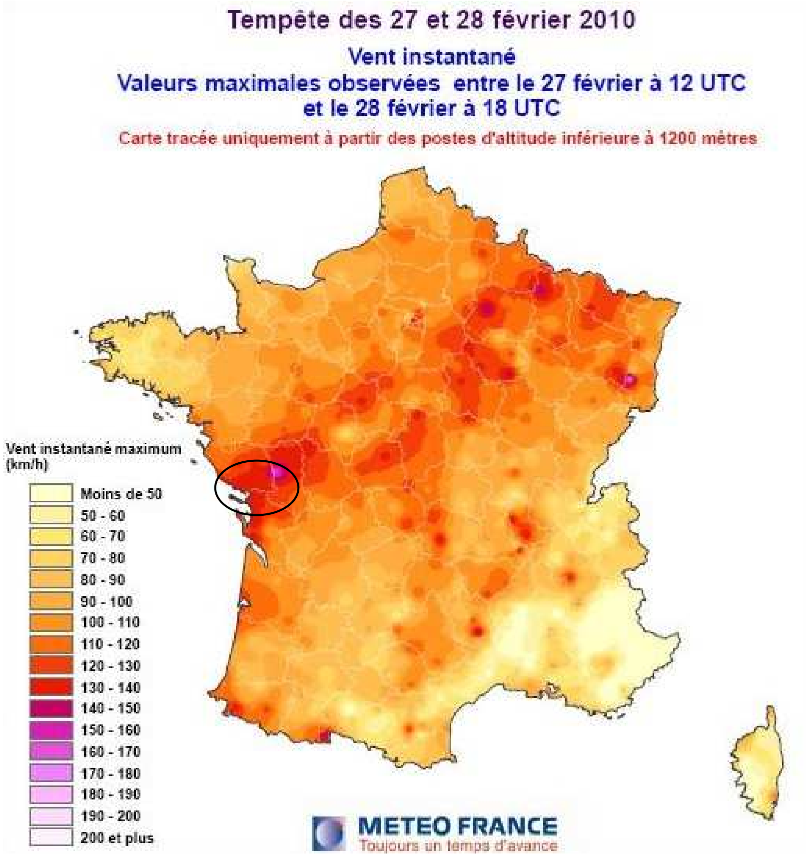


Figure 42: Maximal wind speed during the storm Xynthia (Source: Meteo France)

Figure 42 shows the maximal wind speeds during the storm Xynthia over France. The location of case study area is marked in the figure. The recorded wind speed relevant for case study is in the range from 120 km/h to 130 km/h. Excluding wind effect the tides created show significant values in heights. According to the BRGM (Bureau de Recherches Géologiques et Minières) the measured level of 4.5 m NGF (General Levelling in France) recorded at la Rochelle (northern of case study area) correspond to the very high return period. Up to this moment there is no official statement regarding calculated or estimated return period of this storm. The major threat for the affected area was storm surge and big waves. The storm surge was 1.6 m and the tide approximately 2.75 m.

Table 30: Scenarios considered for FRI evaluation - Chatelaillon-Plage, France

Event	Economic	Urbanization	Measures/actions	Climate change
Xynthia storm - February 2010	current	current	no added measures	not considered

6.3.2 FRI

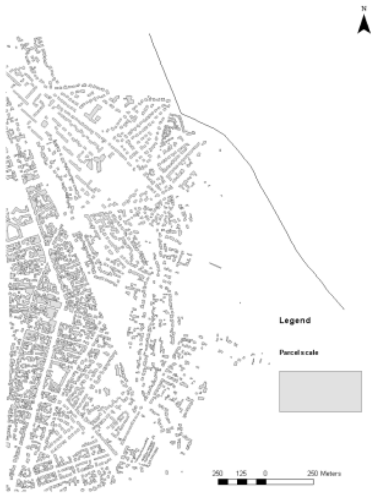
Evaluation of Flood Resilience Index for French case study take into account three scales: parcel, block and district/city scale. In this way, the whole method presented in the first part of the report will be applied. Following the Figure 7 the evaluation started with analysis of urban system.

6.3.2.1 Urban system

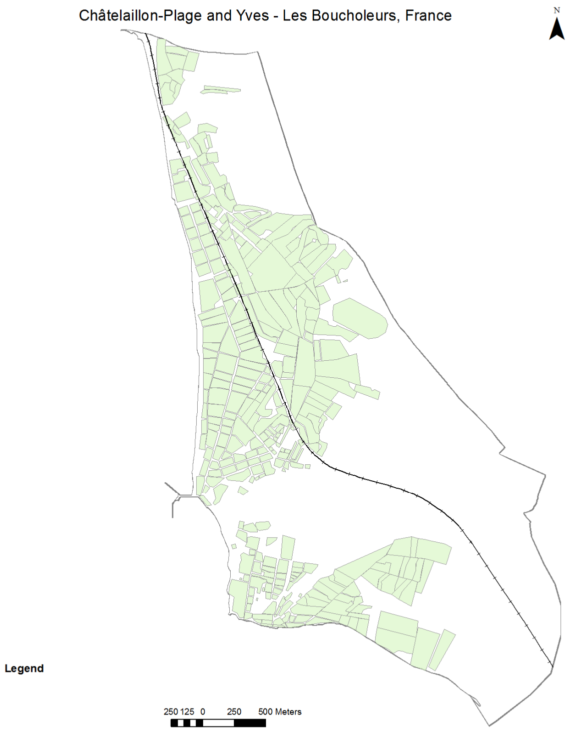
A set of data give by our partner ARTELIA have following layers necessary for FRI evaluation:

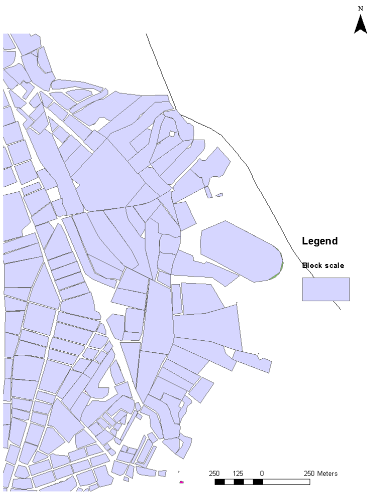
digital elevation model in resolution of 75m, shape files with information on different buildings, roads, water bodies, channels and a corresponding flood map with extracted minimal and maximal flood depths. A figure below shows the scaling of urban system. In total, there are 2295 objects in parcel scale and 286 block objects. Figure below presents 'decomposition of urban system' with parcel and block scale. As defined the block is presented with set of buildings (parcels) surrounded by street.

a) Parcel scale



b) Parcel scale zoomed



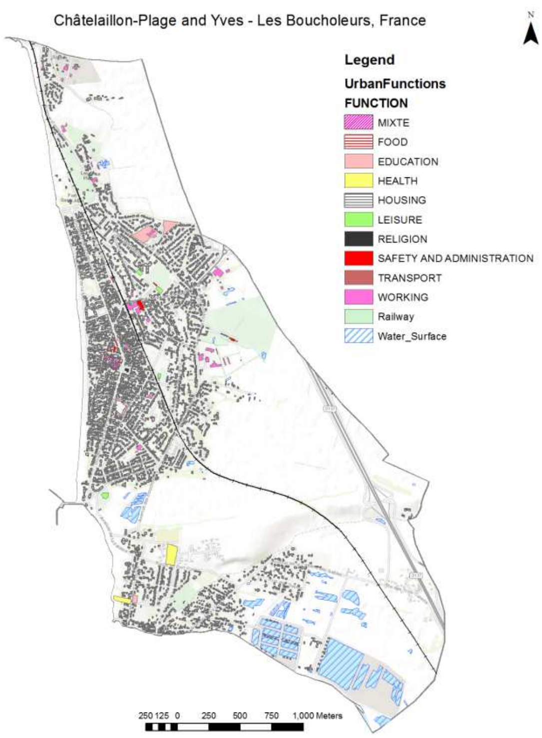


c) Block scale

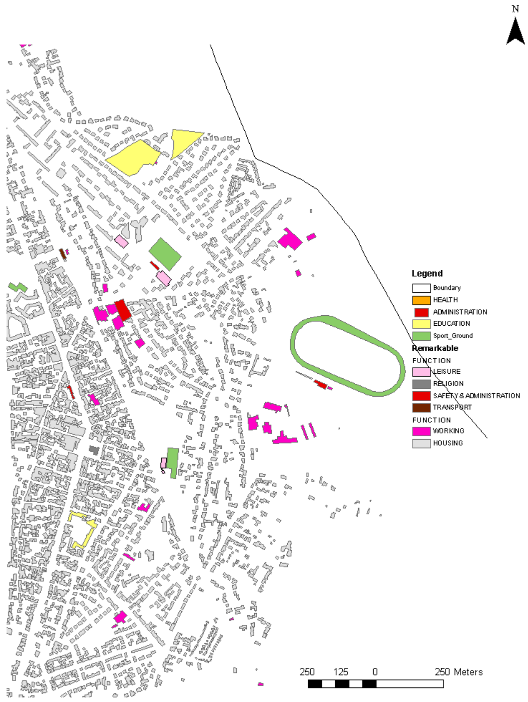
d) Block scale zoomed

Figure 43: Urban system analysis - scaling of urban system - Chatelaillon-Plage, France

Next step in the flood resilience assessment after setting the scales for analysis and evaluation is mapping of urban systems. Within this step, the existing polygons that represent building with different typology are classified into eight urban functions and five city services. Figure below shows the mapped urban system following the classification of urban functions and city services.



a) Case study area



b) Case study zoomed

Figure 44: Urban system analysis - mapping of urban system - Chatelaillon-Plage, France

6.3.2.2 Characterization

There are three components of flood risk assessment relevant for this analysis: (i) flood hazard, (ii) flood exposure and (iii) flood vulnerability. The system analysis for the France case study considers the type of flooding, its character and spatial distribution of the analyzed event.

The multi scale character of flood resilience assessment demands definition of working scale. The general scale division considers (i) macro, (ii) mezzo and (iii) micro scale. The developed methodology, however, consider four scales in the analysis of urban system: (i) city/urban scale, (ii) district, (iii) block and (iv) property/building scale (Batica et al., 2013).

In addition to this case study the scales chosen for flood resilience assessment are (i) city/urban (ii) block and (iii) property/building scale.

For city/urban scale the analysis focuses on system dimensions described earlier while the property/building scale evaluates the flood resilience level for different urban functions within urban system.

Nevertheless the data for analysis is divided with respect to different scales. In the figure below the data are separated according to chosen scale. The analysis and evaluation of FRI is supported by software Arc Gis 10.

Table 31: Analyzed data according to the chosen working scales

Data analysis	City/urban scale	Natural	Hydrological system, unsealed areas

		Physical	Hydraulic infrastructure, monitoring and warning systems, drainage system, GIS data
		Social	Awareness programs, knowledge exchange, education, communication, access to financial services, savings & insurance, and budget & subsidies
		Economic	GDP, funding, insurance, financial resources
		Institutional	Building codes, regulations, urban planning, emergency planning
	Block scale **based on the dominant urban function*	External requirements	Data on energy, water, and waste networks Data on communication and transportation systems
		Internal requirements	Physical on-site inspection
	Property/building scale	External requirements	Data on energy, water, and waste networks Data on communication and transportation systems
		Internal requirements	Physical on-site inspection

6.3.3 Results

Scenario for French case study is chosen rare extreme event, storm Xynthia and its effect on the small community located in the west France. The flood risk assessment includes evaluation of Flood Resilience Index following the steps defined in the first part of this report. The three components of flood risk (hazard, exposure and vulnerability) present in our case: event, exposed area and vulnerability of assets and people.

Characterization

Three scales are analyzed for flood resilience assessment, the city or urban scale takes into account the whole case study area, 6.9 km^2, the block scale and the property/ building scale. There no particular critical areas for analysis due to the relative small case study. All parts of case are treated with same significance.

For the city scale the FRI is calculated using matrix presented within annex A. The matrix has a set of indicators and parameters. Evaluation of FRI considers using different availability and importance levels (weight) assigned to the defined indicators. The following assumptions are made during the evaluation process.

- When no data are available for an indicator or no availability can be assigned, it is left out of the integration of the overall FRI if its weight value is not higher than 3. If the weight is higher, than an availability value must be assumed depending on the context provided and peer analysis.
- Already defined in first part of report, the urban system is consisted with urban cells. A building with all requirements, internal and external, represents an urban cell. Further the urban system is mapped to its functions and services provided to the inhabitants. In addition the main components of urban systems are the eight different urban functions and five city services. They form an urban system together with urban community (inhabitants). A list of urban functions is as follows:
    - Housing
    - Working
    - Education
    - Food (storage)

- Health
- Safety and governance
- Leisure and tourism
- Religion ad cemetery
- And city services:
- Energy
- Water
- Communication
- Transportation
- Solid waste

– Food availability is assigned value of 5 for analyzed flood event. This is done with respect to the characteristics of flood event related to the duration particularly.

– Food availability decreases accordingly to the flood duration.

– "Housing" urban function located in the city centre considers to have a collective character during analysis.

Feedback between scales

In the process of definition the framework for assessing flood resilience the question of feedback between different scales become dominant. This is in addition to prevent incompatibility of results. The two roads of feedback exist in the analysis.

The first one is "top-down" approach where there is a transfer of general characteristic from larger to smaller scale. This means that for assessed FRI of different dimensions (natural, physical, social, economic and institutional) transfer its 'availability' and 'important' to the smaller scales (district, block). This is based on the principle that utilities, social, institutional, and economic conditions in a district bear a similarity to the urban scale they belong to. Following that, the local conditions are improving the accuracy of the assessment, taking into account variations in indicators such as income level, availability of utilities within the different properties, special social conditions.

Second road regarding the feedback has a 'bottom-up' approach. Here, the characteristics of the specific urban function at the property scale let the credentials of trends that have influenced the FRI values of larger scales. In some situations it is considered that a certain requirement (internal or external) is available on a block scale due to analyzed conditions. If, several urban functions show a different pattern from originally assumed requirement, then this feedback is sent to upper scale to adjust FRI value.

For example, the city is considered to have good access to energy supply. This characteristic is carried on to block scale in which several properties have a non-protected electrical network regarding analyzed flood event. In this case the reassessment is made on block or district scale with adjustment of availability of selected requirement or indicator (if it's a district or urban scale).

FRI - property/building scale

The FRI assessment on property/building scale is preformed for the whole case study area. The results obtained within this analysis are transformed in map using GIS. As described within the first part of report 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 2295. The table with evaluation of critical requirement is presented below in teh table. The idea of index introduction was to adapt the method and to be able to map results of FRI evaluation 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. FRI evaluation for each urban function on parcel scale is done for the given flood depths as a result of flood modeling done by ARTELIA.The evaluation of FRI for property/building scale is done for each urban function. Evaluation of FRI deepens on the flood depth so for this evaluation the four different flood depths were considered: 0.2, 0.5, 1 and flood depth above 1m.

Table 32: FRI evaluation for urban function 'Housing' (flood depth 20cm) for flood initiated by Xynthia storm- Châtelaillon-Plage, France

Critical requirement		Description	r_e, r_i	w_i
EXTERNAL DEPENDENCES	Energy	Minor interruptions could be expected.	3	4
	Water	No, no-return valve for waste water. A drinking water provision might be interrupted.	3	3
	Waste	Almost no waste collection can be supported during flooding. Garbage trucks cannot access the premises.	2	3
	Communication	Internet services might be interrupted. Mobile phone reception remains operable.	2	4
	Transport	Road connection exists but existing flood depth of around 20 cm may cause difficulties. Connection to rail, car, and bus transportation is available in all directions but with a delay.	3	4
INTERNAL DEPENDENCES	Food	The building has possibility for food storage, but it does not provide room for long durations of flooding.	4	2
	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..	4	4
FRI			3.11	

In this way, the evaluation is conducted for each urban function for both conditions: (i) dry and (ii) flooded. The table below shows summary of values for each urban function for the whole case study area for flooded urban functions.

Table 33: FRI values for flooded urban functions for flood initiated by Xynthia storm- Châtelaillon-Plage, France

	FRI			
Urban Function	0.2m	0.5m	1m	>1m
Housing	3.11	2.71	2.46	2.18
Working	2.92	2.81	2.65	2.54
Safety & administration	2.97	2.90	2.77	2.60
Health	3.00	2.88	2.75	2.50
Food	3.17	2.91	2.81	2.43
Leisure & tourism	4.00	3.82	3.35	3.12
Religion & cemetery	3.88	3.65	3.35	3.24
Education	3.25	3.08	2.88	2.67
Transportation	3.87	3.47	2.87	2.00

Table 34: FRI values for flooded urban functions for flood initiated by Xynthia storm- Châtelaillon-Plage, France

	FRI			
Urban Function	0.2m	0.5m	1m	>1m
Housing	4.07	3.96	3.74	3.44
Working	4.19	3.92	3.81	3.31
Safety & administration	4.07	3.90	3.60	3.23
Health	4.00	3.63	3.13	2.75
Food	4.04	3.38	3.19	2.67
Leisure & tourism	4.24	3.88	3.59	3.24
Religion & cemetery	4.24	4.06	3.88	3.65
Education	4.25	3.88	3.71	3.42
Transportation	4.33	3.60	3.00	2.60

Tables shows the dynamic character of flood resilience and its change with respect to different flood depths. The internal critical requirements, in the case of evaluation for dry urban functions, 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 influence of flood on areas outside of flood extend are visible within this evaluation. The results are presented in tables 26 and 27.

Presentation of FRI dynamics can be presented in the form of radar chart. In the figures below the values for FRI of different urban functions for different flood depth are presented.

It can be concluded that the influence on FRI values flooded and non-flooded urban functions is significant.

Figure 45: Dynamics of FRI for both flooded and dry urban functions for flood initiated by Xynthia storm- Châtelaillon-Plage, France

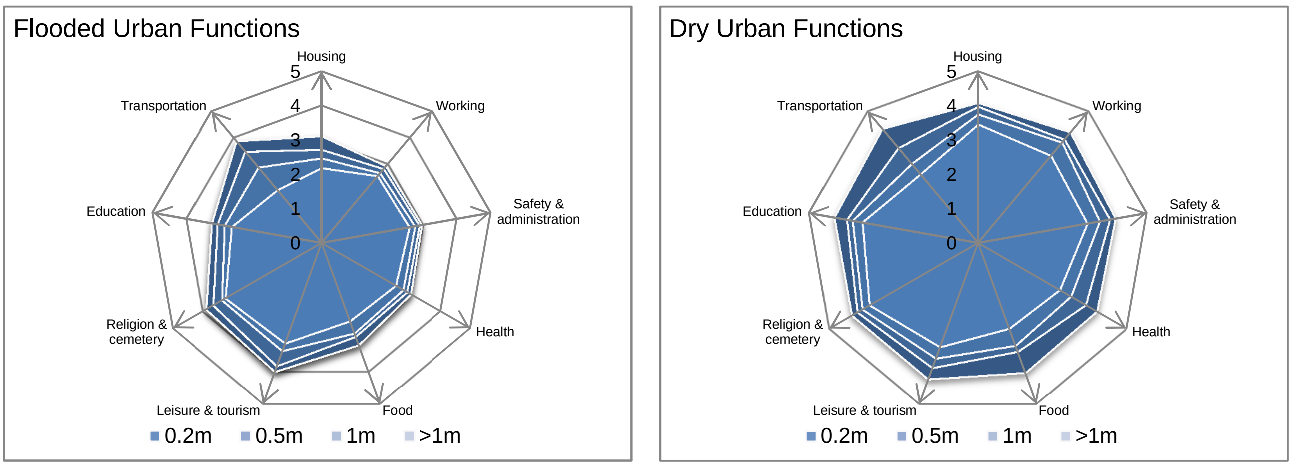
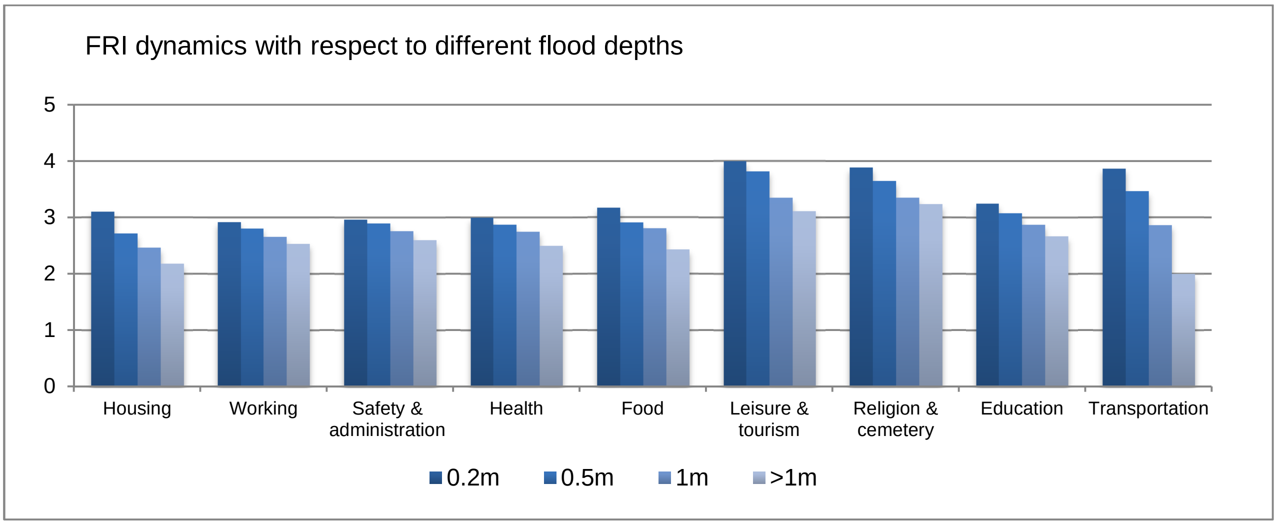


Figure 46: Urban function with decrease values of FRI for different flood depths for flood initiated by Xynthia storm- Châtelaillon-Plage, France



Further, the GIS presentation of preformed evaluation is presented below. The presentation is actually mapping the FRI to urban function for corresponding flood map on parcel scale.

Figure 47: FRI on parcel scale mapped for flood initiated by Xynthia storm- Châtelaillon-Plage, France

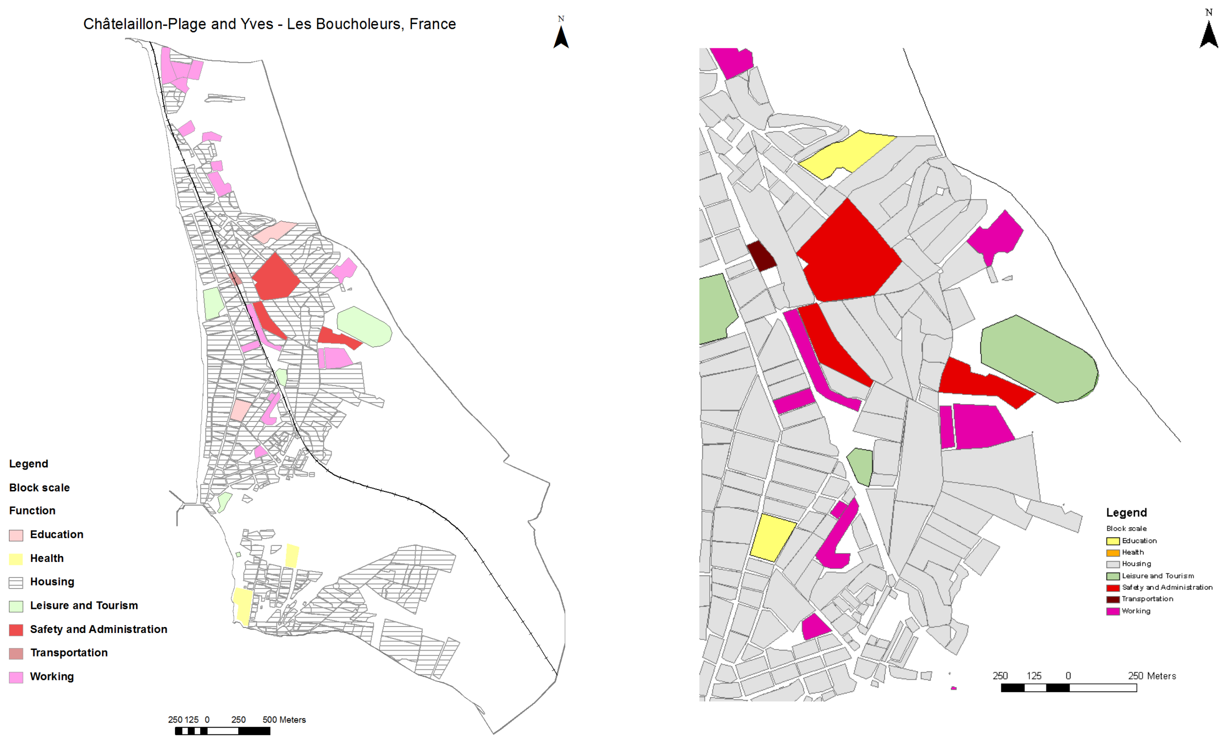
FRI for block scale

Method is the same as for parcel scale. Creation of block scale with Arc Gis involves creation of a new layer of polygons that are representing blocks. The blocks are created in order to separate a set of buildings surrounded by street pattern. In the figure 33 under c) and d) the blocks are presented. Further, each block inherited a dominant urban function. Figure below shows block structure with given topology inherited from .urban function within the block.

In total there are 286 blocks in the case study area from which 257 blocks housing, 2 health, 2 education, 5 leisure, 3 safety, 1 transportation and 16 working

Table 35: Division within block scale with inherited urban function for Châtelaillon-Plage, France

Urban function	Number of blocks
Housing	257
Health	2
Education	2
Leisure and Tourism	5
Safety and Administration	3
Transportation	1
Working	16
Total	**286**



a) case study area

b) zoomed case study area

Figure 48: Presentation of blocks with assigned urban function - Châtelaillon-Plage, France

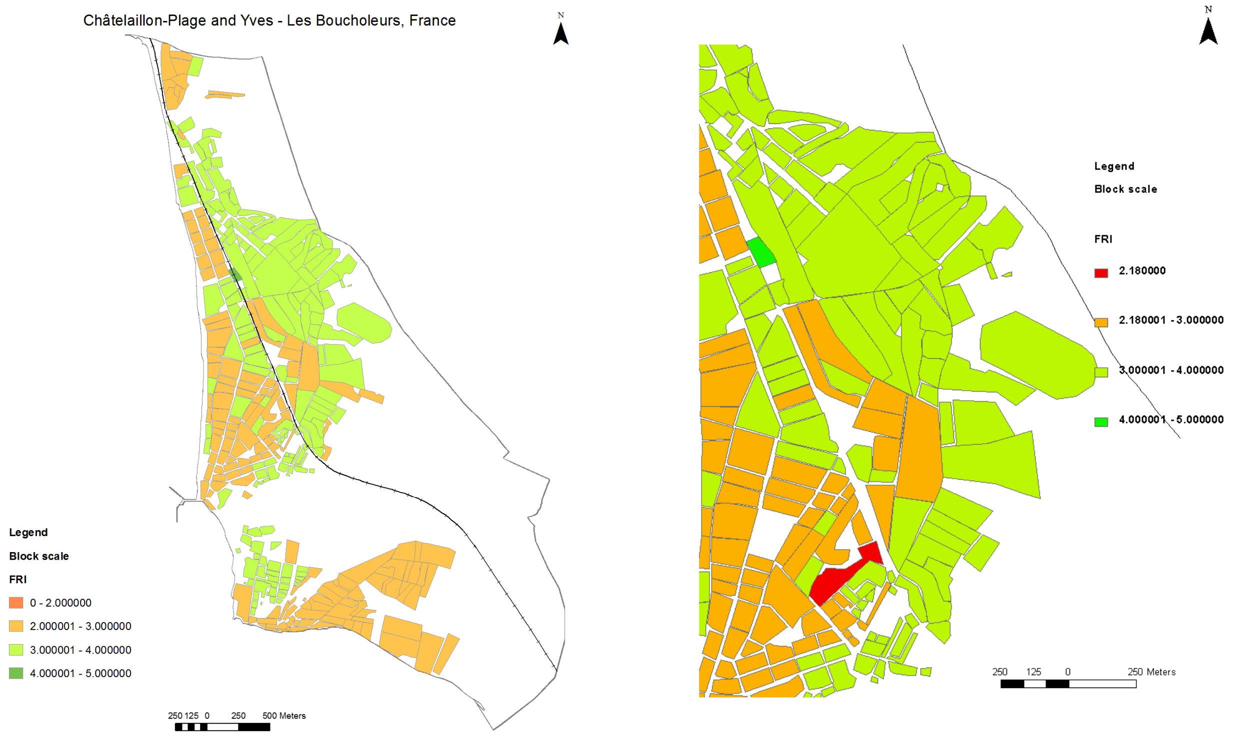


Figure 49: FRI on block scale mapped for flood initiated by Xynthia storm- Châtelaillon-Plage, France

Figure 49 present the FRI mapping for block scale for case study area. Comparison with FRI values on parcel scale shows that the connectivity is present and that due to aggregation of characteristics the resulting values of FRI correspond to results obtained in evaluation on parcel scale.

FRI for city scale

Some assumptions are made before completing matrix presented in Annex A: *When no availability can be assessed for an indicator, it can be left out of the integration of the overall FRI provided that 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 defined by Batica et al., 2013 and presented in this report, 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 at UNS and stakeholders from case study and literature review related to the storm Xynthia.

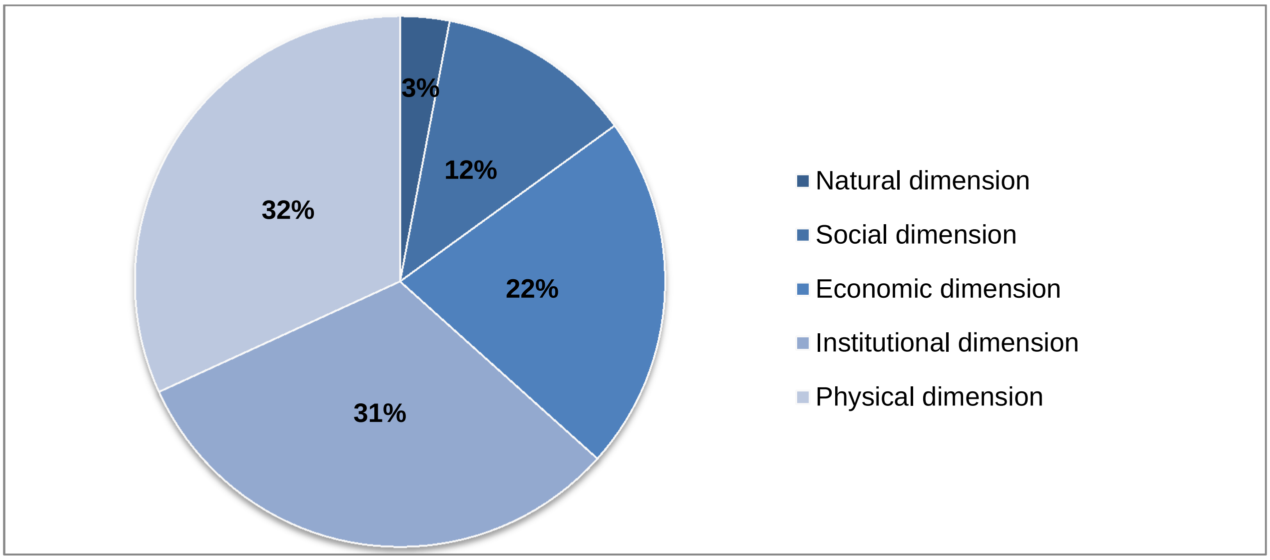


Figure 50: Weight of each dimension on the overall FRI

As presented in Figure 50 the importance of each dimension varies from 3% for natural to 32% for physical dimension.

Evaluation of overall FRI is followed by assigning values to each indicator with their respective weights. For the given conditions, the FRI for the Châtelaillon-Plage is 2.38. The result in the form of table shows separate FRI for each dimension and the overall index.

Results obtained in this analysis demand an interpretation in order to address all the current issues regarding flood resilience

Table 36: Overall FRI for the city/urban scale, for flood initiated by Xynthia storm- Châtelaillon-Plage, France

Châtelaillon-Plage	Indicators	not used categories	Dimension index ∑((xi*wi)/∑wi)	Overall index
Natural dimension	2	0.00	2.50	2.38
Social dimension	10	0.00	2.35	
Economic dimension	16	0.00	2.19	
Institutional dimension	24	3.00	2.76	
Physical dimension	30	6.00	2.12	

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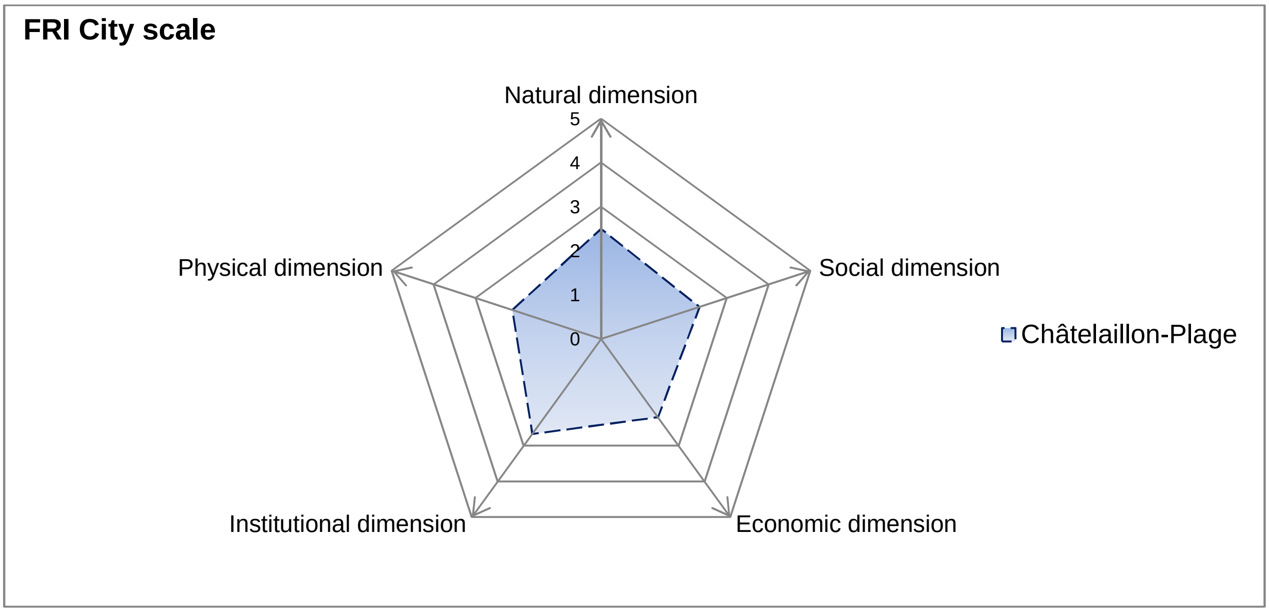

Figure 51: Radar chart presentation of FRI on city scale, for flood initiated by Xynthia storm- Châtelaillon-Plage, France

Results obtained using Matrix with 91 indicators give good interpretation about existing and needed assets and policies (laws, binding documents, etc) that will contribute to increase flood resilience of analyzed case study. The 82 indicators is used out of 91.

Natural dimension with index value 2.5 shows that available green space and existing channel network are not sufficient to avoid huge flooding or peak discharge. Measures that will contribute increasing the capacity of natural environment in accepting flood waves are recommended.

Social dimension with index value 2.35 shows lack in multilevel knowledge exchange between engineer, architect/urban planner, sociologist, economist, politician - city government, etc.

Economic dimension with index value 2.19 shows that availability of financial resources for protection of transportation network is not high. This also transfer influence on ability to provide quick rehabilitation of assets after flooding and insurance compensation.

Institutional dimension with index value 2.76 shows land use control although is important is not on the high level. This is in addition to existing houses and object on flood prone areas.

Physical dimension with index value 2.12 shows that there is an absence of dry and wet proofing in the existing buildings. Since the objects are located in the flood prone area the protection measures are lacking, and so endanger the existing facilities.

With the improvement in these segments the flood resilience of this community can be on higher level.

6.4 Hamburg Case Study, Germany - case study description

The Free and Hanseatic City of Hamburg is located in the North German Plain approx. 100 km upstream of the mouth of the river Elbe in the North Sea (Figure 52). Hamburg has approx. 1.76 Million inhabitants (31.12.2014) living on a city area of 755.3 km². The population density stands at 2,334 inhabitants/km² (31.12.2014).[1] Furthermore, Hamburg is the centre of the homonymic metropolitan area Hamburg, including the counties Dithmarschen, Herzogtum Lauenburg, Pinneberg, Steiburg and Stormarn in Schleswig-Holstein as well as the counties Cuxhaven, Harburg, Lüchow-Dannenberg, Lüneburg, Rothenburg (Wümme), Soltau-Fallingborstel, Stade and Uelzen (Lower Saxony) in the federal state Lower Saxony. The Metropolitan Area Hamburg covers an area of 19,788 km² (LSBG, 2012).

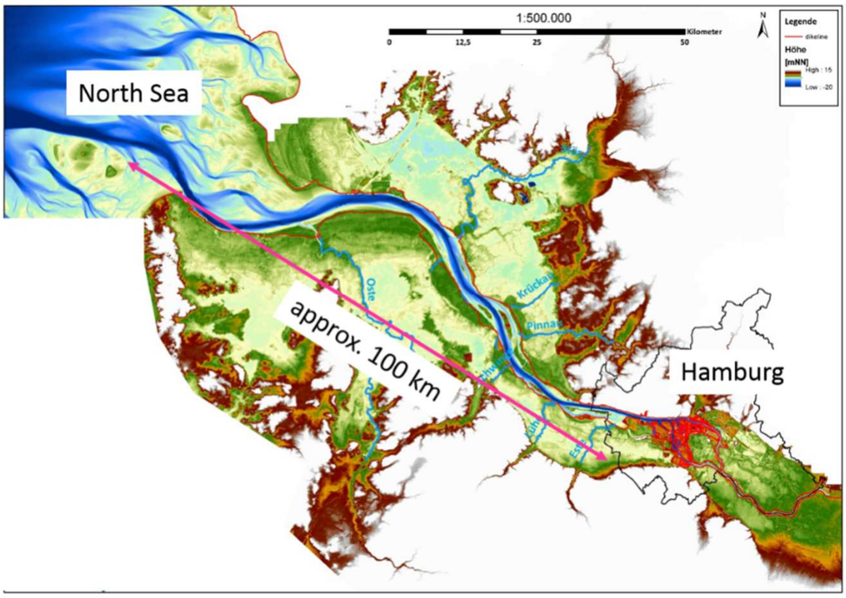

Figure 52: Overview of the Elbe estuary

The Free and Hanseatic City of Hamburg itself and as the centre of the homonymic metropolitan areas has a significant commercial relevance for the region and for entire Germany. Not least because of the sea port of Hamburg, Germany's biggest sea port and the 3rd biggest sea port in Europe (2016)[2].

The central parts of the city area being flown through by the Elbe are relative low lying areas and prone to inundations due to storm surges or even normal high tides. Figure 53 gives an impression of the terrain heights. The lowest natural sink "ImAltenNincop" (Neuenfelde) has a height of NN-0.8m. The highest natural elevation "Harburger Berge" (Neugraben-Fischbeck) has a height of NN+116.1m. One can see from the Figure 53 that the central parts of the city have low terrain heights, especially the island of Wilhelmsburg(Figure 53, red circle), which is a densely populated (1532 inhabitants/km²) island located between the Norderelbe and the Süderelbe.In this area, the terrain heights are below the mean tidal level. Without its ring dike the island of Wilhelmsburgwould be inundated twice a day.

[1] http://www.statistik-portal.de/Statistik-Portal/de_jb01_jahrtab1.asp
[2]http://www.manager-magazin.de/fotostrecke/rotterdam-hamburg-und-co-das-sind-europas-groesste-haefen-fotostrecke-134456-5.html

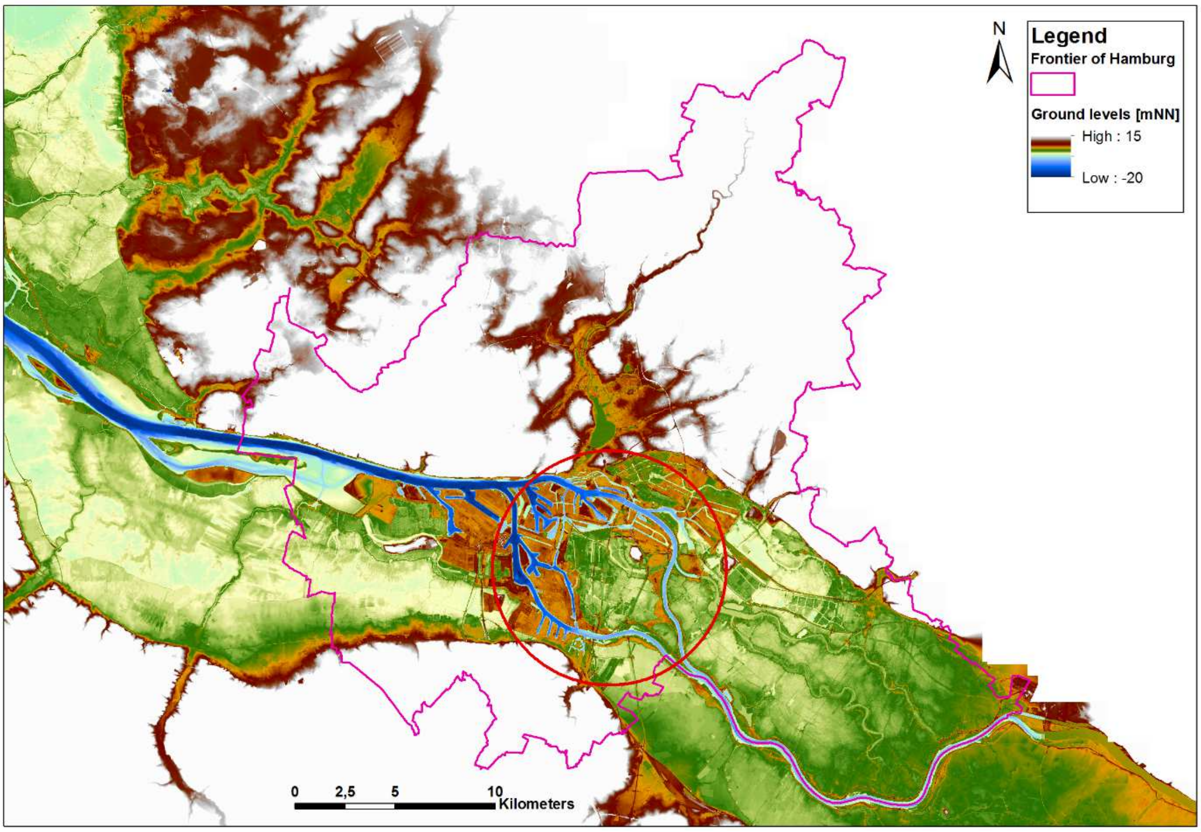

Figure 53: Ground levels on the Hamburg city area

Due to the location of the estuary flowing directly into the North Sea storm surges have to be expected in case of very strong westerly winds. As mentioned above, ground levels on the city area along the Elbe are low and call for an adequate flood protection system. Without a proper flood protection, these areas would be inundated.Figure 54 gives an impression of the extension of the flood prone areas (blue area). In addition heavy precipitation can lead to high discharge in the estuary. Resulting from this one has to expect (extreme) floods in the estuary in case of extreme hydro-meteorological events including failure of the flood protection infrastructure.

Due to past and present developments probability and the consequences of flooding is regarded to be increasing. There are different reasons for this development. On the one hand, one has to face the sea level rise and an increase of storm events. On the other hand, there are higher hydrological loads due to higher precipitation. These are nature side reasons. From the social side we have to consider a growing urbanisation of the hinterland and a higher utilization pressure. More and more people moving to the suburbs.

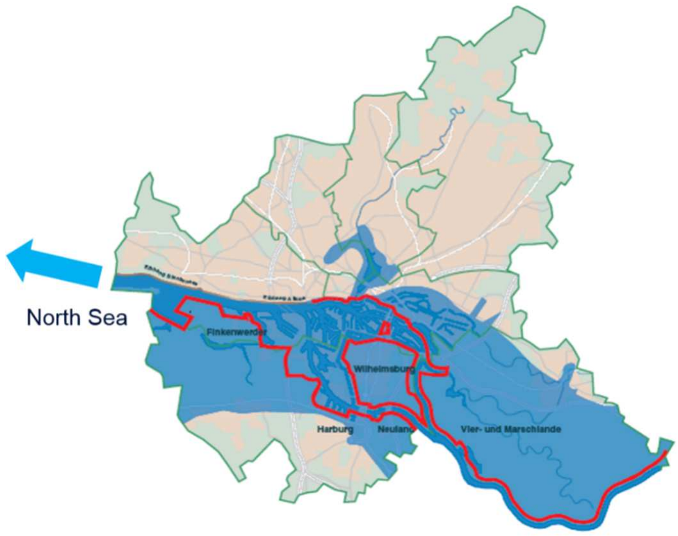

Figure 54: Flood prone areas of Hamburg in case of storm surge without flood protection infrastructures (Lecture notes, 2016)

6.4.1 Scenario description

In the past there have been several storm surges causing more or less devastating damages and casualties. Figure 55 gives an impression of the bigger storm surges which have hit the city of Hamburg. The storm surges are distinguished by their water levels (water levels: until 4,50 m – light blue, until 5,00 m – dark blue, until5,50m – orange, unitl 6,00 m – red, until 6,5 m – magenta). In addition, one can see from the Figure 55 (green lines) the development of the dike heights with the occurring storm surges

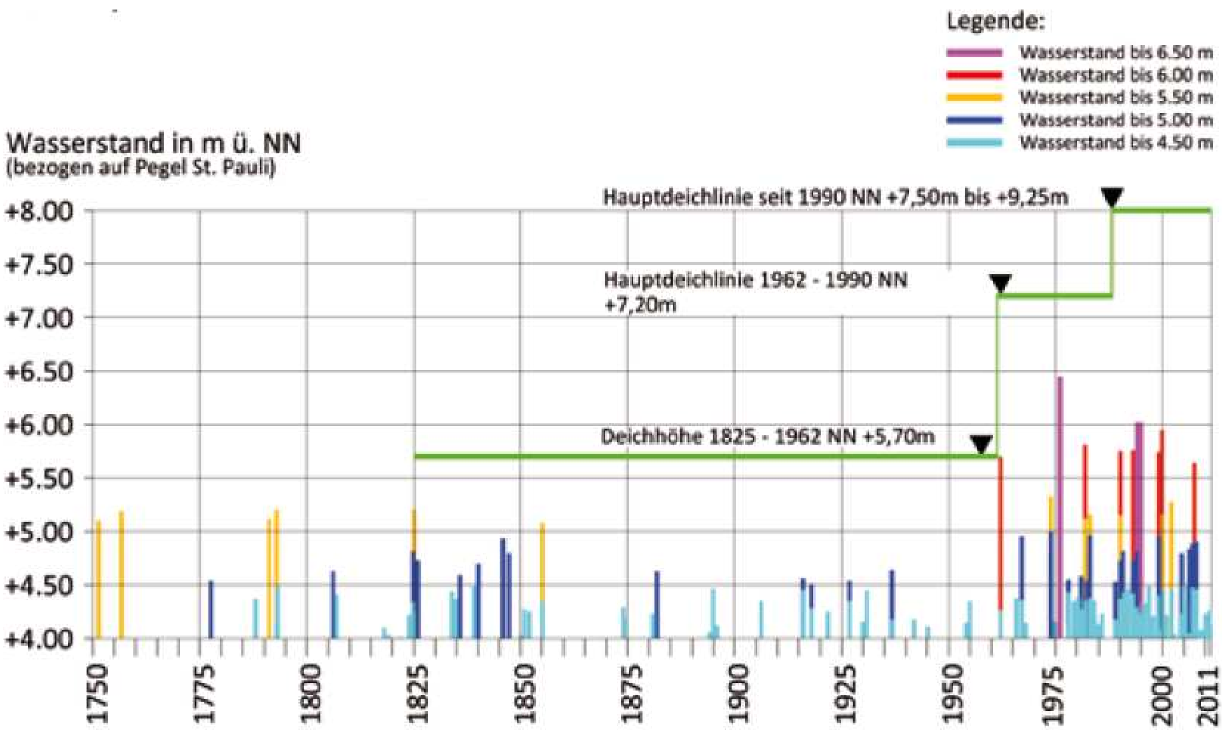

Figure 55: Storm surges since 1750 in Hamburg (reference gauge: Hamburg St. Pauli) with water levels above NN+4,00m (LSBG 2012)

The storm surges of 1962 (most devastating storm surge), 1976 (highest storm surge) and 2013 (second highest storm surge) are described in more detail in the following paragraphs.

The development of the hurricane weather condition of February 16th /17th, 1962, has already begun already on February 12th, 1962 with a strong storm front with a core (945 mb) moving to Scandinavia. This storm front hasn't become a critical storm condition, due to a smaller storm front arising on the back of the storm front with decreasing wind speeds. But nevertheless, this storm caused high waves and extreme high wind surge. During the following day (February 13th, 1962) wind speeds increased again with winds coming from north westerly to north directions on the back of the smaller storm front, lasting until evening of February 14th. Simultaneously, a storm front developed near Newfoundland and moved to the Norwegian Sea. The front of the storm front hit the northern North Sea on February 15th, 1962. Upper air flows and decreasing pressure caused an extension of the storm front to the German Bight and an increase of the wind speed (gale-force winds of 150km/h), which pushed a huge amount of water into the Elbe mouth. In the night to February 16th storm wind directions turned to west. In the morning this day storm winds up to Beaufort scale 9 occurred. During the following day (February 16th, 1962) extreme loads on the dikes along the entire North Sea coast and along the Elbe caused dike failure and inundations. At 3.05am water levels of 5.7m above NN have been reached at the tidal gauge Hamburg St. Pauli (Figure 56, black solid line), 40 min earlier than expected and higher than ever before. At this time many dikes have failed in Hamburg and large areas were flooded (Hötte, 2012, Roediger, 1962).

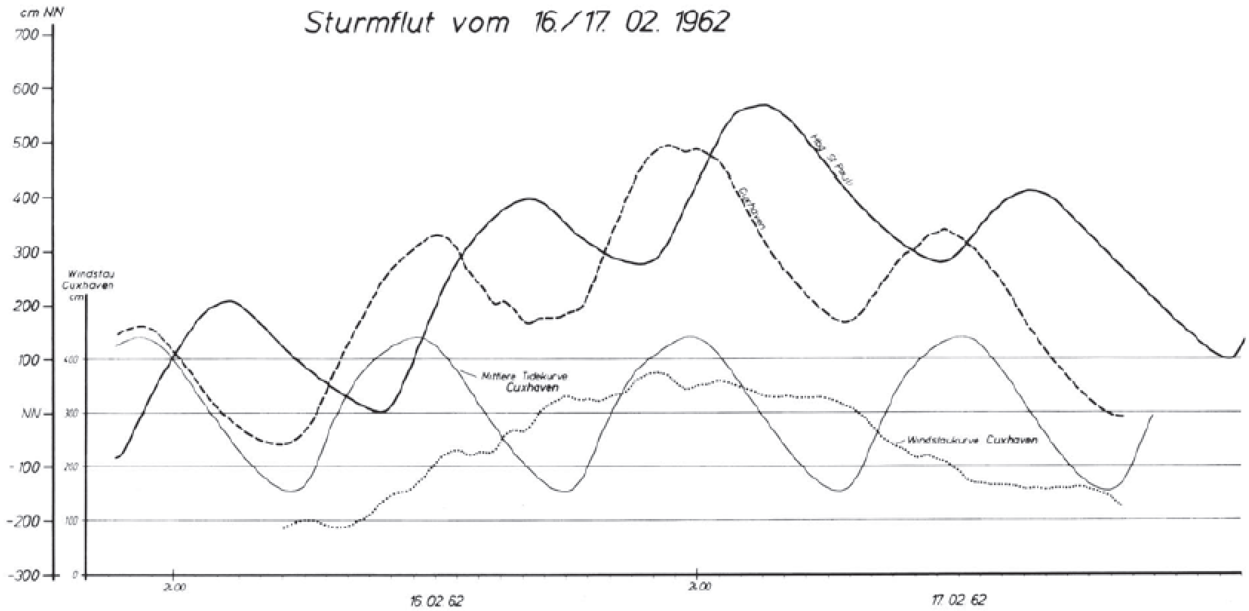

Figure 56: Hydrograph of the storm surge on February 16th / 17th, 1962 (Laucht, 1977)

The peak of the storm was reached in the evening of February 16th at 10 pm (for the German Bight) and shortly after midnight for Hamburg as a trough moved over the German Bight. Storm winds up to Beaufort scale 9 -10 occurred during the peak of the storm.In the late evening of February 16th, 1962, it became clear that the extreme storm was not the only threat. Additionally, a bore approached the river Elbe and Hamburg from the North Sea. An additional increase of the water levels has been recorded (Hötte 2012). In the evening of the February 17th the wind

speeds begun to decrease. Remarkably about this storm were the extremely strong gusts winds with Beaufort scale 11-12, while the average wind speeds kept relatively low (Roediger, 1962).

The Hamburg district of Wilhelmsburg was worst affected during the extreme storm surge event (Figure 57). 222 people lost their lives due to the dike breaching and the resulting inundations. In total, 315 inhabitants lost their lives during this storm event (LSBG, 2012 HW-Schutz heute). The dike breach causing the most severe consequences occurred in the north of Wilhelmsburg in the Spreehafen. From this location wide areas of the Elbe Island have been inundated. Many casualties have been surprised by the flood during sleep. The rescue of the people started slowly (Hötte 2012). The access to the inundated areas was only possible by inflatable boots or by helicopters. In the aftermath of this disastrous event, causing many casualties and damages, the entire flood protection infrastructure and the flood contingency strategy was redesigned (see 6.4.2).

a)

b)

c)

d)

Figure 57: Impression of the devastating storm surge in 1962 (Free and Hanseatic city of Hamburg, 1962)

In the following years after 1962 nostorm surge with such devastating effects occurred. However, in the beginning of 1976 a strong storm surge hit the German Bight, the Elbe estuary and Hamburg, distinguishing from the storm surge of 1962.

On January 2nd, 1976 a subtropical air-mass met cold air in the north of Ireland coming from Iceland.On the previous day polar cold air coming from Scandinavia advanced deep into eastern Central Europe. From this weather situation a strong depression developed, the stormy development of which started towards midday on January 2nd. Further decrease of the depression occurred in the following 12 hours and moved to the Danish Islands and further to South Russia. The storm front reached its peak in the morning hours of January 3rd, 1976 over the eastern and southern North Sea. Wind measuring station along the Lower Elbe recorded wind speeds between Beaufort scale 7 and 8 from westerly directions. Storm winds with a wind speed of 18m/s occurred in Hamburg. In addition, there have been strong storm gusts with wind speed between 29 m/s and 37 m/s (Beaufort 11/12) (Heerten and Partenscky, 1977).

On January 3rd, 1962 spring tide was predicted. This means, higher tides occurred in addition to the strong wind surge. Already before the occurrence of the first tidal low water on January 3rd the storm reached its full wind speed. Therefore, the high wind surge and the spring tide superimposed. This combination led to this extreme storm surge, causing extreme high water levels especially in the area of Hamburg (Figure 58). Here, the previous HHThw (highest high tide) was exceeded by 38 cm at the gauge Schulau, 75 cm at the gauge Hamburg St.-Pauli (Figure 58, solid line). There was no significant reduction of the water level through breaching dikes, as it happened during the storm surge of 1962 (Heerten and Partenscky, 1977).

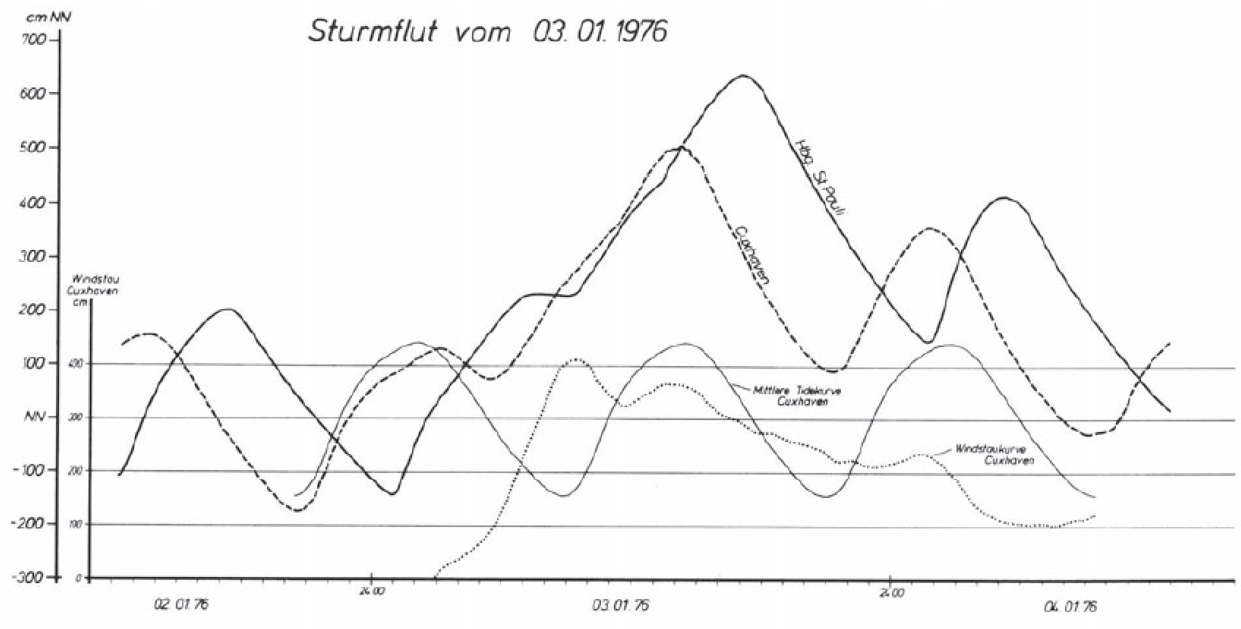

Figure 58: Hydrograph of the storm surge on January 2nd / 3rd , 1976 (Laucht, 1977)

While the dikes in Hamburg and along the Elbe could withstand the storm surge, almost all quay facilities and industrial facilities in the port area and outside of the dikes have been flooded. Large number of goods deteriorated, causing damages of several million Euros (LSBG, 2012).

In the beginning of December 2013, the storm surge “Xaver” hit Hamburg. With a peak storm surge water level of 6.08 mNN[3], “Xaver” has been the second highest storm surge since record-keeping began. The depression causing “Xaver” developed from a warm front over the North Atlantic in area of southern Greenland. During the night to December 5th, 2013 the depression

[3]NN is the official determined datum level for height measurements

intensified to afront, moving across south Scandinavia. In the afternoon of December 5th the front reached northwest Germany causing gale-force winds. In the evening, the peak of the storm was reached. On December 6th, 2013, the storm front moved in the direction of the Baltic Region (LSBG, 2014).

During December 5th and 7th, 2013 storm winds with maximum 111 km/h (average: 77 km/h) at Cuxhaven and maximum 99 km/h (average: 59 km/h) at Hamburg-Fuhlsbüttel occurred. These strong winds have blown over long period of time. Increasing wind speeds during December 5th caused rising water levels against low tide along the Elbe. As a result, the low tide at the gauge Cuxhaven was already increased by more than 3 meters at 20.30 this day. Same conditions hold for the gauge Hamburg-St. Pauli. Here, the water levels during ebb tide decreased marginal. Particular high water levels of (e.g. 6.08 mNN at the gauge Hamburg-St. Pauli, Figure 59 green line) occurred during high tide as a result of the upstream tidal flow and the persistent high wind speeds on December 6th, 2013 (LSBG, 2014).

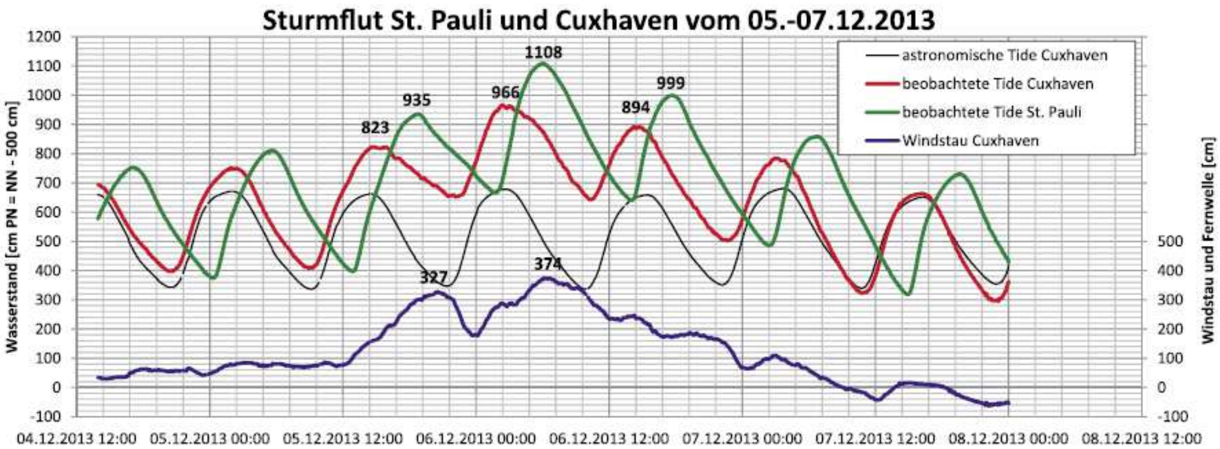

Figure 59: Hydrograph of the storm surge on December 5th – 7th , 2013 (LSBG, 2014)

The developed front has caused a chain of 4 subsequent storm tides, whereas the highest storm tide occurred on December 6th, 2013 (Figure 59).

6.4.2 Flood protection infrastructure prior to and after the events

First dikes have been built back in the 11 century protecting the “Hammaborch” and the associated port, the first settlement becoming the Hamburg metropolitan area in the next centuries. This construction was a ring dike, which was reinforced by a timber work and timber (Aschenberg et.al. 1992). During the next century wide areas around the “Hammaborch” have been diked, such as the marsh islands Hammerbrook, Altengamme, Curslak and Billwerder and the Hamburg area grew significantly. This development continued in the 13th century with the diking of the DritteMeile of the Alten Land and the Lewenbrook. In the 14th century the areas of the Süderelbe, upper Gose and Dove Elbe to protect the Vierlande have been diked. Further dikes have been built in Billhorn and Moorwerder. Besides, the embankment activities the Elbe have been regulated in different sections. As a consequence of the embankment and regulation activities higher tides and storm surges caused higher water levels along Elbe and higher loads on the flood protection infrastructure. Due to strong storm surges during the 15th century additional dikes have been built and due to the awareness of rising threats of the people also in the following centuries. After the February storm surge of 1825 (“Februarsturmflut”) the flood protection infrastructure of Hamburg was renewed once again. Embankments have been risen to +5,7m NN and large landscape fillings until the new dike height have been performed (Kramer

et.al.1992).Additionally, a number of sluices have been constructed. After the construction of the Ernst-August dike between Reiherstieg and Veddel in 1852 the Elbe island Wilhelmsburg received its flood protection in the form of a ring dike.

The construction and the maintenance of the dikes in Hamburg and along the Elbe have been in the responsibility of the people living along a specific dike section organized associations so called “Deichverbänden” and have been voluntary. There was no super ordinate coordination of the construction and maintenance activities. In 1964 the dike law was changed. Since then, the city of Hamburg has been responsible for the construction and maintenance of all flood protection dikes and the public flood protection in general (Hötte, 2012).

After the flood disaster of 1962 it became clear, that the dike in Hamburg and along the Elbe had been in ailing condition. Despite the regular dike inspection, the recorded deficiencies and damages of the dike (e.g. deficiencies of the turf) have not been repaired. Therefore, the dikes had been badly maintained and the dikes could not withstand the loads resulted from the extreme storm surge of 1962. In addition to the bad maintenance level, the dike had been constructively obsolete. Usually, the dikes had a steep and minor reinforced landward slope. During the years before 1962 the dike been regularly heightened repeatedly but not widened in the base resulting in seeward slopes and landward slopes getting continuously steeper. In addition, the dikes were planted and one could find structures on the dikes giving the storm surge many weak points (Hötte, 2012).

Shortly after the storm surge of 1962 the city of Hamburg convened an expert commission to analyse and examine the storm event. The commission came to the conclusion, that the steep inner slopes of the dike were the most frequent reason the breaching. The commission determined that the slope of the dike may not ne steeper than 1:3. Installations and plantings in and on the dike should be removed. In addition the commission derived a new design water level (+6.7 mNN[4]) which was the basis for the redesign of the flood protection infrastructure of Hamburg. On the basis of the new design water level the dike heights have been increased between +7.2 mNN in the city centre of Hamburg and +9.0mNN on the between Cranz and Finkenwerder west of the city centre.Figure 60shows a recent cross section of a typical flood protection dike (Hötte, 2012).

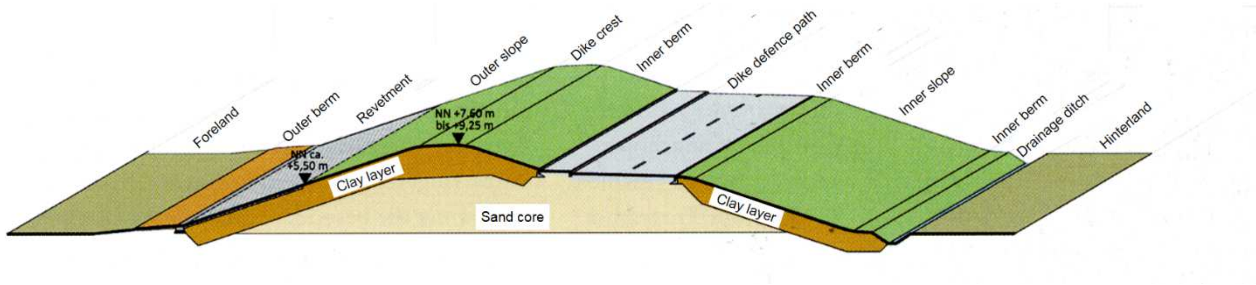

Figure 60: Recent cross section of a flood protection dike (Hötte, 2012)

The new flood protection line is divided into four sections: form Borghorst to St. Pauli Fischmarkt on the northern bank, Fünfhausen until Cranz on the southern bank, the ring dike of Wilhelmsburg and Veddel (Kramer et.al. in Jordan). Between 1962 and 1979 the city of Hamburg invested 780 million German mark (Hötte 2012, Figure 61).

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[4]NN is the officially determined datum level for height measurements

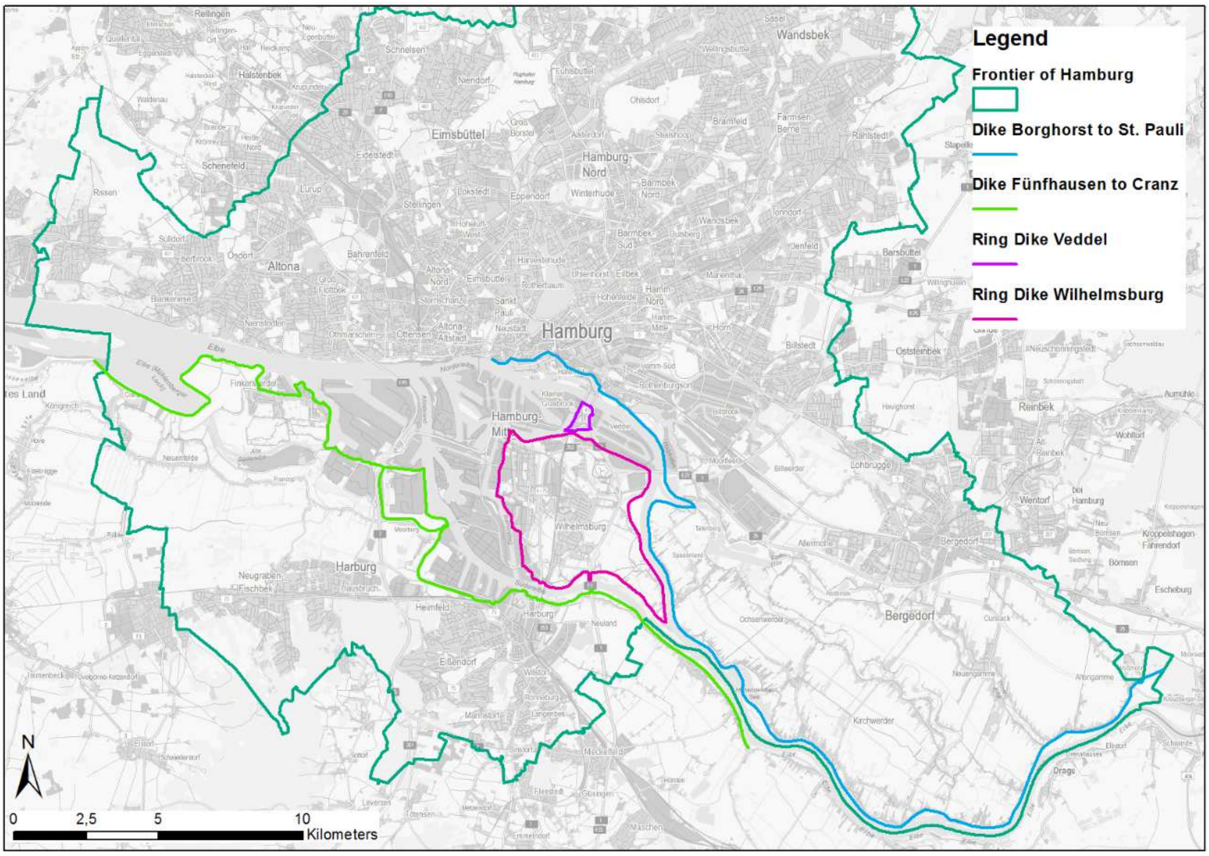


Figure 61: Overview of the sections of the flood protection line

Along the Süderelbe between Finkenwerder und Altenwerder the dikes have been brought forward to the Lower Elbe. On the area of the inner city the embankment has been straightened and in the area of the Niederhafen an 18m wide sea wall provides the flood protection. Further structures completing the flood protection infrastructure are the sluices at the Nikolaifleet and the Herrengrabenfleet. In 1966 the Billwerder bay have been dammed up with a sluice and in 1967 the Alsterfleet was dammed up with a sluice. With the help of the sluices the dike line could be shortened to 18 km.

Furthermore, it was suggested to include the port areas outside of the dike line into the flood protection system. However, this inclusion could not be finished before the storm surge of 1976 hit Hamburg. The dikes along the Elbe and in the city could withstand the storm surge but in the port of Hamburg with its port areas outside of the flood protection infrastructure recorded huge damages. In the aftermath of the storm surge of 1976 the commission decided that the cargo handling areas and the operation areas within the port should be protected by single polders. In total, 60 polders have been built on the port area (Figure 62). The height of the dikes and flood walls forming the flood protection corresponds to the height of flood protection in the city. To take into account the additional load resulting from wave reflection the safety level was set to +7,5mNN (Braaker et.al., 1980). The city of Hamburg bore 75% of the costs. The remaining construction costs have been bored by the located companies. The state provided 180 million German mark for the construction of flood protection of the industrial areas (Hötte, 2012).

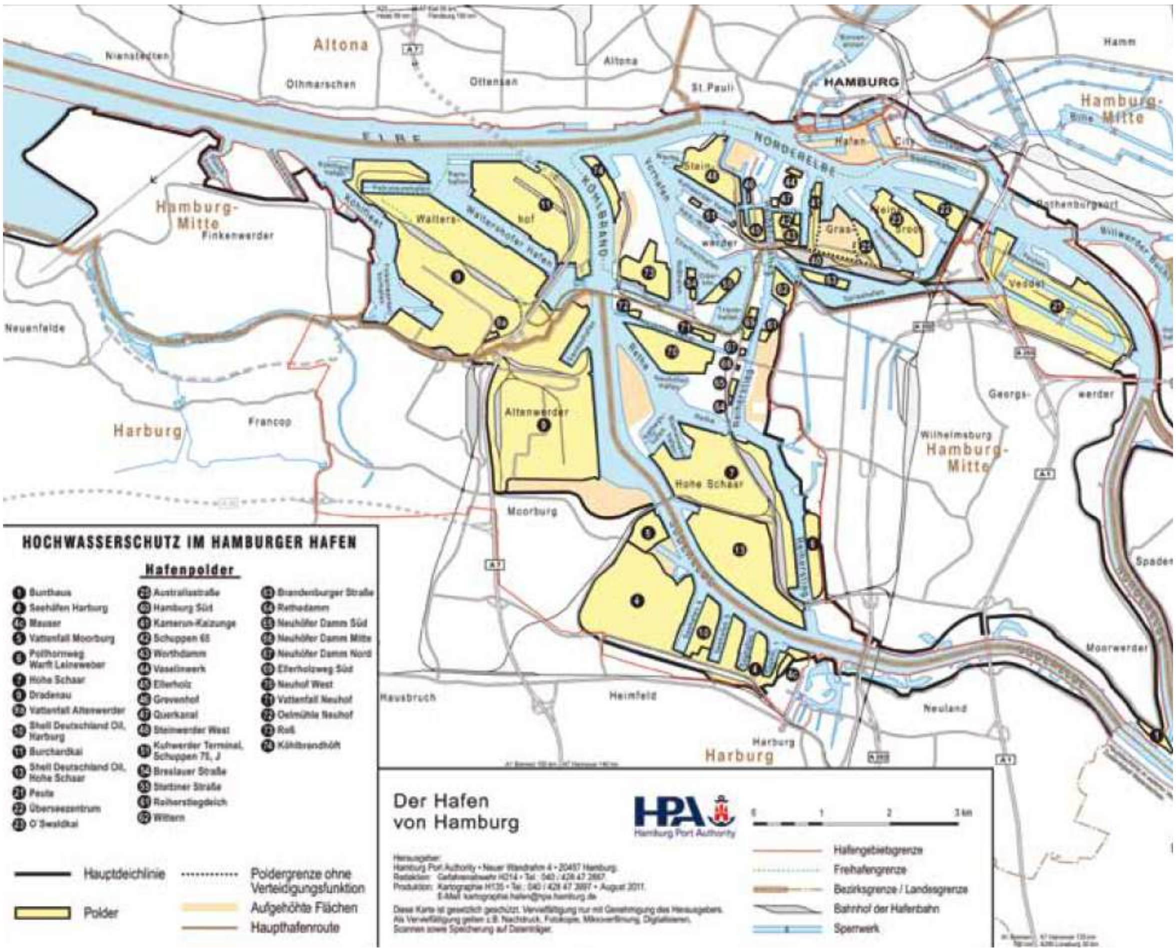


Figure 62: Polders in the Hamburg seaport area

As a result of the severe storm surge of 1976 the recent design water level of +6.7 mNN was re-examine by the independent commission. It was concluded, that the dike height have to be increased due to storm surges occurring more frequently and with higher peak water levels (Hötte, 2012). Thereupon, senate and citizenship passed in 1984 a construction program, the aim of which was the repeated increase of the dike height on the one hand and the improvement of the structural quality of the dikes on the other hand (Hötte, 2012).

In the 90s the Hamburg senate approved the construction program Hamburg ("Bauprogramm Hamburg"). In the course of which the entire flood protection line was increased by approx. one meter. Nowadays, the design water level at the tidal gauge St. Pauli (located in the city centre at the Elbe) is 7.30 mNN. The nominal height of the flood protection infrastructure (dike, walls, sluices etc.) is for longer sections, in the contrary to the past, not uniform anymore, but derived by model simulations on the basis of the local hydrodynamic conditions. Considering a freeboard (expected wave run-up), the nominal heights of the flood protection infrastructure ranges from 7.5 mNN to 9.25 mNN (Hötte, 2012).

In the early 2000s, the re conceptualization of an area of the Hamburg seaport into a district, the so called Hafen City was performed. This district is characterised by diverse usages such as residential and economic use, retail trade, leisure, gastronomy and culture. The Hafen City is located outside of the main dike line(Figure 63, red line) in the tidal influenced section of the Elbe.

Figure 63: Location of the Hafen City outside the flood protection dike (LSBG, 2012)

To provide an adequate flood protection the well know concept of dwelling mounds was adopted to this district. The dwelling mound concept comprises the increase of the area and connecting routes to a ground level of at least 7.5 mNN in the scope of the public flood protection (Figure 64, LSBG, 2012).

a) b)

Figure 64: Illustration of the effectiveness of the dwelling mound concept in the Hafen City (Lecture notes, 2016)

Public streets, evacuation routes, public squares, promenades and base levels are included in the increase of the ground levels (Figure 65). The protection of the private building and the interior is in the responsibility of the owner. Here, moveable gates, walls or special constructions, which are operated by qualified persons, provide the protective effect. (LSBG, 2012).

a)

b)

Figure 65: Higher evacuation routes in the Hafen City (Lecture notes, 2016)

6.4.3 FRI for city scale – Free and Hanseatic City of Hamburg, Germany

Some assumptions are made before completing matrix presented in Annex A: *When no availability can be assessed for an indicator, it can be left out of the integration of the overall FRI provided that 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 3 and 5.
- Emergency evacuation & warning, and accessibility are given an importance of 4 and 5
- Land use and urban expansion have a weight of 5, as well as protected critical facilities
- Volunteers and solid waste management are assigned a weight of 5 and 3.

Following the method defined by Batica et al., 2013 and presented in this report, 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 at our organisation and stakeholders from case study and literature review related to the analysed event.

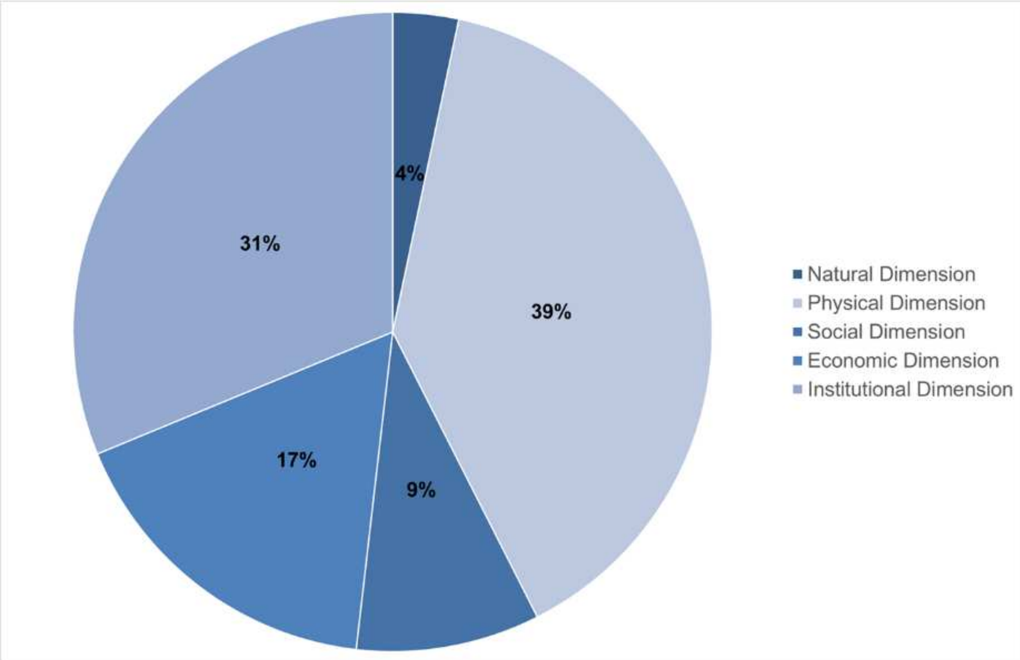


Figure 66: Weight of each dimension on the overall FRI for the Free and Hanseatic City of Hamburg

As presented in Figure 66 the importance of each dimension varies from 4% for natural to 39% for physical dimension.

Evaluation of overall FRI followed by assigning values to each indicator with their respective weights is done. For the given conditions, the FRI for the Free and Hanseatic City of Hamburg is 3.96. The result in the form of table shows separate FRI for each dimension and the overall index.

Table 37: Overall FRI for the city/urban scale; for flood initiated by storm surges and the current status of the flood protection – Free and Hanseatic City of Hamburg, Germany

Free and Hanseatic City of Hamburg	Indicators	not used categories	Dimension index ∑((xi*wi)/ ∑wi)	Overall index
natural	2	0.00	4.00	3.95
social	36	0.00	3.87	
economic	10	0.00	3.96	
institutional	16	0.00	3.71	
physical	27	0.00	4.20	

Results obtained in this analysis demand an interpretation in order to address all the current issues regarding flood resilience.

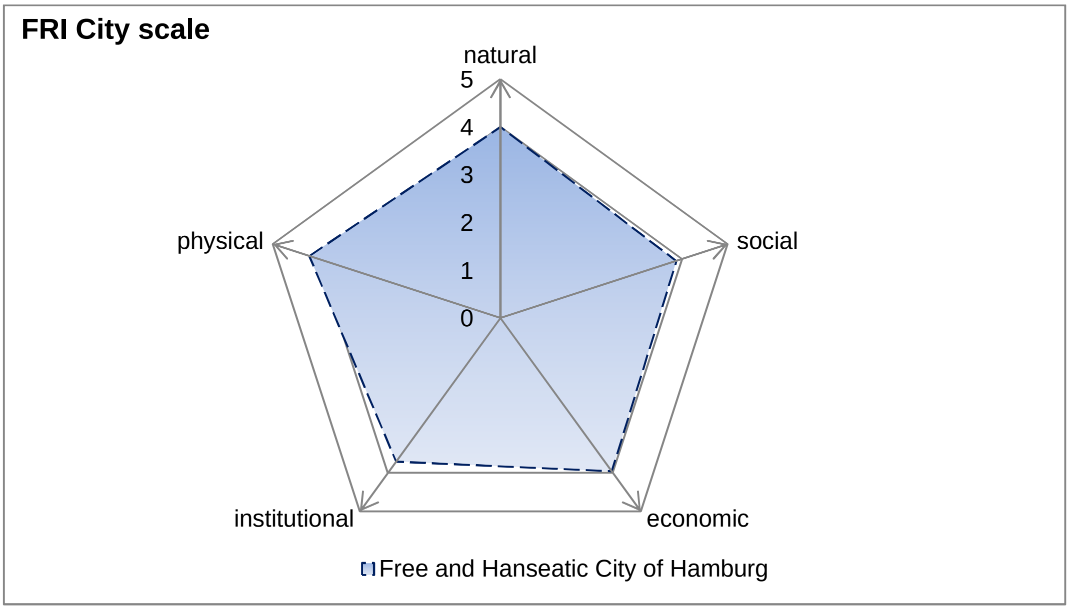


Figure 67: Radar chart presentation of FRI on city scale, for flood initiated by storm surges and the current status of the flood protection – Free and Hanseatic City of Hamburg, Germany

Results obtained using Matrix with 91 indicators give good interpretation about existing and needed assets and policies (laws, binding documents, etc) that will contribute to increase flood resilience of analysed case study. The 91 indicators is used out of 91.

Natural dimension with index value 4 shows that the river network is able to accept the peak discharge from upstream. The discharge feeding the Lower Elbe from upstream can be controlled by the weir in Geesthacht. In the areas being less densely populated or in areas which are originally under agricultural use, polder areas are provided, which can capture certain amount of storm water in case of a storm surge approaching the city of Hamburg.

Social dimension with index value 3.96 shows that there is an intense exchange of knowledge between the planning, legislative and executive (especially with respect to the flood protection) disciplines. During the devastating storm surge of 1962 the public, the legislator and the executive agency learned their lessons. As a result, there was a change of the dike law, a repeated increase of the design water levels (taking into account the climate change), an improvement of the cross section of the flood protection dikes and the implementation further manifold flood protection measures. Nowadays, there are clear-cut responsibilities within the civil protection. Furthermore, the public, living in flood prone areas, is kept informed regularly inter alia about the recent regulations of civil protection and evacuation process.

The economic dimension has a comparatively low index value of 3.71. The main reason can be seen in the missing financial support from insurances. There is only a limited possibility to effect an insurance against inundation. In general, material damages resulting from inflowing surface water are insured. Material damages resulting from storm surges cannot be insured. However, financial support for flood-adapted construction is available. There is no tax deduction for people living in flood prone areas.

Institutional dimension with index value 4.2 shows that recent flood protection concept of Hamburg is well-positioned with respect to the institutional dimension. On the on hand, there are detailed civil protection and evacuation plans and clear-cut responsibilities. Nowadays, the

planning of the public and private flood protection relies on the results from inundation simulation under consideration of the climate change. The stakeholders, especially those who are responsible of the flood protection, are in close co-ordination with respect to their flood protection strategies and flood protection measures. Just like, they rely on recent research findings for the derivation of flood vulnerability, flood maps, flood risk maps, which are open to the public in parts.

Physical dimension received an index value of 3.87. The physical flood protection infrastructure comprising dikes, sluices, walls and gates etc. has been adapted and improved repeatedly during the years after the storm surges of 1962 and 1976. The flood protection infrastructure proved its protective effect against storm surges and flood as the surge “Xaver” of 2013 showed. Possible future adaption of the flood protection infrastructure to changing hydro-meteorological conditions is included in the planning process of the flood protection, so that future increase e.g. of the dike height can be carried out easily.

The overall flood resilience index of 3.96 shows that the flood protection of the city of Hamburg is quite advanced. This status of flood protection can provide the necessary protective effect to the city and its inhabitants. But nevertheless, flood protection is never-ending task and must be adapted and improved in the future.

6.5 Ayutthaya Case Study - case study description

Ayutthaya Island is located approximately 70 km. north of Bangkok and has an area of 7.2 km^2. The population of the island is over 40 000.The island is located at the confluence of three rivers: the Chao Phraya River, the Lopburi River, and the Pa Sak River in the Chao Phraya River Basin. The Historic City of Ayutthaya covers 40 % of the island and was inscribed on UNESCO's World Heritage Site (WHS) as shown in figure below. Ayutthaya city is famous for its cultural tradition.

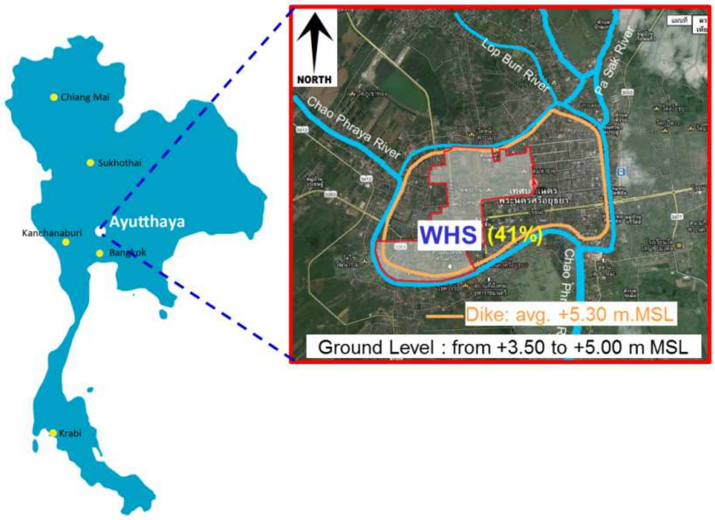


Figure 68: Ayutthaya Island is located in Thailand and represents an urban area. Approximately one-third of the island is protected by UNESCO as a World Heritage Site (WHS)

The cause of flooding is the fluvial flood from the surrounded river, especially Chao Phraya river. The present protection system is perimeter dikes with average elevation +5.30 m Mean Sea Level (MSL). The ground has elevation from +3.50 to +5.00 m MSL. The dike level should be heightening up to fully protect Ayutthaya WHS but the communities especially outside the area did not agree with the measures since the extended dike will elevate the flood depth and consequence flood duration in the area outside island.

Ayutthaya WHS is famous for its ancient water management system. In the old day, Ayutthaya faced floods every year with 1 to 2 month duration and it naturally brought with them silt, which fertilized the rice field in the central plain of Chao Pharaya. Therefore this area is important for rice productivity of the country. The flooding was used as a crucial natural condition in a battle with attacking enemy since they would face flooding and lack of food so that they cannot stand such condition and would withdraw their army. In 16th century period, Ayutthaya wall was 12.4 kilometers long with 20 water gates. The canals inside the city were laid along north-south and east-west all connected together to one system, similar to gridding system. These water gates were closed during floods to protect the city then open again after flood. The function of canal network is to store water and then to drain water systematically to release the water pressure at the wall. In dry season, gates will close to collect water. The present canal and pond systems are degraded in both quantity and quality. Ancient canals were approximately 140 km. long with 5 big ponds while the present system is 18 km long with only 3 ponds. The present canals have only north-south alignment and do not have a good network. Figure below shows ancient and

present ponds and canal network. The rehabilitation of ancient can recover their old function, to assist the present urban drainage and to drain the overflow flooded water over the dike.

Figure 69: Ancients and Present Canals and Pond

6.5.1 Scenario description

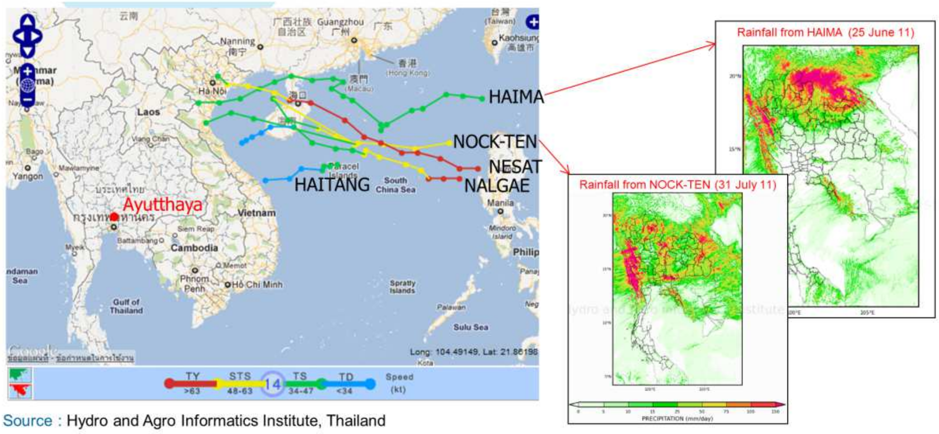
The cause of the great flood 2011 in Thailand can be summarized as follows:

- *Natural factors* – Because of La Niña phenomenon, which occurred from January to August 2011 and again at the end of year 2011, contributed earlier heavy storm compare to normal situation. There are five storms occurred in the year 2011 (Figure 3); HAIMA (26 Jun.), NOCK-TEN (31 Jul.), HAITANG (28 Sep.), NESAT (30 Sep.) and NALGAE (5 Oct.) as shown in Figure 3. Accumulated rainfall is 1,781 mm which is 30% greater than the average value, 1,374 mm as shown in Figure 4. Moreover, most of dams reached their capacities and need to flow the water out of it for reducing a risk of dam break.
- *Physical conditions* – An increasing of deforestation affects to less damping areas and natural floodway. Buildings and houses constructed on floodplain area. Furthermore, the water infrastructure is not adaptive for the current situation.
- *Water management* – The detention and retention ponds in the upstream were deteriorated which effect to decreasing its capacity. Many people constructed their own polders and dikes which make an overall drainage system were less effective. Moreover, the lack of an interactive management and cooperation between each department is main problem of drain the flood water.

As a consequence, the water level in waterways is overflowing and flooding to surrounding area and with its velocity and volume of floods make several dikes breach and uncontrolled flood situation. Undoubtedly, Ayutthaya affected from these worst event. The max volume of flood in a decade record flew to Ayutthaya City Island from all directions and leading the total amount of flood water about 3,300 m^3/s into Chao Phraya River while the capacity of Chao Phraya River at Ayutthaya is only 1,500 m^3/s so it caused significant flooding. Figure shows discharge at rivers around Ayutthaya Island. Moreover, on the Ayutthaya City Island, the Ayutthaya municipality filled up the dike (U-Thong road), the existing average level is +5.30 m MSL with compacted soil

(also called temporary dike) about 1 to 2 m before flooding. Nevertheless, the temporary dike cannot resist floods and was breached on 7 October 2011 which leading Ayutthaya City Island suffered from floodwater up to three meters high for one month long. Figure 6. shows flooding occurred in World Heritage Site and residential area.

Back to the history records Ayutthaya City Island was inundated only two times, year 1995 and 2011. However, the Department of Disaster Prevention and Mitigation (DDPM) reported flood damage of the area outside the Island almost every year since 2006. Although, inflow from Chao Phraya River is the main cause of flooding in Ayutthaya every year, only in year 2011 that inflow from Lopburi River side caused flooding here. There also have a frequency of flooding event along Khlong Mueng, especially for the area outside U-Thong road. Moreover, it can be seen that many dams have been constructed in the upstream, however, it seem like not helping to reduce the water level at S5 station and in some years the water level is even worse. Figure 70 illustrates frequency analysis resulted for maximum water level. It represents flooding event in 2011(5.91m.MSL.) which is almost equal to 100 years return period (5.92m.MSL.). While, the years of 1995, 2006, and 2010 flooding events are an average at 20 years return period.



Source : Hydro and Agro Informatics Institute, Thailand

Figure 70: Rainfall Analysis in 2011 (5 storms occurred, namely: HAIMA (26 Jun.), NOCK-TEN (31 Jul.), HAITANG (28 Sep.), NESAT (30 Sep.) and NALGAE (5 Oct.)

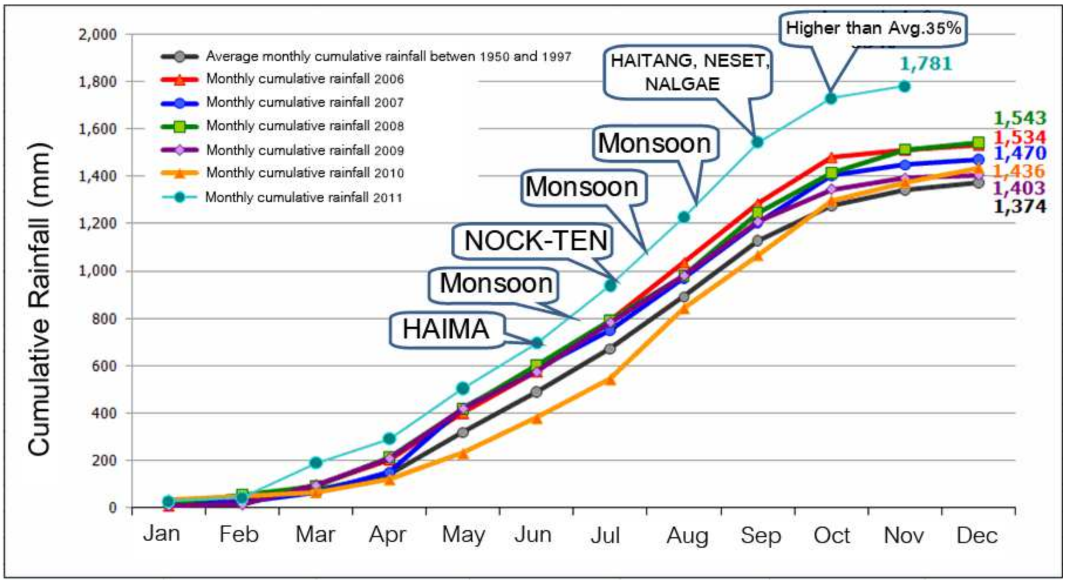


Figure 71: Comparison of Accumulated Rainfall

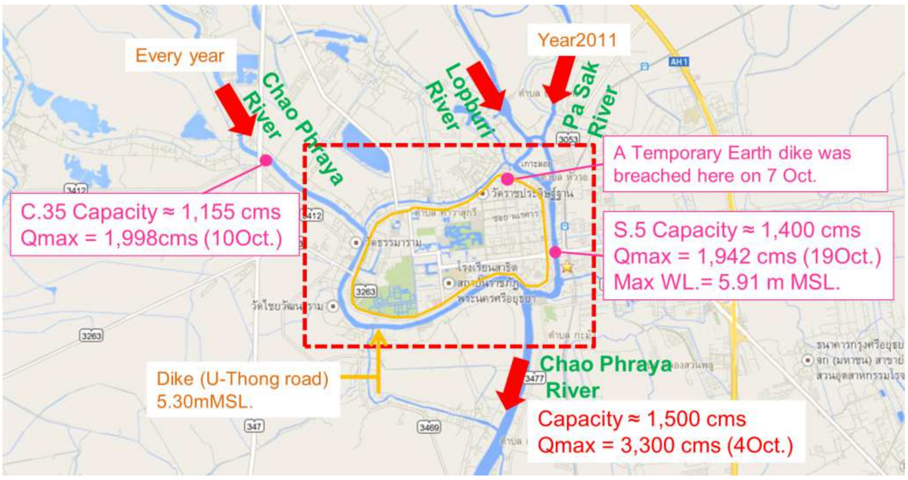


Figure 72: Discharge at rivers around Ayutthaya Island

Figure 73: Flooding in World Heritage Sites

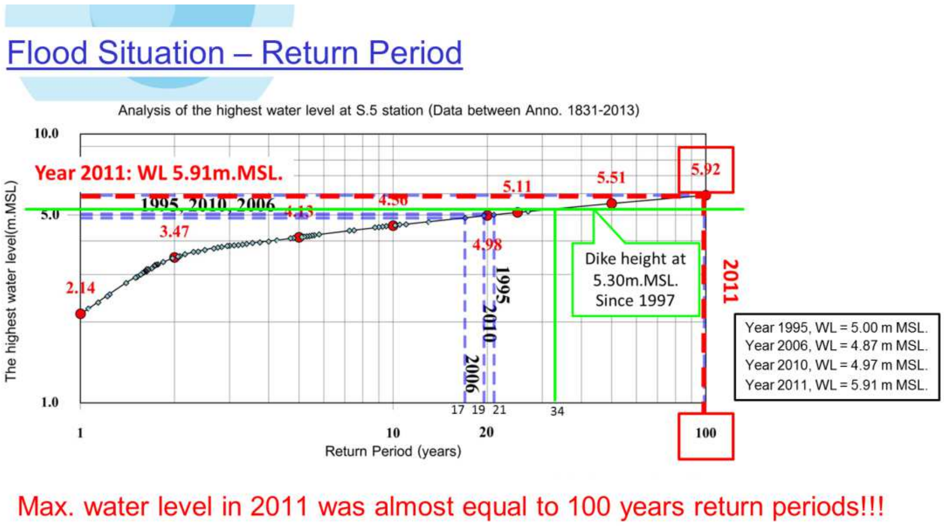


Figure 74: Frequency Analysis of Flooding

6.5.2 Measures that existed before the event and measures added after the event if any

In the past, there were a number of studies to strengthen the dike and heighten up its top elevation to be +6.0 m MSL. The residential along river who will get effect by increased flooding water level did not agree with this idea. Therefore the planning has not approved and moved forward. Next the location of dikes were proposed to move out towards river, even in the river in some area so that local people has less effect. The construction cost was increased and Phra Nakorn Sri Ayutthaya municipality cannot get financial support.

In the comprehensive flood management plan for the Chao Phraya river basin report, JICA (2013) studied and evaluated several flood mitigation measures for the Chao Phraya River basin from three different researches which launched by JICA in 2011, the Strategic Committee for Water Resources Management (SCWRM) in December, 2011 and the Water and Flood Management Commission (WFMC) in July, 2012. Their countermeasures consist of 1) Operation

efficiency of existing dams 2) Construction of new dams 3) Improvement of retarding/retention areas and Land use control 4) To construct East/West diversion channel 5) To construct Outer ring road diversion channel 6) River channel improvement works 7) Roads and dykes raising around economic zones 8) Ayutthaya Bypass channel 9) Reforesting at upstream of river basin 10) Flood management information system development. Although, JICA proposed to combine these countermeasures for the most effective flood management plan, the possibility of these plans is unknown and this research is focus on Ayutthaya area. The Ayutthaya Bypass channel is one of the alternatives as regional solution scale to river channel improvement works, since it is extremely difficult to widen the river channel in the stretch between Bang Sai to Ayutthaya. The Bypass Channel has an effect in reducing water levels of (i) the Chao Phraya River between Bang Sai and Ayutthaya, and (ii) the Pa Sak River. Hence, it is so effective to reduce the risk of dyke breaches along the Ayutthaya areas and downstream. JICA also proposed an optimum capacity of Ayutthaya bypass channel which is 1,400m^3/s. Therefore, only Ayutthaya Bypass channel will be included in measure analysis of this research. Figure 8a shows the location of Ayutthaya Bypass channel proposed by JICA.

The flood management plan for the west side of the Chao Phraya river basin by Royal Irrigation Department (RID, 2013).

One of them is Ayutthaya bypass channel from Bangban to Bangsai in Phranakorn Sri Ayutthaya province with 22 kilometers length and capacity is 1,200m^3/s which is the same alignment as the one proposed by JICA (2013). The proposed bypass channel location is in the same area as in JICA study. It has a high possibility to be constructed in the future and it will directly affect to reduce water level of the Chao Phraya River at Ayutthaya City Island. So this thesis research will consider it as regional flood mitigation measure for Ayutthaya case study.

The Downstream Flood management plan for the east side of the Chao Phraya river basin by Royal Irrigation Department (RID, 2012). The objective of this study is to mitigate flood problems in the lower Chao Phraya River basin which Ayutthaya is a part of it. At the present, the Chao Phraya River has a drainage capacity between 2,000-2,500 m^3/s and drain through canals on the east side 275 m^3/s and 415m^3/s in the west side. The flood volume that the Chao Phraya River can manage without any effect to downstream area is about 3,000 m^3/s. Hence, this study proposed the mitigation measures to reduce an excess flood volume from upstream by i) improvement of the east side canals capacity to 1,000m^3/s ii) improvement the detention area in downstream for collecting flood volume at 171.63 Mm^3. This study proposed seven alternatives of improvement the east side canals and Figure 8b is the one of seven alternatives that has been selected for further development and will be integrated in measure analysis in this study. Therefore, there will be two diversion channel included in the further study. The first one is Ayutthaya by pass channel and the second one is East diversion channel.

According to FAD development plan in the year 1994 and 2014 that proposed to create Ayutthaya atmosphere to be the water city as in ancient time, reviving ancient canals are proposed as part of this strategy. Since at the present, most of the ancient canals are filled up as road, and found many invasions by houses and buildings, this research will discuss and study the possibility of reviving ancient canals. Figure 2 shows the total length of canals which is about 140 kilometers and the total canals length in Ayutthaya City Island at the present is 18.2 kilometers. It can be clearly seen that how much the ancient canals remain until now and why the reviving ancient canal are need. To revive these ancient canals, the study and survey of its existing situation, invasions, drainage capacity and tourism benefits are the main criteria for assessment as mentioned. Although, there are 10 ancient canals in total are evaluated here, only 7 of them are proposed for further development. Local mitigation measures have been

proposed for increased canal length and storage as shown in Figure 2. Multifunction use of canal is considered to use for new tourist boat trip and detention storage to harmonize with the traditional water village in Ayutthaya.

The mathematical model for Ayutthaya in this research was developed based on 1D model of lower Chao Phraya River (CPR) basin hydrodynamic model. The model covers downstream area of Chao Phraya River basin where is downstream of Nakorn Sawan province. Modelling will be used to examine the effectiveness of regional, local measures.

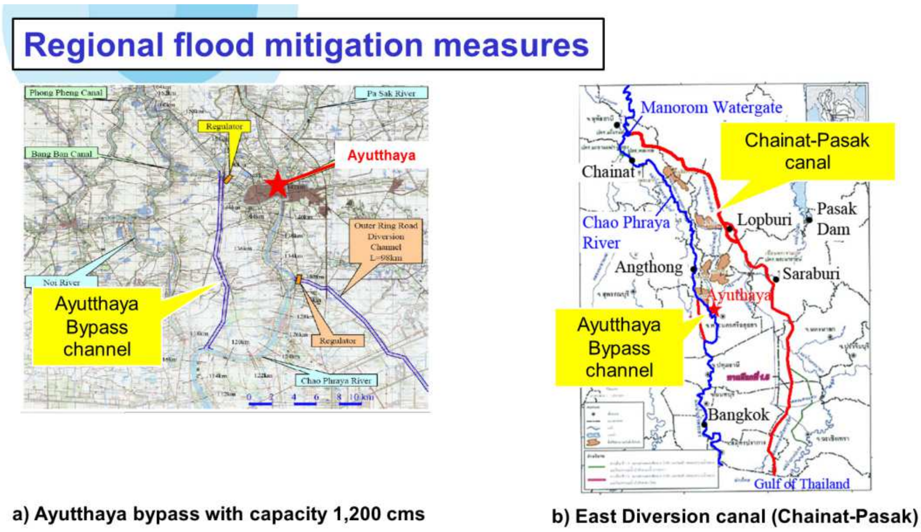


Figure 75: Regional Flood Mitigation Measures (Source: JICA (2013))

1.1.1 FRI for city scale – Ayutthaya, Thailand

Some assumptions are made before completing matrix presented in Annex A: *When no availability can be assessed for an indicator, it can be left out of the integration of the overall FRI provided that 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 3 and 5.
- Emergency evacuation & warning, and accessibility are given an importance of 4 and 5
- Land use and urban expansion have a weight of 5, as well as protected critical facilities
- Volunteers and solid waste management are assigned a weight of 5 and 3.

Following the method defined by Batica et al., 2013 and presented in this report, 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 at our organisation and stakeholders from case study and literature review related to the analysed event.

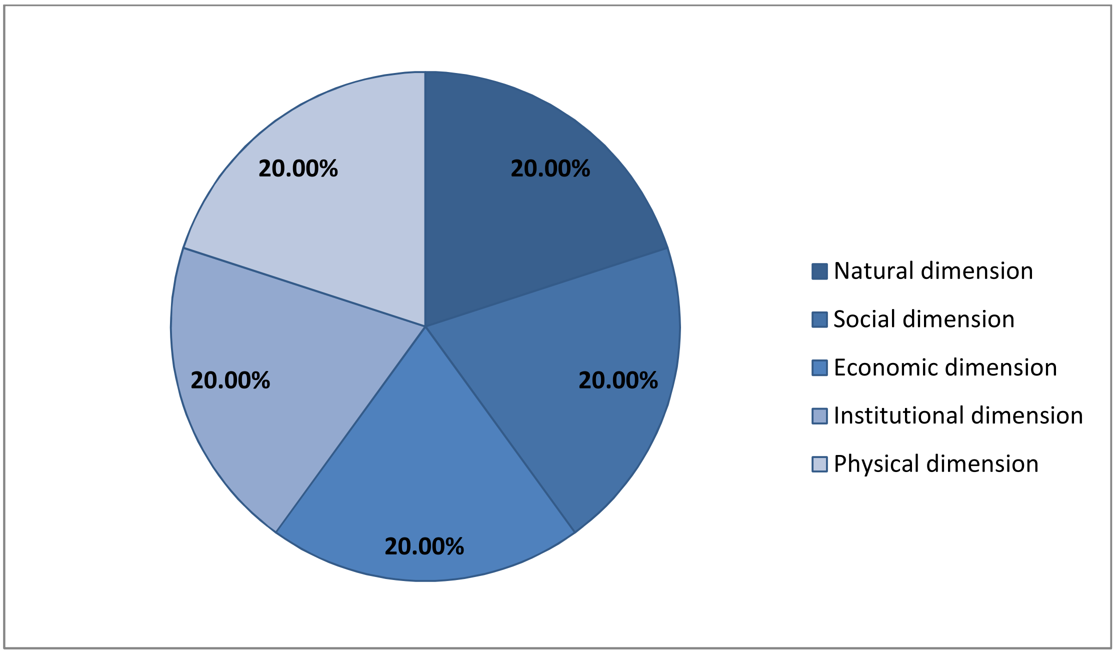


Figure 76: Weight of each dimension on the overall FRI for the Ayutthaya Case Study, Thailand

As presented in Figure 66 the importance of each dimension varies from 3.97% for natural to 43.65% for physical dimension.

Procedure considers evaluation of overall FRI followed by assigning values to each indicator with their respective weights. For the given conditions, the FRI for the Ayutthaya is 2.95. The result in the form of table shows separate FRI for each dimension and the overall index.

Table 38: Overall FRI for the city/urban scale; for flood initiated by storm surges and the current status of the flood protection – Ayutthaya, Thailand

Ayutthaya	Indicators	not used categories	Dimension index ∑((xi*wi)/ ∑wi)	Overall index
natural	2	0.00	3.00	2.90
social	7	0.00	2.76	
economic	13	0.00	3.57	
institutional	23	0.00	1.75	
physical	30	0.00	3.44	

Results obtained in analysis demand further discussion and interpretation. The interpretation is done using spider diagrams with representation of FRI values for each dimension. This way is often more suitable for communication with the stakeholders.

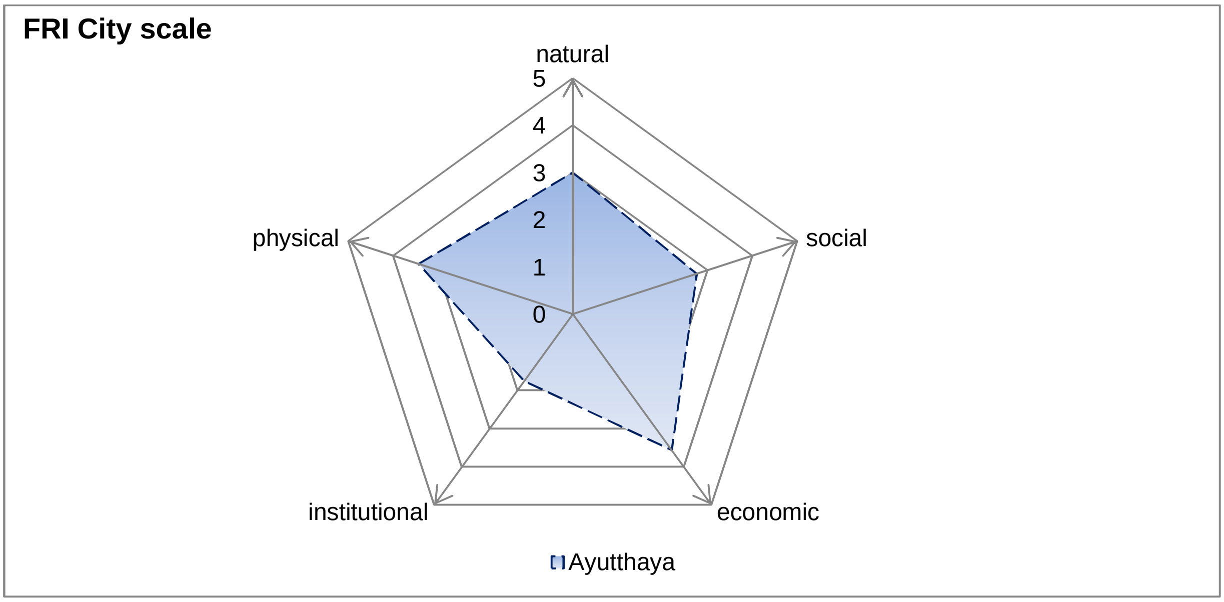


Figure 77: FRI evaluation for city scale - Ayutthaya, Thailand

Results for presented FRI assessment are obtained using given matrix with 91 indicators. For this evaluation all indicators are employed.

Natural dimension with index value 3 shows that the existing river network is able to accept the big part of pick discharge from upstream.

The evaluation of indicators developed for resilience assessment presented on figure 76 shows that institutional dimension does not show capacity for creation of legal framework for implementation of resilient solutions in the area of flood risk management. The value of 1.75 represents current capacity.

The social dimension scored with value 2.76 shows that there is a capacity for developing further knowledge based activities and connecting stakeholders and population.

The physical dimension with value of 3.44 is the highest value for this case study shows that existing building structure has adaptation to flooding. The further increase of flood resilience is followed by application on adaptation measures on parcel scale (building) and on transportation network.