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2nd ERA-NET CRUE Research Funding Initiative
Flood resilient communities – managing the consequences of flooding

SUFRI
Strategies of Urban Flood Risk Management

SUFRI Methodology for pluvial and river flooding risk assessment in urban areas to inform decision-making

Report

July 2011

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ERA-NET CRUE

ERA-Net CRUE is a research network with the vision to establish border conditions for a European research space in regard to the tasks of flood risk management.

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PROJECT SUFRI

“Sustainable Strategies of Urban Flood Risk Management with non-structural measures to cope with the residual risk”

The project **SUFRI** aspires an improvement of flood risk management in case of disaster flood especially in respect of non-structural measures. Flood analyses have shown that structural measures of flood protection are limited applicable, especially in urban areas, and that absolute protection is not feasible.

As flood protection and management are major tasks and of high public interest transnational strategies are needed to implement sustainable flood risk management, aiming for advanced warning systems, vulnerability analysis, and risk communication to optimize the disaster control management.

To achieve this goal, five project partners from four European countries (Austria, Germany, Italy and Spain) and one subcontractor from Austria are working within the ERA-Net CRUE initiative for the period of 2009 - 2011.

This document is part of work package 3 “Residual risk and vulnerability analysis”.

NOTE FOR THE READER

This document is part of the SUFRI project, being compiled by three different institutions. The contained ‘Methodology’ is based on available literature, and draws findings from relevant works. References used are mostly available on the Internet and papers/publications are provided in the “References” section.

July 2011

EXECUTIVE SUMMARY

Flooding from rivers, estuaries, the sea or rainfall poses a risk to people and causes significant economic costs. In the 20th century floods accounted for 12% of all deaths from natural disasters, claiming about 93,000 lives across the world (Flood Risk to People, Defra, UK). As a very recent example, in August 2010, the media reported 3 fatalities in Córdoba (Spain) due to extreme rainfall events of 286 mm in just three hours.

The operation of flood defence systems contribute to reduce risks, however flood risks cannot be completely eliminated. Thus, flood forecasting, warning, planning and other non-structural measures are even more significant on reducing flood risk. For this reason, there is a requirement for methods to estimate flood risk (societal and economic risk) and the effect of these measures on risk reduction.

This research report deals with the “residual risk and vulnerability analysis”, providing overall information about risk estimation, along with the developed methodology “SUFRI Methodology for pluvial and river flooding risk assessment in urban areas to inform decision-making” as well as several case studies.

This report is divided into four sections. First, chapter 1 OVERALL STUDY includes different sections and general concepts (section *1.1. Flooding risk* includes overall concepts on flood risk and the role of structural and non-structural measures; section *1.2. Structural measures for risk reduction* describes different typologies of retention and protection structures; section *1.3. Non-structural measures for risk reduction* identifies strategies such as urban planning, flood forecasting, communication, coordination, etc., and, finally, section *1.4. Tools for risk estimation* includes existent methods based on the study of the two components of risk). Next, in chapter 2, the SUFRI METHODOLOGY FOR PLUVIAL AND RIVER FLOODING RISK ASSESSMENT IN URBAN AREAS TO INFORM DECISION-MAKING is described. Then, in chapter 3, several case studies are summarized as APPLIED FIELDS of the methodology. Finally, in chapter 4, the main CONCLUSIONS of this work package are drawn.

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NOTATION

Af	Potential flooded area (km²). In pluvial flooding, two values are estimated: Af (flood depths < 0.15 m) and Af1 (flood depths > 0.15 m)
Af’	Flooded areas without households (used for estimating economic damages)
A_{ff}	Affected area, used as potential flooded area for calculations (km²)
A_F	Total flooded area (km²)
A_T	Total area of the case study (km²)
b	width of the main waterpath (street)
C	Category for the case study to obtain reference fatality rates (RFR) in river flooding
C_p	Category for the case study to obtain fatality rates (FR_p) in pluvial flooding
CD	Direct costs (€)
CI	Indirect costs (€)
CR	Reference cost, established for each land use category (€/m²)
CT	Total costs: sum of direct and indirect costs (€)
CU	Land use category
d	Density of population at the study area (inhabitants/km^2)
d_C	Density of population to estimate population at risk, from density reduction based on building typology (inhabitants/km^2)
D	Damage
DV	Parameter for the definition of flood severity levels in river flooding (m²/s)
f	Annual probability of exceedance (years^{-1})
f_C	Factor. Ratio of indirect to direct costs (%)
F	Cumulative annual probability of exceedance (years^{-1})
FR	Fatality rate in river flooding
FR_p	Fatality rate in pluvial flooding
h	Height (m)
H	Water depth in river flooding
N	Number of potential fatalities
Q_f	Flow discharge
$Q_{2.33}$	Mean annual river discharge
P_d	Daily rainfall rate
PD	Percentage of damage
P_o	Runoff threshold
PR	Population at risk
S	Flood severity in pluvial flooding
S_v	Flood severity in river flooding

T	Return period
TC	Time category
TW	Warning time
w_{df}	Maximum width of the flood area (m)
y	Water depth in pluvial flooding

ACRONYMS

ACA	Agencia Catalana del Agua (Catalonia Water Agency)
AEP	Annual Probability of Exceedance
ANCOLD	Australian National Committee on Large Dams
ARC	Atlanta Regional Commission
CEDEX	Centro de Estudios y Experimentación
COPUT	Conselleria D'Obres Públiques Urbanisme i Transports Generalitat Valenciana
Defra	Department for Environment, Food and Rural Affairs
EAP	Emergency Action Plan
U.S.	United States
FEMA	Federal Emergency Agency (United States)
FHRC	Flood Hazard Research Centre (United Kingdom)
ICE	Institution of Civil Engineers
MS	Structural measures
MNS	Non-structural measures
NDS	No Drainage System scenario
RN	Natural flow regime (river flooding)
PATRICOVA	Plan Acción Territorial de la Comunidad Valenciana
PFR	Public Education Program on Flood Risk
SuDS	Sustainable Drainage Systems
UK	United Kingdom
UNWWAP	United Nations World Water Assessment Programme
USA	United States of America
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
UPV	Universitat Poiltècnica de Valencia, Polytechnic University of Valencia
WS	Warning System

1 OVERALL STUDY

1.1 Flooding risk

1.1.1 General definitions and components

Directive 2007/60/EC of the European Union defines a flood as a temporary covering by water of land not normally covered by water. As this directive explains, this shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems.

During the period 2000 to 2006 the water-related disasters killed more than 290,000 people, affecting more than 1.5 billion, and inflicting more than US$ 422 billion of damage (*UNWWAP 2009*). There are several factors that have led to a rise in the frequency of these disasters, such as natural pressures, climate variability, and social pressures (i.e. escalation of population and settlements in high-risk areas). In general, these flood consequences will be especially important in urban areas.

In the past, the focus was on steps to prevent floods, but in recent years measures to address the consequences have increasingly also been adopted. This reflects recognition that flood can never be absolutely prevented or predicted, so there can always be flood consequences that must be reduced as much as possible.

In order to study the flood threat, the concept of flood risk has been established. Flood risk can be defined as the combination of probability of a flood event, called hazard, and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event (*Directive 2007/60/EC*), called vulnerability. Consequently, flood risk has two main components, hazard and vulnerability.

Hazard is a potentially damaging physical event, phenomenon or human activity that may cause loss of life or injury, property damage, social and economic disruption, or environmental degradation. This part of the risk is often characterized by the individual risk, which is the probability that an average unprotected person, permanently present at a certain location, is killed due to an accident resulting from a hazardous activity (*Jonkman 2007*). Hazard analysis involves identification, study and monitoring of the hazard to determine its potential, origin, characteristics and behaviour. The main result of the hazard analysis will be the probability of occurrence of the studied hazard.

Therefore, individual risk is based on the probability of being killed of the most exposed person. The units of this risk are number of fatalities per unit of time.

On the other hand, vulnerability can be defined as the conditions determined by physical, social, economic and environmental factors or processes which cause the susceptibility of a community to the impact of hazards. Thus, the vulnerability analysis lies in a description of the consequences produced by a defined hazard.

Risk is commonly expressed by the notation Risk = Hazards x Vulnerability. Its units are the ones used for measuring the vulnerability divided per time, for instance a monetary unit or number of victims per year, because the hazard probability usually has units of time-1. When risk consequences are computed in number of victims, resulting risk is usually called societal risk, which is defined as the relationship between frequency and the number of victims in a given population from the realization of specified hazards. Societal risk includes vulnerability, not only hazard characteristics.

Flood risk analysis is a methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that could involve a potential threat or harm to people, property, livelihoods and the environment on which they depend.

Analyzing flood risk to human life and property is essential to achieve its reduction. Flood risk can be analyzed by calculating the probability of an event occurring and the subsequent impact that it has on a receptor. It is important to consider risk in terms of probability and consequences rather than a unique component.

There are many kinds of measures to reduce flood risk. Generally, they are divided into two groups: structural and non-structural measures. Structural measures refer to any physical construction to reduce or avoid possible impact of floods, which include engineering measures and construction of hazard-resistant and protective structures and infrastructures, such as levees or dams.

Non-structural measures are the policies, awareness, knowledge development, public commitment, and methods and operating practices, including participatory mechanisms and the provision of information, which can reduce risk and related impacts (*UNWWAP 2009*).

The application of structural measures will handle the consequences until a specific severe event, typically called design event. Beyond, even in the case of perfect behaviour of the structure, there is always a residual risk.

Furthermore, non-structural measures will help to reduce this residual risk, but it cannot be completely eliminated. Subsequently, the residual risk contains the consequences that cannot be avoided by the structural and non-structural measures.

1.1.2 **Sources of residual/existing risk in urban areas**

Flood can be caused by complex interaction of a range of sources, especially in urban areas. In general, there is an event which produces the loss of mission of the measures taken against floods. Hence, a flood will be produced with a certain consequences. The main sources that can cause flooding in an urban area are:

- Rainfall: High-intensity runoff may produce flooding in urban areas. This kind of flood will be more hazardous when the drainage system of the city is not capable to drain all the water effectively.
- River flood: Rivers can burst their banks and inundate urban areas. Although river floods are usually associated with storms, it must be analyzed as a different source of flood risk, because storms many kilometers upstream the urban area can produce flooding, independently of urban rainfall. Furthermore, other natural processes like snow melt can also produce important river floods.
- Maritime flood: Sea can inundate urban coastal areas as a result of natural events as hurricanes, cyclones and typhoons. Furthermore, in the case of urban areas below the sea level, if the structures that protect them are not able to contain the sea water, the flood consequences can be very important.
- Structural collapse: The failure of a structure can produce an important flooding and it may increment flood consequences produced by other sources. For example, the failure of a dam will produce a high incremental discharge in the river. Thus, structural measures for flood risk reduction have typically a double role. This double effect on flood risk is analyzed in detail in section 1.2.

Phenomena such as climate change may indeed increase the flooding risk. Other important hazards to be considered are terrorism, sabotage and vandalism, which can aim to destruction of structures as dams and dikes (*ICE 2008*).

1.1.3 **The role of structural and non-structural measures in reducing risk**

As it has been defined in the previous section, residual risk is the risk due to the fact that structural and non-structural measures cannot completely eliminate flood risk.

Structural and non-structural measures are crucial on flood risk reduction, and their reliability and functionality play an important role:

- Functionality of structural measures: All the structural measures (such as dams, dikes, embankments, drainage systems…) are designed for events linked to an annual probability of occurrence. If there is a flood event higher than the design event, the structure will not be able to provide further protection, losing its functionality.
- Reliability of structural measures: dams and dikes prevent consequences as far as

they are reliable and, beyond, their breakage would increase flood consequences, linked to a very low or severely low probability of occurrence for each case.

- Functionality of non-structural measures: Non-structural measures reduce flood risk when the flood is produced, reducing flood consequences. In order to get this reduction, measures as proper urban planning, forecast systems, flood pre-characterization models, warning systems and evacuation procedures are applied. The effectiveness of these measures will identify the limit for consequence reduction.
- Reliability of non-structural measures: Trustworthiness must also be analyzed in order to know if non-structural measures will work correctly and achieve the maximum consequences reduction, as their failure can produce important consequences.

The main structural and non-structural measures are studied in chapters 1.2 and 1.3 respectively, analyzing their influence on flood risk.

1.2 STRUCTURAL MEASURES FOR RISK REDUCTION

Structural measures for flood risk reduction are all measures that involve construction of civil works to protect areas against floods. Strategies can vary widely depending on the situation. In general, they can be divided in three groups:

- Retention structures: Their mission is to retain flood water in order to avoid floods with high discharges, which can produce important damages and the failure of protection structures. The most common retention structures are dams and ponds upstream urban areas.
- Protection structures: These structures protect directly urban areas from water, avoiding it to enter inside the city, like dikes, or forcing it to flow faster through the city inside a delimited protected bank, like embankments. These structures provide protection from river floods and also from maritime floods, like maritime dikes.
- Drainage systems: Drainage systems are designed to manage runoff generated in the urban area and their surroundings.

In addition, structures must be designed taking into account the natural river dynamics, understanding its changing nature. Ideally, they must be designed allowing as much as possible the natural behaviour of the river (*Ureña & Teixeira 2004*).

Structural measures have a really high importance on flood reduction, as they avoid numerous floods. In this chapter, their characteristics, focusing on their advantages, limitations and the potential consequences by their failure, are explained.

1.2.1 Retention structures

Major retention structures in a river

Major retention structures are mainly dams with very different sizes located upstream urban areas. Their function is to store water for diverse purposes, as irrigation, urban water supply, electrical production, recreational uses, shipping and flood protection through flood routing.

Large dams can store large volumes of water and they provide high protection upstream large urban areas. The most common types of large dams are:

- Gravity dams.
- Arch dams.
- Buttress dams.
- Embankment dams.

Dams have an important function as retention structures for flood risk reduction as flood routing reduce peak flows downstream the dam during a severe event. However, flood routing is not always effective, because dams are designed for a certain flood, related to an annual probability of exceedance. If there is a larger flood, the dam may lose effectiveness progressively, but it still provides protection downstream.

Consequently, societal benefits of flood risk reduction prevail over the likelihood of a dam failure, as its probability remains in extremely lower values. Nowadays, social pressure is increasing to make a proper assessment of dam safety, due to the significant flood risks. Thus, the approach of traditional risk analysis, which assumes that there is no risk of dam failure due to the high safety factors with which it was built, is being supplemented by a risk-informed approach that considers the risk failure of the dam, which can be identified, assessed and managed although it may seem unlikely (*Kreuzer 2000*), since large dams are designed for floods of high return periods (5,000 - 10,000 years).

Minor retention structures close to urban areas

Minor retention structures are located in the upstream area of urban zones, managing flow that would reach the city, reducing peak runoff and storing water during a rainfall event.

These structures may have an outflow control that allows to keep constant discharge levels by retaining water. Otherwise, the pick discharge cannot be fixed to a certain value.

Some examples of minor retentions structures are:

- Stormwater ponds: Constructed retention basins that contain water permanently, usually with natural appearance. Runoff is detained and treated in the pool primarily through settling and biological uptake mechanisms.

- Detention basins: Free areas that get flooded during storms, by storing water for a short period of time. They are typically less costly than stormwater ponds for equivalent flood storage, as less excavation is required. They vary from a simple field to an inundated area controlled automatically with outlet works.
- Underground retention structures: Their aim is to also reduce peak discharges. They may allow infiltrations into the soil, or they may be impermeable, returning the stored water at controlled rates.

Retention structures can be constructed for floods with very different return periods, from 1 to 100 years (*ARC 2001*). Since these return periods are not very high, risk assessment will be crucial to understand the consequences of a loss of effectiveness.

1.2.2 **Protection structures**

Direct protection from flooding

Their main function is to prevent flooding of the adjoining countryside. Therefore, these structures are usually located along the sea, rivers, channels, lakes or polders. The most common are:

- Dikes: They are built following the river, sea or lake natural profile. Sea dikes are usually built as a mound of fine materials with a gentle seaward slope in order to reduce the wave run-up and the erodible effect of water.
- Walls: Vertical structures with the main function of preventing overtopping and land flooding. Walls range from vertical face structures, such as massive gravity concrete walls or stone-filled cribwork, to sloping structures, with typical surfaces being reinforced concrete slabs, concrete armour units or stone rubble (*USACE 2006*). Seawalls are built parallel to the shoreline.
- Dune construction: This structural measure for maritime protection relies on piling up of beach quality sand to form protective dune fields to replace those washed away during severe storms. Dune vegetation is essential to help dune reconstruction in order to retain wind-blown sand.
- Storm-surge barriers: These structures are a combined system of dikes and gates. Gates are sliding or rotating steel constructions supported in most cases by concrete structures on pile foundations. They protect estuaries against storm surge flooding and related wave attack.

In this group of structures for direct protection from flooding, measures in buildings and infrastructures to protect them against flooding are also included. These measures change materials on buildings or infrastructures, or their configuration, with the purpose of decreasing flood risk. Some examples of these measures are (*Kreibich et al. 2005*):

- Waterproof sealing: Using impervious construction materials and improving building configuration.
- Fortification of basements: Improving materials used on ground floors and using an especially stable building foundation, in order to avoid a collapse as a consequence of severe floods.
- Flood adapted use: Changing the use of lower building areas to decrease flood consequences. This measure could be considered a non-structural measure.

Retention structures reduce flood risk because they form a barrier for water entering during severe events and their design is defined for a certain return period.

Maritime defences are designed for the maximum wave height associated to a return period, which ranges from 25 to 5,000 years, depending on their economic importance and potential failure consequences, especially in areas located under the sea level.

Design of rivers and channels protection depends on the high-flows distribution. Return periods are usually lower than in maritime defences. They can vary from 5 to 1,000 years.

Severe events related to these return periods define the limits of the structure effectiveness. Therefore, flood risk cannot be completely removed with these structures.

Modification of river characteristics

These protection structures change river morphology in order to increase its drainage capacity in urban areas, reducing flood consequences. These measures act as an indirect protection and they can also be considered part of the drainage system.

The main structural measures that change river characteristics are:

- River bed widening: This measure relies on widening the river bed to achieve more space in the river bed, decreasing its water depth for the same discharge.
- Change of river bed roughness: With lower river roughness, water flows faster through its path, as a result, lower water levels are obtained (i.e. acting on river bank vegetation).
- Embankments: This measure consists of creating a new river bed to contain water in its path through the area. Embankments reduce significantly flood risk, although these structures are more destructive from the environmental point of view.
- New channels: Based on diverting water from the river when there is a high flood risk, with the purpose of avoiding high discharges in urban areas.
- Change of river catchment characteristics: Reforestation of the catchment area

increases water interception and reduces peak flows.

Usually these structures have been designed with return periods from 5 to 1,000 years, depending on the consequences of the structure failure, related to the exceedance of the structure capacity.

1.2.3 **Drainage systems**

Conventional drainage systems

The drainage system of a city collects the rain water, and it includes a complex system of structures like sewers, channels, pipes, manholes, pumping stations, etc. There are two main categories of drainage systems:

- Combined system: This system collects the domestic foul water and the surface rain water in the same sewerage, thus rain water gets more polluted. It is designed for the sum of both discharges, although the maximum discharge from rainfall water is usually much higher.
- Separated system: There are two different sewer systems: one for surface rain water and other for domestic foul water. The first drainage system is larger and it can be superficial, because the water inside is cleaner.

Drainage systems have very different levels of complexity: from channels to complex systems such pumping stations, combined with other structural measures for flood protection. All these elements will affect the capacity of the drainage system.

Two different drainage systems can be distinguished in urban areas. On one hand, the designed sewer system or minor system. On the other hand, the major system, which drains the above ground or exceedance flow (*Balmforth et al. 2006*). High exceedance flows will produce urban flooding when the minor system reaches its maximum capacity.

Traditionally urban drainage systems are designed to meet a specified level of service, related to a return period of severe flooding, which varies from 2 to 30 years depending on local rules. However, existing drainage systems typically do not achieve the level of service required for new systems, due to structural deterioration of the network or due to additional flows from expanding urban areas. Nevertheless, these systems must avoid very frequent floods.

Sustainable drainage systems

Sustainable Drainage Systems (SuDS) are innovative systems developed in line with the ideals of sustainable development. At a particular site, these systems are designed both to manage the environmental risks resulting from urban runoff ant to contribute wherever possible to environmental enhancement. SuDS objectives are, therefore, to minimize the impacts from the development on the quantity and quality of the runoff, and maximize amenity and biodiversity opportunities. The philosophy of SuDS is to replicate, as closely as possible, the natural drainage from a site before development (*Medina & Méndez 2006*).

Peak runoff gets higher in conventional new urbanized areas, as pavement usually reduces infiltration and it has less roughness than the natural floor. These higher runoff peaks can raise significantly the river discharge. Detention structures will decrease these values as it is shown in Figure 1.1.

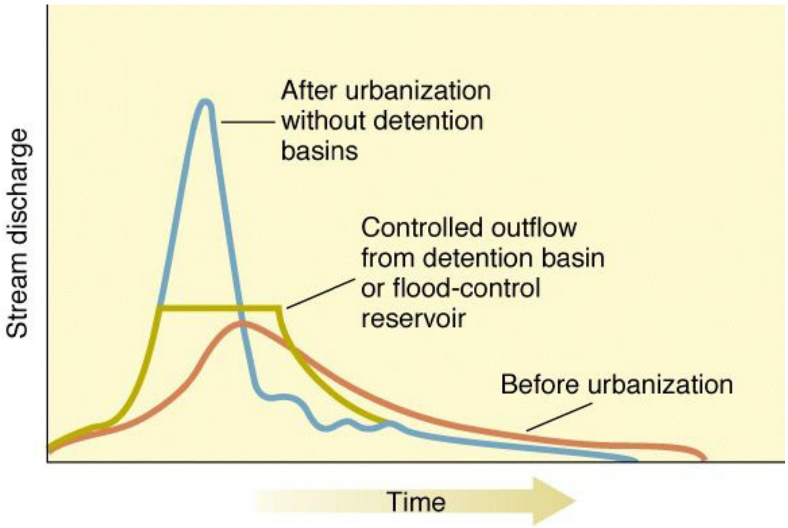


Figure 1.1: Hydrograph with and without a detention basin in an urban area.

SuDS design should aim to reduce runoff by integrating stormwater controls throughout the site in small, discrete units. Through effective control of runoff at source, the need for large flow attenuation and flow control structures should be minimized (*Medina & Méndez 2006*).

As it has described for traditionally urban drainage systems, SuDS are also designed for a specified level of service, related to the same range of return periods (2 to 30 years).

The most common structural SuDS are (*ARC 2001, Woods-Ballard et al. 2007*):

- Greenroofs: A multi-layered system that covers the roof of a building or podium structure with vegetation over a drainage layer. They are designed to intercept and retain precipitation, reducing the volume of runoff and attenuating peak flows.
- Bioretention areas: Structural stormwater controls that capture and treat stormwater runoff from frequent rainfall events. The water quality volume is treated

using soils and vegetation in shallow basins or landscaped areas to remove pollutants.

- Filter strip: Uniformly graded and densely vegetated sections of land, designed to treat runoff and remove pollutants through vegetative filtering and infiltration.
- Enhanced swales: Vegetated open channels that are explicitly designed to capture and treat storm water runoff within dry or wet cells formed by check dams or other means.
- Sand filters: Multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay, a sand bed as its primary filter media and, typically, an underdrain collection system.
- Detention basins and stormwater ponds: Retention structures already described in section 1.2.1.
- Underground retention structures: These structures allow water retention in the subterranean soil, reducing the peak of the discharge by storing water.
- Infiltration trenches: Shallow excavations filled with rubble or stone that create temporary subsurface storage for infiltration of stormwater runoff into the surrounding soils. Ideally they should receive lateral inflow from an adjacent impermeable surface.
- Pervious pavements: Provide a pavement suitable for pedestrian and/or vehicular traffic, while allowing rainwater to infiltrate through the surface and into the underlying layer. Water is temporarily stored before infiltration, reuse, or discharge to a watercourse or other drainage system.

1.2.4 **Structural measures and flood risk**

The main purpose of structural measures is evidently reducing flood risk, but there is a certain probability of failure.

Failures of a structural measure can be classified in two groups:

- Capacity failures: The structure has not enough capacity to provide protection against floods and they depend on the natural environment, thus, there is an important probabilistic component of uncertainty. This kind of failure depends on the functionality of the structure.
- Breakage failures: This failure depends on load uncertainty and it is determined by the characteristics and state of the structure, and its reliability. It is more relevant in dams and dikes, due to the potential consequences, but the annual probability of

exceedance of the event that produces dam breakage is extremely low.

The first group covers drainage systems, embankments, protection of buildings and most of the urban retention structures as their failure mainly depend on the design event.

Structures from the second group reduce flood risk, increasing protection of urban areas, but there is an incremental risk due to a certain failure probability of the structure. Therefore, risk reduction is obtained from the difference between the original flood risk and the existing flood risk with the structure, adding the incremental risk because of its existence (Figure 1.2).

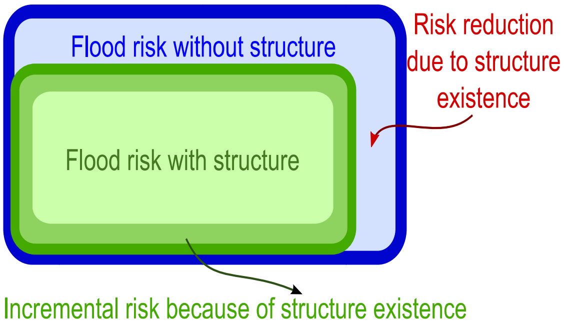


Figure 1.2: Dam effects on flood risk.

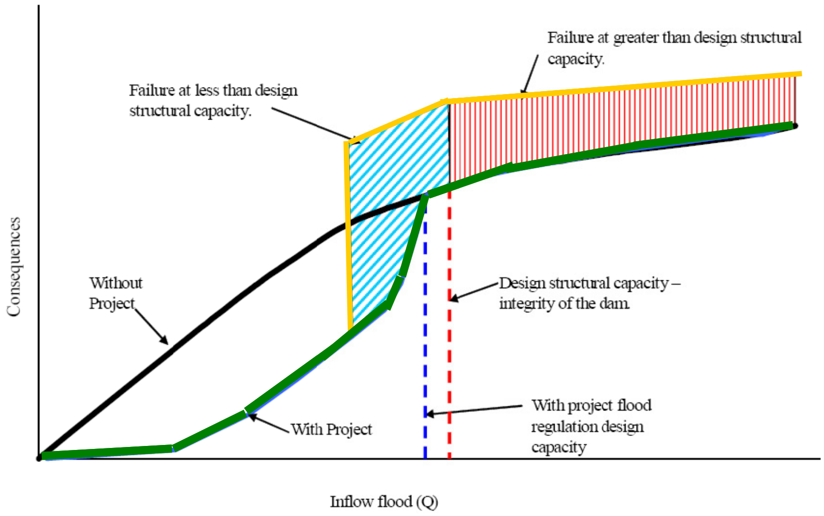


Figure 1.3: Flood consequences in function of the inflow flood and the structure failure (*Kovacs 2011*).

The effect of these structures on flood consequences as a function of the inflow flood is shown in Figure 1.3. The green line shows flood consequences with the structure; the black line shows consequences without the structure and the yellow line shows consequences in case of failure. The vertical blue line indicates the design flood.

Inflow floods higher than flood design have the same consequences with or without the structure, giving rise a capacity failure, and the red area shows the increment of consequences when a failure occurs for an event in that range. Incremental consequences due to a failure for inflow floods lower than the design value are marked in blue. Incremental risk is the sum of both areas and it should be limited and analyzed (*de Membrillera-Ortuño et al. 2005*).

In general, the existence of these structures will reduce flood risk, but an increase on risk may be produced when:

- The probability of a structural failure is high, along with a deteriorated state of the structure.
- Reduction of flood risk in some areas has produced the increment of the urbanization due to a decrease in flood risk perception. Then, a proper urban planning normative will solve it, as is described in section 1.3.
- A structural failure occurs in areas that can only be flooded by this source of risk.

1.3 NON-STRUCTURAL MEASURES FOR RISK REDUCTION

Non-structural measures for flood risk reduction do not involve construction of civil works. They refer to policies, awareness, knowledge development, public commitment and methods and operating practices, including participatory mechanisms and the provision of information (Graham 1999).

Structural measures are usually designed for a hypothetic severe event, with a probability of exceedance, related to the failure of the structure. However, non-structural measures can also reduce significantly flood consequences.

There are several groups and classifications of non-structural measures. Based on the classification given in *Escuder et al. 2010* (Full SUFRI Methodology report, Attachment 1), they have been divided into six general groups.

1.3.1 **Urban planning and policies**

Proper urban planning can reduce risk by discouraging settlements and construction of key installations in hazard-prone areas. This measure requires the development of urban planning normative that restricts constructions and land uses in areas of high flood risk. These limitations can vary from the banning of certain land uses (like residential, industrial…) to requirements in relation with materials and new structural elements to resist against floods.

Furthermore, concise normative regarding with drainage systems is necessary to establish different return periods and identify flood paths for these values in order to avoid future damages (i.e., overflows directed to a surface parking area or a garden instead to a building with underground floors). This urban planning normative must be accompanied of proper tools for flood risk estimation, as described in section 1.4.

Urban planning must be based on conservation and sustainability, being accompanied with education of the population in flood risk.

1.3.2 Flood forecasting

Forecasting is the estimation of the occurrence of a future event using measured data and knowledge of the environment. Therefore, flood forecasting is the estimation of stage, discharge, time of occurrence, and duration of a flood, especially of its peak discharge, at a specified point on a stream, resulting from precipitation and/or snowmelt.

Flood forecasting is an important tool for reducing flood risk, combined with suitable warning systems and evacuation procedures, flood consequences can decrease considerably.

Flood forecasting has two main steps:

- *Weather forecasting:* Based on atmospherical prediction, weather forecasting will be the input for flood pre-characterization models in order to predict floods before their occurrence.
- *Flood pre-characterization:* Flood pre-characterization models are the second stage and rely on estimating stage, discharge, time of occurrence and duration of a flood, at a specified point, using weather forecasting data. These systems estimate continuously water characteristics to assist flood risk management.

1.3.3 Communication

Communication to the public is a key process to reduce flood risk and it is divided into two groups:

- *General communication:* General flood risk communication to the population will provide a better understanding on the existing flood risk, and action procedures during a flood will be known. Risk communication must be carried out continuously through knowledge development and provision of information awareness, with the aim of reaching public commitment.

  The main part of the general communication is public education, which relies on communicating the existing flood risk in normal situations. Thus, people can learn how to act when a severe event happens. This continuous process must reach especially population located in areas with a high flood risk.

An education programme on flood risk should include (*Balmforth et al. 2006*):

- Concept of return periods, together with probability and impact of climate change.
- Understanding on sustainability and effectiveness of structural measures, as their design for floods of very high return periods is not cost effective.
- Knowledge on flooding risk control and minimization.
- Procedures to be followed during a flood and actions that must be avoided.

In conclusion, evacuation procedures will reach lower flood consequences (in terms of human loss of life) if the previous aspects are correctly performed.

- *Communication during a flood event:* Flood warning will focus on reporting people about the impending hazard from warning systems. A proper warning system will decrease significantly loss of life in catastrophic events as these systems are crucial to initiate and develop the evacuation process, combined with a correct public education.

1.3.4 Mobilization

Mobilization procedures are measures that involve direct work of task forces and emergency services to reduce flood consequences, like evacuation processes. These procedures can be classified in three different categories depending on the time available for the evacuation (*Jonkman 2007*):

- *Preventive evacuation:* Evacuation before occurrence of the event. As an example, preventive evacuation of a flooding area before dike breach.
- *Forced evacuation:* Evacuation during event development towards an area where people are not exposed to physical effects.
- *Escape:* Movement of people through an exposed area, being affected by water physical effects related to the impending flood (i.e. reduction of walking speed or sustained injury).

1.3.5 Coordination and operating practices

Coordination practices rely on improving communication between different organizations and stakeholders with an important role in flood risk management. These measures are classified in two groups.

- *Procedures for general coordination:* The first objective of these measures is the definition of the procedures during an emergency event and the role of each task force and administration. The second objective is to enable the coordination between administrations to make decisions for flood risk reduction and to avoid contradictory measures of different organisms.
- *Procedures for coordination during flood events:* Coordination measures during a severe event will reach an effective communication between agents, the correct behaviour of warning systems and evacuation procedures. It includes coordination between weather forecasting, flood characterization, warning and evacuation.

1.3.6 **Insurance and aids mechanisms**

The existence of appropriate schemes of insurance and aids is necessary for post-flood recovery. On one hand, insurances involve the distribution of risks and losses over a high number of people and they will reduce flood indirect consequences. On the other hand, aids will compensate losses not covered by insurances and are based on voluntary solidarity contribution, national assistance, and international help.

1.3.7 **Non-structural measures and flood risk**

Non-structural measures are efficient and sustainable methods of reducing flood risk, but there will be some residual flood risk, whose value depends on the reliability and functionality of these measures:

- Functionality defines the maximum reduction on consequences due to their limitations. In some cases, warning systems or evacuation procedures do not achieve to move all people at risk.
- Reliability defines the possibility of a failure on its structure or procedures. For example, there might be an error in the warning system or a failure in flood pre-characterization models.

1.4 TOOLS FOR RISK ESTIMATION

Risk is commonly expressed by the notation Risk = Hazards x Vulnerability. Tools for flood risk estimation can be divided in partial, if they only evaluate either hazard or vulnerability, or complete, if they evaluate both components. Additionally, they can be classified depending on whether they provide or not a numerical value for the risk (quantitative or qualitative).

Consequently, tools for risk estimation can be classified in four categories:

- *Partial and qualitative:* based on the knowledge of the reality and historical flood events (i.e. tools for estimating environmental and cultural losses – *ACA 2009*).
- *Complete and qualitative:* these methods estimate both risk components by combining qualitative methods to obtain flood components separately (i.e. risk maps).
- *Partial and quantitative*: these tools compute numerically one of the risk components: probability of occurrence (i.e. flood hazard maps) or consequences. Tools which compute only flood consequences may be useful to make a first approximation to the consequences of a severe flood. However, more sophisticated methodologies include shelter, warning and evacuation procedures, such as the LIFESim model (*ANCOLD 2003*).
- *Complete and quantitative:* these tools obtain a numerical value of both risk components. F-N curves are an example of these tools. These curves represent the relation between the probability of occurrence of a hazard and the number of victims.

Examples of each category are described in Escuder et al. 2010 (Full SUFRI Methodology report, Attachment 1).

The SUFRI Methodology for pluvial and river flooding risk assessment in urban areas to inform decision-making is a complete and quantitative tool for flood risk estimation. It provides a numerical value of both components of risk: hazard and vulnerability.

Chapter 2 includes a summary of the SUFRI methodology which is further described in the report developed within the SUFRI project in the year 2010 (Attachment 1).

2 SUFRI METHODOLOGY FOR PLUVIAL AND RIVER FLOODING RISK ASSESSMENT IN URBAN AREAS TO INFORM DECISION-MAKING

The purpose of this chapter is to summarize the developed SUFRI Methodology for pluvial and river flooding risk assessment in urban areas to inform decision-making. The full methodology is available in Attachment 1.

2.1.1 **OVERVIEW**

As it was described in sections 1.1 to 1.4, risk is divided into two components: probability (hazard) and consequences (vulnerability).

The SUFRI methodology describes how to estimate probabilities and potential consequences of flood events.

In this point, some key concepts and definitions are listed below:

- Case study. City or group of population, taking into account the total area or a particular zone. It should include all areas with potential flood damage in case of flooding. In general, the whole urban site is considered.
- Flood scenarios. Flood events that are considered to estimate potential consequences as input data for the risk model.
- Structural measure. Flood defence system or infrastructure that acts on flood mechanisms and propagation, modifying their characteristics.
- Non-structural measure. Flood management system or policy that modifies the vulnerability of an area or population in case of flooding.
- Base-case. It represents the current situation of the case study, including current structural and non-structural defences. The analysis of the Base-case provides flood risk results for the urban area in the present moment.
- Study scenario. For a defined urban area, study scenarios are determined by the number of non-structural measures or alternatives that are considered to compare the effect of non-structural measures with the current situation of the case study.

Thus, the analysis of a urban area will include different study scenarios which can be compared to evaluate the effect of non-structural measures on flood risk reduction (Figure 2.1).

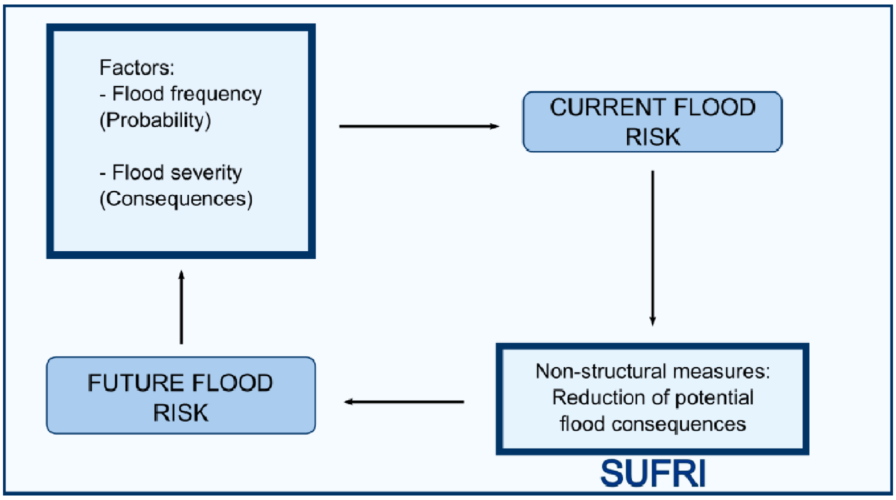


Figure 2.1: Scheme of interaction between flood risk and non-structural measures (SUFRI methodology, Attachment 1).

Different methods found in the literature have been compared and analysed to estimate consequences in case of river and pluvial flooding. References regarding estimationo of loss of life and economic losses for both analyses are described in Attachment 1 (1.5.2). Some examples are *Graham 1999, Jonkman 2007, Reiter 2001, Témez 1991 and Gómez & Russo 2009.*

The methodology also includes the state-of-the-art of risk analysis on dam and levee safety and its application to flood risk in urban areas.

2.1.2 **Basis: Flood risk evaluation from F-N and F-D curves**

In the SUFRI methodology for pluvial and river flooding risk assessment in urban areas to inform decision-making, risk quantification is based on two aspects:

- The use of risk models to enable risk calculations
- The use of F-N and F-D curves to represent risk results for the case study

Therefore, risk quantification is developed by using a software based on influence diagrams and representation is performed by F-N (or F-D) curves.

The situation of a certain urban area can be represented by a risk model which contains, in a simplified scheme, the information required to compute all possible flood event and related consequences. Several case scenarios can be analysed such as the current situation, a scenario with non-structural measures, the construction of a new flood defence infrastructure, etc.

From results of the risk model, different F-N and F-D curves can be developed for the case study, as the profile shown in Figure 2.2 for societal risk of an hypothetic case.

The F-N curve presents values in both axes (cumulative annual exceedance probability and estimated loss of life) and the area under this curve is the total societal risk. If economical consequences are represented, these curves are called F-D curves.

Figure 2.2 shows the profile of an hypothetic case study when analysing three different study scenarios: first, the situation without any measures (red line); next, the situation with only structural measures (green line), and, finally, the situation with structural and non-structural measures for flood risk reduction (blue line). Thus, three different curves are depicted.

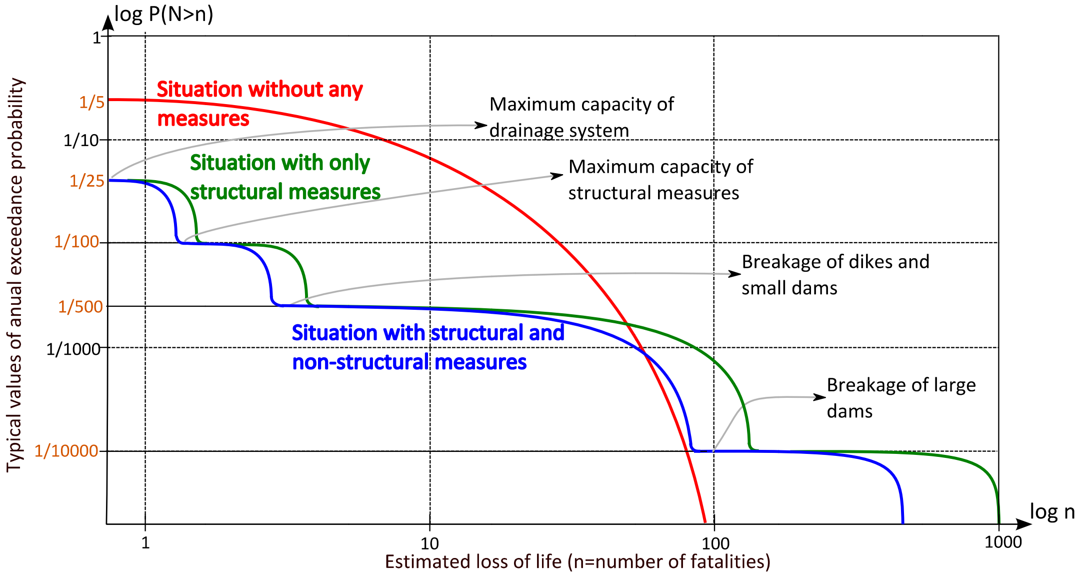


Figure 2.2: Effect of structural and non-structural measures in F-N curves.

Depending on what kind of structural measure is considered, the effect on the F-N curve will be focused on a decrease on the annual probability of exceedance (i.e. drainage systems) or even an increase on the estimated consequences (i.e. breakage of a large dam or levee). Moreover, the F-N curve illustrates as the introduction of non-structural measures may have a high importance in flood consequences reduction, especially in the number of fatalities. This reduction has more significance in cases of high consequences (i.e. large dams or levees). The equivalent graph in terms of economic losses is shown in Figure 2.3. These curves are denoted as F-D curves.

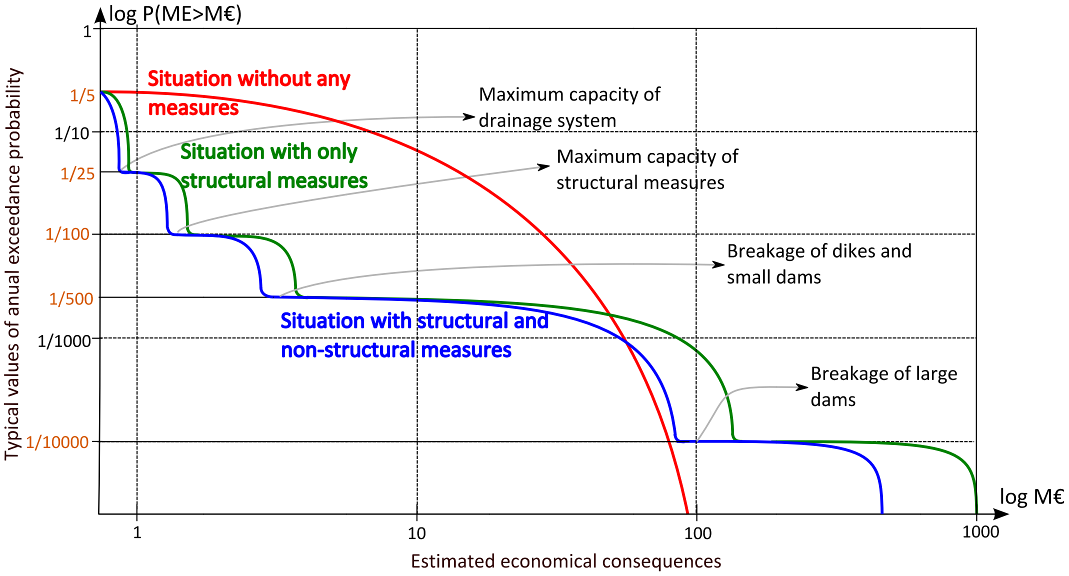


Figure 2.3: Effect of structural and non-structural measures in F-D curves.

The previous figures show the relation between the probability of occurrence of a flood and its consequences (loss of life or economic losses).

If the aforementioned study scenarios are now represented separately, the study of the current situation on flood risk of the case study and its comparison with the situation without any measures (i.e. natural flow regime of the river) enables to analyse the isolated effect of the structural measures, as it is shown in Figure 2.4.

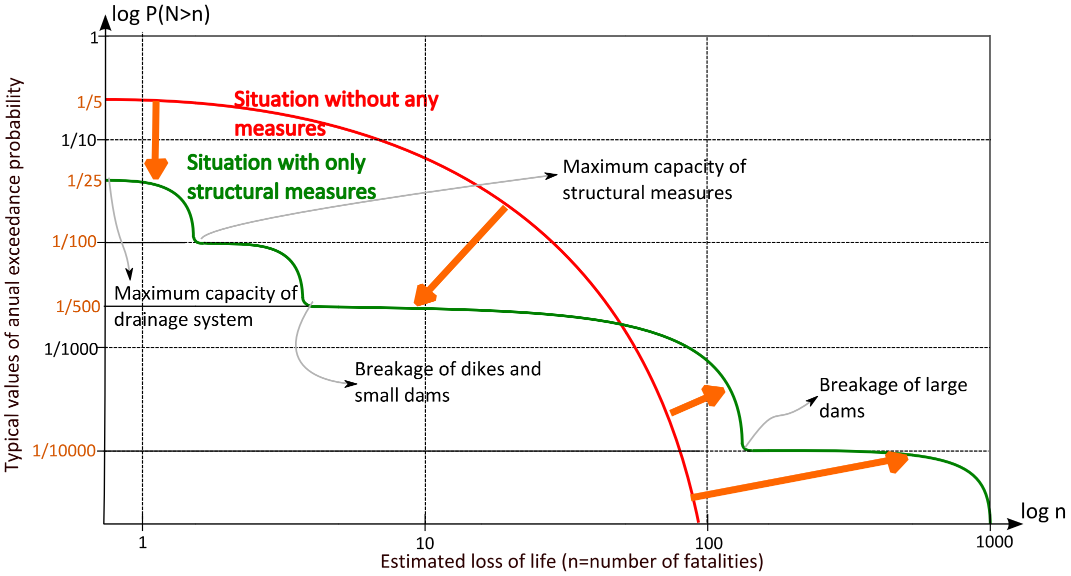


Figure 2.4: Effect of structural measures on the F-N curve for societal flood risk.

This graph shows the effect of several structures, like drainage system, dikes, small dams or large dams on flood risk. Depending on what kind of structural measure is considered, the effect on the F-N curve will be focus on a decrease on the annual probability of exceedance (i.e. drainage systems) or even an increase on the estimated consequences (i.e. breakage of a large dam or levee).

Also, it is possible to analyse the effect of non-structural measures from the representation of the F-N or F-D curves for the situation with and without non-structural measures. Figure 2.5 depicts the reduction on flood consequences that can be achieved by implementing non-structural measures.

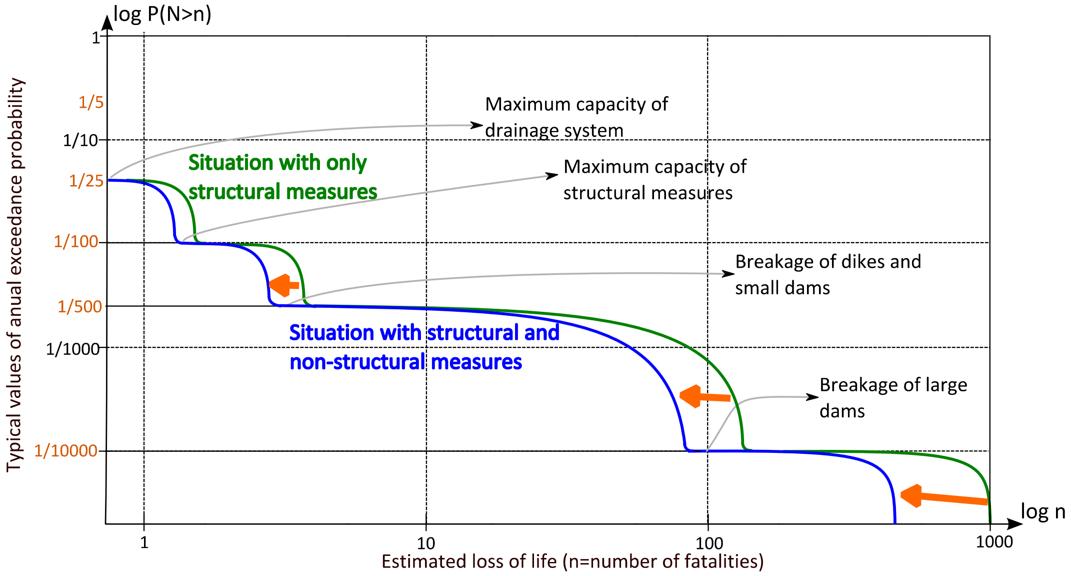


Figure 2.5: Effect of non-structural measures on the F-N curve for societal flood risk.

This F-N curve illustrates as the introduction of non-structural measures may have a high importance in flood consequences reduction, especially in the number of fatalities. This reduction has more significance in cases of high consequences (i.e. large dams or levees).

The previous curves have been used to illustrate how SUFRI methodology can be used for risk quantification and evaluation, by developing F-N and F-D curves that provide a tool for analysing how structural and non-structural measures can reduce flood risk.

The SUFRI methodology can be applied for analysing any source of flood hazard, but it has been developed in detail for river and pluvial flooding. Both sources are analysed separately due to differences on the hydraulic characteristics of the flood events and criteria established to estimate flood consequences in terms of potential life-loss.

The overall scheme proposed by the SUFRI methodology to assess flood risk is presented in next section.

2.1.3 Phases of the methodology

Ten different phases are distinguished in the SUFRI methodology. Figure 2.6 shows the overall scheme of the proposed process for flood risk quantification and assessment. These phases are described in detail in Attachment 1. A short description of each stage is presented below.

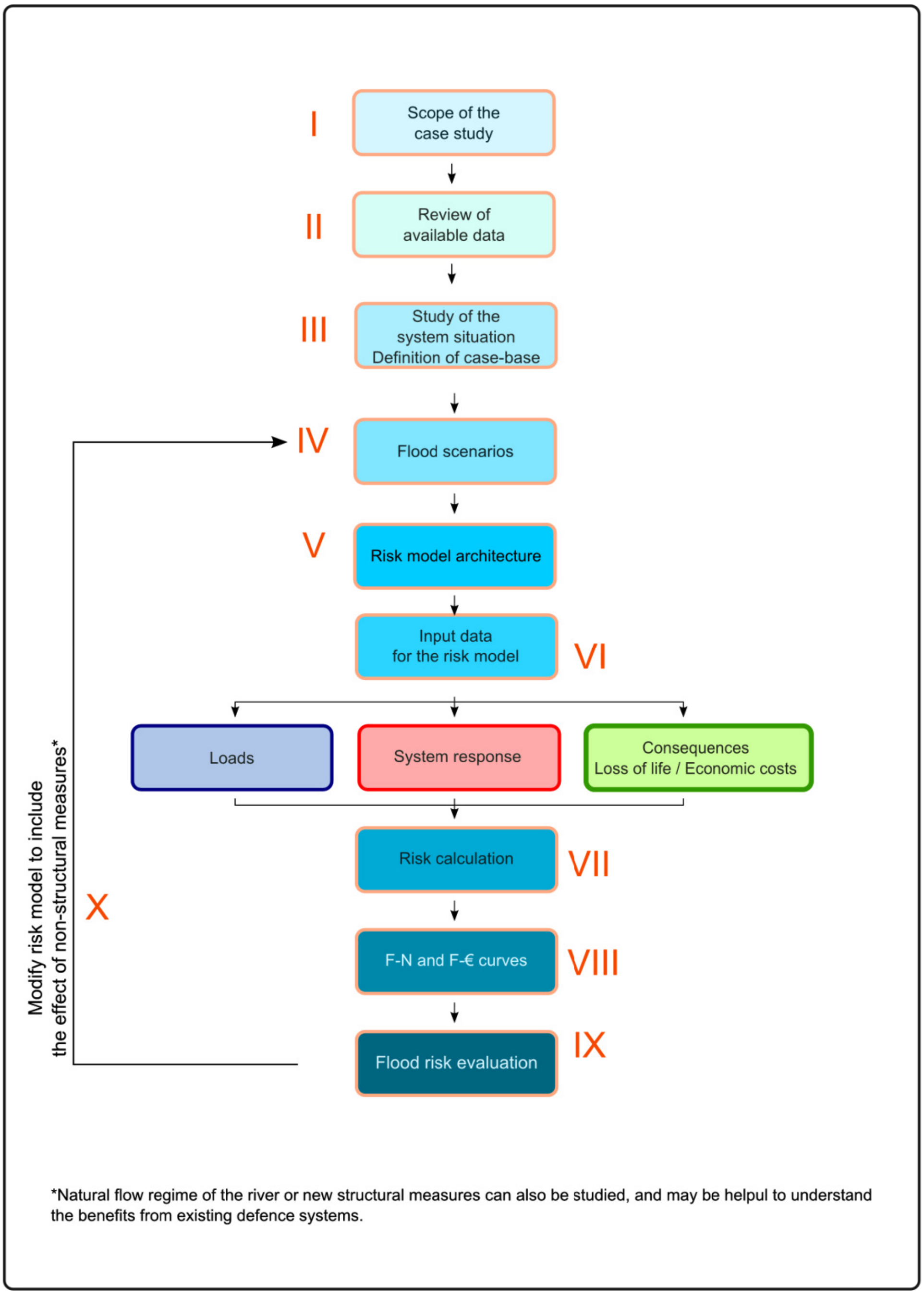


Figure 2.6: Phases of the SUFRI methodology for flood risk assessment.

- *Phase I. Scope of the case study*

The scope of the study should be established, together with the required level of detail, as it determines data and time requirements to perform the risk model and calculations. The level of detail is related to the study area, available data, necessary resources for the study and management (Table 2.1).

Scale	Study area	Management levels	Level of detail	Level of resources	Data requirements
Macro- scale	National	Flood reduction policies	Low	Low	Low
Meso-scale	Regional	Large-scale strategies for flood reduction	Medium	Medium	Medium
Micro-scale	Local	Individual protection measures	High	High	High

Table 2.1: Level of detail of the study.

- *Phase II. Review of available data*

The level of uncertainty in estimating potential damages for the risk model will depend on available data (data collection, site visits, etc.). An analysis of information should consider seasonal and daily variations on population, value of assets, land use distribution, etc.

- *Phase III. Study of the current situation. Definition of the Base-case*

Before analysing non-structural measures, it is necessary to study the current situation of the urban area. This study scenario is called Base-case. The risk model of the Base-case should include the potential failure of all existent infrastructures or measures (levees, dikes, embankments, dams, drainage system, etc.). The Base-case will be used to compare the current situation with other study scenarios in Phase X.

- *Phase IV. Flood scenarios*

Definition of flood scenarios is required to determine the range of possible flood events and evaluate potential damages. A flood scenario can be identified by a return period, a combination of loads that determine the failure scenario, the result of flood routing, etc. The risk model will relate probabilities of each flood event to potential consequences.

- *Phase V. Risk model architecture*

The risk model is performed by an influence diagram which represents the event tree that allows the analysis of the case study. The influence diagram includes nodes (which contain information on flood scenarios, potential consequences, etc.) and connectors (which relate different nodes of the model). In general, three parts of the influence diagram can be distinguished:

- Loads: these nodes include information on load scenarios (for example, for a dam upstream the urban area, it includes data of previous water pool levels, gate functionality, flood routing, etc.).
- System response: these nodes give information on probabilities of the potential failure modes of flood defence systems based on the previous load scenarios.
- Consequences: nodes that include all necessary information to characterize flood vulnerability (loss of life and economic losses for each flood scenario).

- *Phase VI. Input data for the risk model*

First, information from hydrological studies or modelling of the catchment area provides necessary data to establish load scenarios for the risk model. Second, analysis of system response includes the consideration of all potential failure modes, conditional probabilities and hydraulic characteristics of failure and non-failure cases of the flood defence system (dam, levee, drainage system, etc.). Finally, the estimated values of life-loss and economic damage are used as input data to calculate societal and economic risk.

The SUFRI methodology includes guidance to obtain all necessary input data. However, estimation of potential consequences is widely explained.

On one hand, life-loss is estimated following different methods for river and pluvial flooding:

- In river flooding, a classification is provided based on fatality rates found in several sources in the literature (*Graham 1999*). Ten categories (C1 to C10) are established, depending on the existence of public education on flood risk, warning and communication systems, and, coordination between emergency agencies and authorities. Reference fatality rates are defined for each category. Table 2.2 shows the ten categories which have been defined in the methodology. The number of potential fatalities is obtained by multiplying population at risk times the fatality rate for each flood scenario. Fatality rates depend also on the available warning time and flood severity (Table 2.3).

Category	*Description*
C1	- There is no public education on flood risk terms. - No warning systems, no EAP. - There is no coordination between emergency agencies and authorities. - No communication mechanisms to the public.
C2	- There is no public education on flood risk terms. - There is no EAP, but there are other warning systems. - There is no coordination between emergency agencies and authorities. - No communication mechanisms to the public.
C3	- There is no public education on flood risk terms. - There is EAP, but it has not been applied yet. - Some coordination between emergency agencies and authorities (but protocols are not established). - No communication mechanisms to the public.
C4	- There is no public education on flood risk terms. - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - No communication mechanisms to the public.
C5	- There is no public education on flood risk terms. - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public (not checked yet).
C6	- There is no public education on flood risk terms. - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.
C7	- Public education. - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public. (C7 is used for categories 'C8', 'C9' and 'C10' if the analysis of a flood defence failure with no hydrologic scenario is considered)
C8	- Public education - EAP is already applied. It has been proved or used previously. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.
C9	-Public education. - EAP is already applied. It has been proved or used previously. - High coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.
C10	- Regular activities and plans for public education. - EAP is already applied. It has been proved or used previously. - High coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.

**EAP: Emergency Action Plan*

Table 2.2: Fatality rates in river flooding

Flood severity level	DV parameter	
Low severity	DV < 4.6 m^2/s ; Water depth (H) < 3.3 m	$DV = \frac{Q_f - Q_{2.33}}{w_{df}}$
Medium severity	DV > 4.6 m^2/s ; Water depth (H) > 3.3 m	
High severity	Urban areas close to a large dam or flood defence infrastructure.	

*Q_f: *Maximum flow discharge for a flood scenario*

**$Q_{2.33}$: *Mean annual river flow discharge*

***w_{df}: *maximum width of the cross section*

Table 2.3: Flood severity levels in river flooding.

Figure 2.7 shows an overall scheme which includes all described parameters to estimate input data in terms of loss of life in river flooding. In this figure, the main parameters are included: flood scenarios (identified by Q, flow discharge), land use categories (CU), density values (d), flooded areas (A_f), velocity and water depth (v, H), population at risk (PR), flood severity (Sv), fatality rates (FR) and warning times (TW). Finally, the combination of these values results in the number of potential fatalities for each flood scenario (N). Values related to load scenarios are depicted in blue, system response in red and potential consequences in light green. Further description of these parameters can be found in Attachment 1.

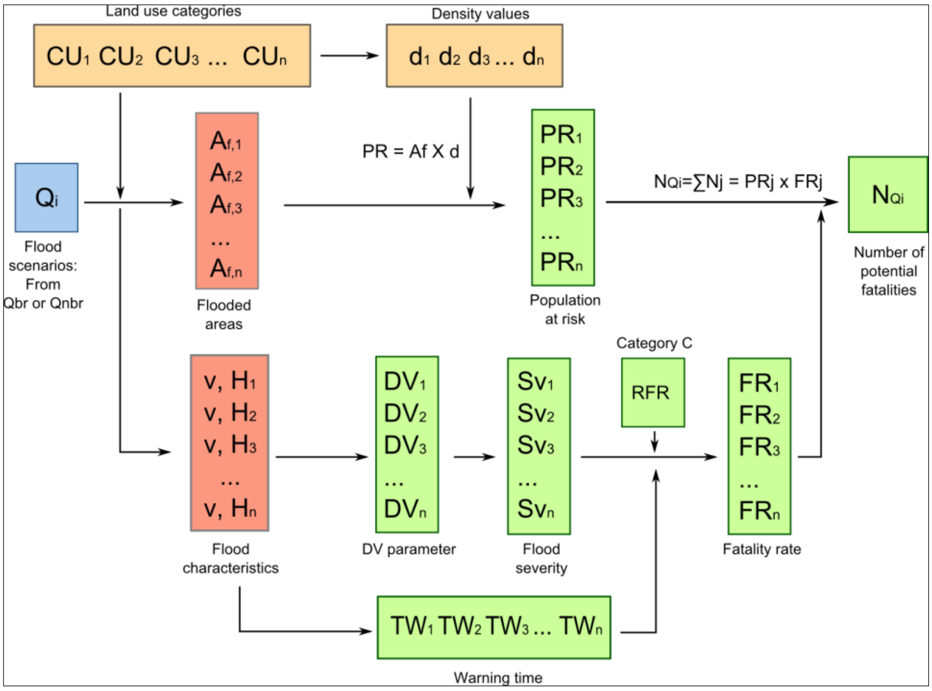


Figure 2.7: Sequence for obtaining input data for consequences in river flooding.

○ In pluvial flooding, loss of life is estimated using a classification of flood severity levels and fatality rates based on previous studies (Gómez & Russo 2009, *Penning-Rowsell et al. 2005*) and combining hydraulic parameters such as flood depth (y), velocity (v), dragging and sliding parameters (v·y and v²·y). Figure 2.8 gives five flood severity levels (S0-S4) based on the previous hydraulic terms.

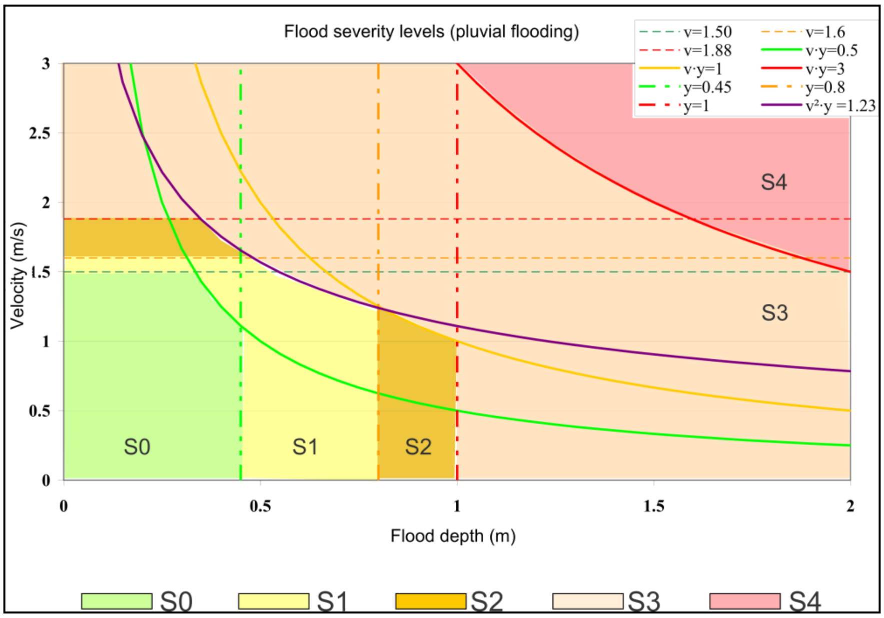


Figure 2.8: Flood severity levels in pluvial flooding.

As an example, fatality rates and the overall scheme for estimating potential loss of life in case of pluvial flooding are also included in this section.

Category C_p	*Flood severity* *S*	*Fatality rate,* FR_p *(Proposed value)*	*Range of values for* FR_p *(Minimum and maximum values)*	
C_{p1}	S0	0.0003	0	0.0009
	S1	0.0021	0.001	0.003
	S2	0.0038	0.0015	0.0045
	S3	0.0105	0.006	0.04
	S4	0.0448	0.01	0.11
C_{p2}	S0	0.0003	0	0.0008
	S1	0.0018	0.0012	0.0024
	S2	0.0033	0.0014	0.0037
	S3	0.009	0.005	0.035
	S4	0.0384	0.01	0.095
C_{p3}	S0	0.0002	0	0.00065
	S1	0.0015	0.001	0.002
	S2	0.0027	0.001	0.003
	S3	0.0075	0.004	0.028
	S4	0.032	0.009	0.08

Table 2.4: Fatality rates in pluvial flooding.

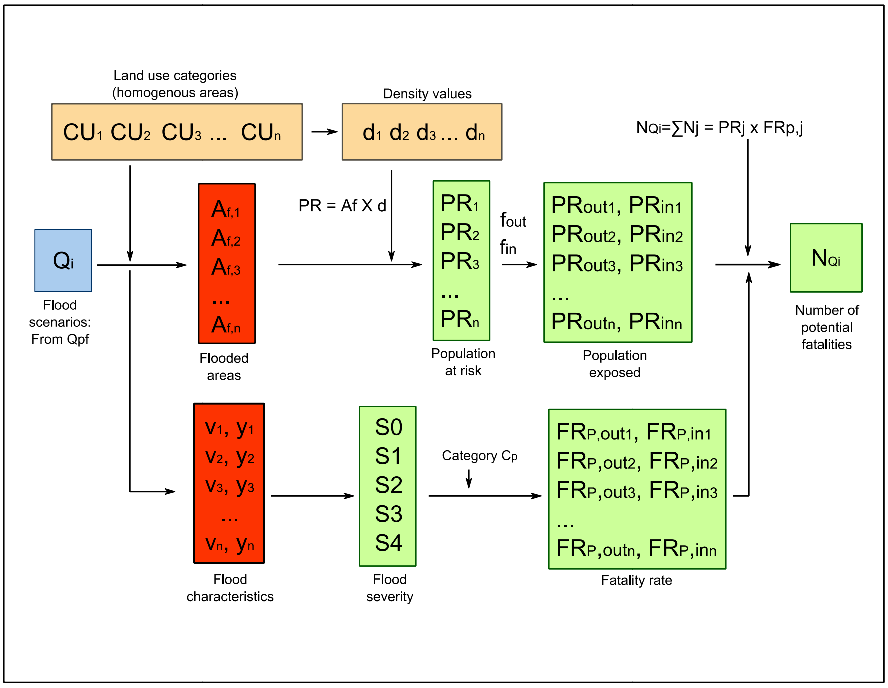


Figure 2.9: Sequence for obtaining input data for consequences in pluvial flooding.

In pluvial flooding analyses, the level of detail will depend on the available data to estimate hydraulic characteristics of the flood such as topographic data, hydraulic models, drainage system maps, etc.

Level		*Available data*	*Identification of areas*
Low	No topographic data, models or information of the drainage system.	Identification of maximum flood depths. Number of fatalities in previous floods.	The urban area is considered as a unique zone. A_T and P_T
Medium	Topographic data (elevation maps). Geometry of streets (slopes, width and cross-section).	Classification of homogenous zones: - Flood depth and velocity for each zone.	Homogenous zones: A_i → with similar characteristics of the flood scenario. A_i and P_i
High	Detailed maps of the urban area. 1D or 2D models (interaction between drainage and surface system).	Results or maps in each point of the urban area. Distribution of velocity and flood depth.	Flood depth and velocity maps.

Table 2.5: Level of detail of the study in pluvial flooding depending on the available data.

On the other hand, economic losses are obtained by identifying homogenous areas, value of assets, defining reference costs, estimating percentages of damage based on water depths in each area and flood scenario, etc.

Direct costs are estimated by multiplying reference costs, affected areas and percentage of damages. Indirect costs can be obtained as a fraction of direct costs and it may vary depending on the role of the urban area in a regional or national scale. Attachment 1 includes depth-damage curves and reference value of assets to obtain potential economic losses.

- *Phase VII. Risk calculation*

The risk model combines all established combinations of probability and consequences to provide values of societal and economic risk. Then, lists of annual probability of exceedance for each value of consequences (loss of life or economic losses) are obtained.

- *Phase VIII. F-N curves*

Risk results can be represented in F-N and F-D curves as it was described in section 2.2. Having obtained the F-N and F-D curve for the Base-case, the risk profile can be easily analysed using this tool for representing flood risk.

- *Phase IX. Flood risk evaluation*

If tolerability criteria are available in the literature and can be applied to the case study, societal and economic risk results may be compared with standards to evaluate the existent flood risk.

- *Phase X. Study of non-structural measures*

The last phase of the methodology relies on the analysis of different non-structural measures as an alternative to reduce flood risk at the urban area.

Each considered non-structural measure (or a set of measures) modifies the vulnerability of the urban area in case of a potential flood. The characteristics of each flood scenario do not vary, but potential consequences are modified by the application of non-structural measures. Thus, the risk model of the Base-case is the basic scheme for each new alternative. However, it is necessary to study all possible variations from the Base-case, obtaining new input data, risk calculations and results on flood risk for the new situation with non-structural measures.

Finally, results for these new study scenarios with non-structural measures can be also represented along with the risk profile of the Base-case with the aim of comparing different situations and hypothesis of new actions in the urban area.

Attachment 1 (1.5.3.5) includes guidance on how to incorporate the existence of non-structural measures into the analyses to estimate input data for the risk model.

In summary, Table 2.5 lists the most frequent data requirements to obtain information and estimate input data for the risk model.

Phase	Description	Data requirements
I	Scope of the case study	Extent and relevance of the urban area. Time and resources for the study.
II	Review of available data	LAND USES Land use maps and cadastral maps. Topography. Statistics (demography, urbanism, economy, etc.). Building typology. PAST FLOOD EVENTS Flooded areas, damages, etc. HYDROLOGY Rainfall rates, catchment area, river characteristics, etc.
III	Study of the current situation. Definition of the base-case	Existing infrastructures (levees, dams, ponds, detentions basin, embankments, etc.).
IV	Flood scenarios	Return periods. Peak discharge rates.
V	Risk model architecture	Loads / System Response / Consequences. Nodes that represent all potential failure modes and combinations.
VI	Input data for the risk model	LOADS Hydrology data. Flood routing, gate functionality, previous water pool levels, etc. SYSTEM RESPONSE Hydraulic characteristics of each flood (from modelling, studies or other data) Flooded areas, depths, velocities, time of occurrence, flow rates, width, etc. Failure modes and conditional probabilities. CONSEQUENCES Loss of life / Economic losses.
VII	Risk calculation	Risk model results
VIII	F-N curves	From lists provided by the risk model. Annual probability of exceedance of each level of potential consequences.
IX	Risk evaluation	Comparison with tolerability criteria.
X	Study of the effect of non-structural measures	Review of the previous phases to perform a new case with non-structural measures. Estimations on the effect of the non-structural measures to include variations on the base-case, obtaining new F-N curves.

Table 2.6: Summary of input data.

3 APPLIED FIELDS

3.1 Case study: Benaguasil (Spain)

In this section the analysis of flood risk in case of pluvial flooding for the case study of Benaguasil is described. This analysis is part of WP3 of the SUFRI project: residual risk and vulnerability analysis, following the guidelines given in the methodology described in chapter 2. The different phases of the SUFRI methodology (described in the previous chapter) are applied for risk calculation and evaluation.

Two case scenarios have been studied: the current situation of the urban area and the situation after implementing non-structural measures of public education and warning. The description of the two study scenarios and input data for the risk model are present herein.

The description of this case study is divided into five subsections: First, an introduction includes information on location and characteristics of Benaguasil. Second, a summary of all information used for calculation is described. Next, the description of the two study scenarios and input data for the risk model is provided. Then, the risk model architecture is shown, and, finally, risk results along with F-N and F-D curves for this case study are compared and discussed.

3.1.1 Introduction: Location and characteristics of Benaguasil

Benaguasil is located in the east of Spain, 20 km inland from the city of Valencia (Figure 3.1).

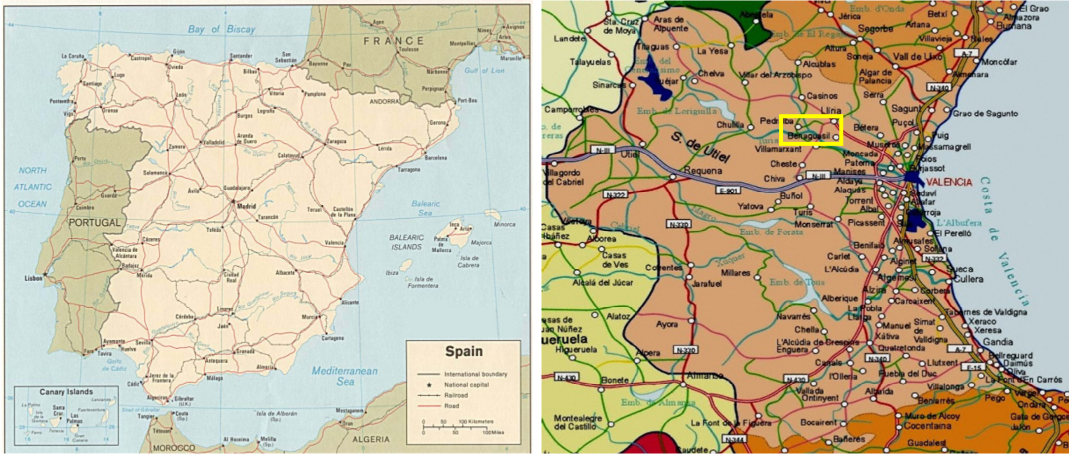


Figure 3.1: a) Map of Spain. B) Map of the Valencian Region.

Benaguasil is placed in the catchment area of the Túria River. However, Benaguasil is not affected by river floods as it is located far from the river bed (see Figure 3.2).

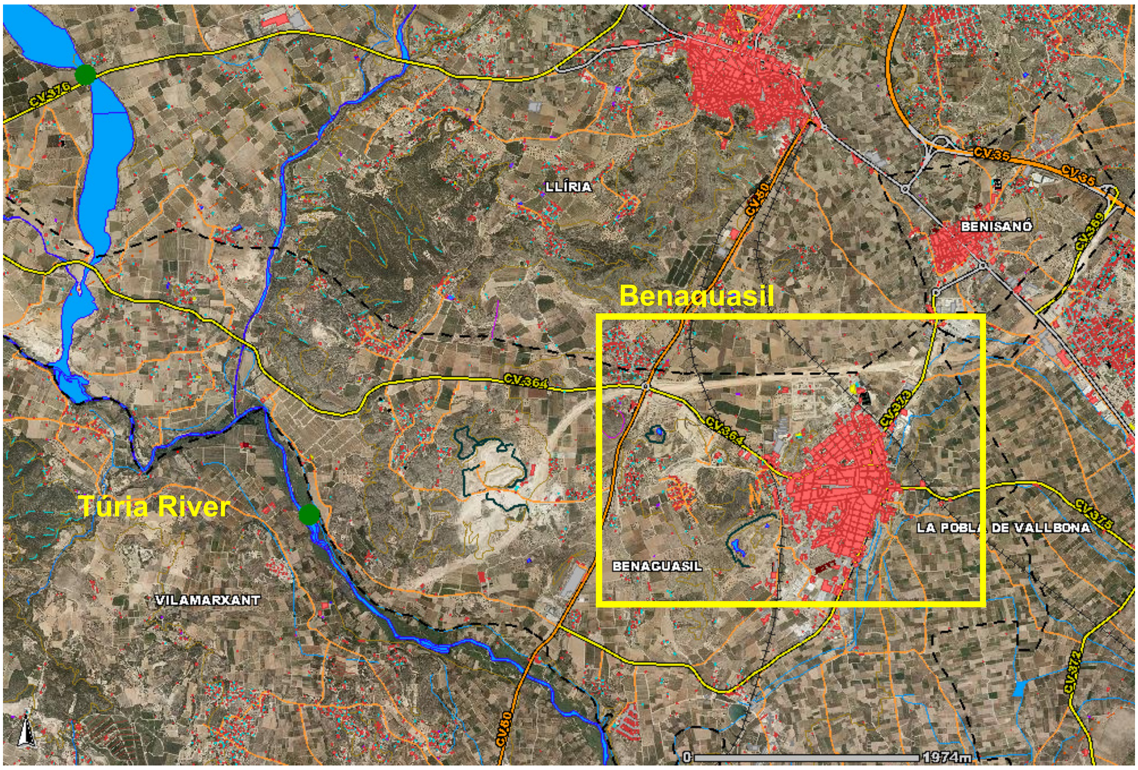


Figure 3.2: Location of Benaguasil.

Flood risk in Benaguasil is mainly due to pluvial flooding. The main cause of the development of flood events and flood propagation in Benaguasil is the incapacity of the drainage system. When heavy storms take place with precipitation rates higher than 20 mm in a few minutes, the drainage system reaches its maximum capacity and runoff flows along several streets reaching high water levels, flooding garages, ground floors, houses and roads.

The inability of the drainage system is the most important problem with regard to structural measures to reduce the flood risk of this town. It produces flooding of basements and ground floors of many houses every year and, consequently, important economical damages. Furthermore, new impermeable areas have been connected directly to the drainage system, without taking into account its problems. Consequently, flooding problems have increased in the last years.

3.1.2 Information

In this section, tasks carried out in phases I (Scope of the study) and II (Review of available data) are summarised.

The scope of this analysis is focused on the study of the current situation of Benaguasil in case of pluvial flooding and the effect of non-structural measures regarding a public education program on flood risk and the existence of a warning system.

Data related to demography, building typologies, land uses, drainage system, hydrological studies, economic rates, etc. has been collected to characterize the urban area and obtain input data for the risk model that will be used to calculate flood risk in the two established study scenarios.

This section describes the main characteristics of this case study. Further information is included and listed within the description of each study scenario.

- *Demography*

Population in Benaguasil is estimated in 11,144 inhabitants (2010), with a distribution of 5,739 men and 5,405 women. Data of daily and seasonal variability of population in Benaguasil shows that the number of inhabitants increases around 2,500 people in summer, and 2,000 people leave the urban area during the day and move to the agricultural zone due to working reasons. Consequently, four time categories are set as it is listed in Table 3.1.

Time category ID	Category	Density (inhabitants/km²)
TC1	Summer / day	10,457
TC2	Summer / night	12,253
TC3	Winter / day	8,212
TC4	Winter / day	10,008

Table 3.1: Time categories.

Each time category is related to a number of people at the urban area. These values are shown in Table 3.2.

Time category ID	Category	Population (inhabitants)
TC1	Summer / day	11,644
TC2	Summer / night	13,644
TC3	Winter / day	9,144
TC4	Winter / day	11,144

Table 3.2: Population at the study site.

- *Building typology*

Benaguasil is mainly composed of one-family houses and multifamily buildings of concrete ranging from 2 to 4 floors. Building height is quite constant in the entire city. As there is no detailed information about the construction materials of each building, the following mean values are used:

-Average number of floors per building:	1.8 floors/building
-Average building height:	1.8 x 3.5 = 6.3 m (height of one floor = 3.5 m)
-Average number of households per building:	1.5 households/building

Table 3.3 shows the total number of households, buildings and business in Benaguasil.

Building typology - Benaguasil	
Average number of floors	1.8
Number of buildings	3,014
Number of households	4,529
Number of business	415

Table 3.3: Households in Benaguasil.

- *Land uses and economic rates*

The total surface of the urban area of Benaguasil is 2.8 km², with a density of 433.57 habitants/km². The whole area which belongs to the municipality of Benaguasil reaches a surface of 25.4 km².

Benaguasil is mainly distributed in residential zones with households and local businesses. Also, there are two main industrial areas, one located at the South and one at the North-East of the town (Figure 3.3). The rest of the municipal area is divided into small agricultural plots.

Direct costs have been estimated based on reference costs, CR, for each land use category, given by the following equation and economic rates in *PATRICOVA (COPUT 2002)* for five different land uses categories (CU), where:

$$CR = \{Rate\} \cdot \{82\ €/m^2\} \cdot \{IPC\ variation\ (2011/2002)\} \tag{3.1}$$

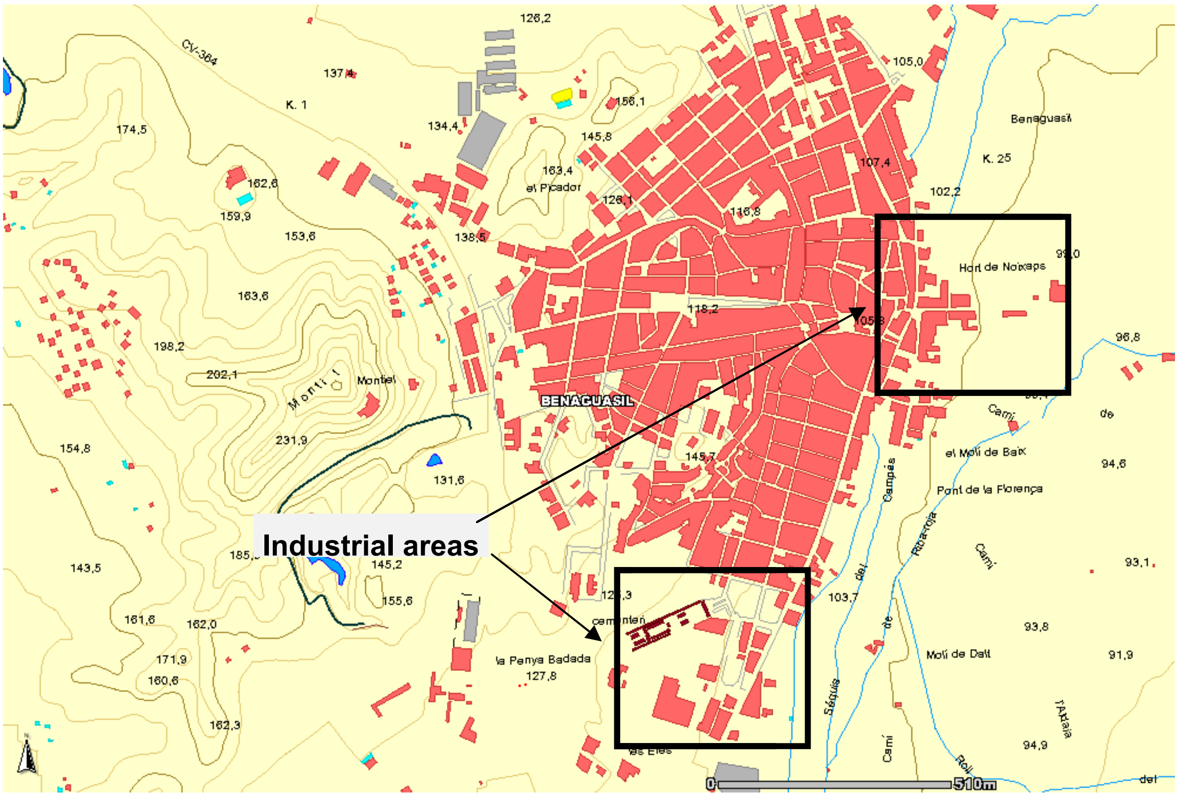


Figure 3.3: Industrial areas in Benaguasil.

- CU1: Residential (Medium density – High magnitude: Rate=56.3/100)
- CU2: Industrial (Medium density – High magnitude: Rate=16.9/100)
- CU3: Residential, without households. It is assumed that the economic value of this type of area is equivalent to a percentage of 5% based on the value of high density residential areas (CU1).
- CU4: Green areas and agricultural uses (Irrigated crops: Rate=0.34/100)
- CU5: Others

The reference cost for each land use category is listed in Table 3.4.

Land use category	Type	ID	Total Area (m²)	Reference cost (€/m²)
CU1	Residential	CR1	1,113,538	55.5
CU2	Industrial	CR2	84,906	16.7
CU3	Urban area	CR3	91,625	2.78
CU4	Green area	CR4	154,407	0.3
CU5	Other	CR5	423,646	0.3

Table 3.4: Land uses and reference costs.

- *Hydrology*

The series of flood scenarios ranges from 2 to 100 years. Seven flood scenarios are defined (2, 5, 10, 15, 25, 50 and 100 years). The maximum daily rainfall rates were obtained for each return period. Table 3.1.5 lists the annual probability of exceedance of each flood scenario and the related maximum daily rainfall rate. These rates are coherent if values are compared with results established by CEDEX (Spanish Public Institution for Experimental Research) as it is shown in Figure 3.4.

Flood scenario	Return period (years)	AEP (1/years)	P_d (mm)
T1	2	0.5	53
T2	5	0.2	79
T3	10	0.1	98
T4	15	0.067	110
T5	25	0.04	125
T6	50	0.02	146
T7	100	0.01	170

Table 3.5: Maximum daily rainfall rates.

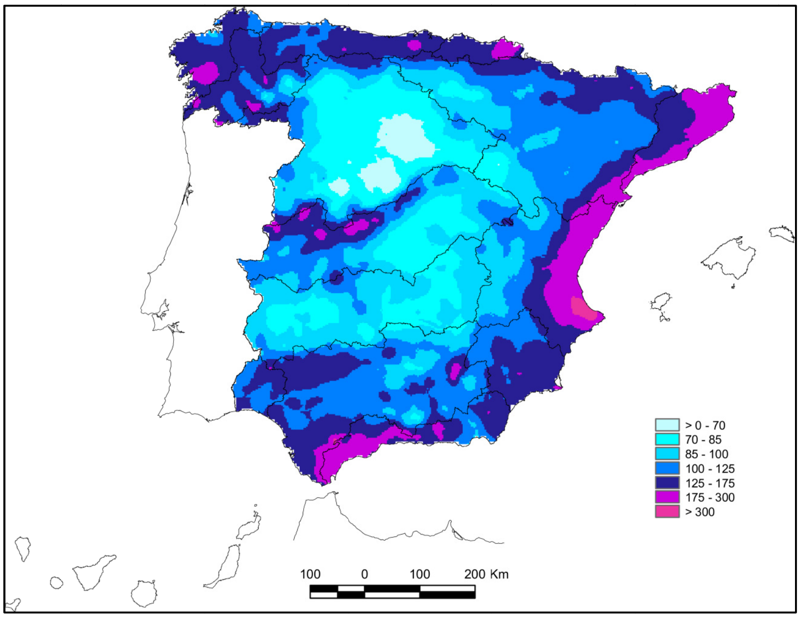


Figure 3.4: Map. Maximum daily rainfall rates in Spain for a return period of 100 years (CEDEX).

The urban area of Benaguasil is divided into six catchments areas (from BNG1 to BNG6). As an example, Figure 3.5 shows the location of all catchment areas.

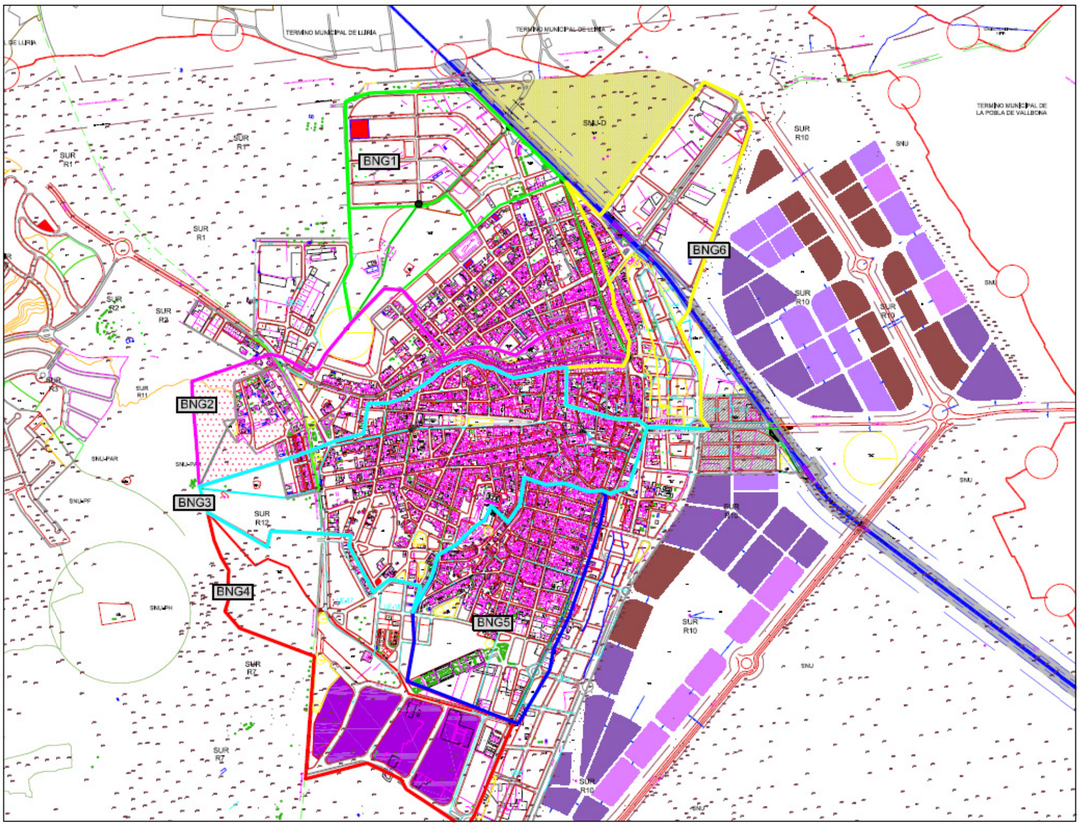


Figure 3.5: Map: Urban catchments.

However, eight different sub-areas are defined for calculations. These areas are denoted by BNG1, BNG2, BNG126, BNG3, BNG4, BNG45, BNG345 and BNG0. In four cases, the defined area is equivalent to a catchment area (and it is denoted by a number, for example, BNG1). Four of these areas are the resulting zones downstream the intersection of two or more catchments areas (for example, BNG126 corresponds with the zone located downstream three catchment areas: 1, 2 and 6).

Each sub-area is divided into three categories and denoted by three suffixes: first, suffix A denotes areas which are located outside the city centre or rural areas (i.e. 1A is the rural area within BNG1); second, B1 denotes low density residential areas and B2 belongs to high density residential areas. These categories have been used for estimating different runoff coefficients.

Additionally, two zones are identified for each sub-area, Af and Af1, which represent a preliminary perimeter of the potential flooded areas in two cases: floods with water depths lower or higher than 0.15 m, respectively. These perimeters have been used to estimate affected areas (see section 3.1.3 for further detail).

Figure 3.6 shows a simplified scheme of the defined sub-areas in Benaguasil.

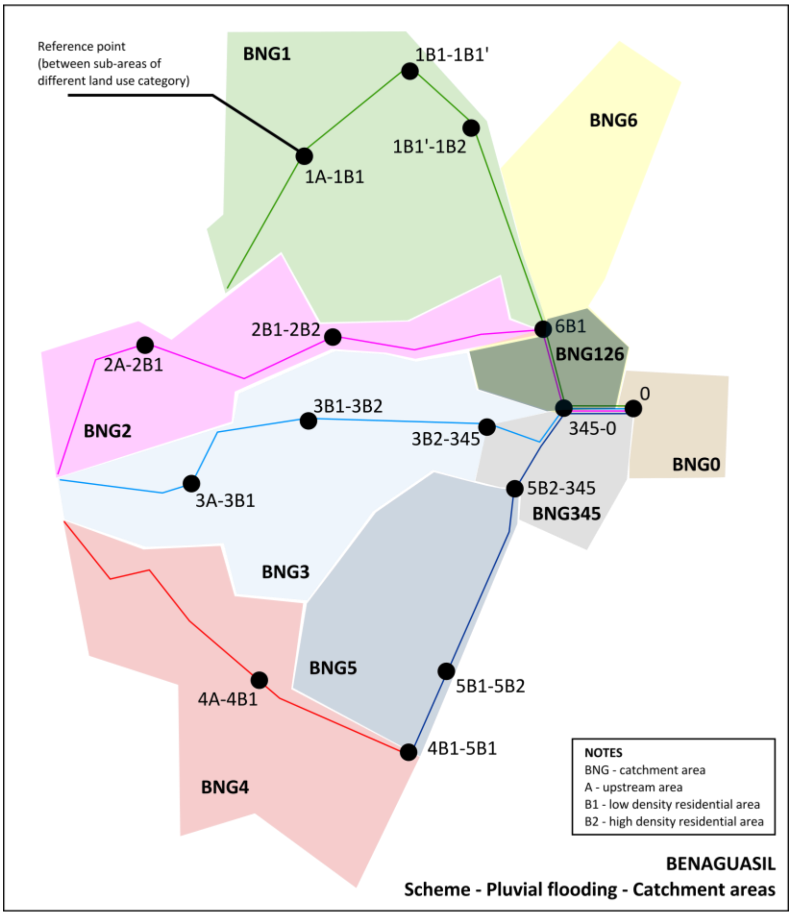


Figure 3.6: Scheme: BNG areas.

Table 3.6 lists some characteristics of each sub-area. The second column includes the upstream areas that are included for the analysis of the runoff rates in each sub-area (ID). Next, the surface of each catchment area is presented. The last three columns represent characteristics of the main water path in each sub-area: length, width and slope.

ID Sub-area	Catchment area	Surface (m^2)	Length (m)	Width b (m)	Slope (m/m)
BNG1	BNG1	423,932	1,482	10.00	0.008
BNG2	BNG2	233,496	1,505	6.00	0.028
BNG126	BNG1+BNG2+BNG6	769,360	1,902	8.00	0.001
BNG4	BNG4	323,195	1,112	12.00	0.072
BNG45	BNG4+BNG5	559,089	1,813	12.00	0.004
BNG3	BNG3	396,014	1,207	10.00	0.038
BNG345	BNG3+BNG4+BNG5	955,103	2,228	8.00	0.008
BNG0	ALL AREAS	1,659,622	2,228	10.00	0.026

Table 3.6: Characteristics of each sub-area.

Runoff rates have been obtained for each flood scenario and area. The Rational Method (Temez, 1992) is used to estimate runoff rates in Benaguasil.

Three different runoff thresholds are defined according to three categories of land typology: agricultural zones, low and high density urban areas. These values are 23, 8 and 5 mm, respectively, and they have been defined with the aim of obtaining runoff coefficients about 0.40, 0.75 and 0.85, for a return period around 10 years. These values are also in the range given by CEDEX. Figure 3.7 shows that Benaguasil belongs to the interval 15-30 mm (CEDEX, 2011).

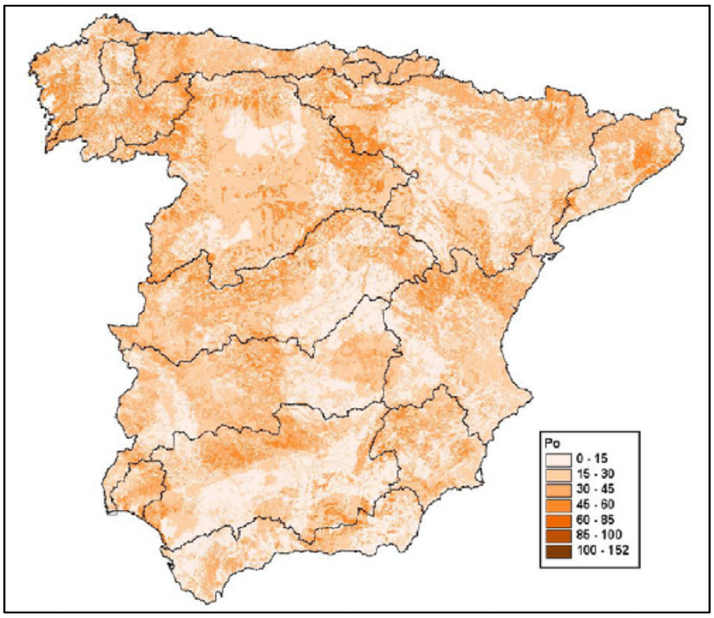


Figure 3.7: Runoff threshold ranges in Spain (CEDEX).

As a result, three series of runoff coefficients, C, are obtained by using the following equation:

$$C = \frac{(\frac{P_d}{P_O} - 1) \cdot (\frac{P_d}{P_O} + 23)}{(\frac{P_d}{P_O} + 11)^2} \qquad (3.2)$$

where Pd is the maximum daily rainfall rate for each flood scenario and Po is the runoff threshold. Table 3.7 shows all values of the runoff coefficient, C.

	Return period, T (years)						
	2	5	10	15	25	50	100
Po (mm)	23	Upstream areas					
C	0.19	0.31	0.38	0.42	0.47	0.52	0.57
Po (mm)	8	Low density residential areas					
C	0.54	0.67	0.73	0.76	0.80	0.83	0.86
Po (mm)	5	High density residential areas					
C	0.69	0.80	0.85	0.87	0.89	0.91	0.93

Table 3.7: Runoff coefficients.

Once all necessary parameters of the Rational Method are obtained, runoff rates are estimated based on the following equation, widely applied to obtain maximum rainfall intensity rates in Spain:

$$\frac{I}{I_d} = \frac{I_1}{I_d}^{\frac{28^{0.1}-D^{0.1}}{28^{0.1}-1}} \tag{3.3}$$

where I_d is the average daily rainfall intensity (mm/h), I is the rainfall intensity (mm/h) for a rainfall event with an effective duration of D hours, D is the rainfall event duration and it is assumed to be equal to the concentration time (tc), I_1 is the hourly intensity, and the ratio I_1/I_d is the relation between hourly and average intensity rates, depending on the geographic area.

The I_1/I_d ratio was obtained by Temez in 1990 and it is equal to 11.4 in the study region (Figure 3.8).

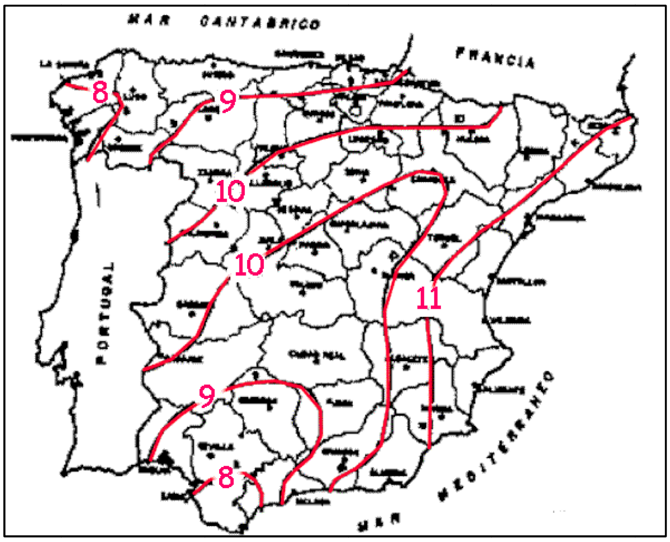


Figure 3.8: Map. Coefficient I_1/I_d (MOPU)

Regarding the hourly rainfall rates, values of I_d are obtained as $P_d/24$ for each flood scenario.

With reference to the rainfall duration, D is set as the value of time concentration, t_c (min), which can be obtained by two different equations, depending on the catchment. In rural areas, the time of concentration is given by:

$$t_c = \frac{0.30}{60} \cdot \left(\frac{L}{J^{0.25}} \right)^{\wedge 0.76} \tag{3.4}$$

where L is the length of the main waterpath (km) and J is the average slope (m/m).

For underground drainage systems within urban areas, the value is commonly obtained as follows:

$$t_c = t_0 + \frac{1.2}{60} \cdot \sum_{i=1}^{n} \frac{L_i}{v_i} \tag{3.5}$$

where L is the length of each pipe (m), v is the velocity inside the pipe if it is considered that water reaches the 100% of its capacity, and t_o is the time required to cross the distance between the furthest point within the catchment area and the first pipe.

In Benaguasil, different typologies of sub-areas within BNG1, BNG2, etc. have been identified, according with the urban development (rural, low density or high density zones). Thus, t_c is established as the combination of the two aforementioned equations:

$$t_c = 0.30 \cdot \left(\frac{L}{J^{0.25}} \right)^{\wedge 0.76} + \frac{1.2}{60} \cdot \sum_{i=1}^{n} \frac{L_i}{v_i} \tag{3.6}$$

Finally, the last step relies on estimating runoff rates by means of the following formula:

$$Q = \frac{k \cdot C \cdot I \cdot A}{3.6} \tag{3.7}$$

where k is a coefficient which varies depending on the geographical location of the urban area (Figure 3.9) and it corrects the runoff coefficient value (in this case, it is equal to 2.2), C is the runoff coefficient, I is the maximum rainfall intensity (mm/h), and A is the catchment area (km²). Due to the existence of different zones in each area, the previous equation is used for each flood scenario as follows:

$$Q = \frac{k \cdot I \cdot}{3.6} \sum_{i=1}^{n} C_i \cdot A_i \tag{3.8}$$

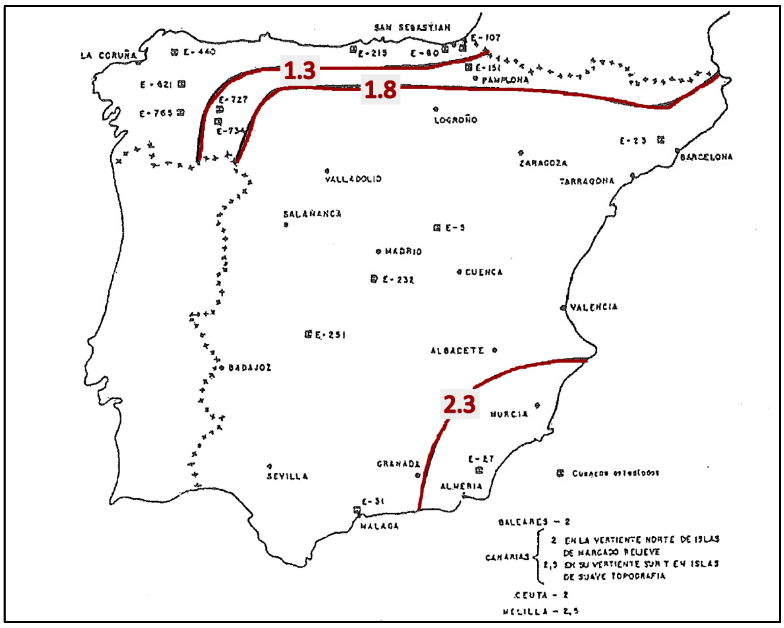


Figure 3.9: Map: Coefficient k (CEDEX, 1994).

- *Drainage system*

The existing network is shown in Figure 3.10.

Figure 3.10: Map. Drainage system.

After analysing the drainage system of Benaguasil and past flood events, it is assumed that the existing capacity of the network cannot manage the runoff flows that result from rainfall events with a return period of 2 years or higher.

For that reason, the first flood scenario (return period: 2 years) will produce runoff in the city.

3.1.3 Input data for the risk model

As it is recommended in the SUFRI methodology, the third phase of the process (Phase III: Definition of the Base-case) is focused on the analysis of the current situation of the urban area. Consequently, the analysis of the Base-case is developed before evaluating the effect of non-structural measures. A second case scenario with non-structural measures is evaluated after the analysis of the Base-case.

Base-case

After data collection and review, four time categories and seven flood scenarios have been defined.

Figure 3.11 shows the overall scheme to estimate data for the risk model.

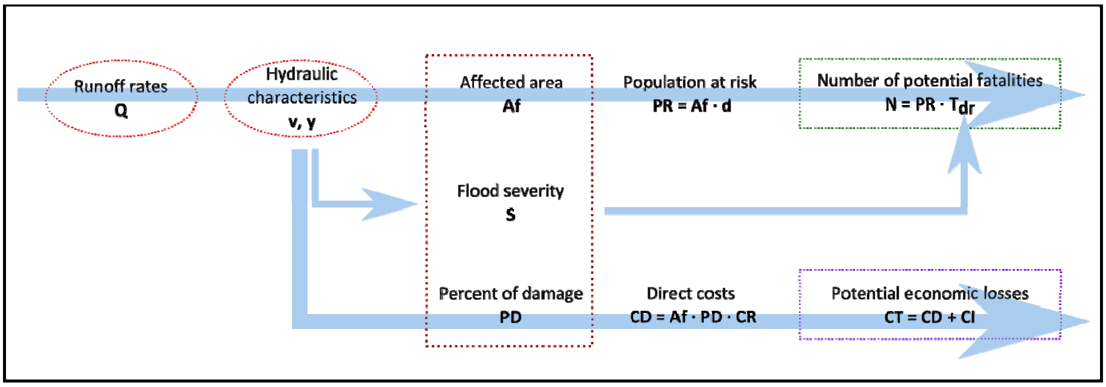


Figure 3.11: Overall scheme of the process for obtaining input data for the risk model.

Runoff rates

Runoff thresholds are estimated for three different categories: upstream areas, low and high density residential areas. Thus, different runoff coefficients are obtained for each sub-area and flood scenario (return period).

Estimations of runoff rates have been developed using the Rational Method.

Runoff flows due to rainfall events related to return periods higher than 2 years cannot be managed by the current drainage system of Benaguasil. Consequently, water flows through the streets. Thus, hydraulic characteristics of the flood have been obtained by considering width and slope of streets. The main path in each sub-area is identified and water depths and velocities are obtained based on this approach. A deeper estimation of the hydraulic characteristics will require detailed models which are not available. The main objective is providing simplified results for the risk model to analyze the situation with available information.

Table 3.8 includes the established values to calculate hydraulic characteristics of the flood. The ratio between the runoff flow and the average width of the streets (Table 3.6) in each sub-area (Q/b) is used to obtain velocities and water depths in each sub-area and flood scenario.

ID	Width (m)	Slope (m/m)	T1	T2	T3	T4	T5	T6	T7
BNG1	10.00	0.008	0.64	1.16	1.56	1.82	2.15	2.62	3.15
BNG2	6.00	0.028	0.51	0.98	1.37	1.62	1.95	2.41	2.96
BNG126	8.00	0.001	1.16	2.12	2.87	3.36	3.97	4.84	5.84
BNG4	12.00	0.072	0.28	0.56	0.79	0.94	1.14	1.43	1.77
BNG45	12.00	0.004	0.52	0.97	1.33	1.57	1.87	2.29	2.78
BNG3	10.00	0.038	0.74	1.33	1.79	2.09	2.46	2.99	3.60
BNG345	8.00	0.008	1.37	2.52	3.42	4.00	4.74	5.79	7.00
BNG0	10.00	0.026	1.99	3.66	4.97	5.81	6.89	8.41	10.18

Table 3.8: Width and slope of main paths in each sub-area and Q/b (m^2/s) rates for each flood scenario.

Flooded areas

Two steps are distinguished to estimate affected areas: first, two zones are identified for each sub-area, Af and Af1. These two zones are the potential flooded areas for water depths lower or higher than 0.15 m, respectively. This threshold has been established to determine two different situations: low water depths that flow through the main street and floods with high water depths that may reach adjacent streets and more households as water exceed the level of kerbs at streets (in general, 0.15 m high). Af' denotes areas with no households that are not used for estimating loss of life but considered for estimating economic damages (these areas are classified as land use category CU3).

Based on topographical data and geometry of each street, both perimeters have been estimated and all streets potentially affected by the flood are identified. Length and width of each flooded stretch are calculated.

Figure 3.12 shows the scheme which has been identified to obtain flooded areas in BNG1 (first sub-area of Benaguasil). Af and Af1 denote preliminary perimeters used for calculations and lower-case letters denote each stretch that has been considered to estimate the total flooded area in BNG1. In this particular case, ‘a’ has been used to estimate affected area for low water depths and the whole set shown in Figure 3.12 includes the flooded area if water depths are higher than 0.15 m. In BNG1, all areas are classified as CU1 and, consequently, no areas denoted as Af’ are included in Figure 3.12.

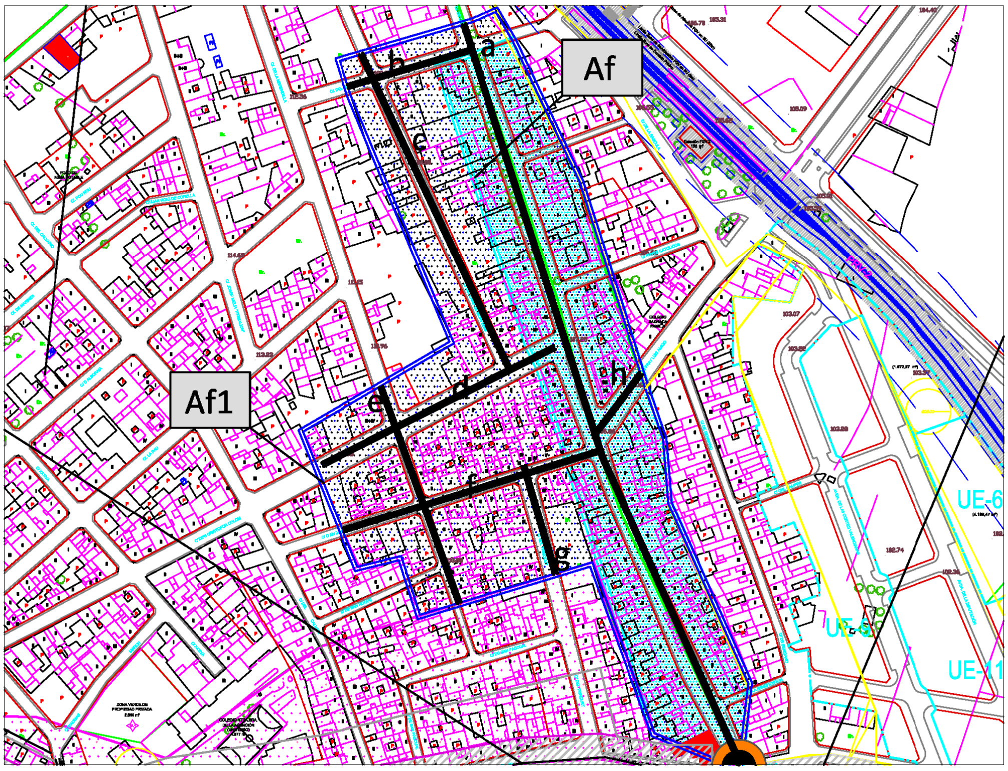


Figure 3.12: Scheme used for estimating flooded areas in sub-area BNG1.

Table 3.9 shows the estimated affected areas (A_{ff}) for each case and land use category.

ID	Width b (m)	Area CU1 (m²)	Area CU2 (m²)	Area CU3 (m²)	ID	Area CU1 (m²)	Area CU2 (m²)	Area CU3 (m²)
BNG1	10.00	13,140	0	0	BNG1	30,335	0	0
BNG2	6.00	13,450	0	0	BNG2	16,405	0	0
BNG126	8.00	7,050	0	0	BNG126	9,730	0	6,700
BNG4	12.00	0	29,900	0	BNG4	0	29,900	0
BNG45	12.00	17,500	0	0	BNG45	22,900	0	0
BNG3	10.00	18,300	0	0	BNG3	26,350	0	0
BNG345	8.00	13,075	0	0	BNG345	13,075	0	7,200
BNG0	10.00	0	0	20,600	BNG0	0	0	20,600

Table 3.9: Areas for estimating potential consequences.

Characteristics of the flood

Hydraulic characteristics of all flood scenarios have been obtained based on the runoff rates described in the previous section and the urban characteristics of Benaguasil (slope, width of the streets, etc.).

Hydraulic characteristics of each flood scenario have been used to estimate three main parameters: affected areas, flood severity levels and percentage of damages in assets.

Flood severity categories in each area and flood scenario are established based on the SUFRI methodology and the classification of five flood severity levels established for pluvial flooding, shown in Figure 3.13. Flood severity levels estimated for Benaguasil are listed in Table 3.10.

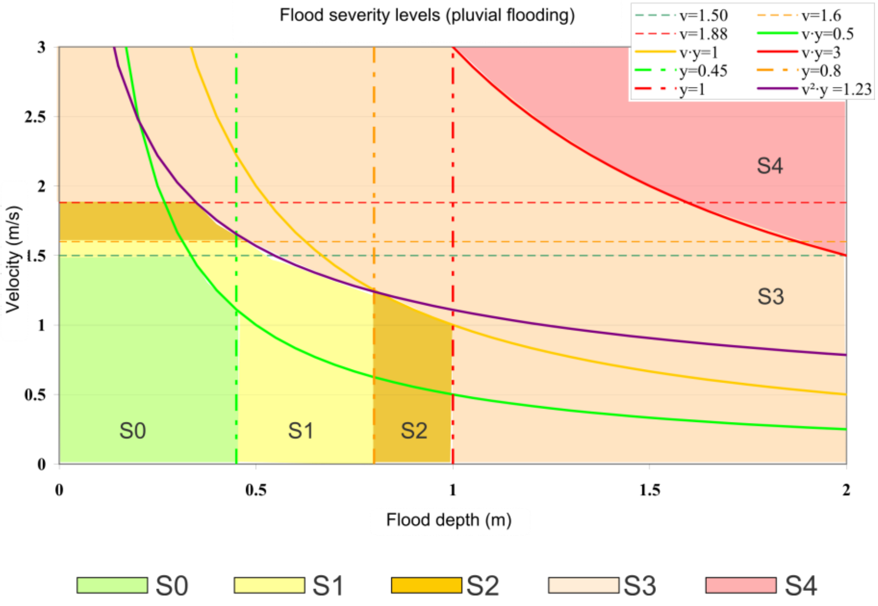


Figure 3.13: Classification of flood severity levels (SUFRI methodology).

	T1	T2	T3	T4	T5	T6	T7
BNG1	3	3	3	3	3	3	4
BNG2	3	3	3	3	3	3	3
BNG126	3	3	3	4	4	4	4
BNG4	3	3	3	3	3	3	3
BNG45	3	3	3	3	3	3	3
BNG3	3	3	3	3	3	3	4
BNG345	3	3	4	4	4	4	4
BNG0	3	4	4	4	4	4	4

Table 3.10: Flood severity levels for each flood scenario (T) and sub-area.

Finally, percentage of damages is estimated by a depth-damage curve which relates water depth to a certain level of damages (see Figure 3.14).

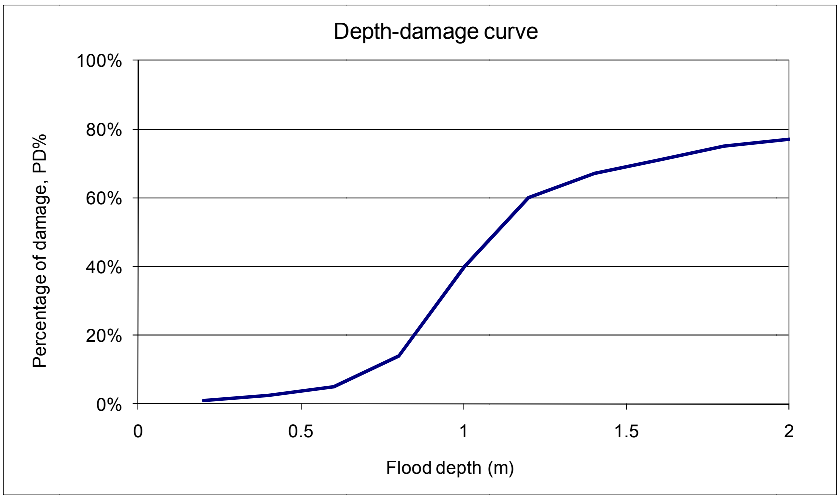


Figure 3.14: Depth-damage curve (PATRICOVA, 2002).

Loss of life

Potential fatalities for each time category and flood scenario are obtained by multiplying population at risk and fatality rates which correspond to the flood severity level of each flood scenario and area.

Population at risk (PAR) is obtained as a percentage of the number of inhabitants in the affected area (P) based on the time category and the level of flood risk understanding of the inhabitants of Benaguasil (Table 3.11).

Time category	TC1	TC2	TC3	TC4
Factor f PAR=f·P ; P=d·A_{ff}	10%	2%	5%	0.2%
Density, d (inhabitants/km²)	10,457	12,253	8212	10,008

Table 3.11: Population at risk. Base-case.

No warning systems are available in Benaguasil in case of flood. Therefore, Benaguasil belongs to the first category given in the SUFRI methodology (Cp1) to estimate fatality rates. These values are shown in Table 3.12.

Flood severity level	S0	S1	S2	S3	S4
Rate (fatalities / people at risk)	0.0003	0.0021	0.0038	0.0105	0.0448

Table 3.12: Fatality rates. Base-case.

The number of potential fatalities (N) is estimated by multiplying population at risk (PAR) and fatality rates.

Economic losses

Economic losses are estimated by the combination of the percentage of damage, which depends on the average flood depth, the affected area and the reference cost of each land use category.

Table 3.13 lists direct (CD) and total costs (CT) in each sub-area for the Base-case. Indirect costs are estimated as a percentage of 27% of direct costs.

ID	CD (€)						
	T1	T2	T3	T4	T5	T6	T7
BNG1	21,280	34,406	43,701	52,277	62,516	76,095	107,734
BNG2	5,230	9,823	13,073	15,031	17,390	20,549	24,796
BNG126	44,269	209,264	332,380	359,616	383,502	407,276	426,186
BNG4	1,796	2,748	3,391	3,778	4,242	4,862	5,800
BNG45	17,636	28,891	39,477	46,961	55,931	79,117	125,597
BNG3	11,618	17,665	22,612	25,546	29,040	33,661	39,998
BNG345	17,167	32,347	58,552	82,013	121,314	230,521	337,615
BNG0	1,117	1,978	2,691	3,795	5,639	8,281	15,984
CT (€)	152,542	428,144	655,166	748,052	863,060	1,092,658	1,376,311

Table 3.13: Economic losses.

PFR+WS-case

The same risk model scheme is used to analyze the second study scenario, denoted as PFR+WS-case. Time categories, flood scenarios and hydraulic characteristics of the flood do not vary. However, estimations of potential consequences have to be evaluated based on the existence of warning systems in Benaguasil and the implementation of public education programme on flood risk. As a result, better understanding and awareness of the population can be assumed.

Loss of life

Fatality rates for this study scenario are obtained based on category Cp3 (Table 3.14), as the implementation of warning systems is related to a different category in comparison with the Base-case.

Category Cp3					
Flood severity level	S0	S1	S2	S3	S4
Rate (fatalities / people at risk)	0.0002	0.0015	0.0027	0.0075	0.0320

Table 3.14: Fatality rates. PFR+WS-case.

Population at risk (PAR) is estimated based on values given in Table 3.15. In this case, lower percentages of population at risk are considered (reductions of 50% during the day and 25% at night have been established).This reduction refers to the effect of public education on population at risk. People are supposed to be aware of the hazard, and, consequently, the percentage of people outside their households can be considered lower than for the Base-case. Other actions such as the installation of waterstops to reduce economic damages result in a reduction of people exposed to the flood due to the fact that they will not be able to leave their house as easily as if no measures are taken to protect their properties.

Time category	TC1	TC2	TC3	TC4
Factor f $PAR=f\cdot P$; $P=d\cdot A_{ff}$	5%	1.5%	2.5%	0.15%
Density, d (inhabitants/km²)	10,457	12,253	8212	10,008

Table 3.15: Population at risk. PFR+WS-case.

Economic losses

The existence of warning systems and high flood risk understanding of the population can be implemented in the risk model as a reduction on economic damages due to the installation of water stops and barriers in household with the aim of avoiding water entrance. Different studies are found in the literature (*Parker et al. 2005*) which relate water depth, warning time and percentage of reduction. Figure 3.15 shows the values applied in Benaguasil to estimate reduction on assets for this PFR+WS-case.

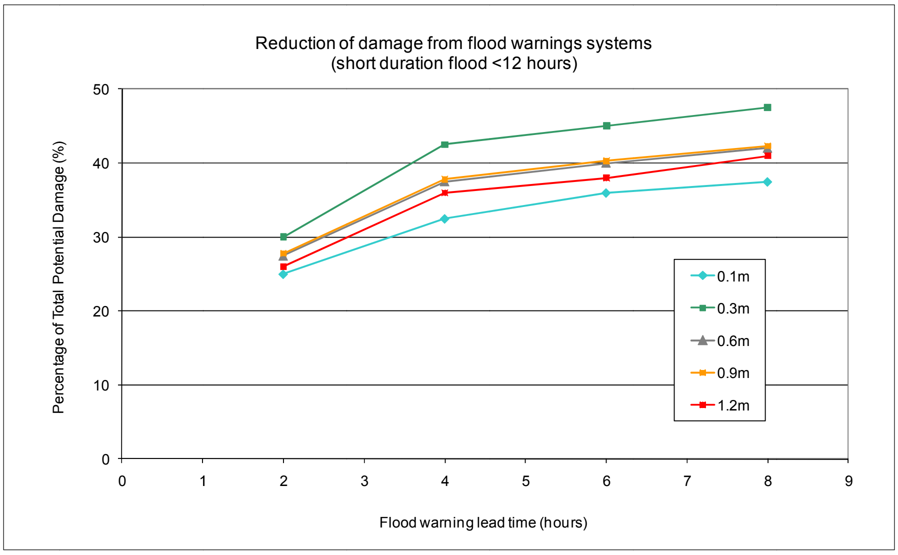


Figure 3.15: Reduction on damages (*Parker et al. 2005*).

A warning time of 3 hours is assumed and the following values are used for calculations.

Water depth y (m)	0	0.1	0.3	0.6	0.9	1.2
Reduction (·100)	0.29	0.29	0.36	0.33	0.33	0.31

Table 3.16: Percentage (·100) of reduction depending on water depth levels.

Water depths vary in each flood scenario and sub-area. Table 3.17 lists the estimated values of reduction in direct costs.

	Flood scenario						
	T1	T2	T3	T4	T5	T6	T7
BNG1	0.34	0.36	0.35	0.35	0.34	0.33	0.33
BNG2	0.30	0.33	0.35	0.36	0.36	0.35	0.35
BNG126	0.33	0.32	0.31	0.31	0.31	0.31	0.31
BNG4	0.29	0.29	0.30	0.31	0.31	0.32	0.33
BNG45	0.34	0.35	0.35	0.34	0.33	0.33	0.33
BNG3	0.31	0.33	0.35	0.36	0.36	0.35	0.35
BNG345	0.35	0.34	0.33	0.33	0.33	0.33	0.32
BNG0	0.36	0.34	0.33	0.33	0.33	0.33	0.33

Table 3.17: Percentage (·100) of reduction on direct costs.

New input data of potential consequences is obtained to analyse the PFR+WS-case.

3.1.4 Risk model

All the aforementioned information is summarized as input data for the risk model of Benaguasil. The risk model can be divided into three main parts: loads, system response and consequences.

Figure 3.16 shows the risk model scheme for the analysis of Benaguasil. Seven nodes are necessary to develop the influence diagram which represents the event tree of the case study.

Figure 3.16: Risk model scheme of this case study.

The first node, PF, identifies an overall parameter to calculate total risk by adding the results of societal and economic risk of all branches of the event tree (Figure 3.17). Other two nodes, TC_i and TC_ii, include probabilities of each time category. Then, all flood scenarios and associated probabilities are included in the next node, Flood. The system response is represented by a node which includes runoff flows in Benaguasil for each flood scenario. Finally, potential consequences are set in two nodes which relate runoff flows and potential fatalities or economic costs.

Figure 3.17 represents a section of the complete development of the event tree of this case study, where T denotes return period, f is the probability which results of the combination of time category and flood scenario of each branch of the event tree, N the number of potential fatalities and CT are economic costs.

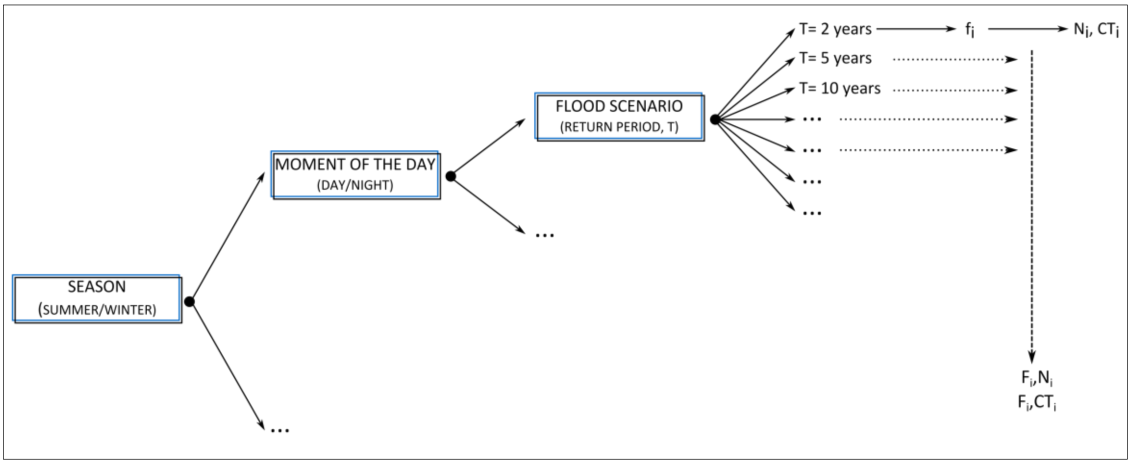


Figure 3.17: Example of the event tree of this case study.

Two risk calculations are performed with different input data for consequences based on estimations for both study scenarios: Base-case and PFR+WS-case.

3.1.5 Results: F-N and F-D curves for all study scenarios

Results of societal and economic risk are represented in this section for each study scenario: Base-case and PFR+WS-case.

Figures 3.18 and 3.19 show the F-N and F-D curves of both study scenarios: base-case and PFR+WS-case. These curves represent the cumulative annual probability of exceedance (F) for each level of potential fatalities (N) or economic losses (D).

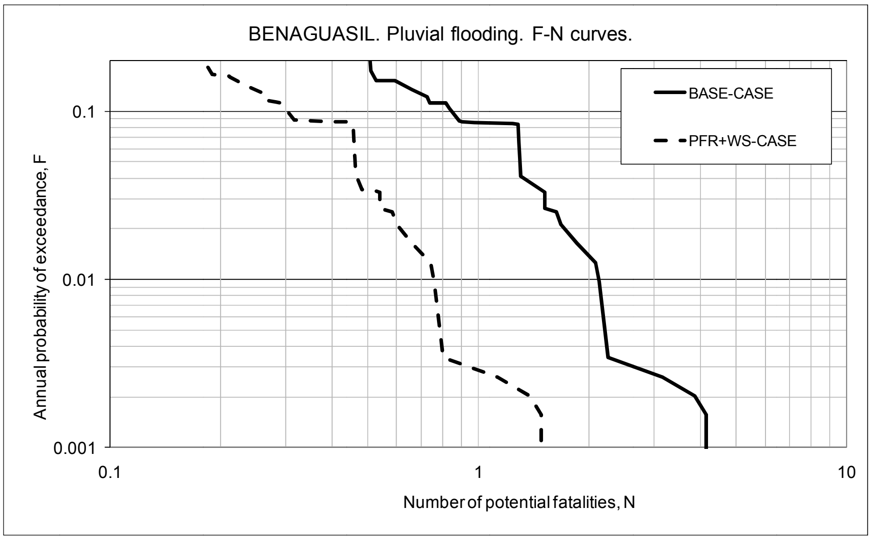


Figure 3.18: F-N curves. Benaguasil. Pluvial flooding. Base-case and PFR+WS-case.

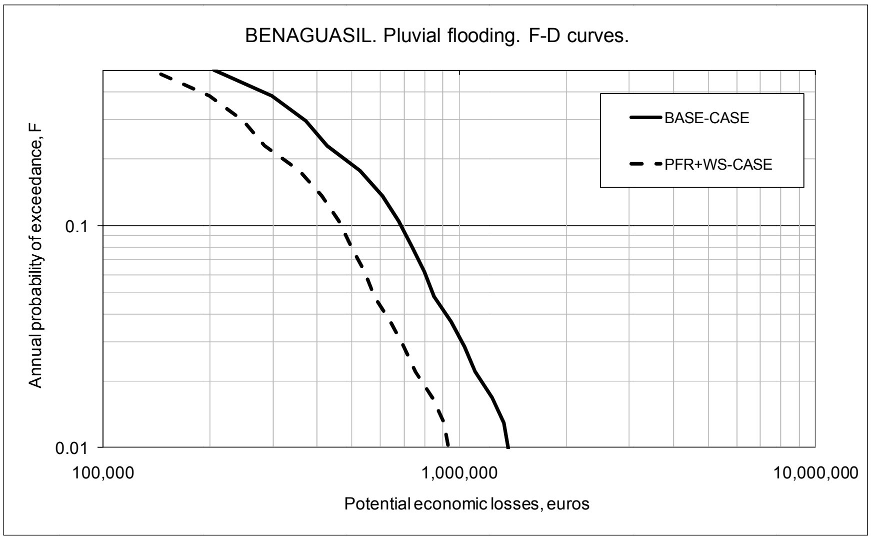


Figure 3.19: F-D curves. Benaguasil. Pluvial flooding. Base-case and PFR+WS-case.

In this case study, economic risk has more significance than societal risk. However, there is no doubt that public education and warning systems have an effect on risk reduction. For example, societal risk moves decreases a 67% in potential fatalities for an annual cumulative probability of exceedance equal to 0.001. Additionally, economic risk for an annual probability of exceedance equal to 0.01 decreases a 32% for the situation with non-structural measures (Fig. 3.19).

These risk profiles will be used to develop the Municipal Action Plan for the city of Benaguasil, following the guidelines of the overall study developed in WP5 of the SUFRI project. This Plan will include organization and communication schemes, procedures in case of flood emergency, risk reduction measures and recommendations.

3.2 Case study: Lodi (Italy)

3.2.1 Introduction: Location and characteristics of Lodi

The investigated area is Lodi town located in the north of Italy, crossed by the Adda river, with a dam located at Olginate, 75 km upstream the town (Figure 3.20). During the last century, this country recorded 30 flood events (10 of these caused by Adda river during the 60's that produced damages mainly to Lodi Town. All the flood events were caused by the main tributaries (Brembo and Serio river).

The case study of Lodi was chosen due to the flood event occurred in 2002. Nowadays, the Administration is still developing both structural and non structural measures to cope with flood risk in Lodi.

For this analysis, the Olginate Dam has not been considered as it is located 75 km upstream the urban area.

Hydrographs with return periods ranging from 2 to 500 years have been obtained from hydrological studies of the river basin. These hydrographs have been used to evaluate flood risk in the urban area.

The urban area is mainly composed of residential areas. Additionally, there are agricultural areas located at the northern of the town (Figure 3.21).

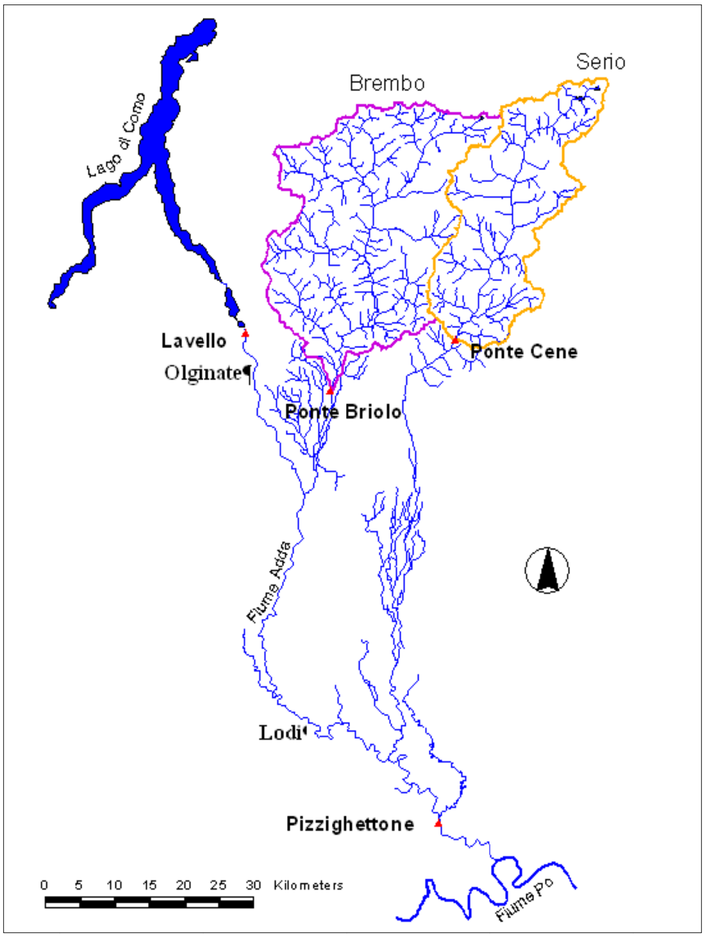


Figure 3.20: Adda river and tributaries.

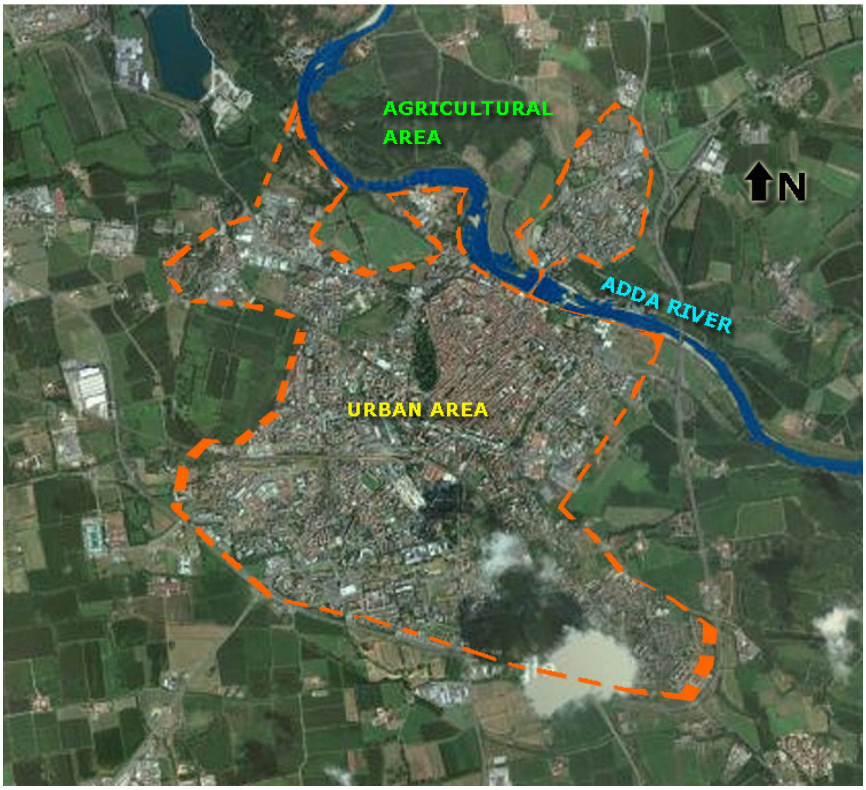


Figure 3.21: View of the Lodi urban area.

Two case scenarios have been established: the analysis of the current situation and the scenarios with non-structural measures of flood risk reduction. The comparison between both scenarios will show how effective non-structural measures are to reduce flood risk.

This study focuses on the analysis of the existent flood risk in Lodi due to river flooding generated by exceptional rainfall events and to estimate the flood risk reduction achievable through the application of non-structural measures.

3.2.2 Information

Once the aim of the study is established, all necessary data and information of this location has to be obtained to perform the risk model, including:

- Overall information of past flood events. Full description and simulation of the greatest flood occurred in Lodi in November 2002.
- Mathematical model used to simulate the study case, based on Shallow Water equations written in a conservative form.

Input data can be divided into different categories such as demography, building typology, land uses and economic rates, hydrology, existent structural measures, etc. These categories are described below:

Demography

- Statistics of demography. (ISTAT census 2001 data, Appendix 2)
    - Total population: 38,939 inhabitants (resident population).
    - Daily variability: 17,864 inhabitants.
    - Seasonal variability: 2,000 inhabitants (no data available, hypothesis for summer season).

Building typology

- Building typologies, number of households, etc. (Appendix 2)
    - Average number of floors per building*:* 2.53 floors/household.

Land uses and economic rates

- Land use maps.
    - Residential and agricultural areas (Appendix 1)
- Definition of land use categories (CU). Two land use categories are proposed in this example: residential areas (land use category CU_1 as it is defined in the

methodology) and agricultural areas (land use category CU_5).

- Identification of vulnerable areas or sectors: campsites, hospitals, schools, etc.
    - There are some vulnerable areas in the city centre (Ospedale Maggiore and some schools). No distinction has been made in the analysis.
- Economic statistics and value of assets.
    - No available data has been found to characterize the value of assets in Lodi. For that reason, these values are defined from the table included in the Regional Action Plan against Flood Risk of the Valencian Autonomous Region (*COPUT 2002*). For this case, an intermediate rate for high density residential areas has been chosen. The following reference costs have been established: residential, 68.7 €/m^2 and agricultural 0.34 €/m^2.

Hydrology and catchment areas

The catchment area of the Adda River is located downstream Como lake. Adda river has two tributaries, Brembo and Serio river, as it is shown in figure 3.20. The catchment area at the inflow in Po is 6,300 km² and the total length of the river is 280 km.

Adda river springs from the Retiche Alps, after collecting Frodolfo torrent, crosses the whole Valtellina and enters in Como Lake approximately in Colico (Lecco) with a length of 110 km and a basin of 2,600 km². Then, the river flows out of Como lake at the Olginate dam with a basin of 4,552 km². It receives water from Brembo river (with a basin of 940 km²) near Vaprio d'Adda. At Lodi town the area of the basin is 5,990 km².

The Serio river inflow is located upstream Pizzeghettone town and then flows into Po River.

Adda flow is regulated by Como lake close at the Olginate dam. The average annual discharge is 190 m³/s, ranging from 18 to 1000 m³/s. There are two small dams used for hydroelectric purposes in its river course. These three structures are classified as "dams" by the Italian Law, that is all regulation structures higher than 10 m or with a storage volume larger than 1.0 hm³. However, they are commonly considered as "barrages". Adda River is a tributary of Po river, which is managed by Po River Agency.

The hydraulic structure on Adda river are classified by the Italian Law as III class (R.D. 3598/1867, 4706/1868, L. 919/1910).

The outflow from Como lake is regulated by the Olginate dam at Lavello section (managed by "Consorzio of Adda" Agency): the flow discharge ranges from a minimum of 273 m³/s (in 1949) and a maximum of 940 m³/s (in 1987 and 2002 during the flood in

Lodi).

Downstream Como lake, Adda river can be divided into three reaches: the first between Lavello and Brembo mouth, the second between Brembo and Serio mouths, and, the third downstream Serio mouth.

The first reach is 28 km long with a watershed between 4,552 km^2 and 4,697 km^2. The river channel is deeply embanked, with a limited flood routing capacity. A 3.6 percentage of this area can be considered as rural areas. The maximum elevation of the catchment is 4,050 m.a.s.l., with an average elevation equal to 1,569 m.a.s.l. and the closing cross section is 197 m.a.s.l.

The second reach differs hydrologically from the first one due to Brembo confluence. Its flood wave is very rapidly changing and with high maximum values of discharge, compared with Adda flows coming out Como lake. The reason can be found in the alpine features of Brembo Valley. Moreover, Brembo and Adda floods occur simultaneously. Due to the nature of the floods coming out from the lake (very long in time with small temporal fluctuations), there is often no time lag between Brembo and Adda peak discharges. The maximum discharge from Brembo River can reach 1,000 - 1,200 m^3/s. As a result, there is an important discharge addition downstream Brembo confluence. Additionally, irrigation diversions by seven main Agencies have to be mentioned (Martesana, Vailata, Retorto, Rivoltana, Muzza, Vacchelli and Consorzio pianura bergamasca) which diverse from the river up to 220 m^3/s and 100 m^3/s, during summer and winter season, respectively.

The third reach has a short river length and the characteristics of the river channel show a limited flood routing capacity.

Flow gauging data

Four flow gauging stations are available downstream the Como lake: two in Adda River (Lavello and Pizzighettone), one in Brembo river and one in Serio river (see figures 3.22, 3.23, 3.24 and 3.25).

The hydrological study has been based on flow measures recorded at these four stations to estimate flood waves (discharge vs. duration) using the Gumbel and GEV (Generalized Extreme Value) probability distributions to evaluate discharges for an assigned return period.

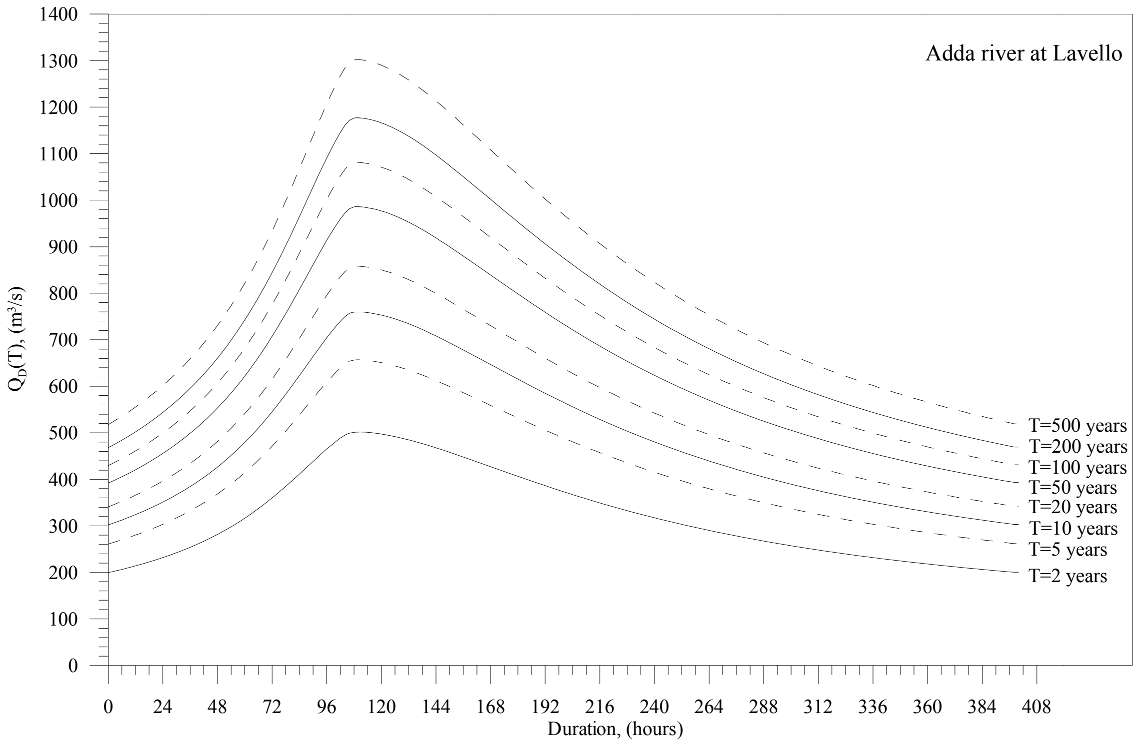


Figure 3.22: Adda river at Lavello: flood waves for different return periods.

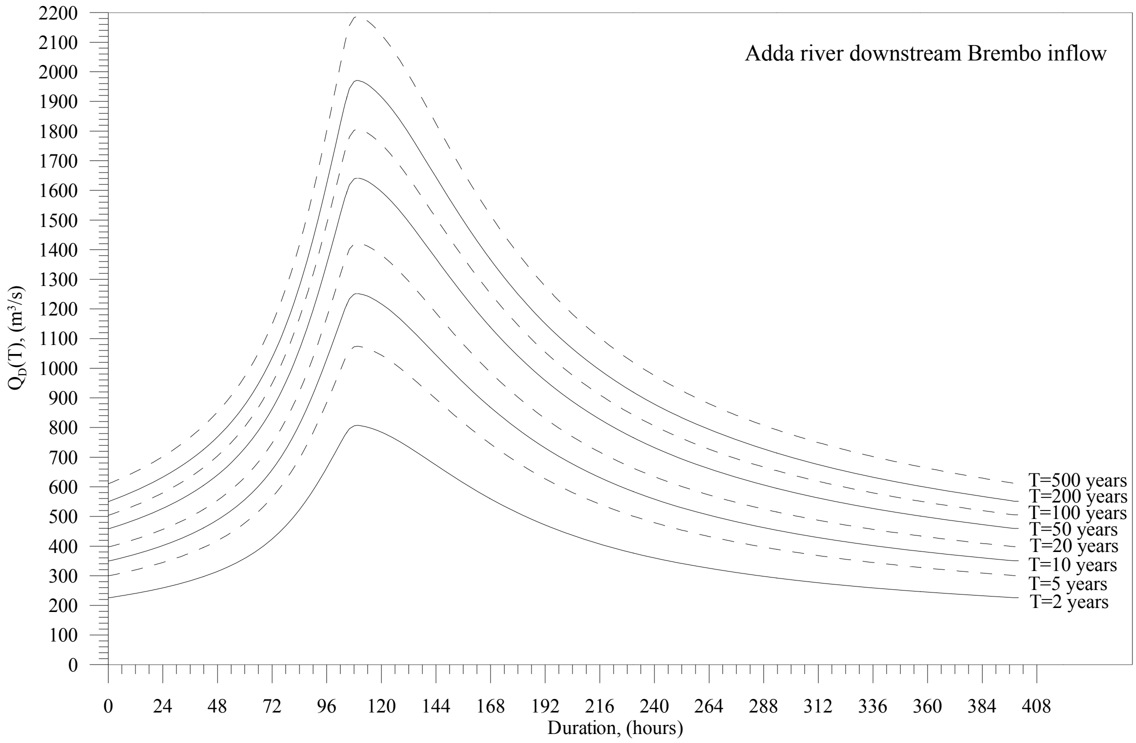


Figure 3.23: Adda river downstream Brembo inflow: flood waves for different return periods.

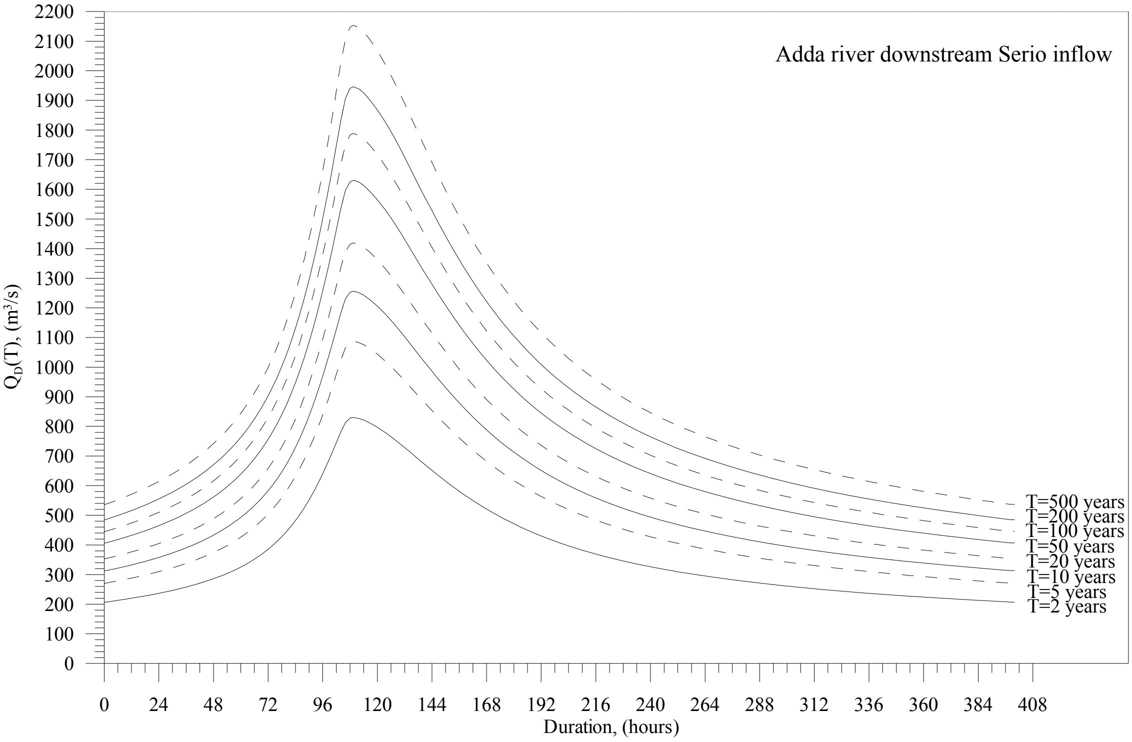


Figure 3.24: Adda river downstream Serio inflow: flood waves for different return periods.

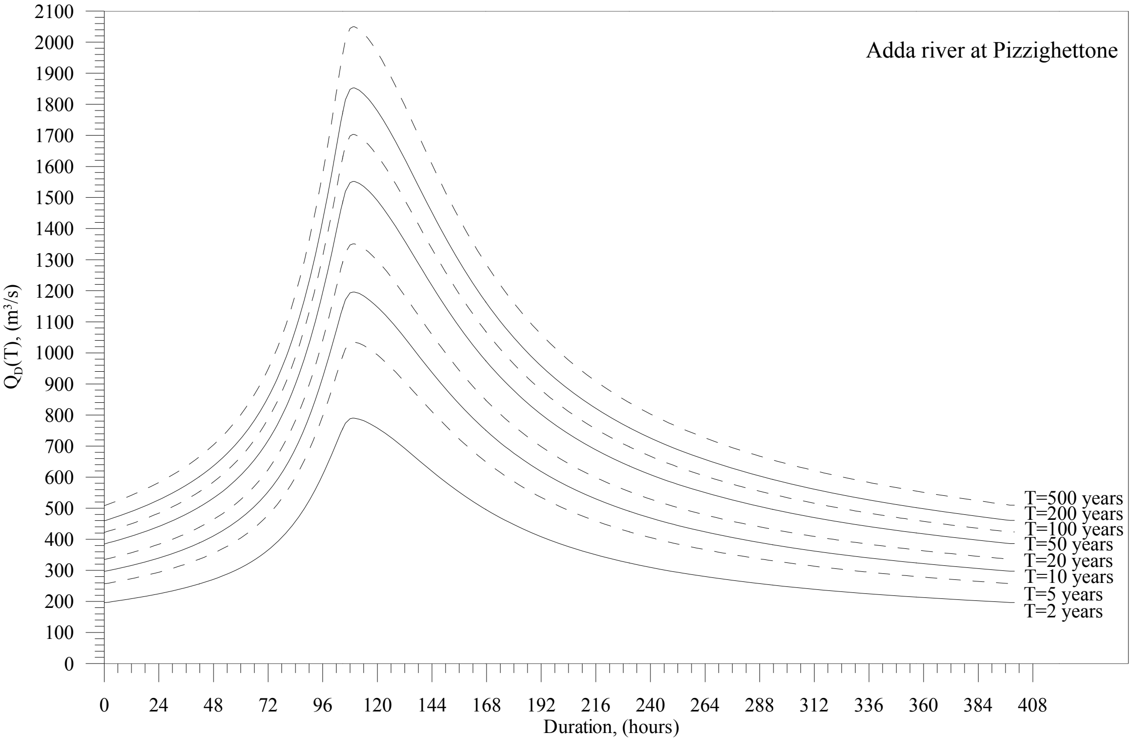


Figure 3.25: Adda river at Pizzighettone: flood waves for different return periods.

Return Period T (years)	Adda at Lavello	Adda after Brembo mouth	Adda after Serio mouth	Adda at Pizzighettone
2	502	807	830	790
5	657	1,074	1,087	1,035
10	760	1,252	1,256	1,196
20	858	1,422	1,419	1,351
50	986	1,642	1,630	1,552
100	1,081	1,806	1,788	1,703
200	1,177	1,971	1,946	1,853
500	1,302	2,187	2,153	2,050

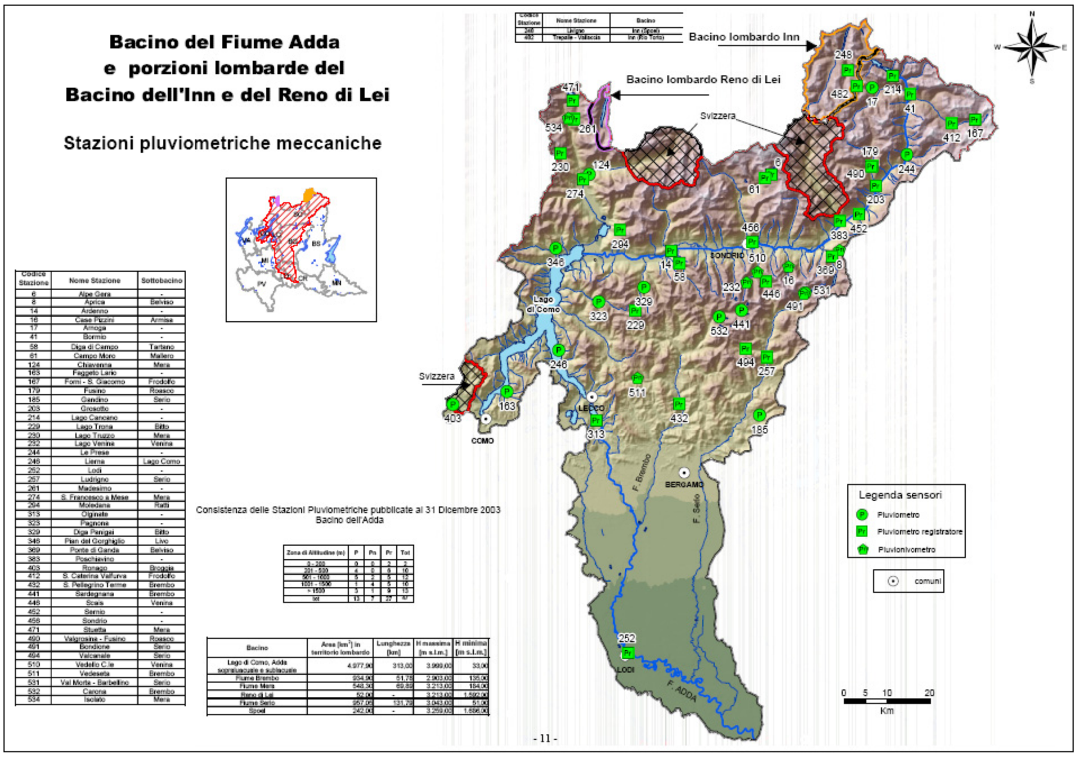
Table 3.18: Peak discharge for Adda river for different return period.

Pluviometer Data

There are a several rainfall stations that record rainfall and snow placed mainly in the mountain region within Adda river basin.

Figure 3.26 shows the position of these stations in Adda basin. Other electronic or automatic stations that are used for monitoring rainfall events might be used for flood pre-characterization as a non-structural measure for risk of flooding reduction.

No rainfall gauging stations has been used for the hydrological study of this case.



Codice Stazione	Nome Stazione	Bacino
248	Livigno	Inn (Spoel)
482	Trepalle - Vallaccia	Inn (Rio Torto)

Codice Stazione	Nome Stazione	Sottobacino
6	Alpe Gera	-
8	Aprica	Belviso
14	Ardenno	-
16	Case Pizzini	Armisa
17	Arnoga	-
41	Bormio	-
58	Diga di Campo	Tartano
61	Campo Moro	Mallero
124	Chiavenna	Mera
163	Faggeto Lario	-
167	Forni - S. Giacomo	Frodolfo
179	Fusino	Roasco
185	Gandino	Serio
203	Grosotto	-
214	Lago Cancano	-
229	Lago Trona	Bitto
230	Lago Truzzo	Mera
232	Lago Venina	Venina
244	Le Prese	-
246	Lierna	Lago Como
252	Lodi	-
257	Ludrigno	Serio
261	Madesimo	-
274	S. Francesco a Mese	Mera
294	Moledana	Ratti
313	Olginate	-
323	Pagnone	-
329	Diga Pescegallo	Bitto
346	Pian del Gorghiglio	Livo
369	Ponte di Ganda	Belviso
383	Poschiavino	-
403	Ronago	Breggia
412	S. Caterina Valfurva	Frodolfo
432	S. Pellegrino Terme	Brembo
441	Serdegnana	Brembo
446	Scais	Venina
452	Sernio	-
456	Sondrio	-
471	Stuetta	Mera
490	Valgrosina - Fusino	Roasco
491	Bondione	Serio
494	Valcanale	Serio
510	Vedello C.le	Venina
511	Vedeseta	Brembo
531	Val Morta - Barbellino	Serio
532	Carona	Brembo
534	Isolato	Mera

Consistenza delle Stazioni Pluviometriche pubblicate al 31 Dicembre 2003
Bacino dell'Adda

Zona di Altitudine (m)	P	Pn	Pr	Tot
0 - 200	0	0	2	2
201 - 500	4	0	6	10
501 - 1000	5	2	5	12
1001 - 1500	1	4	5	10
> 1500	3	1	9	13
tot	13	7	27	47

Bacino	Area [km²] in territorio lombardo	Lunghezza [km]	H massima [m s.l.m.]	H minima [m s.l.m.]
Lago di Como, Adda sopralacuale e sublacuale	4.977,90	313,00	3.999,00	33,00
Fiume Brembo	934,90	51,78	2.903,00	135,00
Fiume Mera	548,30	69,88	3.213,00	184,00
Reno di Lei	52,00	-	3.213,00	1.592,00
Fiume Serio	957,05	131,79	3.043,00	51,00
Spoel	242,00	-	3.259,00	1.696,00

Figure 3.26: Rainfall station in Adda basin.

Information of river characteristics

The following data is available:

- Hydrographs of the natural flow regime of the river with return periods that range from 2 to 500 years.
- Mean annual peak discharge: $Q_{2.33}$=190 m³/s.
- Peak discharge that reaches the capacity of the river embankment at the urban area: Q= 650 m³/s.
- Peak discharge that reaches the first households at the urban area: Q=1,040 m³/s.
- Flooding maps of Adda river.

Structural and non-structural measures

Como lake is regulated by the Olginate dam (Figure 3.27). Olginate dam started the regulation of Como lake in 1946. On Adda river, smaller barrages are used for hydroelectric and irrigation purposes that are not able to influence the river flow. Actually, Olginate is more similar to a “barrage” than a dam. In fact, the maximum discharge which corresponds to the full opening of the sluice gate (940 m^3/s) is comparable with the discharge that can occur with the collapse of the structure (1,040 m^3/s).

Table 3.19 lists the main characteristics of the Olginate dam.

Figure 3.27: Figure 3.2.8: Olginate dam view from right site of the river.

Characteristics	Data
Catchment area at Olginate Dam (km^2)	4,552
Como lake area (km^2)	145
Dam height (m)	3.9
Dam length (m)	153
Active storage (hm^3)	245
Maximum daily inflow in the lake (18-7-1987) (m^3 /s)	1,836
Maximum daily outflow from the lake (20-7-1987) (m^3/s)	918
Minimum daily outflow from the lake (4-4-1953) (m^3/s)	18

Table 3.19: Main characteristics of Olginate dam.

Drainage system

Lodi city counts about 40,000 inhabitants in a surface of 4,164 ha, of which only 878 are urbanised. The drainage system is 140 km long and ends in a sewer treatment plant in Cascina Maldotta, in the south east outskirts, managed by Astem.

From the hydraulic point of view, Lodi drainage system is divided into two independent basins. The first basin is named “collettore Cotta-Baggia” with a big polycentric section (300 cm x 200 cm) with the original function of irrigation channel in the south of the town. The second pipe has a section of 100 cm x 150 cm. The system is mainly combined. The draining system is divided into combined sewer system (50%), meteoric sewer system (24%) and waste water system (26%). No pluvial flooding due to low capacity of the drainage system is considered.

Other structural measures

Several levees are constructed nearby the urban area (Figure 3.28). A hydraulic model of the river course is available for calculations.

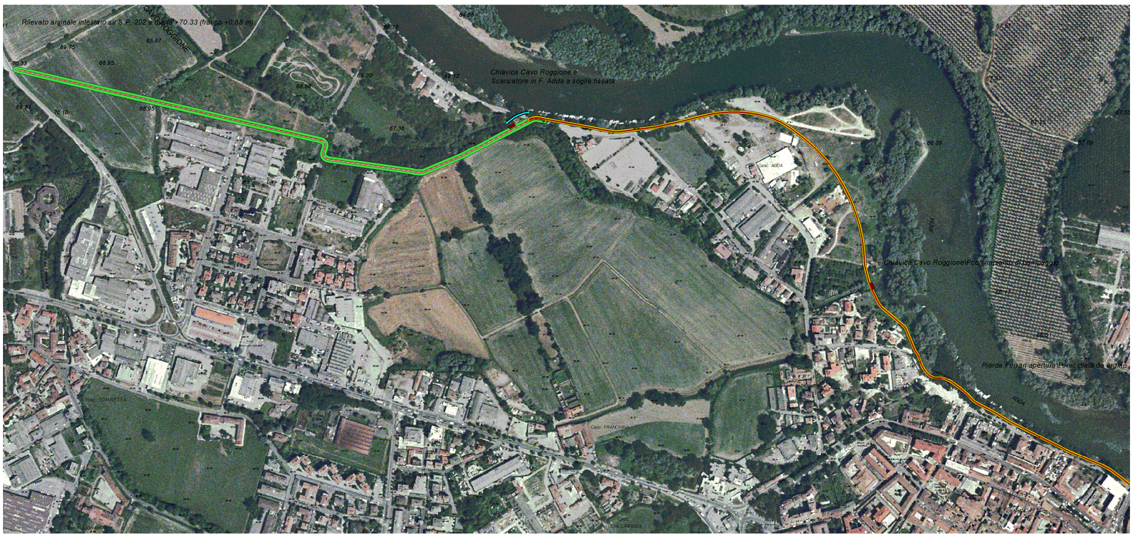


Figure 3.28: Position of the levees that complete the protection of Lodi town.

Non-structural measures

Flood precharacterization and prediction can be considered as an example of non-structural measure for flood risk reduction in this case. These measures may support the town emergency plan described in the following pages.

Land planning as a result of the PAI (Program of the Hydrogeological Assesment) suggests some measures for risk reduction such as:

- Limitation of land uses in zones where exist flood risk with a land planning that supports the delocalisation of all structures that could be damaged;
- Real time forecasting using meteorological data and hydrographic monitoring that, giving a pre-characterization of the flood, allows the beginning of protection actions.

Additionally, other non-structural measures can be mentioned:

- Flooding maps of Adda river to evaluate inundation risk for return periods of 20, 200 and 500 years.
- “Program of the Hydrogeological Assesment” (PAI) of Po river, and all its tributaries, by the Po River Agency in 2001 indicates deadlines to reduce flood risk.
- Existence of an Emergency Action Plan.

3.2.3 **Input data for the risk model**

Flood scenarios

Flood scenarios are defined from hydrological studies of the river basin. A series of return periods should be established for defining flood scenarios related to the river flow regime. The values used are those from the station upstream Lodi town. Maximum peak discharges for each return period are presented in Table 3.20.

T (years) from hydrological studies	2	5	10	20	50	100	200	500
Q_{max} (m^3/s)	807	1,074	1,252	1,422	1,642	1,806	1,971	2,187

Table 3.20: Peak discharges from hydrographs.

Definition of time categories

Based on daily and seasonal variability, four time categories are defined to estimate the number of people located at the urban area.

Total population is equal to 38,939 inhabitants (2001). This value is associated to winter-night period (time category TC_4) and it decreases in winter during the day in 21,075 people due to labour reasons. In summer, population is supposed to decrease an amount of 4,000 people due to the vacancy period. Then, population is estimated in 34,939 people in summer at night and it decreases in 18,075 people during the day. Table 3.21 shows these four time categories.

Time category	Summer/day (TC_1)	Summer/Night (TC_2)	Winter/day (TC_3)	Winter/night (TC_4)
Inhabitants	16,864	34,939	17,864	38,939
Range Summer/winter	Summer: From July 1st to September 15th Winter: Rest of the year			
Range Day/night	Day: 8:00 a.m. - 10:30 p.m. Night: 10:30 p.m. - 8:00 a.m.			

Table 3.21: Time categories.

Study scenarios

Two different study scenarios from river flooding are considered:

- Current situation with structural measures (existence of levees nearby the urban area, denoted as Base-case). The effects of the dam will not be considered due as flood is not supposed to be a consequence of dam failure. Thus, the Base-case is developed without considering the dam.
- Situation with non-structural measures (effect of a Public Education Program on Flood Risk, denoted as PFR-case).

Base-case – Estimation of potential loss of life and economic damages

LOSS OF LIFE

Category for the Lodi base-case to define reference fatality rates

Based on the classification of ten categories proposed in the methodology, category C2 can be used to identify Lodi Base-case. This category will be modified to C9 to analyse the situation with non-structural measures.

Population at risk (PR)

Flooded areas are obtained from comparison of land use and flooding maps. For each flood scenario, population at risk for each time category is obtained by multiplying population for each time category by the ratio between flooded area (A_f) and total area of the urban site (A_T).

Reduction on population at risk is established due to the characteristics of the urban site. An average number of 2.53 floors per household has been estimated. Thus, population at risk is obtained as follows:

$$dC = \frac{d}{np} \qquad PR_{calc}(TC_i) = \frac{PR(TC_i)}{2.53} \tag{3.9}$$

where *d* denotes density, *dC* is the value of density population for calculations and np is the average number of floors per building.

Consequently, population at risk is reduced by a factor of 2.53 for each time category.

	Total area, A_T (m²)	8,780,000	Population at risk, PR			
Q_{max} (m³/s)	Flooded area, A_f (m²)	% total	Time category TC_1	TC_2	TC_3	TC_4
807	175,600	2.00%	133	276	141	308
1074	702,400	8.00%	533	1,105	565	1,231
1252	1,317,000	15.00%	1,000	2,071	1,059	2,309
1422	1,756,000	20.00%	1,333	2,762	1,412	3,078
1642	2,634,000	30.00%	2,000	4,143	2,118	4,617
1806	3,512,000	40.00%	2,666	5,524	2,824	6,156
1971	4,390,000	50.00%	3,333	6,905	3,530	7,695
2187	6,146,000	70.00%	4,666	9,667	4,943	10,774

Table 3.22: Population at risk. River flooding. Lodi base-case.

Warning times (TW)

Warning times are defined as the time difference from the first-notice flow, 650 m³/s, and first-damage flow, 1,040 m³/s.

Flood severity (Sv)

Flood severity of each flood scenario is obtained based on the DV parameter. All flood scenarios are within the category of medium flood severity, except for the first one (DV equal to 3.5 < 4.6 m²/s). Peak discharge values at the study site correspond to the maximum discharge of each flood scenario.

Fatality rates (FR)

Fatality rates are obtained by interpolating reference fatality rates of category C2 based on warning times and flood severity categories.

Number of potential fatalities (N).

The number of potential fatalities is estimated by multiplying population at risk (from each time category) times the estimated fatality rate (FR).

Table 3.23 includes all estimated parameters to obtain the resultant number of potential fatalities for Lodi base-case.

Q_{max} (m³/s)	TW day (h)	TW night (h)	DV	Sv	FR day	FR night	Time category			
							TC_1	TC_2	TC_3	TC_4
807	-	-	3.5	1	-	-	-	-	-	-
1,074	6	5.75	4.7	2	2.E-04	2.E-04	0.1	0.2	0.1	0.2
1,252	3.00	2.75	5.3	2	2.E-04	2.E-04	0.2	0.4	0.2	0.5
1,422	1.75	1.50	5.4	2	2.E-04	2.E-04	0.3	0.6	0.3	0.6
1,642	1.50	1.25	5.8	2	2.E-04	5.5E-02	0.4	114	0.4	127
1,806	1.25	1.00	6.0	2	4.E-02	4.5E-02	74	304	78	339
1,971	1.15	0.90	6.1	2	4.E-02	6.E-02	128	418	136	465
2,187	1.10	0.85	5.7	2	5.E-02	6.6E-02	205	611	218	681

Table 3.23: Number of potential fatalities, N. River flooding. Lodi base-case

ECONOMIC LOSSES

Economic losses are obtained from the definition of a reference cost for the flooded area and a percentage of damages from depth-damage curves. Indirect costs are estimated as a 20% of direct costs. Results are included in Table 3.24.

Q_{max} (m³/s)	Flood depth H (m)	Reference cost CR (€/m²)	Percentage of damage PD (%)	Direct costs CD (€)	Indirect costs CI (€)	Total costs CT (€)
807	0.00	68.70	0.00%	0	0	0
1,074	1.65	68.70	10.00%	4,825,488	965,098	5,790,586
1,252	1.78	68.70	20.00%	18,095,580	3,619,116	21,714,696
1,422	1.85	68.70	25.00%	30,159,300	6,031,860	36,191,160
1,642	1.95	68.70	40.00%	72,382,320	14,476,464	86,858,784
1,806	2.28	68.70	50.00%	120,637,200	24,127,440	144,764,640
1,971	2.90	68.70	55.00%	165,876,150	33,175,230	199,051,380
2,187	3.30	68.70	65.00%	274,449,630	54,889,926	329,339,556

Table 3.24: Economic losses. River flooding. Lodi base-case.

Percentage of damage PD (%)

Depth-damage curves are distributions that represent flood depth and the percentage of damage in assets. The flood event of November 2002 has been used for calibration of a more representative percentage based on depth-damage curve found in the literature (*COPUT 2002*).

PFR-case – Estimation of potential loss of life and economic damages

Non-structural measures do not modify the hydraulic characteristics of the established flood scenarios for the Base-case. However, flood consequences vary from the Base-case due to the application of non-structural measures.

The aim of town emergency plan is focused on improving the knowledge of population on flood risk. This case, denoted as PFR-case (Public Education Programme), includes the effect of giving guidance on evacuation and shelter in case of flood emergency.

This scenario is studied by including the following variations on the Base-case:

LOSS OF LIFE

If a PFR is implemented, it can be considered that the case example belongs to category C9 (see categories proposed by SUFRI methodology). Consequently, reference fatality rates differ from the Base-case.

The same values of population at risk, warning times and flood severity categories have been adopted for this PFR-case.

ECONOMIC LOSSES

According to SUFRI methodology and possible Lodi case solutions, it is proposed that inputs of economic losses are modified from Base-case as follows:

- Reference costs are modified from a starting value of 68.7 €/m² (residential land use - high rate) to 37.55 €/m². This cost is referred to residential medium density land use with an intermediate rate between high and low. This variation on reference cost aims to introduce the possibility to locate vulnerable areas to non-risk zones and to use ground floor of existing buildings for other land uses (storage, parking, etc.).
- Estimation of indirect costs: town emergency plan provides useful devices to keep economic and social activities as normal as possible (no loss of production, traffic or facilities disruption, etc.). Thus, indirect costs are set as a 10% of direct costs (this value was defined as 20% for the Base-case).

- Estimation of percentage of damage (PD): PFR-case is performed with a decrease of 50% on damages. This hypothesis is supported by prevention activities set by the town emergency plan and PAI devices. For example, avoiding residential uses in ground floors and using materials with high resistance.

Tables 3.25 and 3.26 include all estimated parameters to obtain the resultant number of potential fatalities and economic costs for Lodi PFR-case.

Q_{br} (m^3/s)	TW day (h)	TW night (h)	DV	Sv	FR day	FR night	Time categories			
							TC_1	TC_2	TC_3	TC_4
807	-	-	3.5	1	-	-	-	-	-	-
1,074	6	5.75	4.7	2	2.0E-04	2.0E-04	0.1	0.2	0.1	0.2
1,252	3.00	2.75	5.3	2	2.0E-04	2.0E-04	0.2	0.4	0.2	0.5
1,422	1.75	1.50	5.4	2	2.0E-04	2.0E-04	0.3	0.6	0.3	0.6
1,642	1.50	1.25	5.8	2	2.0E-04	2.1E-03	0.4	8.7	0.4	9.7
1,806	1.25	1.00	6.0	2	2.1E-03	4.0E-03	5.6	24.6	5.9	22.1
1,971	1.25	1.00	6.1	2	2.1E-03	4.0E-03	9.5	35.0	10.1	39.0
2,187	1.10	0.85	5.7	2	4.0E-03	7.5E-03	15.1	54.1	16.0	60.3

Table 3.25: Number of potential fatalities. N. River flooding. PFR-case.

Q_{br} (m^3/s)	Flood depth H (m)	Reference cost CR (€/m^2)	Percentage of damage PD (%)	Direct costs CD (€)	Indirect costs CI (€)	Total costs CT (€)
807	0.00	37.55	0.00%	0	0	0
1,074	1.65	37.55	5.00%	1,318,756	131,876	1,450,632
1,252	1.78	37.55	10.00%	4,945,335	494,534	5,439,869
1,422	1.85	37.55	12.50%	8,242,225	824,223	9,066,448
1,642	1.95	37.55	20.00%	19,781,340	1,978,134	21,759,474
1,806	2.28	37.55	25.00%	32,968,900	3,296,890	36,265,790
1,971	2.90	37.55	27.50%	45,332,238	4,533,224	49,865,461
2,187	3.30	37.55	32.50%	75,004,248	7,500,425	82,504,672

Table 3.26: Economic losses. River flooding. PFR-case.

3.2.4 **Risk model**

The risk model can be divided into three main parts: loads, system response and consequences. The risk model for the Lodi base-case is performed to represent the current situation of Lodi without non-structural measures. Levees influence the extent of flooded areas and their effects are considered in mathematical model. The risk model of the PFR-case will include the estimations of flood consequences after public education as non-structural measure.

Figure 3.29 shows the risk model architecture for Lodi and Table 3.27 includes the name of each node, description of input data requirements, file name and parameters for identifying flood scenarios and potential consequences. This scheme is used for both study scenarios: Base-case and PFR-case. However, input data for consequences will vary for each situation.

Figure 3.29: Risk model scheme of Lodi.

Node	Category	Description	Input data file	Parameter
Risk	-	Defines a parameter 'risk' to obtain overall results of total risk	totalrisk.txt	risk
Flood	Loads	Return periods (T) and annual probabilities of exceedance (AEP)	flood.txt	T, AEP
Qmax	System	Peak discharges for each return period	Qmax.txt	T, Qmax
TC (i)	-	Defines probabilities of each season (summer or winter) to identify time categories. i.e. summer=0.2084; winter=0.7916 (rest of the year)	tc_i.txt	season = summer, winter
TC (ii)	-	Defines probabilities of moment of the day to identify time categories. i.e. day=0.42; night=0.58 (summer); day=0.625. night=0.375 (winter)	tc_ii.txt	moment = day, night
Cons_N	Consequences	Consequences in terms of loss of life for each flood scenario (identified by the maximum peak discharge of the hydrograph) and time category	RN_lives.xls	Qmax, lives
Cons_CT	Consequences	Consequences in terms of economic losses for each flood scenario (identified by the maximum peak discharge of the hydrograph) and time category	RN_euros.txt	Qmax, euros

Table 3.27: Nodes of the risk model scheme of the Lodi base-case.

LOADS

Flood scenarios from the given return periods (Table 3.20) are established as loads for the risk model of Lodi.

SYSTEM RESPONSE

System response corresponds with flood characteristics and flooded areas as a result of the previous flood scenarios.

The mathematical model used is based on Shallow Water equations written in a conservative form. The relevance of this study and the detail of the simulation requires a mathematical model written in a complete form without dropping the conveyance term. In deed, the spatial variations of the velocity may be very high due to the number of constructions that cross the river.

The mathematical model is numerically integrated with finite volumes techniques with two different numerical schemes. Estimation of the roughness coefficient has been performed using a method that refers to the formulation proposed by *Arcement 2001*.

A Geological Survey that correlates the roughness coefficient (using Manning) with the dimension of the grains and vegetation in the river bed has been used.

CONSEQUENCES

Flood consequences are divided into two categories: loss of life and economic losses. Estimations will differ from the Base-case to the situation with non-structural measures.

3.2.5 Results: F-N and F-D curves for all study scenarios

After obtaining results of the risk model for both study scenarios, Base-case and PFR-case, F-N and F-D curves for Lodi can be represented to show the resultant social and economic risk, respectively.

The F-N curve represents the annual probability of exceedance (cumulative) of a certain level of potential fatalities and the F-D curve depicts potential economic losses.

Figures 3.30 and 3.31 show the results for both study scenarios: Base-case and PFR-case.

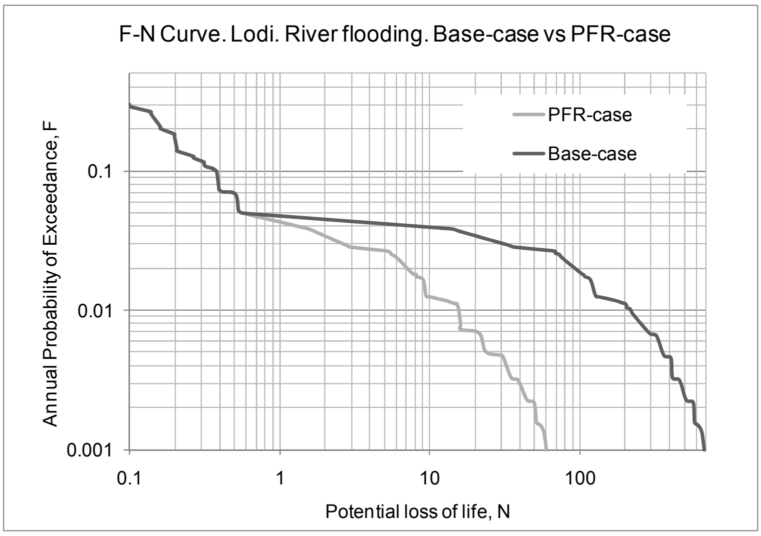


Figure 3.30: F-N curves. Lodi. River flooding. Base-case and PFR-case.

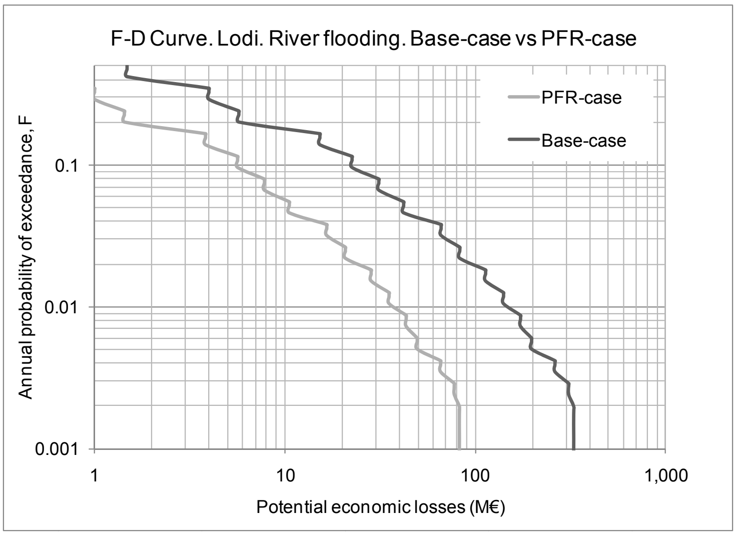


Figure 3.31: F-D curves. Lodi. River flooding. Base-case and PFR-case.

Results show that the established flood scenarios produce a maximum potential loss of life around 680 fatalities for an annual probability of exceedance equal to $1{\cdot}10^{-3}$, approximately, for the Base-case. Potential economic losses reach a value of 329 M€ for the same annual probability of exceedance. However, results of the PFR-case show a reduction on social risk ranging from 680 to 60 potential fatalities for the aforementioned probability and economic risk decreases in magnitude from 329 to 82.5 M€. If the annual probability of exceedance equal to 0.1 is considered, then a reduction on potential economic losses from 22.5 to 5.7 M€ is expected (75% of risk reduction). This reduction is not significant if potential life-loss is analysed due to the minor social risk associated with low probabilities.

4 CONCLUSION

SUFRI methodology provides a tool to support flood risk evaluation in urban areas and it can be applied to inform authorities, local entities and stakeholders on decision-making to establish strategies for risk reduction.

F-N and F-D curves show the societal and economic flood risk, respectively, in an understandable way, as they are useful to evaluate the effect of the several measures on it. Although these curves do not indicate the flood risk distribution in an area, they can be very useful for defining tolerability criteria for flood risk.

As it was described on SUFRI methodology (Attachment 1), these curves are the basis to illustrate risk quantification and the effect of different measures on flood risk reduction, thus providing a guide for planning and managing.

Therefore, risk model results and F-N curves from the established alternatives (base-case, non-structural measures, etc.) can provide information in terms of flood risk to assist the following applications:

- Preliminary evaluations on flood risk.
- Management of flood defences and appraisal of new flood defence schemes.
- Flood hazard and risk mapping.
- Flood warning and emergency planning.
- Identification of high-risk areas to prioritise flood warning and emergency response.
- Flood awareness campaigns.
- Flood Defence regulation, design and development control.
- Spatial planning.
- Urban planning.
- Flood plans for reservoirs.
- Information for ongoing and new research projects.
- Public education plans.
- Etc.

SUFRI methodology is based on the identification of all the important factors that influence risk quantification: sources of flood risk (river, heavy rainfall, defence failure, inefficient drainage system, etc.), vulnerability of the study area, etc.

The use of F-N curves enables the comparison of the current situation of the urban area with other situations from the consideration of non-structural measures.

Also, it should be emphasized that this method considers the study of total risk evaluation (from the analysis of flood scenarios in case of flood defence failure and non-failures) differing from risk evaluation on dam and levee safety, where typically incremental risk is analysed (from the difference between damages due to the dam or levee failure and the situation with non-failure).

Uncertainty on the results will depend on available data and the level of detail of hydrologic and hydraulic models or calculations. However, SUFRI methodology provides a scheme that can be applied for different levels of information: from basic evaluations on flood risk to highly detailed estimations.

In addition, it should be emphasized that risk evaluations from low levels of information require assumptions and should be more conservative. Consequently, uncertainty in the results is high, particularly in the number of people who will be exposed to a flood and hydraulic characteristics of the flood event. However, it should be kept in mind that people can be very resilient during floods and the number of deaths is often less than expected.

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APPENDIX

APPENDIX 1

Case Study: Lodi. Map.

APPENDIX 2

Case Study: Lodi. ISTAT Census Data 2001

Appendix LODI 2

ISTAT Data _ Census 2001

- POPULATION

Table: Resident population aged 6 and over - Lodi

CITY	Total n° of persons
Lodi	**38939**

Table: Resident population that moves daily - Lodi

CITY	Resident population that moves daily
Lodi	**21075**

Extimated Lodi data

Population estimate in **"winter"** (from September 16th to June 30th)
Night value is equal to the total.
Day value is equal to the total- Resident population that moves daily

Period of the year	day	night
winter	TC_3 17864	TC_4 38939

Population estimate in **"summer"**(from July 1st to September 15th)
Hypothesis of a possible decrease of population due to holidays reasons (4000 persons, 3000 of them are from resident population that moves daily)
Night value is equal to the total- 4000
Day value is equal to the total- Resident population that moves daily + 3000

Period of the year	day	night
summer	TC_1 16864	TC_2 34939

- AVERAGE NUMBER OF STOREYS (buildings)

Table: Buildings for residential use by the number of AVERAGE NUMBER OF STOREYS - Lodi

CITY		N° of floors (by the groundfloor)					
		1	**2**	**3**	**4 e più**	**Total**	
Lodi	**n° of buildings**	234	1884	820	669	3607	
	percentage	6,49	52,23	22,73	18,55	100	%

METHOD OF CALCULATION OF **AVERAGE NUMBER OF STOREYS**

Σ n° of buildings x n° of floors) / total number of the buildins

ATTACHMENT 1

SUFRI PROJECT. WP3 OVERALL STUDY. SUFRI Methodology for pluvial and river flooding risk assessment in urban areas to inform decision-making. Full Methodology. September 2010.

SUFRI
Strategies of Urban Flood Risk Management

WP3

Flooding Risk (3.1.1)

Structural measures for Risk Reduction (3.1.2)

Non-structural measures for Risk Reduction (3.1.3)

Tools for Risk estimation (3.1.4)

Methodology (3.1.5)

Overall Study

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NOTE FOR THE READER

This document is part of the SUFRI project, being compiled by six different institutions. The contained 'Methodology' (3.1.5.) is based on available literature, and draws findings from relevant works. References used are mostly available on the Internet and papers/publications are provided in the "References" section.

This document is in draft form and elements of this methodology may be developed further or changed, based on sharing opinions and experiences with other project partners and research groups related to this area of study. For this purpose, comments and other inputs are cordially invited.

ACKNOWLEDGEMENT

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PROJECT	SUFRI

Sustainable Strategies of Urban Flood Risk Management with non-structural measures to cope with the residual risk

Work package 3

Residual risk and vulnerability analysis

DATE	September 2010

EXECUTIVE SUMMARY

Flooding from rivers, estuaries, the sea or rainfall poses a risk to people and causes significant economic costs. In the 20th century floods accounted for 12% of all deaths from natural disasters, claiming about 93,000 lives across the world (Flood Risk to People, Defra, UK [32]). As a very recent example, in August 2010, the media reported 3 fatalities in Córdoba (Spain) due to extreme rainfall events of 286 mm in just three hours.

The operation of flood defence systems contribute to reduce risks, however flood risks cannot be completely eliminated. Thus, flood forecasting, warning, planning and other non-structural measures are even more significant on reducing flood risk. For this reason, there is a requirement for methods to estimate flood risk (societal and economic risk) and the effect of these measures on risk reduction.

Six project partners from four European countries (Austria, Germany, Italy and Spain) are working within the ERA-Net CRUE initiative for the period of 2009-2011, developing a European project called SUFRI (Sustainable Strategies of Urban Flood Risk Management with non-structural measures to cope with the residual risk).

The main objective of the SUFRI project is to improve flood risk management in case of disaster floods by means of non-structural measures. This project aims to define sustainable flood risk management strategies, including advanced warning systems, vulnerability analysis and risk communication to optimize the disaster control management.

This document is the second of two reports within the third work package entitled "residual risk and vulnerability analysis", providing a tool to characterize residual flood risk in urban areas that can be used to inform strategies to reduce flood risk. In this document, the methodology for applying this tool is developed.

This report is divided into six sections. First, in section *1.1. Flooding risk,* overall concepts on flood risk and the role of structural and non-structural measures are included. Secondly, in section *1.2. Structural measures for risk reduction*, different typologies of retention and protection structures are described, together with drainage systems. Next, in section *1.3. Non-structural measures for risk reduction*, several strategies are identified like urban planning, flood forecasting, communication, coordination, etc. In section *1.4., Tools for risk estimation*, existent methods are classified based on the study of the two components of risk (hazard and vulnerability) and risk quantification; and, section *1.5. Methodology* describes the proposed method (called SUFRI methodology) for evaluating the effect of non-structural measures on flood risk. Finally, section *1.6.* summarises the main conclusions of this work package.

WP3 - RESIDUAL RISK AND VULNERABILITY ANALYSIS

LIST OF CONTENTS

LIST OF FIGURES AND TABLES

NOTATION

A_F	Total flooded area (km²).
$A_{f,i}$	Flooded area for each land use category (CU). $A_F=\Sigma A_{f,i}$.
A_T	Total area of the case study (km²).
w_{df}	Maximum width of the flood area (m).
C	Category for the case study to obtain reference fatality rates (RFR) in river flooding.
C_p	Category for the case study to obtain fatality rates (FR_p) in pluvial flooding.
CD	Direct costs (€).
CI	Indirect costs (€).
CT	Total costs: sum of direct and indirect costs (€).
CR	Reference cost, established for each land use category (€/m²).
CU	Land use category.
d	Density of population at the study area (inhabitants/km^2).
d_C	Density of population to estimate population at risk, from density reduction based on building typology (inhabitants/km^2).
DV	Parameter for the definition of flood severity levels in river flooding (m²/s).
f	Annual probability of exceedance (years^{-1}).
f_C	Factor. Ratio of indirect to direct costs (%).
F	Cumulative annual probability of exceedance (years^{-1}).
FMF	Factor Mode of Failure (hours). Variable for the estimation of the warning time in river flooding (dam failure).
FR	Fatality rate in river flooding.
FRp	Fatality rate in pluvial flooding.
h	Height (m).

h_m	Average-height of buildings (m).
H	Flood depth (m), in river flooding.
m,n,p,q,r	Generic notation for schemes and flow charts.
n_p	Average number of floors, obtained as the mean value of the number of floors of the existent buildings in the urban area.
N	Number of potential fatalities (lives).
PD	Percentage of damage (%).
PR	Population at risk (inhabitants).
$PR_{OUT, IN}$	Population exposed to the flood (outdoors/indoors) in pluvial flooding (inhabitants).
PT	Total population at the urban area (inhabitants).
Q	Flow (m^3/s).
Q_1	First-notice flow (m^3/s). Flow that reaches the capacity of the embankment.
Q_2	First-damage flow (m^3/s). Flow that reaches the first buildings and households.
Q_f	Maximum water flow at the study site in river flooding (m^3/s).
Q_{br}	Peak discharge of the flood scenario related to the failure of the flood defence (m^3/s).
Q_{max}	Peak discharge of the hydrograph for each flood scenario (m^3/s).
Q_{nbr}	Peak discharge of the flood scenario due to non-failure cases (m^3/s).
Q_{pf}	Runoff rate of the flood scenario in pluvial flooding (m^3/s).
RFR	Reference fatality rate in river flooding (related to a category C).
S	Flood severity in river flooding.
Sv	Flood severity in pluvial flooding.
t_{Q1}	Time of occurrence of the first-notice flow, Q1 (hours).
t_{Q2}	Time of occurrence of the first-damage flow, Q2 (hours).
T	Return period (years).

TW	Warning time (hours).
TBR	Time of breach development (hours). Variable for the estimation of the warning time in river flooding (dam failure).
TC	Time category
TD	Range of time between t_{Q1} and t_{Q2} (hours).
Twv	Arrival wave time (hours).
v	Velocity (m/s).
y	Flood depth (m), in pluvial flooding.

ACRONYMS

AEP	Annual Probability of Exceedance
ANCOLD	Australian National Committee on Large Dams
Defra	Department for Environment, Food and Rural Affairs
EAP	Emergency Action Plan
U.S.	United States
FEMA	Federal Emergency Agency (United States)
FHRC	Flood Hazard Research Centre (United Kingdom)
MS	Structural measures
MNS	Non-structural measures
NDS	No Drainage System scenario
RN	Natural flow regime (river flooding)
PFR	Public Education Program on Flood Risk
UK	United Kingdom
USA	United States of America
USACE	United States Army Corps of Engineers

USBR	United States Bureau of Reclamation
UPV	Polytechnical University of Valencia

1.1 FLOODING RISK

1.1.1. GENERAL DEFINITIONS AND COMPONENTS

Directive 2007/60/EC of the European Union [20][1] defines a flood as a temporary covering by water of land not normally covered by water. As this directive explains, this shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems.

During the period 2000 to 2006 the water-related disasters killed more than 290,000 people, affecting more than 1.5 billion, and inflicting more than US$ 422 billion of damage [51]. There are several factors that have led to a rise in the frequency of these disasters, such as natural pressures, climate variability, and social pressures (i.e. escalation of population and settlements in high-risk areas). In general, these flood consequences will be especially important in urban areas.

In the past, the focus was on steps to prevent floods, but in recent years measures to address the consequences have increasingly also been adopted. This reflects recognition that flood can never be absolutely prevented or predicted, so there can always be flood consequences that must be reduced as much as possible.

In order to study the flood threat, the concept of flood risk has been established. Flood risk can be defined as the combination of probability of a flood event, called hazard, and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event [20], called vulnerability. Consequently, flood risk has two main components, hazard and vulnerability.

Hazard is a potentially damaging physical event, phenomenon or human activity that may cause loss of life or injury, property damage, social and economic disruption, or environmental degradation. This part of the risk is often characterized by the individual risk, which is the probability that an average unprotected person, permanently present at a certain location, is killed due to an accident resulting from a hazardous activity [27]. Hazard analysis involves identification, study and monitoring of the hazard to determine its potential, origin, characteristics and behaviour. The main result of the hazard analysis will be the probability of occurrence of the studied hazard.

Therefore, individual risk is based on the probability of being killed of the most exposed person. The units of this risk are number of fatalities per unit of time.

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[1] [ ] indicates the reference listed at the end of this document

On the other hand, vulnerability can be defined as the conditions determined by physical, social, economic and environmental factors or processes which cause the susceptibility of a community to the impact of hazards. Thus, the vulnerability analysis lies in a description of the consequences produced by a defined hazard.

Risk is commonly expressed by the notation Risk = Hazards x Vulnerability. Its units are the ones used for measuring the vulnerability divided per time, for instance a monetary unit or number of victims per year, because the hazard probability usually has units of time^{-1}. When risk consequences are computed in number of victims, resulting risk is usually called societal risk, which is defined as the relationship between frequency and the number of victims in a given population from the realization of specified hazards. Societal risk includes vulnerability, not only hazard characteristics.

Flood risk analysis is a methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that could involve a potential threat or harm to people, property, livelihoods and the environment on which they depend.

Analyzing flood risk to human life and property is essential to achieve its reduction. Flood risk can be analyzed by calculating the probability of an event occurring and the subsequent impact that it has on a receptor. It is important to consider risk in terms of probability and consequences rather than a unique component.

There are many kinds of measures to reduce flood risk. Generally, they are divided into two groups: structural and non-structural measures. Structural measures refer to any physical construction to reduce or avoid possible impact of floods, which include engineering measures and construction of hazard-resistant and protective structures and infrastructures, such as levees or dams.

Non-structural measures are the policies, awareness, knowledge development, public commitment, and methods and operating practices, including participatory mechanisms and the provision of information, which can reduce risk and related impacts [51].

The application of structural measures will handle the consequences until a specific severe event, typically called design event. Beyond, even in the case of perfect behaviour of the structure, there is always a residual risk.

Furthermore, non-structural measures will help to reduce this residual risk, but it cannot be completely eliminated. Subsequently, the residual risk contains the consequences that cannot be avoided by the structural and non-structural measures.

1.1.2. SOURCES OF RESIDUAL/EXISTING RISK IN URBAN AREAS

Flood can be caused by complex interaction of a range of sources, especially in urban areas. In general, there is an event which produces the loss of mission of the measures taken against floods. Hence, a flood will be produced with a certain consequences. The main sources that can cause flooding in an urban area are:

- Rainfall: High-intensity runoff may produce flooding in urban areas. This kind of flood will be more hazardous when the drainage system of the city is not capable to drain all the water effectively.

- River flood: Rivers can burst their banks and inundate urban areas. Although river floods are usually associated with storms, it must be analyzed as a different source of flood risk, because storms many kilometres upstream the urban area can produce flooding, independently of urban rainfall. Furthermore, other natural processes like snow melt can also produce important river floods.

- Maritime flood: Sea can inundate urban coastal areas as a result of natural events as hurricanes, cyclones and typhoons. Furthermore, in the case of urban areas below the sea level, if the structures that protect them are not able to contain the sea water, the flood consequences can be very important.

- Structural collapse: The failure of a structure can produce an important flooding and it may increment flood consequences produced by other sources. For example, the failure of a dam will produce a high incremental discharge in the river. Thus, structural measures for flood risk reduction have typically a double role. This double effect on flood risk is analyzed in detail in section 1.2.

Phenomena such as climate change may indeed increase the flooding risk. Other important hazards to be considered are terrorism, sabotage and vandalism, which can aim to destruction of structures as dams and dikes [26].

1.1.3. THE ROLE OF STRUCTURAL AND NON-STRUCTURAL MEASURES IN REDUCING RISK

As it has been defined in the previous section, residual risk is the risk due to the fact that structural and non-structural measures cannot completely eliminate flood risk.

Structural and non-structural measures are crucial on flood risk reduction, and their reliability and functionality play an important role:

- Functionality of structural measures: All the structural measures (such as dams, dikes, embankments, drainage systems…) are designed for events linked to an annual probability of occurrence. If there is a flood event higher than the design event, the structure will not be able to provide further protection, losing its functionality.

- Reliability of structural measures: dams and dikes prevent consequences as far as they are reliable and, beyond, their breakage would increase flood consequences, linked to a very low or severely low probability of occurrence for each case.

- Functionality of non-structural measures: Non-structural measures reduce flood risk when the flood is produced, reducing flood consequences. In order to get this reduction, measures as proper urban planning, forecast systems, flood pre-characterization models, warning systems and evacuation procedures are applied. The effectiveness of these measures will identify the limit for consequence reduction.

- Reliability of non-structural measures: Trustworthiness must also be analyzed in order to know if non-structural measures will work correctly and achieve the maximum consequences reduction, as their failure can produce important consequences.

The main structural and non-structural measures are studied in chapters 1.2 and 1.3 respectively, analyzing their influence on flood risk.

1.2 STRUCTURAL MEASURES FOR RISK REDUCTION

Structural measures for flood risk reduction are all measures that involve construction of civil works to protect areas against floods. Strategies can vary widely depending on the situation. In general, they can be divided in three groups:

- Retention structures: Their mission is to retain flood water in order to avoid floods with high discharges, which can produce important damages and the failure of protection structures. The most common retention structures are dams and ponds upstream urban areas.

- Protection structures: These structures protect directly urban areas from water, avoiding it to enter inside the city, like dikes, or forcing it to flow faster through the city inside a delimited protected bank, like embankments. These structures provide protection from river floods and also from maritime floods, like maritime dikes.

- Drainage systems: Drainage systems are designed to manage runoff generated in the urban area and their surroundings.

In addition, structures must be designed taking into account the natural river dynamics, understanding its changing nature. Ideally, they must be designed allowing as much as possible the natural behaviour of the river [16].

Structural measures have a really high importance on flood reduction, as they avoid numerous floods. In this chapter, their characteristics, focusing on their advantages, limitations and the potential consequences by their failure, are explained.

1.2.1. RETENTION STRUCTURES

Major retention structures in a river

Major retention structures are mainly dams with very different sizes located upstream urban areas. Their function is to store water for diverse purposes, as irrigation, urban water supply, electrical production, recreational uses, shipping and flood protection through flood routing.

Large dams can store large volumes of water and they provide high protection upstream large urban areas. The most common types of large dams are:

- Gravity dams.

- Arch dams (an example is shown in Figure 1.2.1.).

- Buttress dams.

- Embankment dams.

Dams have an important function as retention structures for flood risk reduction as flood routing reduce peak flows downstream the dam during a severe event. However, flood routing is not always effective, because dams are designed for a certain flood, related to an annual probability of exceedance. If there is a larger flood, the dam may lose effectiveness progressively, but it still provides protection downstream.

Figure 1.2.1. Aldeadávila arch dam (Spain-Portugal).

Consequently, societal benefits of flood risk reduction prevail over the likelihood of a dam failure, as its probability remains in extremely lower values. Nowadays, social pressure is increasing to make a proper assessment of dam safety, due to the significant flood risks. Thus, the approach of traditional risk analysis, which assumes that there is no risk of dam failure due to the high safety factors with which it was built, is being supplemented by a risk-informed approach that considers the risk failure of the dam, which can be identified, assessed and managed although it may seem unlikely [34], since large dams are designed for floods of high return periods (5,000 - 10,000 years).

Minor retention structures close to urban areas

Minor retention structures are located in the upstream area of urban zones, managing flow that would reach the city, reducing peak runoff and storing water during a rainfall event.

These structures may have an outflow control that allows to keep constant discharge levels by retaining water. Otherwise, the pick discharge cannot be fixed to a certain value.

Some examples of minor retentions structures are:

- Stormwater ponds (Figure 1.2.2.): Constructed retention basins that contain water permanently, usually with natural appearance. Runoff is detained and treated in the pool primarily through settling and biological uptake mechanisms.

- Detention basins: Free areas that get flooded during storms, by storing water for a short period of time. They are typically less costly than stormwater ponds for equivalent flood storage, as less excavation is required. They vary from a simple field to an inundated area controlled automatically with outlet works.

- Underground retention structures: Their aim is to also reduce peak discharges. They may allow infiltrations into the soil, or they may be impermeable, returning the stored water at controlled rates.

Retention structures can be constructed for floods with very different return periods, from 1 to 100 years [5]. Since these return periods are not very high, risk assessment will be crucial to understand the consequences of a loss of effectiveness.

Figure 1.2.2. Stormwater pond.

1.2.2. PROTECTION STRUCTURES

<u>Direct protection from flooding</u>

Their main function is to prevent flooding of the adjoining countryside. Therefore, these structures are usually located along the sea, rivers, channels, lakes or polders. The most common are:

- Dikes: They are built following the river, sea or lake natural profile. Sea dikes are usually built as a mound of fine materials with a gentle seaward slope in order to reduce the wave run-up and the erodible effect of water.

- Walls: Vertical structures with the main function of preventing overtopping and land flooding. Walls range from vertical face structures, such as massive gravity concrete walls or stone-filled cribwork, to sloping structures, with typical surfaces being reinforced concrete slabs, concrete armour units or stone rubble [52]. Seawalls are built parallel to the shoreline.

- Dune construction: This structural measure for maritime protection relies on piling up of beach quality sand to form protective dune fields to replace those washed away during severe storms. Dune vegetation is essential to help dune reconstruction in order to retain wind-blown sand.

- Storm-surge barriers (Figure 1.2.3): These structures are a combined system of dikes and gates. Gates are sliding or rotating steel constructions supported in most cases by concrete structures on pile foundations. They protect estuaries against storm surge flooding and related wave attack.

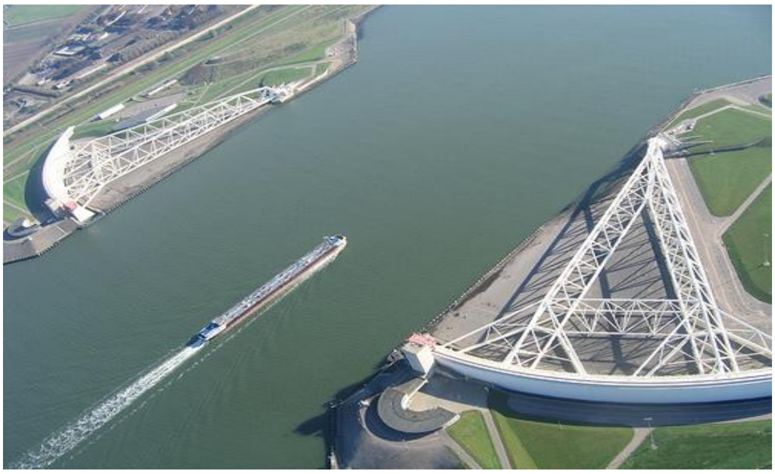

Figure 1.2.3. Storm-surge barriers in The Netherlands.

In this group of structures for direct protection from flooding, measures in buildings and infrastructures to protect them against flooding are also included. These measures change materials on buildings or infrastructures, or their configuration, with the purpose of decreasing flood risk. Some examples of these measures are [33]:

- Waterproof sealing: Using impervious construction materials and improving building configuration.

- Fortification of basements: Improving materials used on ground floors and using an especially stable building foundation, in order to avoid a collapse as a consequence of severe floods.

- Flood adapted use: Changing the use of lower building areas to decrease flood consequences. This measure could be considered a non-structural measure.

Retention structures reduce flood risk because they form a barrier for water entering during severe events and their design is defined for a certain return period.

Maritime defences are designed for the maximum wave height associated to a return period, which ranges from 25 to 5,000 years, depending on their economic importance and potential failure consequences, especially in areas located under the sea level.

Design of rivers and channels protection depends on the high-flows distribution. Return periods are usually lower than in maritime defences. They can vary from 5 to 1,000 years.

Severe events related to these return periods define the limits of the structure effectiveness. Therefore, flood risk cannot be completely removed with these structures.

Modification of river characteristics

These protection structures change river morphology in order to increase its drainage capacity in urban areas, reducing flood consequences. These measures act as an indirect protection and they can also be considered part of the drainage system.

The main structural measures that change river characteristics are:

- River bed widening: This measure relies on widening the river bed to achieve more space in the river bed, decreasing its water depth for the same discharge.

- Change of river bed roughness: With lower river roughness, water flows faster through its path, as a result, lower water levels are obtained (i.e. acting on river bank vegetation).

- Embankments (Figure 1.2.4): This measure consists of creating a new river bed to contain water in its path through the area. Embankments reduce significantly flood risk, although these structures are more destructive from the environmental point of view.

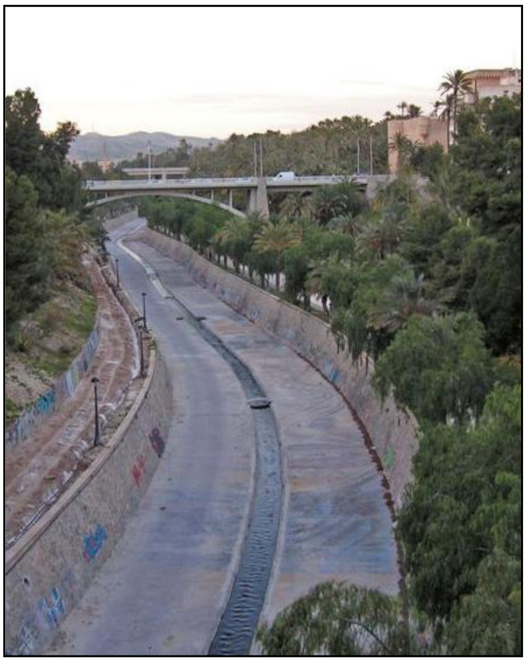

Figure 1.2.4. River embankment in Elche (Spain).

- New channels: Based on diverting water from the river when there is a high flood risk, with the purpose of avoiding high discharges in urban areas.
- Change of river catchment characteristics: Reforestation of the catchment area increases water interception and reduces peak flows.

Usually these structures have been designed with return periods from 5 to 1,000 years, depending on the consequences of the structure failure, related to the exceedance of the structure capacity.

1.2.3. DRAINAGE SYSTEMS

Conventional drainage systems

The drainage system of a city collects the rain water, and it includes a complex system of structures like sewers, channels, pipes, manholes, pumping stations, etc. There are two main categories of drainage systems:

- Combined system: This system collects the domestic foul water and the surface rain water in the same sewerage, thus rain water gets more polluted. It is designed for the sum of both discharges, although the maximum discharge from rainfall water is usually much higher.
- Separated system: There are two different sewer systems: one for surface rain water and other for domestic foul water. The first drainage system is larger and it can be superficial, because the water inside is cleaner.

Drainage systems have very different levels of complexity: from channels to complex systems such pumping stations, combined with other structural measures for flood protection. All these elements will affect the capacity of the drainage system.

Two different drainage systems can be distinguished in urban areas. On one hand, the designed sewer system or minor system. On the other hand, the major system, which drains the above ground or exceedance flow [7]. High exceedance flows will produce urban flooding when the minor system reaches its maximum capacity.

Traditionally urban drainage systems are designed to meet a specified level of service, related to a return period of severe flooding, which varies from 2 to 30 years depending on local rules. However, existing drainage systems typically do not achieve the level of service required for new systems, due to structural deterioration of the network or due to additional flows from expanding urban areas. Nevertheless, these systems must avoid very frequent floods.

Sustainable drainage systems

Sustainable Drainage Systems (SuDS) are innovative systems developed in line with the ideals of sustainable development. At a particular site, these systems are designed both to manage the environmental risks resulting from urban runoff ant to contribute wherever possible to environmental enhancement. SuDS objectives are, therefore, to minimize the impacts from the development on the quantity and quality of the runoff, and maximize amenity and biodiversity opportunities. The philosophy of SuDS is to replicate, as closely as possible, the natural drainage from a site before development [39].

Peak runoff gets higher in conventional new urbanized areas, as pavement usually reduces infiltration and it has less roughness than the natural floor. These higher runoff peaks can raise significantly the river discharge. Detention structures will decrease these values as it is shown in Figure 1.2.5.

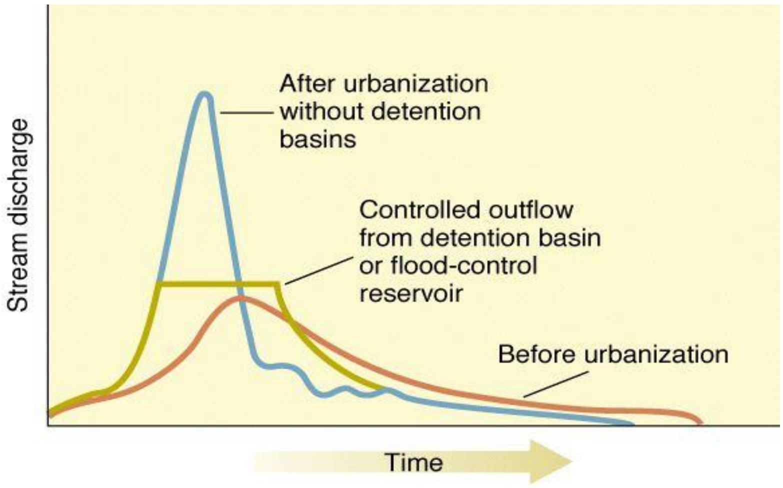

Figure 1.2.5. Hydrograph with and without a detention basin in an urban area.

SuDS design should aim to reduce runoff by integrating stormwater controls throughout the site in small, discrete units. Through effective control of runoff at source, the need for large flow attenuation and flow control structures should be minimized [39].

The most common structural SuDS are [5], [54]:

- Greenroofs: A multi-layered system that covers the roof of a building or podium structure with vegetation over a drainage layer. They are designed to intercept and retain precipitation, reducing the volume of runoff and attenuating peak flows.

- Bioretention areas: Structural stormwater controls that capture and treat stormwater runoff from frequent rainfall events. The water quality volume is treated using soils and vegetation in shallow basins or landscaped areas to remove pollutants.

- Filter strip: Uniformly graded and densely vegetated sections of land, designed to treat runoff and remove pollutants through vegetative filtering and infiltration.

- Enhanced swales: Vegetated open channels that are explicitly designed to capture and treat storm water runoff within dry or wet cells formed by check dams or other means.

- Sand filters: Multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay, a sand bed as its primary filter media and, typically, an underdrain collection system.

- Detention basins and stormwater ponds: Retention structures already described in section 1.2.1.

- Underground retention structures: These structures allow water retention in the subterranean soil, reducing the peak of the discharge by storing water.

- Infiltration trenches: Shallow excavations filled with rubble or stone that create temporary subsurface storage for infiltration of stormwater runoff into the surrounding soils. Ideally they should receive lateral inflow from an adjacent impermeable surface.

- Pervious pavements: Provide a pavement suitable for pedestrian and/or vehicular traffic, while allowing rainwater to infiltrate through the surface and into the underlying layer. Water is temporarily stored before infiltration, reuse, or discharge to a watercourse or other drainage system.

SuDS have also capacity limits, since they are not conceived to drain severe events. Their capacity is limited by either the inflow, for example the inlet capacity of a pervious pavement, or the volume of storage of the retention structures.

In addition, water surface pathways (streets, channels…) can be considered as a retention structure, as they have some water storage capacity, reaching lower flow peaks, but producing unexpected flow depths and velocities.

1.2.4. STRUCTURAL MEASURES AND FLOOD RISK

The main purpose of structural measures is evidently reducing flood risk, but there is a certain probability of failure.

Failures of a structural measure can be classified in two groups:

- Capacity failures: The structure has not enough capacity to provide protection against floods and they depend on the natural environment, thus, there is an important probabilistic component of uncertainty. This kind of failure depends on the functionality of the structure.

- Breakage failures: This failure depends on load uncertainty and it is determined by the characteristics and state of the structure, and its reliability. It is more relevant in dams and dikes, due to the potential consequences, but the annual probability of exceedance of the event that produces dam breakage is extremely low.

The first group covers drainage systems, embankments, protection of buildings and most of the urban retention structures as their failure mainly depend on the design event.

Structures from the second group reduce flood risk, increasing protection of urban areas, but there is an incremental risk due to a certain failure probability of the structure. Therefore, risk reduction is obtained from the difference between the original flood risk and the existing flood risk with the structure, adding the incremental risk because of its existence (Figure 1.2.6.).

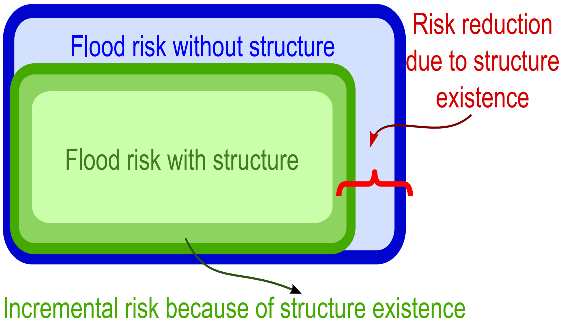

Figure 1.2.6. Dam effects on flood risk.

The effect of these structures on flood consequences as a function of the inflow flood is shown in Figure 1.2.7. The green line shows flood consequences with the structure; the black line shows consequences without the structure and the yellow line shows consequences in case of failure. The vertical blue line indicates the design flood.

Inflow floods higher than flood design have the same consequences with or without the structure, giving rise a capacity failure, and the red area shows the increment of consequences when a failure occurs for an event in that range. Incremental consequences due to a failure for inflow floods lower than the design value are marked in blue. Incremental risk is the sum of both areas and it should be limited and analyzed [15].

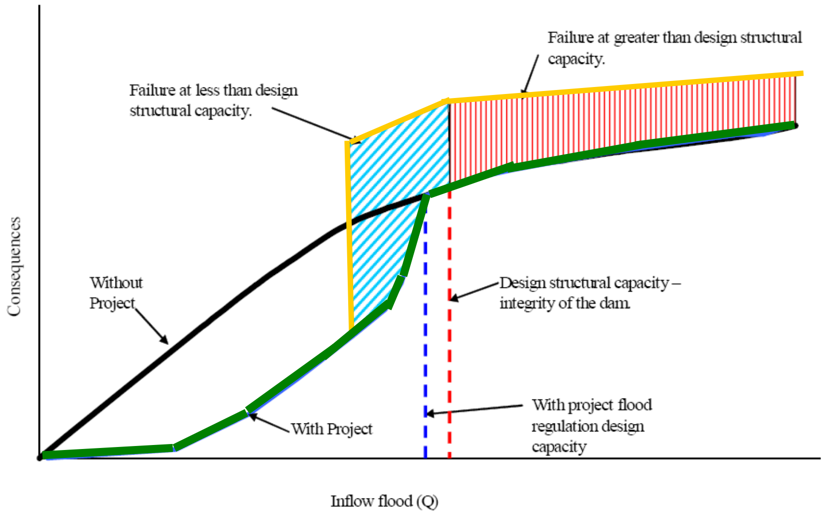

Figure 1.2.7. Flood consequences in function of the inflow flood and the structure failure [32].

In general, the existence of these structures will reduce flood risk, but an increase on risk may be produced when:

- The probability of a structural failure is high, along with a deteriorated state of the structure.
- Reduction of flood risk in some areas has produced the increment of the urbanization due to a decrease in flood risk perception. Then, a proper urban planning normative will solve it, as is described in section 1.3.
- A structural failure occurs in areas that can only be flooded by this source of risk.

1.3 NON-STRUCTURAL MEASURES FOR RISK REDUCTION

Non-structural measures for flood risk reduction do not involve construction of civil works. They refer to policies, awareness, knowledge development, public commitment and methods and operating practices, including participatory mechanisms and the provision of information [24].

In the previous chapter, structural measures for flood risk reduction have been explained. They are usually designed for a hypothetic severe event, with a probability of exceedance, related to the failure of the structure. However, non-structural measures can also reduce significantly flood consequences. Therefore, non-structural measures must be developed to reduce notably population vulnerability from previous planning before the flood event.

There are several groups and classifications of non-structural measures, in this document they have been divided into six general groups:

- Urban planning and policies
- Flood forecasting
- Communication
- Mobilization
- Coordination and operating practices
- Insurance and aids mechanisms

Last section explains their limitations as they cannot eliminate completely flood risk, as a residual flood risk will exist, which must be reduced as much as possible.

1.3.1. URBAN PLANNING AND POLICIES

In most urban areas, buildings and infrastructures have occupied potential flooding areas that are now urbanized due to a decrease of flood risk perception after the construction of new structural measures, changing the natural river dynamics and increasing flood risk.

Therefore, proper urban planning can reduce risk by discouraging settlements and construction of key installations in hazard-prone areas. This measure requires the development of urban planning normative that restricts constructions and land uses in areas of high flood risk. These limitations can vary from the banning of certain land uses (like residential, industrial…) to requirements in relation with materials and new structural elements to resist against floods.

Furthermore, concise normative regarding with drainage systems is necessary to establish different return periods and identify flood paths for these values in order to avoid future damages (i.e., overflows directed to a surface parking area or a garden instead to a building with underground floors). This urban planning normative must be accompanied of proper tools for flood risk estimation, as described in section 1.4.

In addition, urban planning in river areas must be based on conservation and sustainability. Afterwards, river behaviour must be as similar as possible to the natural river dynamics, as urban planning must respect natural flood plains, dividing the river bed area in different zones [16].

On the other hand, urban planning policies must be accompanied with education of the population in flood risk, with the aim of increasing the effectiveness of urban planning restrictions adopted for flood risk reduction [22], based on land use restrictions and leaving potential flooding areas not completely urbanized.

1.3.2. FLOOD FORECASTING

Forecasting is the estimation of the occurrence of a future event using measured data and knowledge of the environment. Therefore, flood forecasting is the estimation of stage, discharge, time of occurrence, and duration of a flood, especially of its peak discharge, at a specified point on a stream, resulting from precipitation and/or snowmelt.

Flood forecasting is an important tool for reducing flood risk, combined with suitable warning systems and evacuation procedures, flood consequences can decrease considerably. In addition, it can be very useful for managing of structural and non-structural measures. For instance, if a heavy rainfall event is predicted in the river catchment, dams can be managed to reduce flood impacts downstream and temporal barriers can be set to protect urban areas.

The period of time in advance is the time interval from the event has been forecasted until the event starts. This time is crucial to manage measures, and it is called warning time or forecast lead time. A larger warning time will increase the effectiveness of the established measures for avoiding flood consequences; however, forecasts will be less accurate.

Flood forecasting has two main steps. The first step is weather forecasting and relies on science and new technology to predict atmospherical state for a future time and a given location. Flood pre-characterization models are the second stage, considering future weather situation to predict floods, by means of hydrological models. The combination of both phases (from cooperation between meteorological and hydrological communities) is crucial to get accurate flood forecasting [38].

Weather forecasting

Weather forecasting will be the input for flood pre-characterization models in order to predict floods before their occurrence and the main methodologies are [9]:

- *Persistence method*: This is the simplest method of performing a forecast and it predicts that weather conditions in the future will be the same that present conditions. Thus, this method is suitable in places without important seasonal variations.

- *Trends method*: This method determines the speed and direction of movement for fronts, high and low pressure centres, and areas of clouds and precipitation. Using this information, it is possible to predict where those features are expected to be at the future time. It is especially used for rainfall predictions, only a few hours into the future.

- *Climatology*: This methodology involves averaging weather statistics accumulated over many years. It is suitable when the weather pattern is similar to that expected for the chosen time of year, but not appropriate for severe events.

- *Analog method*: This method analyzes forecast scenario today with the aim of relating it to another day in the past, when the weather scenario was very similar (an analog scenario).

- Numerical weather predictions: Forecast models (complex computer programs) provide predictions on many atmospheric variables such as temperature, pressure, wind and rainfall. Then it is analyzed how these features will interact to produce the weather today. Models and input data are not completely precise, consequently their uncertainty should be considered.

Depending on each methodology, weather forecasting uncertainties will vary. As there will always be an important level of uncertainty, this must be analyzed and delimited, with the aim of managing and making decisions correctly.

Flood pre-characterization

This measure relies on estimation of stage, discharge, time of occurrence and duration of a flood, at a specified point, using weather forecasting data. These systems estimate continuously water characteristics to assist flood risk management.

In general, this procedure analyzes superficial water pathways like rivers, streams and runoff processes, by means of hydrological and hydraulic models, which will define flood characteristics in each point. These models are used continuously, thus the stage and discharge in rivers and streams is predicted and checked incessantly, enabling to predict floods in any moment, being a very suitable tool for the decision making.

The main input data in these models are [41]:

- *Physical data*: Characteristics of watershed, river bed, relief, structural measures and urban areas.
- *Weather measured data*: These models use a network of meteorological stations (gauges) to implement current weather characteristics, especially rainfall.
- *Weather forecasting data*: Data obtained from forecasting are introduced in the model for flood predictions.
- *Stream gauges data*: A network of stream gauges to check and improve flood predictions.
- *Management manoeuvres*: The affections of the structures management manoeuvres must also be known and considered in predictions.

In addition to hydrological models, maritime models predict the state of the sea and tides, being extremely useful to reduce maritime flood risk. Severe maritime events are usually defined by the maximum wave height, which implies an important statistical treatment of data, because wave height distributions can have important variations [39]. In this case, special weather measurements (i.e. data of pressure and wind speed) and forecasts are necessary to predict maritime dynamics.

In conclusion, these models must be verified and validated with directly measured data, in order to correct processes, model parameters and final results. Model limitations depend on the inaccuracy of input data and their parameters, although they are a very useful tool for structural and non-structural measures management and the decision making process.

1.3.3. COMMUNICATION

Communication to the public is a key process to reduce flood risk and it is divided into two groups. On one hand, general flood risk communication to the population will provide a better understanding on the existing flood risk, and action procedures during a flood will be known. On the other hand, the communication process during a flood event will focus on reporting people about the impending hazard from warning systems.

General communication

Risk communication must be carried out continuously through knowledge development and provision of information awareness, with the aim of reaching public commitment.

The main part of the general communication is public education, which relies on communicating the existing flood risk in normal situations. Thus, people can learn how to act when a severe event happens. This continuous process must reach especially population located in areas with a high flood risk.

An education programme on flood risk should include [7]:

- Concept of return periods, together with probability and impact of climate change.
- Understanding on sustainability and effectiveness of structural measures, as their design for floods of very high return periods is not cost effective.
- Knowledge on flooding risk control and minimization.
- Procedures to be followed during a flood and actions that must be avoided.

In conclusion, evacuation procedures will reach lower flood consequences (in terms of human loss of life) if the previous aspects are correctly performed.

<u>Communication during a flood event: Warning systems</u>

Flood warning relies on cautioning population about an imminent flood. A proper warning system will decrease significantly loss of life in catastrophic events as these systems are crucial to initiate and develop the evacuation process, combined with a correct public education.

Warning systems must be initiated when forecasts predict a flood with important consequences or when a structural failure (i.e. a dam failure) will occur in a short period of time. Task forces and government institutions that are in charge of emergencies management [40] will define the moment for evacuation procedures, following the indications of designed Emergency Plans. Different emergency levels are set depending on probability of occurrence and flood magnitude.

People at risk can be warned either by direct perception of the threat (i.e. increase on water levels) or indirectly by other sources such as [27]:

- Media: television, radio, internet, etc.
- Warning systems: loudspeakers or sirens.
- Personal dissemination: by emergency personnel or social networks.
- Other communication systems: (mobile) telephone calls or text messages.

The effectiveness of these systems depends on their characteristics and it differs among the aforementioned sources. In general, this effectiveness is determined by the level of preparation and the possibilities for communication between authorities and public, but it also depends on the warning time.

1.3.4. MOBILIZATION

Mobilization procedures are measures that involve direct work of task forces and emergency services to reduce flood consequences, like evacuation processes. These procedures can be classified in three different categories depending on the time available for the evacuation [27]:

- Preventive evacuation: Evacuation before occurrence of the event. As an example, preventive evacuation of a flooding area before dike breach.

- Forced evacuation: Evacuation during event development towards an area where people are not exposed to physical effects.

- Escape: Movement of people through an exposed area, being affected by water physical effects related to the impending flood (i.e. reduction of walking speed or sustained injury).

Organization levels vary considerably within these three categories. In the first case, flood pre-characterization systems have given information in advance and loss of life will be lower. However, in the third case, mobilization is less organized and a high number of fatalities can be produced.

Evacuation plans in areas of high flood risk will define evacuation procedures and the role of each task force, authority and emergency service [21]. The efficiency of these evacuations will depend on the effectiveness of warning systems and the time available for evacuation before flooding, being mandatory for the most catastrophic cases. These aspects are explained in section 1.3.5.

In addition to evacuation procedures, temporal barriers can reduce flood consequences considerably as they are used to avoid water entering urban areas when a flood is coming up or to reinforce other structural measures (Figure 1.3.1). The effectiveness of these barriers will depend on the time available before flood arrival, proper planning and availability of personnel and materials (i.e. sand sacks).

Figure 1.3.1. Settlement of sand sacks to reinforce dikes in Rumania in 2006.

1.3.5. COORDINATION AND OPERATION PRACTICES

The main objective of coordination practices relies on improving communication between different organizations and stakeholders with an important role in flood risk management. These measures are classified in two groups. The first one describes measures to facilitate coordination between all agents involved, developing plans for emergencies and defining strategies to reduce flood risk, which include operation practices. The second group includes measures for a correct coordination during emergencies, improving the effectiveness of other non-structural measures.

Procedures for general coordination

The first objective of these measures is the definition of the procedures during an emergency event and the role of each task force and administration. The second objective is to enable the coordination between administrations to make decisions for flood risk reduction and to avoid contradictory measures of different organisms.

These measures depend severely on the administrative structure, legislation, institutions and stakeholders of each area, thus specific recommendations are not suitable. Some examples of general coordination measures are:

- Organism for flood management: Creation of a specific organism for flood management and risk reduction [17] [13]. In this organism, all the institutions and stakeholders must be represented.

- Flood risk management plan [6]: European Directive 2007/60/EC [20] establishes the obligation of developing flood risk management plans to fix objectives for flood risk reduction and to coordinate all the administrations.

- Emergency plans [13]: They define the procedures during a disaster and the role of each task force in order to reduce consequences, designed for a structure failure or general flood emergencies.

These measures improve the effectiveness of the rest of structural and non-structural measures, as coordination is crucial to reduce risk successfully.

<u>Procedures for coordination during flood events</u>

Coordination measures during a severe event will reach an effective communication between agents, the correct behaviour of warning systems and evacuation procedures.

A hierarchy for emergencies must be established to improve the results of other measures. The main coordination measures must be implemented between:

- Weather forecasting and flood pre-characterization: Weather forecasts must be continuously sent to agencies in charge of flood pre-characterization models.

- Flood pre-characterization and warning systems: A proper coordination between these entities will allow to notify warning to the population with enough time.

- Warning systems and evacuation: Warning systems must inform task forces to evacuate population at risk as soon as possible in an impending flood.

In conclusion, a proper coordination between the entities in charge of these measures will help to increase the time available for mobilization, and consequently flood consequences will decrease, together with flood risk.

1.3.6. INSURANCES AND AIDS

The existence of appropriate schemes of insurance and aids is necessary for post-flood recovery. On one hand, insurances involve the distribution of risks and losses over a high number of people. On the other hand, aids will compensate losses not covered by insurances. These mechanisms will help flood victims in recovering after damages and regain livelihood [35].

Proper insurance schemes will reduce flood indirect consequences. Losses should be paid promptly to re-establish the previous situation. In developed countries, insurers are the main mechanism to fund disaster loss issues [32]. Properties located in flood-prone areas may be paid higher insurances to obtain compensations after a flood.

However, disaster aid is based on voluntary solidarity contribution, national assistance, and international help. It is essential to restore livelihood and employment of survivors, and these mechanisms must be planned before flood occurrence.

1.3.7. NON-STRUCTURAL MEASURES AND FLOOD RISK

Non-structural measures are efficient and sustainable methods of reducing flood risk, but there will be some residual flood risk, whose value depends on the reliability and functionality of these measures:

- Functionality defines the maximum reduction on consequences due to their limitations. In some cases, warning systems or evacuation procedures do not achieve to move all people at risk.

- Reliability defines the possibility of a failure on its structure or procedures. For example, there might be an error in the warning system or a failure in flood pre-characterization models.

1.4 TOOLS FOR RISK ESTIMATION

Risk was defined in section 1.1 as the combination of a hazard probability and the vulnerability of an affected area, which is a measure of the consequences of this hazard. Afterwards, flood risk can be computed by multiplying both components, thus risk units depend on the values used for estimating probability and consequences.

Tools for flood risk estimation compute a general value of risk in order to assist on management of flood risk reduction measures. However, flood risk tools are not as developed as other methods are in nuclear and aeronautical industries [15].

These tools can be divided in partial, if they only evaluate either hazard or vulnerability, or complete, if they evaluate both components. Additionally, they can be classified depending on whether they provide or not a numerical value for the risk (quantitative or qualitative).

PARTIAL AND QUALITATIVE

These tools are the simplest methods for flood risk estimation and generally they are based on the experience and knowledge of the reality, without estimating a numerical value for probability or consequences.

There are some limitations as they do not provide a whole knowledge of the existing risk. Therefore, in some cases, they can produce wrong conclusions about the requirement of applying measures for risk reduction. For example, the estimation of the flood probability in two areas with different population density will show the same priority for risk reduction, although consequences will differ considerably.

These tools can be divided in two groups, depending on the part of the risk equation that they characterize.

First, tools for the estimation of hazard probability are usually based on historical flood events, defining the flood occurrence in terms of past events (Figure 1.4.1). They can also use simplified hydrological and hydraulic calculations, without making a detailed computation on probability of exceedance.

However, when the method is focussed on consequence estimation, it will be crucial to define areas with potential loss of life and, in a similar way, to estimate direct economic consequences of flooding, from different qualitative levels of potential consequences depending on the land use.

Qualitative tools for measuring flood consequences could be the only option to estimate environmental and cultural losses [4], being widely used to describe social trauma and indirect economical effects of floods.

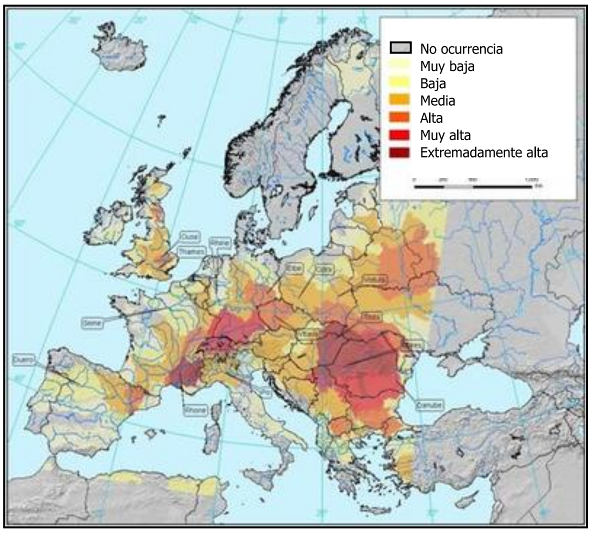

Figure 1.4.1. European map of the levels of flood occurrence in the river catchments, based on historical flood events in the period 1998-2005 [12].

In general, these tools are usually represented as a description of past events, lists of consequences or maps in a large scale, but they cannot provide inundation maps in a detailed scale (Figure 1.4.1). More detailed results should be performed from a quantitative analysis. However, they may assist a preliminary flood risk assessment, since historical flood events and environment knowledge are the basis for detailed flood risk assessments.

1.4.1. COMPLETE AND QUALITATIVE

These methods estimate both risk components by means of a combination of qualitative methods to obtain flood components separately.

One of the most common complete and qualitative tools are risk maps, which are obtained by combination of a quantitative estimation of flood occurrence, using hydrologic and hydraulic models, and a qualitative consequence estimation (Figure 1.4.2). Therefore, risk levels are obtained directly quantifying only one component.

These methods identify areas where measures for flood risk reduction may be applied in first place, being a useful tool for planning and managing. However, their lack of accuracy, especially due to the estimation of consequences, should be considered as a limitation with regard to other analyses.

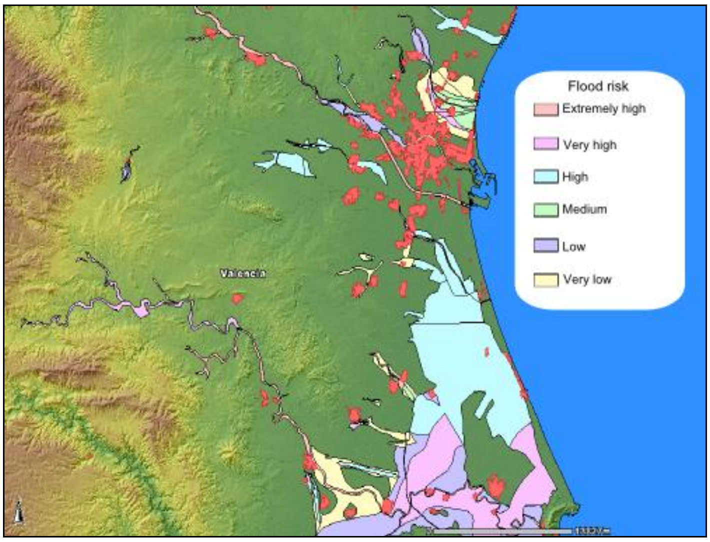

Figure 1.4.2. Flood risk map in the area of Valencia (Spain) [7].

1.4.2. PARTIAL AND QUANTITATIVE

These tools compute numerically one of the risk components: probability of occurrence or consequences. They perform a numerical approximation of risk, but they have the same limitations related to partial analyses.

Flood hazard maps are the most common method (Figure 1.4.3) and define the inundation area for different flood events, with an annual probability of exceedance. Therefore, they provide the probability risk component, without considering flood consequences.

The general process that must be followed to develop flood hazard maps is [49]:

- Historical analysis: Historical floods and variations of the river morphology must be studied using aerial photos and other records.
- Geomorphologic analysis: A proper study of the morphology and geology of the potential inundated area is crucial to analyze flood behaviour.
- Hydrological studies: Frequency and magnitude of floods are analyzed statistically to estimate their magnitude associated to each probability of occurrence.
- Hydraulic modelling: When geomorphological analysis and flood magnitude are known, a correct hydraulic model provides the inundated area.
- Calibration and comparison: The hydraulic model must be calibrated and its results compared with historical flood data.

There are tools that compute only flood consequences and they can be useful to make a first approximation to the consequences of a severe flood. Methodologies will depend on the estimated consequences: economical losses or loss of life.

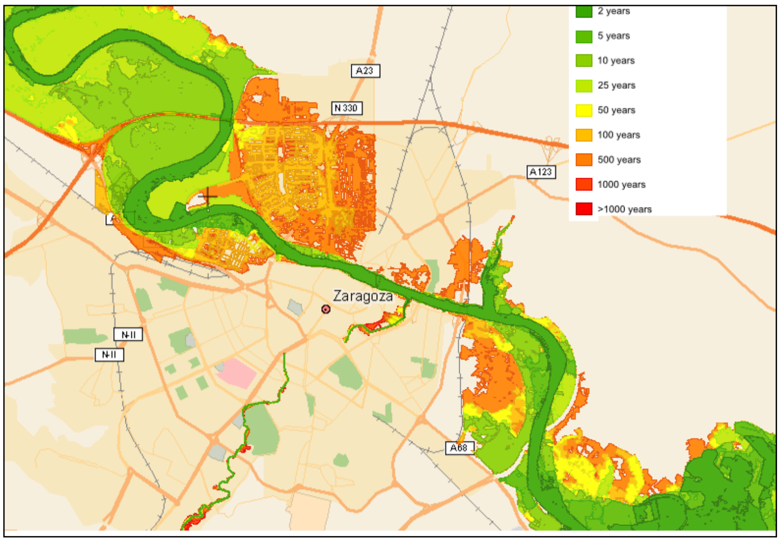

Figure 1.4.3. Hazard map for different floods defined by its return period in Zaragoza (Spain) [29].

Data from the expected loss of life for different historical flood events show that the average event mortality rates are quite constant for each flood [30]. Consequently, most of the methodologies rely on the application of constant mortality rates to the population at risk. Currently, other more sophisticated methodologies include warning and evacuation procedures and shelters resistance, such as the methodologies proposed by Jonkman [27], Reiter [46] and the model LifeSIM developed in GIS [8].

Regarding with the estimation of economical consequences, most of the existing methodologies are based on original works of Kates [31], using water depth as a basic parameter and depth-damage curves to estimate direct economical losses depending on the land use [13]. More recent methods are supported by GIS and use depth-damage calibrated curves for different sectors (industry, services, sales, single family homes, multifamily housing and vehicles). In general, indirect costs are calculated as a fraction of the direct costs.

1.4.3. COMPLETE AND QUANTITATIVE

These tools obtain a numerical value of both risk components with the final purpose of obtaining a numerical value for flood risk, multiplying both values: probability and consequences.

These tools rely on combining the computation of hazard maps and the estimation of flood consequences. Flood risk must be defined for an area which depends on the level of detail of the analysis to apply measures for risk reduction. In each defined area, the probability of inundation with a given depth is obtained and consequences are estimated. The sum of the resulting products of the probability of occurrence and consequences of each flood event will give the total flood risk in the area. In general, risk units are the one used for measuring the consequences divided per time, for instance a monetary unit or number of victims per year, as the hazard probability usually has units of time^{-1}.

Currently, risk analysis methodologies are being developed for structural measures, like dams and dikes, computing the incremental flood risk due to the existence of these structures.

A tool for computing total flooding risk in urban areas could be based on flood risk maps, dividing the area in small cells and drawing a map with the risk value of each unit [27]. The total flood risk of the area will be the sum of the results of each cell. Currently, these maps need detailed methodologies, thus flood risk maps are usually a combination of hazard maps with a list of points with high damages and the quantifications of these consequences for each flood [13]. Although these maps and lists can also be considered a complete and quantitative tool, they do not provide a numerical value for flood risk.

F-N curves are an example of complete and quantitative tools (Figure 1.4.4). These curves represent the relation between the probability of occurrence of a hazard and the number of victims. The area under this curve is the total societal risk. These curves are obtained simulating hazards with different probability of occurrence and estimating the number of fatalities. In addition, these curves can also be performed for economical consequences.

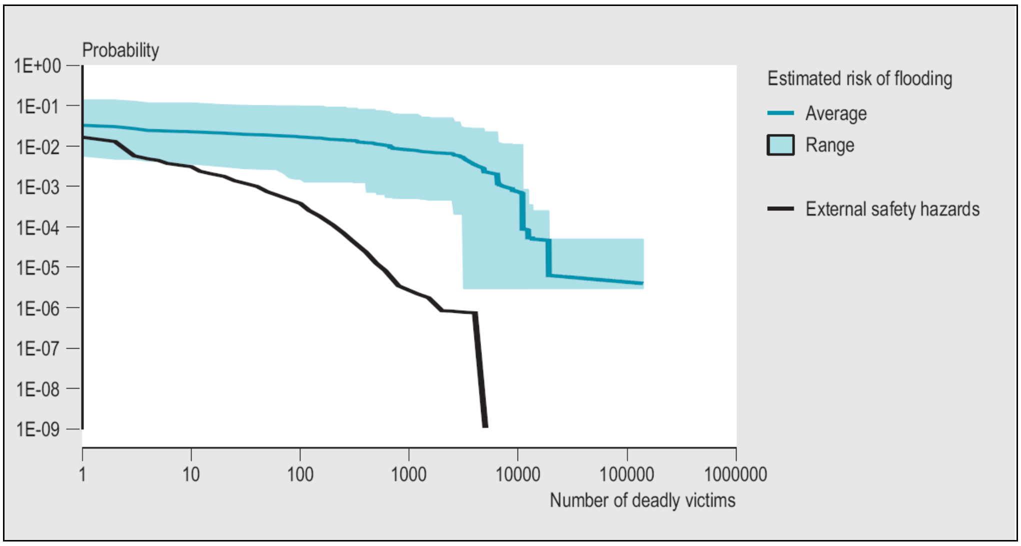

Figure 1.4.4. Societal risks of flooding in The Netherlands and sum of external safety risks [33].

1.5 METHODOLOGY

The purpose of this chapter is to describe a methodology for flood risk analysis in urban areas (river and pluvial flooding) and summarise the calculation procedure. Risk quantification is developed by using a software based on influence diagrams and representation is performed by F-N curves (annual exceedance probability for each value of flood consequences).

1.5.1. OVERVIEW

As it was described in previous chapters (1.1 to 1.4), risk is divided into two components: probability and consequences (vulnerability).

This methodology describes how to estimate probabilities and potential consequences of flood events. Thus, different study scenarios of the urban area can be compared to evaluate the effect of non-structural measures on flood risk reduction (Figure 1.5.1).

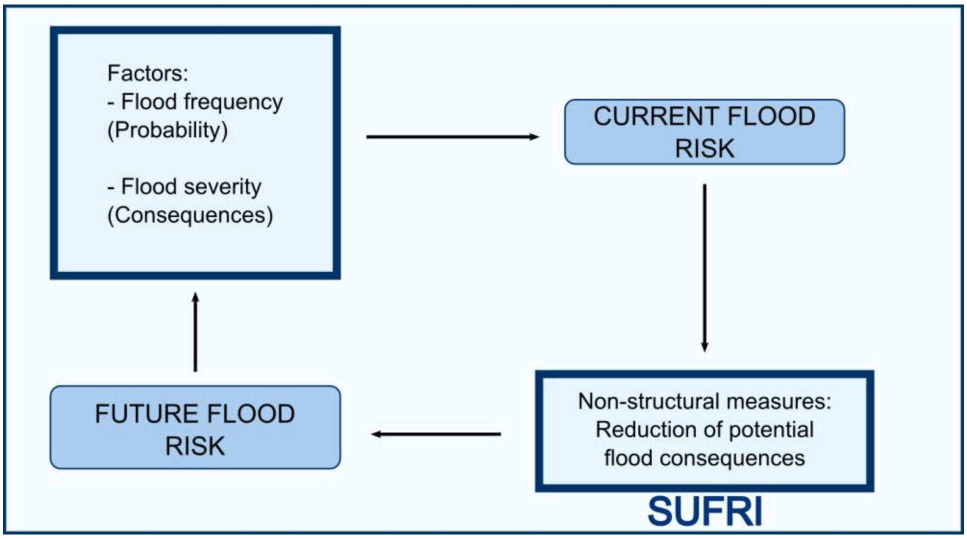

Figure 1.5.1. Scheme of interaction between flood risk and non-structural measures. (Developed specifically for SUFRI methodology).

In this point, some key concepts and definitions are listed below:

1. Geographic study area. Area that covers different urban areas, located along a river course or downstream a large dam or other flood defence systems.
2. Case study. City or group of population, taking into account the total area or a particular zone. It should include all areas with potential flood

damage in case of flooding. In general, the whole urban site is considered.

3. Flood scenarios. Flood events that are considered to estimate potential consequences as input data for the risk model.

4. Structural measure. Flood defence system or infrastructure that acts on flood mechanisms and propagation, modifying their characteristics.

5. Non-structural measure. Flood management system or policy that modifies the vulnerability of an area or population in case of flooding.

6. Base-case. It represents the current situation of the case study, including current structural and non-structural defences. The analysis of the base-case provides flood risk results for the urban area in the present moment.

7. Study scenario. For a defined urban area, study scenarios are determined by the number of non-structural measures or alternatives that are considered to compare the effect of non-structural measures with the current situation of the case study.

1.5.2. STATE-OF-THE-ART

In this section, several of the so-far developed methods of risk analysis are included as a reference for SUFRI guidelines that will be provided in the next section (1.5.3).

1.5.2.1. METHODS TO ESTIMATE CONSEQUENCES DUE TO RIVER FLOODING

Loss of life

There are different methods for the estimation of loss of life due to river flooding. These methods are based on historical floods and statistical studies (Graham, 1999 [24] or Jonkman, 2007 [27]), together with parameters that characterize the flood event and the vulnerability of the flooded area (Reiter et al, 2005 [14][46]).

During the last decades some methods have been performed, they combine flood simulation with aspects like loss of shelter, warning and evacuation. Some examples are listed here: LIFESim model (Utah State University, U.S.A.) or LSM (developed by BC Hydro, Canada). Several entities and institutions are now working in this scope like the Department of Homeland Security (DHS, U.S.A.), United States Bureau of Reclamation (USBR) or United States Army Corps of Engineers (USACE).

Results and recommendations of the DSO-99-06 procedure (Graham, 1999 [24]) on life-loss estimation due to dam failure are included in that method as the procedure covers most of the historical dam break flood events occurred in U.S.A. in the last decades. This procedure is widely used and it is used as a main reference for the estimation of fatality rates in SUFRI methodology.

Economic losses

Some of the existing methods and techniques for economic evaluation of flood damages are the guidelines given in two methodologies developed in Spain: the Action Plan on Flood Risk of the Valencian Region (*Plan de Acción Territorial de Carácter Sectorial del Riesgo de Inundación en la Comunidad Valenciana,* PATRICOVA) in 2002 [13] and the Flooding Emergency Plan developed by the Catalan Water Agency (Plà d'emergència especial per inundacions, INUNCAT) in 2009 [2]. Also, it is included in this point the Economic Guidance Memorandum, developed by USACE in 2003 [14].

The previous methods are fundamentally based on the use of depth-damage relationships that assign a percentage of damage from the resulting water depth during the flood. An economic value of assets or land use is established and economic losses are obtained from the destruction rate (percentage of damage) within the flooded area.

Regarding the incorporation of damage reduction on risk quantification due to the existence of warning lead times, some guidance is found, based on expert judgement and other studies (Parker et al., 2005 [44]). Damage reduction is considered when waterstops or other elements can be placed to prevent water entrance in households and buildings.

In SUFRI methodology, economic evaluation of potential damages is focused on the estimation of direct and indirect costs of the flood event.

1.5.2.2. METHODS TO ESTIMATE CONSEQUENCES DUE TO PLUVIAL FLOODING

Loss of life

The main part of risk criteria related to pluvial flooding is based on hydraulic characteristics of the event: maximum flood depth (Témez, 1991 [50]; Nanía, 2002 [43]), velocity (Témez, 2002 [29]) or their combination (Gómez and Russo, 2009 [23]; Reiter, 2001 [46]). The main part of these studies are based on theoretical considerations on stability of people exposed to fast flowing flood water (sliding, and of people) for different levels of flood severity. There are some experimental studies (Gómez and Russo, 2009 [23]) that establish different ranges of velocity to determine flood severity in terms of injury.

In SUFRI methodology, a combination of different criteria together with a classification on flood severity is provided, establishing five impact levels from the expected values of depth and velocity of the flood event in urban areas (low water depths and high velocities).

Once this impact levels are settled, the estimation of fatality rates in pluvial flooding for SUFRI methodology is based on recommendations and the method described in the Flood Risk to People project, developed by the Department for Environment, Food and Rural Affairs (Defra, UK).

Economic losses

In general, no differences are found on guidelines for the economic evaluation of flood damages from different flood sources. Thus, the same procedure is established for river and pluvial flooding to estimate economic losses.

In SUFRI methodology, several references found in the literature are included as guidance for estimating economic losses.

1.5.2.3. RISK ANALYSIS ON DAM AND LEVEE SAFETY AND ITS APPLICATION TO FLOOD RISK IN URBAN AREAS

Nowadays, risk analysis has acquired significantly relevance on dam and levee safety management [10]. After the failure of Teton dam in 1976, this discipline has been applied across the world and research groups from different institutions and universities are working on methodologies for risk evaluation as a tool to assist the decision-making process on flood defence safety management. Some of these organisms are: *U. S. Bureau of Reclamation* (USBR) [11], *U. S. Army Corps of Engineers* (USACE), *Federal Emergency Agency* (FEMA, U.S.A.), *BC Hydro* (Canada), *Australian National Committee on Large Dams* (ANCOLD) ([3], [4]) , etc.

Also, research projects and publications by Dr. Bowles (Utah State University), Dr. Baecher (University of Maryland), Dr. Wol (Michigan State University) and Dr. McCann (Stanford University) in U.S.A., together with Dr. Vrijling and Dr. Jonkman ([2],[27]) in the Netherlands, have established guidelines for life-loss estimation and risk evaluation of flooding. In these days, workshops and conferences are organized from different institutions to develop new studies and improved estimations. As an example, two events are shown here: the 1st and 2nd International Workshops of Risk Analysis on Dam Safety (Valencia, 2005 and 2008), organized by the *iPresas* research group of the Polytechnical University of Valencia.

In the last years, new tools have been developed for risk quantification. From similarities between dam and levee safety and flood risk in urban areas, SUFRI methodology proposes the use of a tool performed, initially, for risk analysis on dam safety, but, adapted, for flood risk analysis from different sources of flooding (pluvial, natural regime of the river, flood defence failure, etc.). Therefore, results can be obtained to evaluate different alternatives for flood risk reduction.

This tool, iPresas software [48], enables the solution of event trees by means of influence diagrams, providing a simple interface to represent risk models in a clear and robust way. Influence diagrams are constructed using nodes and connectors: nodes contain necessary data for calculations, and connectors specify the relationships between nodes.

Thus, this software allows for performing the risk model of a dam (or system of dams), from an influence diagram which includes the necessary nodes to capture all factors and combinations that govern the system. From the same approach, influence diagrams that represent all sources of flood risk in a particular site (not only a dam located upstream the area) can be obtained for flood risk analysis and used to analyze the current flood risk situation (failure of flood defence systems, levees, detention basins, drainage system, etc.). In general, it enables to develop the risk model of current and future scenarios.

Once risk calculations are obtained, it is possible to evaluate the current flood risk against existent tolerability criteria. SUFRI methodology includes some tolerability criteria on societal risk as a reference for risk evaluation (Appendix 8).

1.5.3. SUFRI METHODOLOGY FOR FLOOD RISK EVALUATION IN URBAN AREAS

This methodology is divided into two parts: river and pluvial flooding. Despite the similarities between both sources of flood hazard, there are significant differences on the hydraulic characteristics of the flood events and different criteria are found to estimate flood consequences in terms of potential life-loss.

Firstly, the use of F-N and F-D curves is described as a tool for flood risk evaluation (section 1.5.3.1). Secondly, phases of SUFRI methodology are identified (section 1.5.3.2). Once the overall scheme of SUFRI methodology is defined, these phases are described in detail for river and pluvial flooding separately (sections 1.5.3.3 and 1.5.3.4). Each description is intended to be self-contained and there should be no need to cross-reference between river and pluvial flooding to develop the risk analysis, however both are clearly linked.

Flow charts are provided for both cases to facilitate their understanding (Appendix 1 and 2). These charts include points of the procedure where differences between the base-case and alternatives with non-structural measures are relevant for the process to perform the risk model of the case study. Finally, some considerations are included to incorporate the existence of non-structural measures in the base-case to evaluate their effect on flood risk (section 1.5.3.5).

1.5.3.1. *FLOOD RISK EVALUATION FROM F-N AND F-D CURVES*

This section includes an overall review of how SUFRI methodology can provide a complete and quantitative way to characterize urban flood risk as a tool for planning and managing.

From results of the risk model performed for the current situation of the urban area and other alternatives from the consideration of non-structural measures, a F-N curve with the effect of structural and non-structural measures on flood risk could be developed, as the profile shown in Figure 1.5.2 for societal risk of an hypothetic case study.

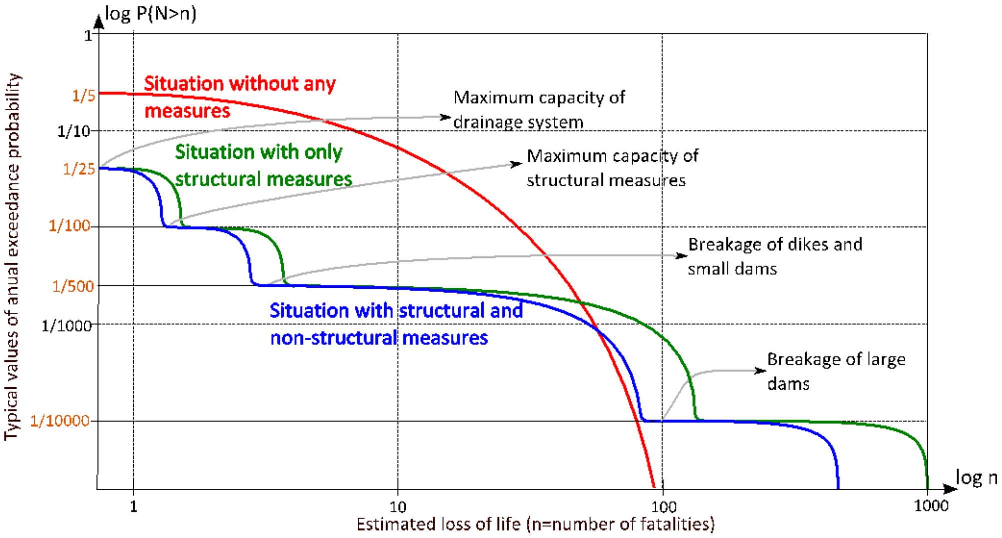

Figure 1.5.2. Effect of structural and non-structural measures on the F-N curve for societal flood risk (Figure developed specifically for WP3 SUFRI METHODOLOGY)

The F-N curve presents values in both axes (annual exceedance probability and estimated loss of life) that have to be properly studied for each particular case.

In Figure 1.5.3, the equivalent graph in terms of economic losses is shown, called F-D curve.

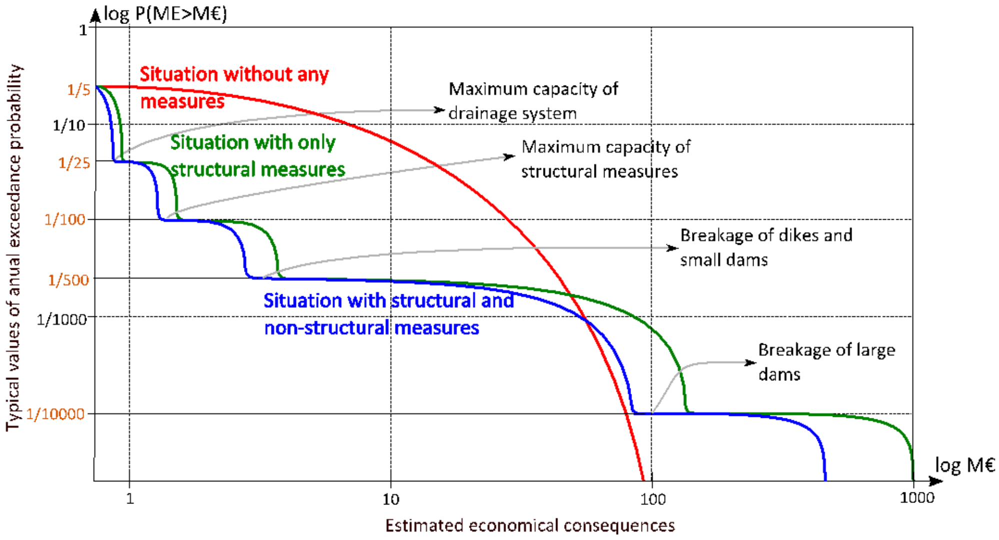

Figure 1.5.3. Effect of structural and non-structural measures on the F-D curve for flood risk (Figure developed specifically for WP3 SUFRI METHODOLOGY)

The previous figures show the relation between the probability of occurrence of a flood and its consequences (loss of life or economic losses). The area under the curve is the total flood risk, because is the integration of the probability of occurrence by the consequences, thus they are a very useful tool to characterize flood risk.

The study of the current situation on flood risk of the case study and its comparison with the situation without any measures (i.e. natural flow regime of the river) enables to analyse the isolated effect of the structural measures, as it is shown in Figure 1.5.4.

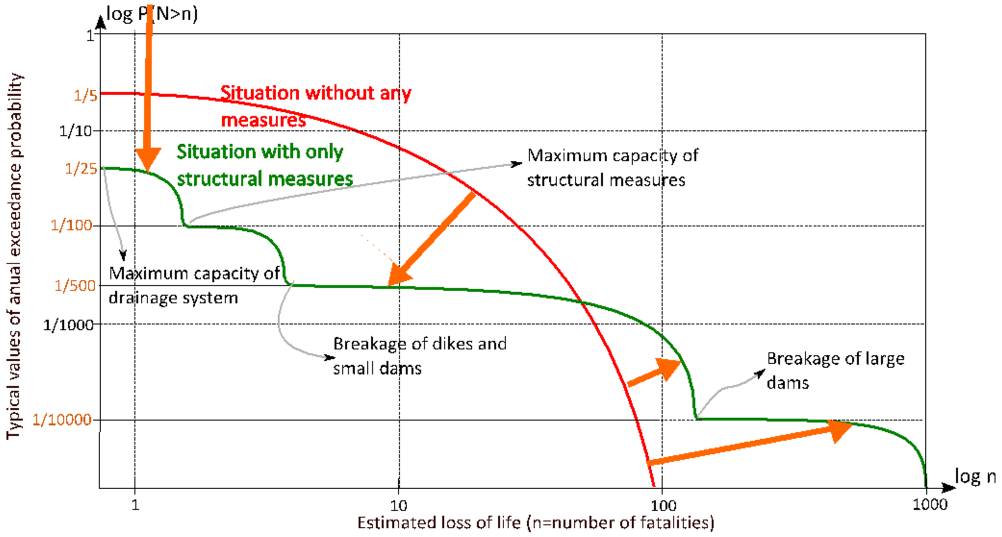

Figure 1.5.4. Effect of structural measures on the F-N curve for societal flood risk (Figure developed specifically for WP3 SUFRI METHODOLOGY)

This graph is a F-N curve, in which the effect of several structures, like drainage system, dikes, small dams or large dams can be observed. Depending on what kind of structural measure is considered, the effect on the F-N curve will be focus on a decrease on the annual probability of exceedance (i.e. drainage systems) or even an increase on the estimated consequences (i.e. breakage of a large dam or levee).

Also, it is possible to analyse the effect of non-structural measures from the representation of the F-N or F-D curves for the current situation (base-case) and the situation with non-structural measures. Figure 1.5.5 gives an example of the differences for an hypothetical case study from F-N curves with only structural measures or with structural and non-structural measures.

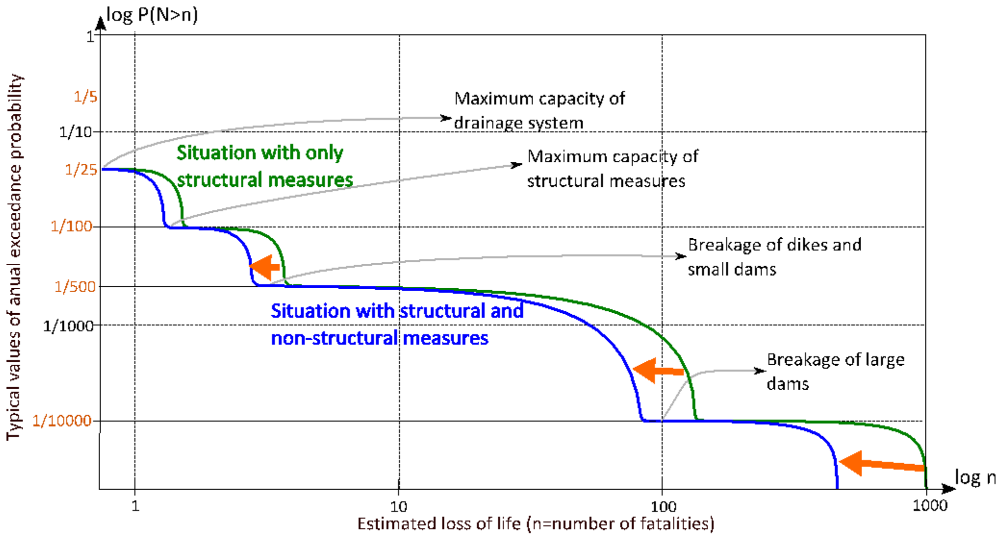

Figure 1.5. 5. Effect of non-structural measures on the F-N curve for societal flood risk (Figure developed specifically for WP3 SUFRI METHODOLOGY)

This F-N curve illustrates as the introduction of non-structural measures may have a high importance in flood consequences reduction, especially in the number of fatalities. This reduction has more significance in cases of high consequences (i.e. large dams or levees).

The previous curves (Figures 1.5.2, 1.5.3, 1.5.4 and 1.5.5) have been used to illustrate how SUFRI methodology can be used for risk quantification and evaluation, by developing F-N and F-D curves that provide a tool for analysing how structural and non-structural measures can reduce flood risk.

1.5.3.2. <u>PHASES FOR FLOOD RISK EVALUATION IN URBAN AREAS</u>

The different phases of the methodology are defined in this section to allow for overall understanding of the procedure for flood risk evaluation.

Figure 1.5.6 shows a scheme that divides the procedure into 10 phases.

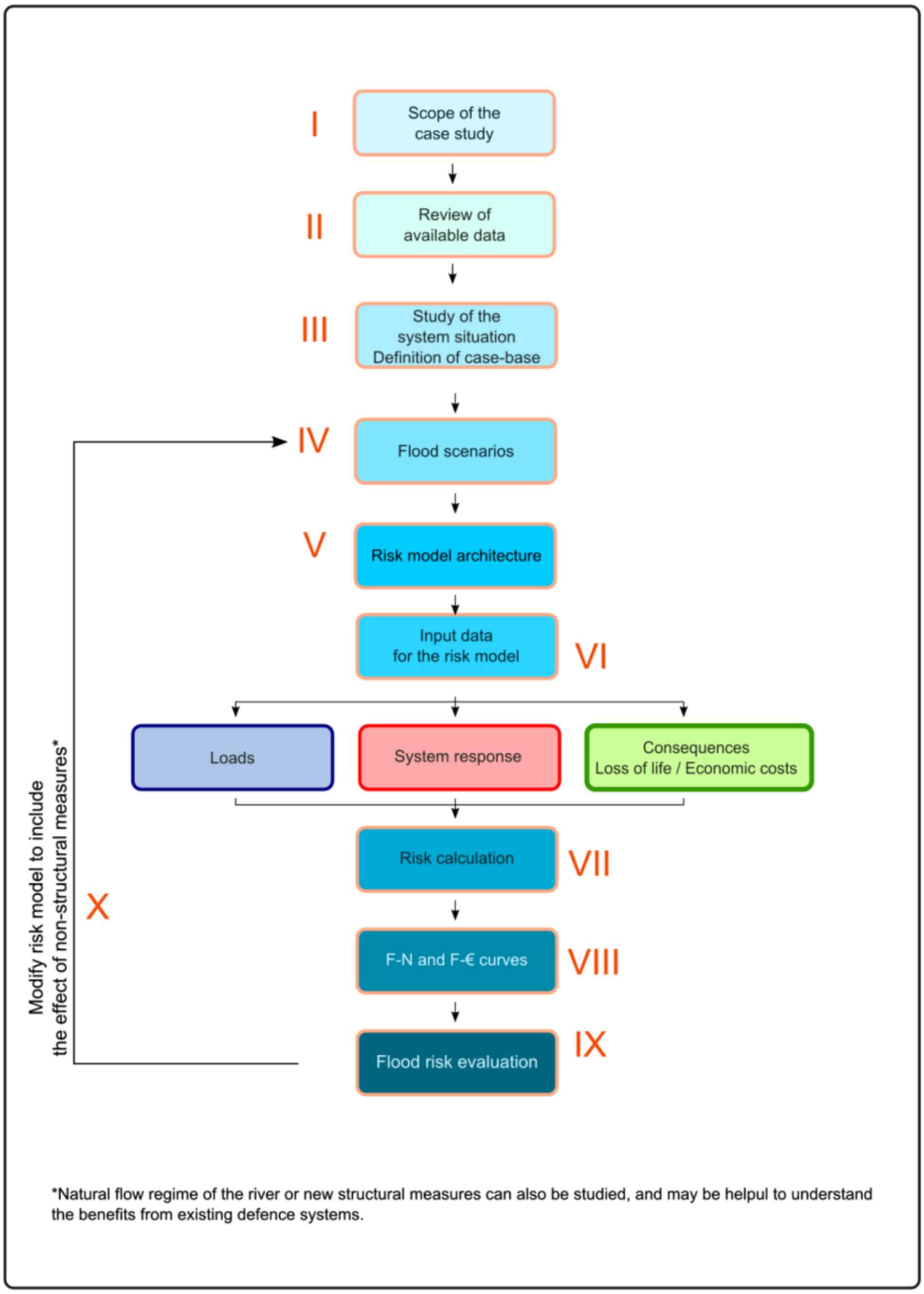

Figure 1.5.6. Simplified flow-chart for flood risk calculation (Developed specifically for SUFRI methodology).

These phases can be summarized as follows:

-	Phase I	Scope of the case study
-	Phase II	Review of available data
-	Phase III	Study of the system situation. Definition of the base-case

-	Phase IV	Flood scenarios
-	Phase V	Risk model architecture
-	Phase VI	Input data for the risk model
-	Phase VII	Risk calculation
-	Phase VIII	F-N curves
-	Phase IX	Flood risk evaluation
-	Phase X	Study of non-structural measures

The following sections (1.5.3.3 and 1.5.3.4) give guidance on the development of the methodology for flood risk evaluation in case of river and pluvial flooding.

1.5.3.3. <u>GUIDELINES FOR FLOOD RISK ANALYSIS DUE TO RIVER FLOODING</u>

In this section, the different phases of the methodology for flood risk analysis in urban areas from river flooding are described. The scheme A.1 (Appendix 1) includes a flow chart to support the description.

<u>PHASE I. SCOPE OF THE CASE STUDY</u>

The scope of the study should be established (urban area, locations, etc.), together with the required level of detail, as it determines data and time requirements to perform the risk model and calculations of potential damages. Thus, all phases of the methodology should be studied to know what kind of information is needed to feed the risk model.

Therefore, the level of detail is related to the study area, available data, necessary resources for the study and management (Table 1.5.1).

Scale	Study area	Management levels	Level of detail	Level of resources	Data requirements
Macro- scale	National	Flood reduction policies	Low	Low	Low
Meso-scale	Regional	Large-scale strategies for flood reduction	Medium	Medium	Medium
Micro-scale	Local	Individual protection measures	High	High	High

Table 1.5.1. Level of detail depending on the scope of the study (Source: HR Wallington Ltd. [37])

Once the scope of the study is established, information for further calculations and risk model architecture should be obtained from two different sources:

- Data collection. Data for obtaining inputs such as demographics, population, land use maps and statistics, economic rates, assets, households, building typology, hydrology, etc. It is necessary to consider carefully all possible variations in population at the urban area due to seasonal or daily variability. Data from all existent flood defence infrastructures such as levees, embankments, dams, etc, should be collected.

- Fieldwork. Site visits for obtaining further information regarding the characteristics of the urban area, catchment area, river courses, drainage system, infrastructures, etc.

PHASE II. REVIEW OF AVAILABLE DATA

After data gathering, information should be analyzed to establish the level of detail of further calculations for applying SUFRI methodology. The level of uncertainty of the estimation of potential damages for the risk model will depend on available data.

First of all, after a preliminary analysis of information on the case study conditions, the following aspects should be defined:

- *Study units.* Study units are the number of cities within the study area. A risk model for each city or urban area should be performed. In general, the case study includes one location or urban site.

- *Time categories (TC).* Time categories are established for defining different values for population at risk at the study area. These categories set seasonal and daily variations on population at the study site. Time categories should include variations between day and night (labour, studies, etc.), at different seasons, special events, etc. A common classification consists of the consideration of four categories (i.e. summer-day, summer-night, winter-day and winter-night). Each time category is related to a number of people at the urban area (total population, PT).

- *Land use categories (CU).* If the case study shows differences in land use distribution, then a certain number of categories (CU) can be defined to capture variations on population or the economic value of assets (i.e. residential, industrial, agricultural,…).

PHASE III. STUDY OF THE SYSTEM SITUATION. DEFINITION OF THE BASE-CASE

Before the evaluation on flood risk reduction from application of non-structural measures, it is necessary to analyze the current situation of the urban area, including the study of the existent flood defence system. The base-case enables later comparison of different scenarios from several alternatives (Phase X).

The risk model of the base-case represents the current situation of the urban area on flood risk. This model should include the potential failure of all existent infrastructures that change the natural flow regime of the river. Generally, the risk model of the base-case would include infrastructures such as levees, dikes, embankments, dams, etc. that influence the river dynamics.

PHASE IV. FLOOD SCENARIOS

Definition of flood scenarios is required to determine the range of possible flood events and evaluate potential damages.

A flood scenario can be identified by a return period (and a corresponding peak flow of the hydrograph, Q_{max}), a combination of loads that determine the failure scenario (identified by a maximum flow rate, Q_{br}) or the resulting flow at the river due to flood routing (identified by a maximum flow rate, Q_{nbr}), etc. In any case, despite the source of flooding, each flood scenario is identified by a flow rate at the study site (Q_f).

The risk model uses the aforementioned rates (T, Q_{max}, Q_{br}, Q_{nbr}, …) to identify each flood scenario and relate probabilities of each event to potential consequences.

The choice of flood events should include the following range:

- For an undefended area with regular flooding, return periods of 20, 50, 100, 250 and 1,000 years.
- For a defended area with flood defence systems (75 to 100 years), return periods of 100, 200, 300, 500 and 1,000 years.
- For a highly defended area (large dam or levee), return periods of 1,000, 1,500, 2,000, 5,000 and 10,000 years.

In addition, some considerations are given below:

- When the natural flow regime of the river is studied as a complementary model, a range of return periods (T) is defined to obtain a distribution of potential floods in the urban area. Each return period is related to certain flood characteristics at the study site and an amount of consequences (loss of life and economic losses). The estimation of these damages is included as input data for the risk model.

- If one or more infrastructures are located at the influence area of the case study, their failure should be considered to establish the range of potential floods. Thus, there are two series of flood scenarios: on one hand, a number of flood events, resulting from the failure of the flood defence system (i.e. levee, dam, etc.); on the other hand, a series of flood scenarios from flood routing.

PHASE V. RISK MODEL ARCHITECTURE

In general, three parts of the influence diagram for the risk model can be distinguished:

- Loads (First block of nodes). These nodes include information on load scenarios, including return periods and annual probabilities of exceedance. If a flood defence system (such a large dam) is located upstream the study site, the risk model includes data of previous water pool levels, gate functionality, flood routing, etc. in this part.

- System response (Second block of nodes). These nodes give information on probabilities of the potential failure modes of flood defence systems from the previous load scenarios.

- Consequences (Third block of nodes). These nodes include all necessary information to characterize flood vulnerability of the case study (loss of life and economic losses for each flood scenario).

Combining the three abovementioned type of data, the risk model provides results in terms of societal and economic risk to develop F-N curves that enable risk evaluation and comparison of alternatives. Appendix 7 shows examples of risk model schemes.

PHASE VI. INPUT DATA FOR THE RISK MODEL

Input data for the risk model is necessary for the abovementioned three parts. Data gathering from phases I and II should provide all required information for the definition of frequency of floods and vulnerability of the urban area in case of flooding. The description of required input data is divided into the same three blocks of the previous phase: loads, system response and consequences.

a) LOADS

Information from hydrological studies of the catchment area and the river flow regime provide necessary data to establish load scenarios for the risk model. Return periods, hydrographs, peak flows, annual probabilities of exceedance (AEP), etc. are obtained from these studies.

Thus, maximum peak flows at the study site for each defined flood scenario in phase IV are obtained from hydrological studies or modelling (i.e. HEC-HMS, Hydrologic Modelling System).

In case of levees or dams located upstream the urban area, this part of the model include data from previous water pool levels at the reservoir, flood routing, etc. Flow discharges due to failure cases or flood routing should be obtained from information related to the existent flood defence system.

b) SYSTEM RESPONSE

For a base-case with flood defence systems at the urban area, input data for the system response should include all potential failure modes and conditional probabilities, together with hydraulic characteristics of flood scenarios from structural failure and non-failure cases. Thus, hydraulic simulations of two series of flow discharges should be implemented: failure and non-failure flood scenarios[2].

Hydraulic simulation

Estimation of hydraulic characteristics can be obtained from:

- Use of flooding maps or topographic data: It provides information on flood depth but it does not allow obtaining velocities. Simplified calculations or expert judgement can provide estimations on velocities.
- One-dimensional hydraulic models: Estimation of average flood depths and velocities. In this case, results may overestimate the hydraulic conditions of the flood event if lateral flow is significant.
- Two-dimensional hydraulic models: They provide detailed information on flood hydraulics but it requires a high quantity of input data and parameters.

Table 1.5.2 shows the main hydraulic characteristics of the flooding and their relevance.

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[2] In case of performance of the risk model for the natural flow regime of the river, the hydraulic model of the river course, from the Digital Elevation Model (if available), should be implemented to obtain the characteristics of the flood scenarios at the urban area.

Hydraulic characteristics	Relevance
Flooded area (A_f)	Determines which zones and assets are at risk.
Depth (H)	Indicates flood magnitude. Used for estimating flood consequences.
Velocity (v)	Indicates flood magnitude. Used for estimating flood consequences.
Rise-rate	Related to the efficiency of warning times.
Arrival wave time	Related to the efficiency of warning times.

Table 1.5.2. Hydraulic characteristics of the flood event (Source: HR Wallington Ltd. [37])

From hydraulic simulations or data of flood characteristics, the following variables of each flood scenario should be obtained:

- Flow rate that identifies the flood scenario (Q_{max}, Q_{br}, Q_{nbr}): Peak flow discharge of the hydrograph (natural flow regime, failure or non-failure).
- Flow rate at the study site (Q_f): Maximum flow discharge at the particular study site.
- Depth (H): Height of flood water above ground level at the location site.
- Velocity (v): Flow velocity of the flood wave.
- Total flooded area (A_F): Flooded surface at the study area.
- Flooded area for each land use category ($A_{f,i}$): Flooded area divided into several zones according to land use categories.
- Maximum flooded width (w_{df}): Maximum width that reaches the flood at the study site.
- Arrival wave time (t_{wv}): Time of occurrence of the flood wave.

In case of non-failure flood scenarios, the following variables are necessary:

- First-notice flow (Q_1): Flow that reaches the capacity of the river bank.
- First-damage flow (Q_2): Flow that produces the first damages on buildings or households.
- Time of first notice flow (t_{Q1}): Time of occurrence of the first notice flow.

- Time of first damage flow (t_{Q2}): Time of occurrence of the first damage flow.

c) CONSEQUENCES

Vulnerability of the urban area should be estimated to obtain input data for the risk model. From hydraulic characteristics of each flood scenario, estimations of potential loss of life and economic losses are necessary. The estimated values of life-loss and economic damage are used as input data to calculate societal and economic risk.

c.1. LOSS OF LIFE

For river flooding, estimation of life-loss is based on the DSO-99-06 procedure (Graham, 1999 [24]), which has been adapted to include other aspects such as public education, shelter, day-night distinction, etc. The process for obtaining fatality rates for each flood scenario depends on the characteristics of the case study (in terms of public education, existent warning systems, etc.), flood severity and the available warning time.

Therefore, SUFRI methodology proposes a combination of the aforementioned method with other aspects, enabling the consideration of different warning times and the effect of emergency actions on risk reduction. A classification is provided in this methodology, based on fatality rates of DSO-99-06, including different case study scenarios from existence of public education, communication systems, warning and coordination between emergency agencies and authorities.

Ten categories are established (from C1 to C10), and reference fatality rates are defined for each category. Thus, different levels of warning and preparation in case of flooding are linked to different reference fatality rates. For each category, reference fatality rates (RFR) are established for six levels of warning time (t_w) and three categories of flood severity (Sv), from combination of different criteria (DSO-99-06 [1] [24]and USBR [10]).

Calculations for estimation of life-loss due to the established flood scenarios can be organised in an Excel file. Templates are given in Appendix 6. The steps for calculating loss of life are given below.

c.1.1. Category of the case study to determine reference fatality rates

The first stage for estimating loss of life is to establish the category that represents the case study, related to the reference fatality rates that are used for calculations. These reference fatality rates are based on the results and recommendations of the DSO-99-06 procedure [24] and additional considerations on risk understanding, public education, etc.

Table 1.5.3 shows the ten categories defined for SUFRI methodology.

Category	*Description*
C1	- There is no public education on flood risk terms. - No warning systems, no EAP. - There is no coordination between emergency agencies and authorities. - No communication mechanisms to the public.
C2	- There is no public education on flood risk terms. - There is no EAP, but there are other warning systems. - There is no coordination between emergency agencies and authorities. - No communication mechanisms to the public.
C3	- There is no public education on flood risk terms. - There is EAP, but it has not been applied yet. - Some coordination between emergency agencies and authorities (but protocols are not established). - No communication mechanisms to the public.
C4	- There is no public education on flood risk terms. - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - No communication mechanisms to the public.
C5	- There is no public education on flood risk terms. - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public (not checked yet).
C6	- There is no public education on flood risk terms. - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.
C7	- Public education. - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public. (C7 is used for categories 'C8', 'C9' and 'C10' if the analysis of a flood defence failure with no hydrologic scenario is considered)
C8	- Public education - EAP is already applied. It has been proved or used previously. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.
C9	- Public education. - EAP is already applied. It has been proved or used previously. - High coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.
C10	- Regular activities and plans for public education. - EAP is already applied. It has been proved or used previously. - High coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.

Table 1.5.3. Categories for reference fatality rates. River flooding. (Developed specifically for SUFRI methodology).

The current situation, or base-case, corresponds with a certain category depending on the existent warning systems, action plans, procedures, etc. If alternatives from different non-structural measures are considered, then a different category should be defined, taking into account the variations that the non-structural measure will produce in the urban area in terms of public education, coordination, communication, etc. Section 1.5.3.5 describes in detail this aspect.

c.1.2. Population at risk

The next step deals with the estimation of population at risk in the urban area for each time and land use category (defined in phase II).

Population at risk (PR) is equal to the amount of people that is expected within the flooded area for a given time and land use category. Thus, it can be obtained from density values or a fraction of the total population at the urban area.

In general, for a case study with *p* flood scenarios, *m* time categories (with the corresponding seasonal and daily variations of population) and *n* land use categories (i.e. residential, industrial, etc.), there are $p{\cdot}m{\cdot}n$ values of population at risk. The total population at risk for a certain flood scenario and time category is given by:

$$PR = \sum_{i=1}^{n} PR_i = \sum_{i=1}^{n} d_i \cdot A_{f,i} \qquad \text{(eq. 1)}$$

where PR denotes population at risk, d is the density rate and $A_{f,i}$ is the flooded area for each land use category.

If information of the overall area for each land use is considered (P_T and A_T), then the expression remains as follows:

$$PR = \sum_{i=1}^{n} PR_i = \sum_{i=1}^{n} P_{Ti} \cdot \frac{A_{f,i}}{A_{T,i}} \qquad \text{(eq. 2)}$$

Table 1.5.4 shows the possible combinations of population at risk as it has been described above (where TC denotes time categories, CU corresponds to land use categories and Q_f denotes the peak discharge for each flood scenario).

Q_f	TC_1				TC_k				TC_m			
	CU_1	CU_j	…	CU_n	CU_1	CU_j	…	CU_n	CU_1	CU_j	…	CU_n
$Q_{f,1}$	PR_{111}											
$Q_{f,i}$						PR_{ikj}						
…												
$Q_{f,p}$												PR_{pnm}

Table 1.5.4. Example of data estimation: Population at risk (Developed specifically for SUFRI methodology)

c.1.3. Warning times

As the estimation of fatality rates (FR), from reference values, depends on flood severity and warning times (TW), the next step is to obtain warning times for each flood scenario.

In case of non-failure flood scenarios (flooding from flood routing due to existent flood defence infrastructures), if there are no warning times or data is not available, the available warning time is estimated from the difference between the time of occurrence of the first-notice-flow (Q_1) and the first-damage-flow (Q_2). This consideration determines the available warning time as the time since the flood wave reaches the capacity of the river bank or flood defence system to the first contact of the flood wave with buildings or households.

If the base-case considers the existence of a dam upstream the urban area of study, then warning times are estimated from different factors (see Appendix 1, Table A.1.4):

- Breach development.
- Dam failure mode.
- Arrival wave time.
- Existence of Emergency Action Plan.
- Moment of the day. For time categories such as summer-night or winter-night, a reduction of 15 minutes on the warning time is defined.

c.1.4. Flood severity

Three levels of flow severity can be distinguished as follows:

- *Low severity.* This level can be set when no buildings are expected to be washed off their foundations due to the flood.

- *Medium severity.* In flood cases that would produce important damages but total destruction of the area is not expected.

- *High severity.* This level is used for locations flooded by the instantaneous failure of the flood defence as the urban area is located just downstream a dam or levee, or areas that will be totally destroyed by the flood (i.e. campsites).

Flood severity can be established from a parameter, DV (Appendix 1, Table A.1.3), which relates the peak flow rate at the study site (Q_f) to the mean annual discharge of the river ($Q_{2.33}$) and the maximum width of flooding (w_{df}). From Graham, 1999 [24], this parameter is given by the expression:

$$DV = \frac{Q_f - Q_{2.33}}{w_{df}} \qquad \text{(eq. 3)}$$

Consequently, flood severity categories can be classified as:

- *Low severity.* When DV is less than 4.6 m^2/s or water depths are less than 3.3 m.

- *Medium severity.* This flood severity level is used when DV is more than 4.6 m^2/s or water depths are higher than 3.3 m.

- *High severity.* No DV values are provided for classifying the flood as a high severity event.

c.1.5. Fatality rates

After defining flood severity and available time for each flood scenario, fatality rates (FR) are necessary to quantify the number of potential fatalities.

Fatality rates are obtained from interpolation of the corresponding reference values for the given category of the case study (from C1 to C10).

If several time categories are defined, then two fatality rates for each flood scenario should be obtained due to the definition of two warning times (a warning time during the day and other at night).

c.1.6. Number of fatalities

The number of potential fatalities (N) should be obtained for each flood scenario (Q_f) and time category (TC). The number of population at risk is multiplied by the fatality rate.

If different land use categories are defined, then the number of fatalities should be obtained for each sub-area (N_i). Thus, for each land use sub-area, the following parameters are obtained:

- Population at risk (PR). It depends on the flood scenario (defined by Q_f) and a certain time category (TC).
- Fatality rate (FR). It depends on the category (C), flood scenario (from available warning time and flood severity) and a time category (warning times differ from day to night).

Consequently, the number of potential fatalities is calculated using the following equation:

$$N(Q_f,TC)=\sum_{i=1}^{n}N_i=\sum_{i=1}^{n}PR(Q_f,TC)_i\cdot TR(C,Q_f,TC)_i \qquad \text{(eq. 4)}$$

This formula should be applied to the established categories (TC, CU, ...) for each case study.

Table 1.5.5 shows an example of the list of input data for the risk model in terms of life-loss. The list contains three columns of data: time category (TC), flood scenario (identified by the peak discharge of the hydrograph: Q_{max}) and number of potential fatalities (N). Figure 1.5.7 (see also Appendix 1) shows a simplified scheme as a summary of the estimation of loss of life data.

TC	Q	N
TC_1	$Q_{max,1}$	N_{11}
…	$Q_{max,2}$	N_{12}
…	…	…
TC_1	$Q_{max,p}$	N_{1p}
TCi	$Q_{max,1}$	N_{i1}
…	$Q_{max,2}$	N_{i2}
…	…	…
TCi	$Q_{max,p}$	N_{ip}
TC_m	$Q_{max,1}$	N_{m1}
…	$Q_{max,2}$	N_{m2}
…	…	…
TC_m	$Q_{max,p}$	N_{mp}

Table 1.5.5. Example list of input data. Loss of life (Developed specifically for SUFRI methodology).

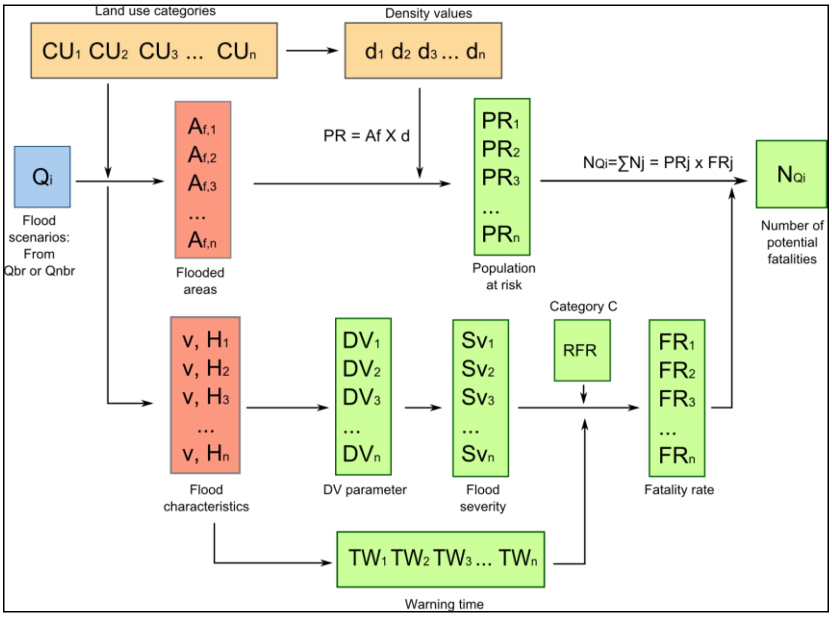

Figure 1.5.7. Sequence for obtaining input data in terms of loss of life. River flooding (Developed specifically for SUFRI methodology).

c.2. ECONOMIC LOSSES

In SUFRI methodology, economic risk is composed of direct and indirect costs that have to be estimated.

Several factors can be considered for estimating economic losses due to flooding in urban areas, such as:

- Depth (H)
- Velocity (v)
- Time of flooding
- Debris

A highly-detailed study would include all the previous factors. However, data estimation of economic losses is described in SUFRI methodology in terms of water depth (H).

Figure 1.5.8 includes the proposed sequence to obtain potential economic losses for the defined flood scenarios (see also scheme A.1A, Appendix 1).

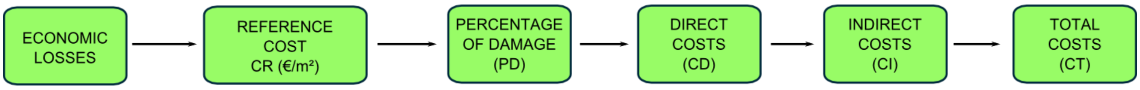

Figure 1.5.8. Steps for obtaining input data in terms of economic losses. River flooding (Developed specifically for SUFRI methodology).

The process is divided into four steps: identification of homogenous areas, definition of a reference cost, estimation of a percentage of damage and calculation of direct and indirect costs.

c.2.1. Identification of homogenous areas

An inventory should be elaborated to identify all possible assets or households that would be damaged in a flood event, including residential areas, industrial areas, schools, hospitals, etc., including also artistic and cultural heritage.

The land use categories established in phase II can be used in this part. However, extra categories can be added to this classification to include other assets or relevant buildings on the economic estimation.

As an example, the variety of assets and land uses could be divided into the following main categories:

- CU_1. Residential areas.
- CU_2. Industrial and business areas.
- CU_3. Residential areas.
- CU_4. Campsites.
- CU_5. Agricultural areas.
- CU_6. Infrastructures and road links (roads, highways, etc.)

c.2.2. Reference cost definition

Each land use category is related to a reference cost (CR).

This value expresses the economic value of a given asset or area in €/m^2. If relevant buildings or heritage could be damaged during a hypothetical flood event, then these assets can be classified separately with a fixed reference cost.

The reference cost reflects the economic loss that occurs in case of total destruction of the area.

It could be estimated from market prices, statistics, etc. In general, reference values can be obtained from different sources. Thus, they should be converted to the present year (if economic studies were performed several years ago) and adjusted by GDP (Gross Domestic Product) indicators if data is obtained from other countries.

As an example, two sources are included in this document to obtain reference values. These are, the Action Plan on Flood Risk of the Valencian Region *("Plan de Acción Territorial de carácter sectorial sobre prevención del Riesgo de Inundación en la Comunidad Valenciana (PATRICOVA)",* in 2002 [13]) and the Flooding Emergency Plan (*"Plan Especial de Emergencias por Inundación (INUNCAT)"*, in 2009 [2]), published by the Catalan Water Agency. These two studies are widely used in Spain to establish economic losses in case of flooding. Their reference values have been translated and included in Appendix 5, and depend on the land use and population density.

c.2.3. Estimation of damages

In general, the percentage of damage (PD) can be estimated from damage-depth curves. These functions relate inundation characteristics (mostly depth) and damage for a certain category of elements at risk.

There are several studies that propose damage-depth curves and provide the level of damage from flood water depth. Appendix 5 includes some examples of depth-damage curves.

Then, for each flood scenario, damage-depth curves are used to estimate the percentage of damage at the flooded area.

c.2.4. Direct, indirect and total costs

From each flood scenario, the corresponding flooded areas for each land use category have been determined. Consequently, a list of flooded areas ($A_{f,i}$ to $A_{f,n}$) is available for each flood scenario.

Direct costs of each flood scenario (including damage to buildings, economic assets, loss of benefit, etc.) are obtained from the combination of the reference cost (CR), the flooded area (A_f) and the percentage of damage (PD) for each land use category.

$$CD_i = A_{f,i} . PD_i \cdot CR_i \qquad \text{(eq. 5)}$$

where sub-index *i* indicates each land use category (CU).

The total direct cost (CD_T) of each flood scenario is estimated from the sum of direct costs of each land use category:

$$CD_T = \sum_{i=1}^{n} CD_i \qquad \text{(eq. 6)}$$

In addition, if flood scenarios related to the structural failure of a flood defence system (i.e. dam, levee, etc.) are considered, then it should be included the cost of reconstruction of the infrastructure. As a preliminary approach, Ekstrand [18] proposes the estimation of this cost based on reservoir capacity as follows:

$$CRc = 17.606 + 0.13965 \cdot KAF \qquad \text{(eq. 7)}$$

where CR denotes reconstruction cost (in 10^6 dollars) and KAF is the reservoir capacity in acree-feet (x10^3). However, in SUFRI methodology it is recommended to estimate this cost from the transposition of the total construction cost of the infrastructure to the present day, by using retail price index (RPI) or economic rates as the values proposed by USBR [1], based on several dam projects from 1977 in USA. In case of flood defence infrastructures that were built several decades ago, this cost can be established from the cost of building of a new infrastructure with similar characteristics.

However, estimation of indirect costs requires more detail information of the urban area (loss of production, traffic disruption, costs of emergency services, etc.) and it implies a complex study of a high number of factors.

A more detailed analysis of indirect costs can be necessary in the following cases:

- Flood events of long duration (several weeks)
- Large areas (a whole region or country)
- Existence of highly specialized industries
- Damage on relevant points or road links (transport, energy, etc.)
- Low stock rates (shortage of resources)

Therefore, a simplified method is recommended in SUFRI methodology to estimate indirect costs of flooding. Indirect costs are obtained from a percentage of the total direct costs by means of a parameter, denoted by f_C. This parameter usually ranges from 0% to 55% [13] depending on the characteristics of the case study (higher values can be established if the study area has important infrastructures, economic centres, etc.).

Consequently, indirect costs are obtained as:

$$CI_T = f_c \cdot CD_T \qquad \text{(eq. 8)}$$

Finally, total costs of each flood scenarios are obtained from:

$$CT = CD + CI = (1 + f_c) \cdot CD_T \qquad \text{(eq. 9)}$$

For example, if *p* flood scenarios are defined for the study of the base-case, then *p* estimation of total costs are obtained as input data for the risk model. These values are included in a list, linked to a node of the risk model.

Table 1.5.6 gives a scheme for this list of input data. The first column includes each flood scenario (identified by the peak discharge of the hydrograph, Q_{max}) and the second column contains the estimated total costs (CT) of each potential flood event.

The risk model uses the parameters given at the first row (Q_{max} and CT) to combine probability with flood damage data.

Q_{max}	CT
$Q_{max,1}$	CT_1
$Q_{max,2}$	CT_2
…	…
$Q_{max,p}$	CT_p

Table 1.5.6. List of input data in terms of economic losses (Developed specifically for SUFRI methodology).

As a summary, Figure 1.5.9 includes the scheme of the different parameters that are used for economic-loss estimation. In addition, Appendix 6 includes several templates as an example on how to organize calculations to obtain input data for the risk model from the steps described above.

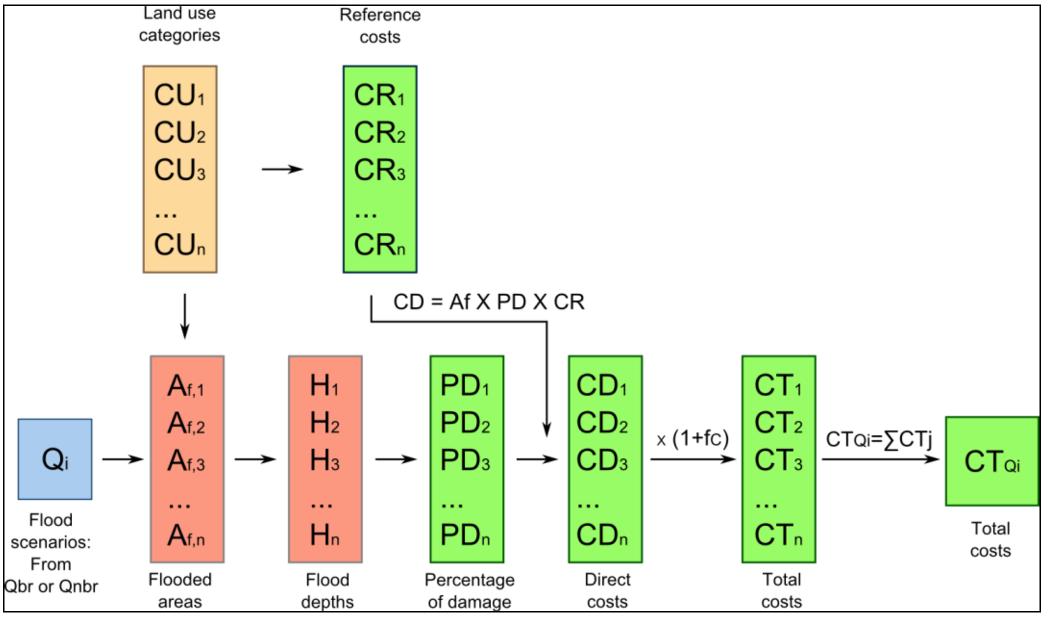

Figure 1.5.9. Sequence used for obtaining input data in terms of economic losses (Developed specifically for SUFRI methodology).

PHASE VII. RISK CALCULATION

The aim of phase VII relies on risk calculation. The risk model combines all established combinations of probability and consequences. Results provide values of societal and economic risk for the base-case.

Different output data can be obtained from the risk model such as number of branches of the event tree, annual probability of failure of the flood defence system, conditional probabilities for each failure mode, etc. All these results can be classified by time category or type of consequences (life-loss or economic-loss).

PHASE VIII. F-N CURVES

On one hand, societal risk for the base-case gives the current risk in case of flood in terms of loss of life (lives per year). On the other hand, economic risk expresses the risk in terms of economic damage (euros per year).

Lists of annual probability of exceedance in each value of consequences (loss of life or economic losses) are obtained from the risk model. These lists (f-N or f-D) provide data of the base-case to perform F-N and F-D curves, where F denotes cumulative annual probability of exceedance.

The representation of F-N curves enables to evaluate flood risk and it provides a useful tool for comparison of results from different risk models. Figure 1.5.10 shows an example of a generic F-N curve.

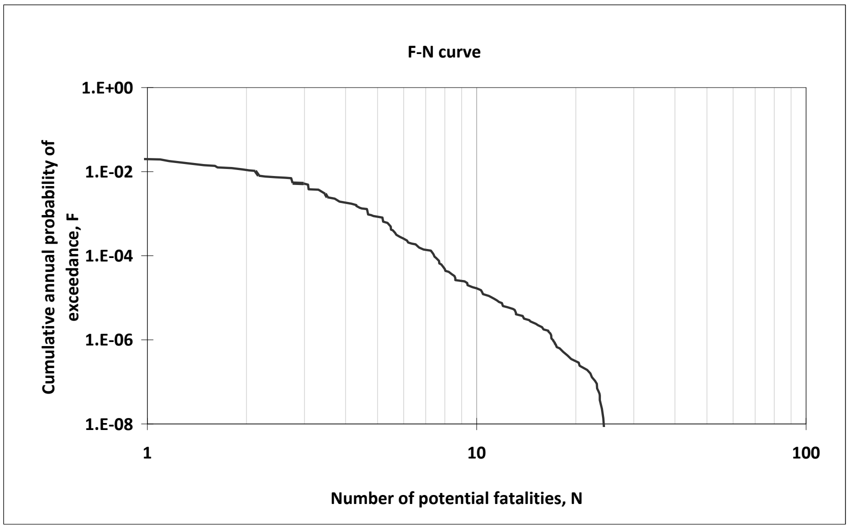

Figure 1.5.10. Example of an F-N curve (Developed specifically for SUFRI methodology).

PHASE IX. FLOOD RISK EVALUATION

The scope of phase IX consists of risk evaluation of the current situation of the urban area. Thus, societal and economic risks are studied and compare with tolerability criteria on flood risk. Appendix 8 includes references to risk criteria in terms of societal flood risk.

PHASE X. STUDY OF NON-STRUCTURAL MEASURES

After evaluating the base-case, the last phase of the methodology relies on the analysis of different non-structural measures as an alternative to reduce flood risk at the urban area. These measures can consider the implementation of emergency plans, warning systems, new communication systems, protocols, public education, etc.

Each considered non-structural measure (or a set of measures) modifies the vulnerability of the urban area in case of a potential flood. The characteristics of each flood scenario do not vary, but potential consequences are modified by the application of non-structural measures. Then, the risk model of the base-case is the basic scheme for each new alternative. Loads and system response remain as in the base-case, but new input data on potential damages (life-loss and/or economic-loss) should be estimated.

Consequently, if the effect of a non-structural measure is going to be analysed, then it is necessary to evaluate phases IV to IX (Figure 1.5.6) for the new case: studying all possible variations from the base-case, obtaining new input data, risk calculation and results on flood risk for the new situation with non-structural measures. Then, comparison of F-N curves from both cases (base-case and the alternative with non-structural measures) can be performed to analyse the effect on flood risk reduction.

Section 1.5.3.5 describes the effect of non-structural measures on the different steps of this method to estimate potential consequences of flooding.

Finally, Table 1.5.7 gives a short overview of the aforementioned phases for risk evaluation from river flooding and includes examples of data gathering (depending on the case study, additional data could be required).

Phase	Description	Data requirements
I	Scope of the case study	Extent and relevance of the urban area. Time and resources for the study.
II	Review of available data	LAND USES Land use maps and cadastral maps. Topography. Statistics (demography, urbanism, economy, etc.). Building typology. PAST FLOOD EVENTS Flooded areas, damages, etc. HYDROLOGY Rainfall rates, catchment area, river characteristics, etc.
III	Study of the current situation. Definition of the base-case	Existing infrastructures (levees, dams, ponds, detentions basin, embankments, etc.).
IV	Flood scenarios	Return periods. Peak discharge rates.
V	Risk model architecture	Loads / System Response / Consequences. Nodes that represent all potential failure modes and combinations.
VI	Input data for the risk model	LOADS Hydrology data. Flood routing, gate functionality, previous water pool levels, etc. SYSTEM RESPONSE Hydraulic characteristics of each flood (from modelling, studies or other data) Flooded areas, depths, velocities, time of occurrence, flow rates, width, etc. Failure modes and conditional probabilities. CONSEQUENCES Loss of life / Economic losses.
VII	Risk calculation	Risk model results
VIII	F-N curves	From lists provided by the risk model. Annual probability of exceedance of each level of potential consequences.
IX	Risk evaluation	Comparison with tolerability criteria.
X	Study of the effect of non-structural measures	Review of the previous phases to perform a new case with non-structural measures. Estimations on the effect of the non-structural measures to include variations on the base-case, obtaining new F-N curves.

Table 1.5.7. Overview of phases and data gathering (Developed specifically for SUFRI methodology).

1.5.3.4. GUIDELINES FOR FLOOD RISK ANALYSIS DUE TO PLUVIAL FLOODING

Flood water due to pluvial flooding as a result of extreme rainfall events may produce economic damages and, in some cases, can be a source of loss of life.

Flood water depths are usually lower in pluvial flooding than in river flooding, although the velocity of the flow becomes an important factor to consider. People are unable to stand in deep or fast flowing floodwater. Once they are unable to stand, there is a high risk of death or serious injury.

Thus, SUFRI methodology describes a different way to estimate fatality rates and population at risk than in river flooding. However, estimation of economic losses is defined as the same sequence.

In this section, the different phases of SUFRI methodology are described to analyze flood risk due to pluvial flooding (Appendix 2 includes schemes and tables as a tool to support the established steps).

PHASE I. SCOPE OF THE CASE STUDY

As it was described for river flooding, the scope and degree of detail should be established, obtaining data and information regarding to the defined level.

All available data should be obtained (topographic, population, economic indicators, etc.), supplemented by more detailed data from:

- Roads and topography (width and typology of streets, slopes, etc.).
- Drainage system, including detention basins and other elements.
- Information on previous flood events.

PHASE II. REVIEW OF AVAILABLE DATA

After data gathering, information should be analyzed to establish the level of detail of further calculations. The level of uncertainty of the estimation of potential damages for the risk model will depend on available data.

After a preliminary analysis of information on the case study conditions, the following aspects should be defined:

- *Study units.* Study units are the number of cities within the study area. A risk model for each city or urban area should be performed. In general, the case study includes one location or urban site.

- *Time categories (TC).* Time categories are established for defining different values for population at risk at the study area. These categories set seasonal and daily variations on population at the study site. Time categories should include variations between day and night (labour, studies, etc.), at different seasons, special events, etc. A common classification consists of the consideration of four categories (i.e. summer-day, summer-night, winter-day and winter-night). Each time category is related to an amount of population at the urban area (total population, PT).

- *Land use categories (CU).* If the case study shows differences in land use distribution, then a certain number of categories (CU) can be defined to capture variations on population or the economic value of assets (i.e. residential, industrial, agricultural,…).

- *Homogenous areas.* Each land use category can be divided into several areas with similar topographic characteristics (slope and width of streets). These areas should be classified from the expected hydraulic characteristics.

PHASE III. STUDY OF THE SYSTEM SITUATION. DEFINITION OF THE BASE-CASE

Before the evaluation on flood risk reduction from application of non-structural measures, it is necessary to analyze the current situation of the urban area, including the study of the existent drainage system.

Then, the risk model of the base-case represents the current situation of the urban area on flood risk due to pluvial flooding. This model should include the potential flood events from different rainfall rates.

PHASE IV. FLOOD SCENARIOS

Definition of flood scenarios is required to determine the range of flood events and evaluate potential damages for the base-case.

In general, drainage systems are designed for return periods around 10 years. In case of high return periods, two systems should be considered: drainage system and runoff at the surface. This second system is analyzed to estimate potential damages. A series of return periods from 5 to 500 years is recommended (i.e. flood events for 5, 10, 25, 50, 100 and 500 years).

PHASE V. RISK MODEL ARCHITECTURE

In general, three parts of the influence diagram for the risk model can be distinguished:

- Loads (First block of nodes). These nodes include information on load scenarios, including return periods (as indicated above) and annual probabilities of exceedance.
- System response (Second block of nodes). These nodes contain the information on runoff rates from the previous flood scenarios.
- Consequences (Third block of nodes). These nodes include all necessary information to characterize flood vulnerability of the case study (loss of life and economic losses for each flood scenario).

Combining probabilities and consequences from the sequence of the influence diagram from these three parts, the risk model provides results in terms of societal and economic risk to develop F-N curves also enable risk evaluation and comparison of alternatives.

Appendix 7 shows an example of a risk model scheme for pluvial flooding.

PHASE VI. INPUT DATA FOR THE RISK MODEL

The risk model of the base-case needs information on loads, system response and consequences. In this point, calculations are described to obtain all necessary input data.

a) LOADS

Hydrological studies provide information for the risk model: return periods, probability of exceedance, etc. From these studies different rainfall events are related to a series of return periods that define the flood scenarios. The hydrological study includes the following steps:

a.1. INFORMATION OF THE STUDY AREA

All available data of the study area in terms of previous heavy rainfall events should be analyzed. Information can be obtained from:

- Data of historical records.
- Time series of precipitation at the study area or series from statistical methods.
- IDF curves (Intensity-Duration-Frequency).

a.2. RAINFALL RATES FOR EACH FLOOD SCENARIO (RETURN PERIOD)

From the previous information from hydrological studies, rainfall rates for each flood scenario.

a.2.1. IDF curves

For each return period, rainfall intensity (mm/h) and duration should be obtained. In general, 24-hours rainfall intensity values are obtained from gauges and local studies. Then, it is recommended to obtain synthetic IDF curves.

In Spain, the following equation is widely applied to obtain maximum rainfall intensity rates:

$$\frac{I}{I_d} = \frac{I_1}{I_d}^{\frac{28^{0.1}-D^{0.1}}{28^{0.1}-1}} \qquad \text{(eq. 10)}$$

where I_d is the mean daily intensity (mm/h), I is the maximum intensity (mm/h), D is the duration (h) and the ratio I_1/I_d is the relation between 1-hour and mean intensity, depending on the geographic area. However, this ratio has been obtained just for Spain.

Other methods can be applied to obtain rainfall intensity values.

a.2.2. Hyetographs

IDF curves are used to determine design storms for each flood scenario. There are several methods to obtain design storms such as the alternating block method (Chow et al [12]).

a.2.3. Loss of rainfall

Hyetographs provide information on total rainfall over a certain area. However, precipitation losses occur during the rainfall event. Rainfall losses depend on interception, depression storage and infiltration. In urban areas, rainfall losses due to infiltration cause hydrographs that vary from non-urban areas. These losses can be estimated from Horton or SCS methods.

a.3. RAINFALL-RUNOFF TRANSFORMATION

Once rainfall rates, precipitation losses and design storms are known, the next step includes the estimation of runoff rates for each flood scenario. There are numerous models for calculating rainfall-runoff and the process is well described in the literature (SCS model, isochrones method, kinematic wave model, etc. [43])

b) SYSTEM RESPONSE

Runoff rates for each flood scenario are related to specific hydraulic characteristics of the flood event (water depths, velocities, etc.).

The risk model for the base-case in pluvial flooding requires a parameter to identify each flood scenario (a return period, T, or a runoff rate, Q_{pf}). This parameter is used to relate the probability of the flood event to potential damages. The risk model itself does not need information on hydraulic characteristics of the flooding, but they are necessary to estimate potential damages as input data for consequences.

Therefore, the hydraulic study of the urban area for the given runoff rates provides necessary data for calculating potential consequences. This study should include:

b.1. Study of the current drainage system

Study of the drainage system and characteristics of the urban area (slope, width, cross section, crossroads, etc.), including identification of narrow streets and any other "pinch points" at the urban area. When detailed information is available, the model of the drainage system can be performed to analyze interaction between both systems: drainage system and surface water.

b.2. Hydraulic characteristics for each flood scenario

Flood water depths, velocities and flooded areas for each flood scenario are necessary to estimate flood consequences. In this section, three levels of detail are distinguished from the available data (Table 1.5.8).

Level		*Available data*	*Identification of areas*
Low	No topographic data, models or information of the drainage system.	Identification of maximum flood depths. Number of fatalities in previous floods.	The urban area is considered as a unique zone. A_T and P_T
Medium	Topographic data (elevation maps). Geometry of streets (slopes, width and cross-section).	Classification of homogenous zones: - Flood depth and velocity for each zone.	Homogenous zones: $A_i \rightarrow$ with similar characteristics of the flood scenario. A_i and P_i
High	Detailed maps of the urban area. 1D or 2D models (interaction between drainage and surface system).	Results or maps in each point of the urban area. Distribution of velocity and flood depth.	Flood depth and velocity maps.

Table 1.5.8. Levels of detail for obtaining hydraulic characteristics. Pluvial flooding (Developed specifically for SUFRI methodology).

Levels medium and high provide the following data for estimating consequences: runoff rates (Q_{pf}), flood depths (y) and velocities (v).

c) CONSEQUENCES

The third block of the risk model requires information on potential consequences of each flood scenario. The steps for estimating loss of life and economic losses for each flood scenario in case of pluvial flooding are given below.

c.1. LOSS OF LIFE

The estimation of potential fatalities on pluvial flooding is based on the cause of loss of life, related to the inability of people to stand in a depth of still water or flowing floodwater with high velocity. Many deaths in floods occur because people attempt to drive through floodwater and get swept away or they are trapped in their cars. Thus, fatality rates are based on specific criteria on pluvial flooding. The main differences between pluvial and river flooding are associated with the estimation of fatality rates and flood severity.

In SUFRI methodology, the definition of fatality rates in pluvial flooding is based on several studies such as Jonkman et al [28], Penning-Rowsell et al [45] and recommendations from Defra [36]. On the other hand, classification on different flood severity levels is based on different criteria in the literature (Appendix 3), from experimental studies and theoretical considerations. The existence of warning systems determines the category of the case study (C_p) to establish fatality rates (FR_p). These reference rates depend on flood severity (S).

Potential fatalities in case of pluvial flooding are calculated as follows:

c.1.1. Category of the case study to determine reference fatality rates

A classification of three levels is determined regarding to the existence of warning systems (Table 1.5.9).

Category	*Description*
C_{p1}	No warning systems are available.
C_{p2}	There is a warning system, but it has never been used.
C_{p3}	Warning systems are available and checked (i.e. protocols, flood drills and planning).

Table 1.5.9. Categories to determine reference fatality rates (Developed specifically for SUFRI methodology).

c.1.2. Population at risk

The chance of people being exposed to floodwater depends on where they are, for example outdoors on foot, in a vehicle or in a building.

People are more exposed to a flood in some types of buildings. For this reason, a factor is applied to reduce the amount of people within the urban area for calculations (Appendix 2), using a density value (d_C) lower than the existent density population at the urban area (d).

Then, population at the study area is reduced to a number of people at risk (PR).

In addition, it is considered that population at risk can be divided into two groups: people located outside buildings during the flood and people that remains in their households. Thereby, two values should be determined to establish the percentage of people outside (f_{out}) and people in their households (f_{in}). Consequently, two values of people exposed to the flood are obtained as follows:

$$PR_{out} = f_{out} \cdot PR = f_{out} \cdot d_C \cdot A \qquad \text{(eq. 11)}$$

$$PR_{in} = f_{in} \cdot PR = f_{in} \cdot d_C \cdot A \qquad \text{(eq. 12)}$$

These values should be obtained for each homogenous zone and time category.

c.1.3. Flood severity

Different criteria for estimating vulnerability of people in floodwater are found in the literature and they depend on the following parameters:

- Flood depth (y)
- Velocity (v)
- Dragging parameter (related to $v \cdot y$)
- Sliding parameter (related to $v^2 \cdot y$)

For SUFRI methodology, five levels of flood severity in pluvial flooding are defined from several criteria (Gómez and Russo [23], Reiter [46], Nanía [43], etc.).

Table 1.5.10 includes the limits of these five levels. These categories are shown in Figure 1.5.11 from a velocity-depth graph. The highest level of flood severity, S4, is related to structural damages on buildings.

Flood severity levels should be determined for each established area within each land use category (if land use categories are divided into homogenous areas with similar hydraulic characteristics).

Flood severity (S)		*Depth* *y(m)*	*Velocity* *v (m/s)*	*Dragging parameter* $v \cdot y$ (m^2/s)	*Sliding parameter* $v^2 \cdot y$ (m^3/s^2)
S0	No victims are expected. People expected to survive.	<0.45	<1.50	<0.50	<1.23
S1	Low severity Pedestrians may suffer loss of stability. People in danger.	<0.80	<1.60	<1.00	<1.23
S2	Medium severity Significant loss of stability. Cars can lose road holding. Floating.	<1.00	<1.88	<1.00	<1.23
S3	High severity High risk for people outside Low risk for buildings	>1.00	>1.88	>1.00	>1.23
S4	Extreme severity Structural damages on buildings	>1.00	>1.88	>3.00	>1.23

Table 1.5.10. Flood severity levels in pluvial flooding (Developed specifically for SUFRI methodology).

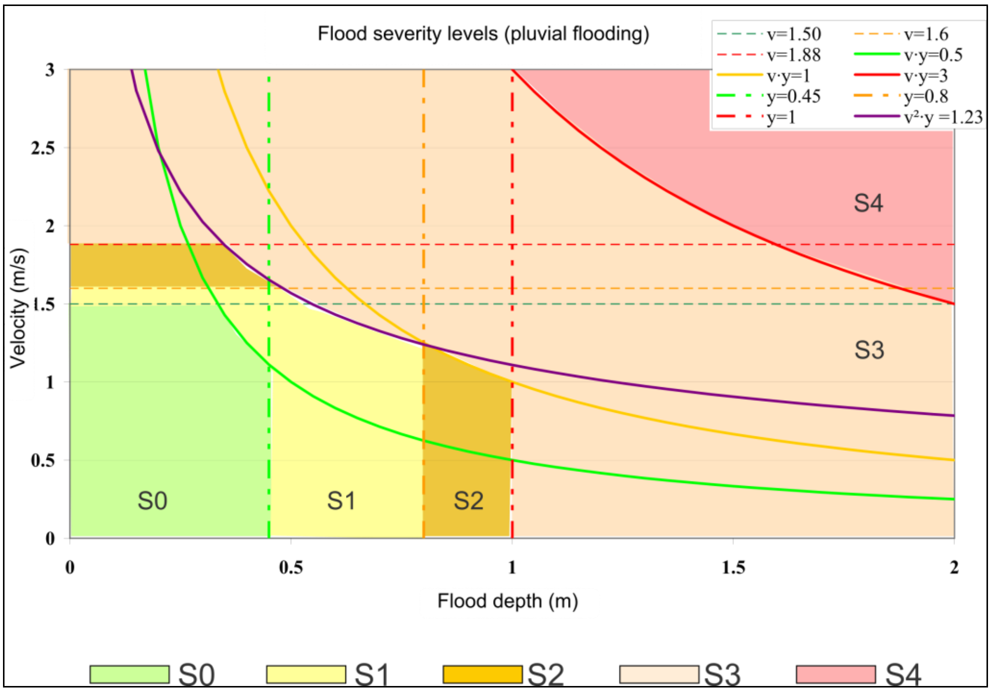

Figure 1.5.11. Flood severity levels. Pluvial flooding (Developed specifically for SUFRI methodology).

As there are two estimations of people exposed to the flood, concerning with different levels of exposure (outdoors or indoors), the flood severity level should be obtained for each group.

Flood severity levels related to people located outdoors, category PR_{out}, are obtained from the hydraulic characteristics of the flood (velocity and water depth). However, in case of people located indoors, category PR_{in}, flood severity should be estimated by considering the same water depth and a flow velocity equals to 0 m/s (it is assumed that they will be just affected by the water depth).

c.1.4. Fatality rates

Fatality rates in case of pluvial flooding are obtained from studies published by Jonkman et al [28] and Penning-Rowsell et al [45], from statistics on number of fatalities in past floods and other existent tools in the literature [36].

Appendix 4 includes the procedure that has been performed to obtain fatality rates for each category of the case study (C_{p1} to C_{p3}).

For each category, a mean value and a range of fatality rates are established. Thus, the category for the base-case corresponds with the values shown in Table 1.5.11.

Category C_p	*Flood severity S*	*Fatality rate, FR_p (Proposed value)*	*Range of values for FR_p (Minimum and maximum values)*
C_{p1}	S0	0.0003	0 - 0.0009
	S1	0.0021	0.001 - 0.003
	S2	0.0038	0.0015 - 0.0045
	S3	0.0105	0.006 - 0.04
	S4	0.0448	0.01 - 0.11
C_{p2}	S0	0.0003	0 - 0.0008
	S1	0.0018	0.0012 - 0.0024
	S2	0.0033	0.0014 - 0.0037
	S3	0.009	0.005 - 0.035
	S4	0.0384	0.01 - 0.095
C_{p3}	S0	0.0002	0 - 0.00065
	S1	0.0015	0.001 - 0.002
	S2	0.0027	0.001 - 0.003
	S3	0.0075	0.004 - 0.028
	S4	0.032	0.009 - 0.08

Table 1.5.11. Fatality rates in pluvial flooding (Developed specifically for SUFRI methodology).

For the estimation of fatality rates for each category, standard values to characterize vulnerability of population at risk are used (Appendix 4). However, some people are more vulnerable to floods than others. In general, vulnerable groups include the elderly, the disabled and long-term sick, single parents with children, infant school children, newcomers to an area, campers and tourist, the homeless, etc [36]. In case studies with a high level of vulnerable groups, it is recommended to multiply the given values in Table 1.5.11 by an additional index that depends on the age of the population and disable and long-term sick people. For this reason, Table 1.5.12 includes the aforementioned index (denoted by Y/0.5).

Y=P1+P2		***%Disabled and long-term sick, P2***		
		Above the average (0.50)	**Around the average (0.25)**	**Below the average (0.10)**
People older than 75 years, P1	**Above the average (0.50)**	**1**	**0.75**	**0.6**
	Around the average (0.25)	**0.75**	**0.5**	**0.35**
	Below the average (0.10)	**0.6**	**0.35**	**0.2**

Table 1.5.12. Index to include vulnerable groups (Adapted from Penning-Rowsell et al, 2005 [45])

c.1.5. Number of potential fatalities

The last step for life-loss estimation relies on the combination of fatality rates and population at risk to obtain the number of potential fatalities for each flood scenario.

For each identified area (from land uses or homogenous characteristics), the number of fatalities is obtained for each flood scenario (given by a return period, T) and time category (TC) from:

$$N(T,TC)=\sum_{i=0}^{n} N_i=\sum_{i=0}^{n} PR_{out}(T,TC)_i \cdot FR_{p,out}(T)_i + PR_{in}(T,TC)_i \cdot FR_{p,in}(T)_i \qquad \text{(eq.13)}$$

where *n* is the number of identified areas.

Then, from *m* time categories and *p* flood scenarios, *m·p* estimations of potential fatalities are obtained. These values are listed in a file that is associated with the corresponding node of the risk model.

Table 1.5.13 shows an example for classifying input data in terms of life-loss. Each time category (TC) and flood scenario (identified as a return period or a runoff rate Q_{pf}) is related to a number of potential fatalities (N).

TC	Q_{pf}	N
TC_1	$Q_{pf,1}$	N_{11}
…	$Q_{pf,2}$	N_{12}
	…	…
TC_1	$Q_{pf,p}$	N_{1p}
TCi	$Q_{pf,1}$	N_{i1}
…	$Q_{pf,2}$	N_{i2}
	…	…
TCi	$Q_{pf,p}$	N_{ip}
TC_m	$Q_{pf,1}$	N_{m1}
…	$Q_{pf,2}$	N_{m2}
	…	…
TC_m	$Q_{pf,p}$	N_{mp}

Table 1.5.13. Example of input data for life-loss.

The risk model in iPresas software uses the first row to identify each combination of flood scenario and time category and then it relates consequences to probabilities of occurrence.

Figure 1.5.12 illustrates a summary of the different parameters for estimating loss of life in pluvial flooding as indicated above.

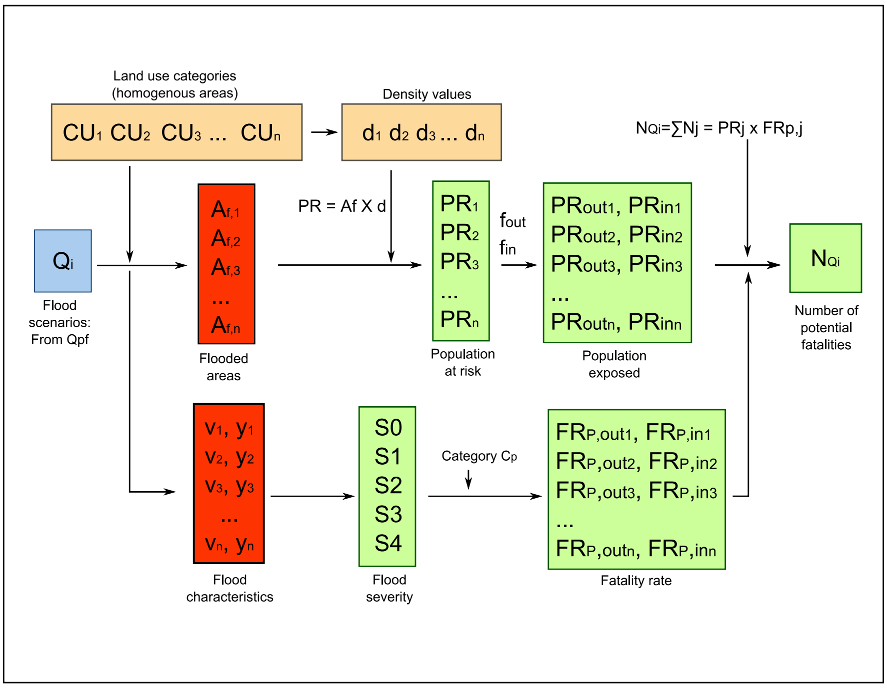

Figure 1.5.12. Parameters used for obtaining input data in terms of loss of life. Pluvial flooding.

Appendix 6 includes several templates to show how calculations can be organised for estimating the aforementioned values.

c.2. ECONOMIC LOSSES

In this methodology, the estimation of economic losses in case of pluvial flooding is defined as the same sequences described for river flooding (section 1.5.3.3).

PHASE VII. RISK CALCULATION

Once all input data is linked to each node of the risk model for the base-case, then results are obtained from calculations with iPresas software. From these results, societal and economic risk from pluvial flooding is obtained for the base-case.

PHASE VIII. F-N CURVES

With regard to societal and economic risk, results of annual probability of exceedance and potential fatalities or economic losses are obtained from output data of the risk model. From these results, it is possible to represent F-N and F-D curves for the base-case. Appendix 7 shows an example of an F-N curve.

PHASE IX. FLOOD RISK EVALUATION

Results of the base-case can be used to compare the current risk of the urban area with tolerability criteria on flood risk.

PHASE X. NON-STRUCTURAL MEASURES

For the analysis of the effect on flood risk reduction of non-structural measures, several modifications should be performed on the base-case risk model to include their effect.

> New input data of potential consequences should be obtained after considering the situation with non-structural measures, modifying the parameters described in SUFRI methodology.

The base-case is the basic scheme to evaluate non-structural measures. Loads and system response remain the same for studying these alternatives (it is assumed that non-structural measures do not modify hydraulic characteristics of the studied flood scenarios, otherwise, if new structural measures are analyzed, then flood characteristics should be re-evaluated).

Section 1.5.3.5 describes how the effect of non-structural measures can be incorporated in this methodology.

1.5.3.5. INCORPORATING THE EFFECT OF NON-STRUCTURAL MEASURES

In this section, variations on SUFRI methodology to analyse the effect of non-structural measures on flood risk are described. The base-case is compared with other alternatives for evaluating flood risk in different scenarios. Several examples of how to modify the base-case due to the consideration of non-structural measures are included.

LOSS OF LIFE

One or more variables of SUFRI methodology can be modified for the base-case to analyse the situation with non-structural measures. When analysing river and/or pluvial flooding, the existence of a certain non-structural measure is included as the variation of one or more parameters of SUFRI methodology (affecting the risk model for river and/or pluvial flooding). Then, new results can be obtained to study the effect of non-structural measures on the existent flood risk (base-case).

For example, the effect of a non-structural measure based on urban planning can be analysed as a reduction on the amount of population at risk (PR). This effect can be similarly considered in both risk models (river and pluvial flooding). However, if the implementation of a new warning system is considered, then SUFRI methodology captures this new situation for river and pluvial flooding separately, by defining different categories C (for river flooding) and C_p (for pluvial flooding) with regard to the base-case.

RIVER FLOODING

The study of the effect of non-structural measures is based on the results of the hydraulic modelling for the base-case of each flood scenario and the same risk model architecture. However, the existence of non-structural measures implies variations on input data for the model:

Definition of the category of the case study to determine reference fatality rates

A category (C) is established for the base-case according to the existing systems of warning, communication, etc. (see Appendix 1). The application of non-structural measures modifies the situation of the urban area in relation with potential flood events. Consequently, this category can change from one level to another depending on the improvements on warning, evacuation, communication, etc. Thus, a new category for the case study should be established (from C1 to C10).

Definition of warning times

If the current situation includes the existence of a dam located upstream the urban area and the base-case does not include the implantation of an Emergency Action Plan, then warning times should be modified when implantation of an EAP is considered as a non-structural measure (Appendix 1, Table A.1.4.).

PLUVIAL FLOODING

Definition of the category of the case study to determine reference fatality rates

As it has been described for river flooding, a different category (C_p) for the case study should be defined if non-structural measures that include improvements on warning system (Appendix 2). As a result, reference fatality rates for the case with non-structural measures vary from the base-case.

Definition of population at risk

If public education measures are considered to evaluate their effect on risk reduction, a reduction on the population exposed to the flood is recommended (public education measures are supposed to improve the knowledge of people, for example, on how to find shelter in higher floors). This reduction should be defined from expert judgement or existing studies, taking into account the characteristics of the case study and its population.

ECONOMIC LOSSES

RIVER AND PLUVIAL FLOODING

SUFRI methodology proposes the analysis of the effect of the existence of warning systems as a reduction on economic damages. However, it is considered that this measure should be implemented together with public education, as it is assumed that warning lead times are effective only if population at risk have a certain level of knowledge on how-to-act during a flood event.

From the previous concept, reduction on potential economic damages from warning lead times (i.e. from installation of waterstops to avoid water entrance on households and buildings) can be considered only if there is a certain degree of public education on how to act and proceed in case of flooding. In that case, the existence of these waterstops during the flood is added to the estimation of potential consequences as a reduction of the estimated damages (obtained from the flood water depth) for the base-case.

Two parameters can be included in SUFRI methodology to incorporate the existence of removable/temporary waterstops: a percentage of damage reduction (RD) and an additional factor for each time category (K_{TC}). The percentage of damage reduction can be obtained from several studies that relate warning lead times and flood depths with a certain percentage of damage reduction (Parker et al, 2005 [44]). In addition, this percentage should be modified by a factor, K_{TC}, that represents the existence of empty households. In case studies with high variations on population from summer to winter, it is expected a high number of empty households in winter. In that case, it is not possible to consider that their owners will be able to apply any defence measure against floods. Consequently, the percentage of damage reduction is assumed to be higher if property owners are in their households.

In these cases, if non-structural measures are considered, then economic losses follow the expression:

$$CT_{N-S} = CT_{base} \cdot (1 - RD \cdot K_{TC}) \quad \text{(eq. 14)}$$

where CT_{N-S} denotes total costs from the existence of non-structural measures (warning systems and public education) and CT_{base} denotes total costs of the base-case.

In this point, some examples for obtaining the percentage of damage reduction (RD) are described.

Residential areas

In 1970, Day defined an estimation of benefits due to warning systems in case of flooding. From this study, a maximum percentage of reduction was established in 35% of the total costs.

From 1970, new studies and research have obtained the effect of warning systems on economic damage reduction (Penning-Rowsell et. al., 1978, Parker, 1991) [44]. Figure 1.5.13 shows a set of curves that represent the reduction of damage from flood warning system, depending on the flood warning lead time (from 2 to 8 hours) and the water depth (from 0.1 m to 1.2 m). Reduction on damage is not recommended if water depths reach levels higher than 1.2 m.

Non-residential areas

Several studies on estimation of damage reduction for non-residential uses have been carried out during the last years. Recent work by FHRC (Flood Hazard Research Centre, UK) give more detailed information on actions related to estimate the reduction on flood damages in other land uses (Parker et al, 2005 [44]).

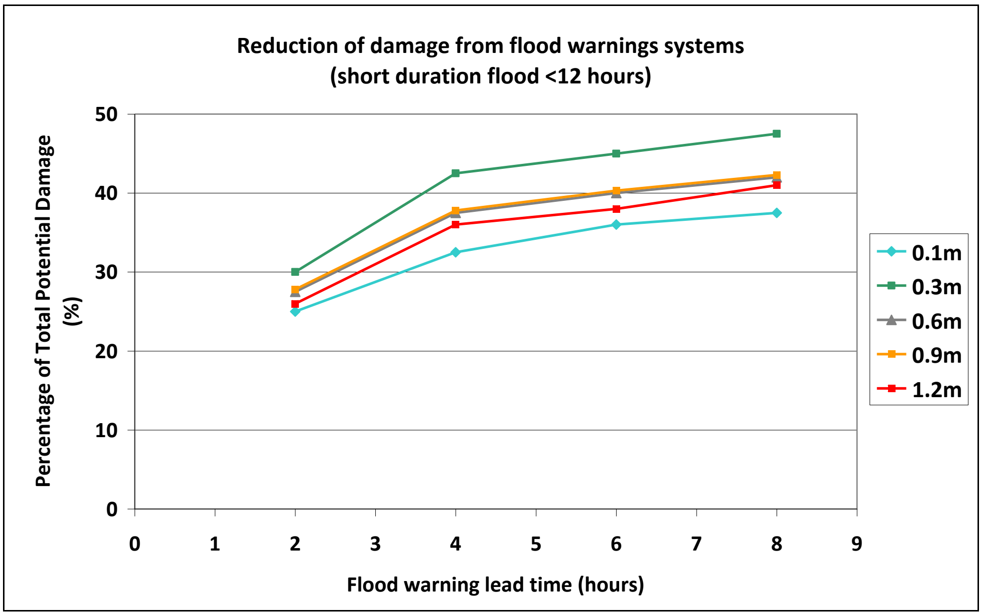

Figure 1.5.13. Percentage of damage reduction from several flood warning lead times [44].

1.6 CONCLUSIONS

SUFRI methodology provides a tool to support flood risk evaluation in urban areas and it can be applied to inform authorities, local entities and stakeholders on decision-making to establish strategies for risk reduction.

F-N and F-D curves show the societal and economic flood risk, respectively, in an understandable way, as they are useful to evaluate the effect of the several measures on it. Although these curves do not indicate the flood risk distribution in an area, they can be very useful for defining tolerability criteria for flood risk.

As it was described on SUFRI methodology, these curves are the basis to illustrate risk quantification and the effect of different measures on flood risk reduction, thus providing a guide for planning and managing.

Therefore, risk model results and F-N curves from the established alternatives (base-case, non-structural measures, etc.) can provide information in terms of flood risk to assist the following applications:

- Preliminary evaluations on flood risk.
- Management of flood defences and appraisal of new flood defence schemes.
- Flood hazard and risk mapping.
- Flood warning and emergency planning.
- Identification of high-risk areas to prioritise flood warning and emergency response.
- Flood awareness campaigns.
- Flood Defence regulation, design and development control.
- Spatial planning.
- Urban planning.
- Flood plans for reservoirs.
- Information for ongoing and new research projects.
- Public education plans.
- Etc.

SUFRI methodology is based on the identification of all the important factors that influence risk quantification: sources of flood risk (river, heavy rainfall, defence failure, inefficient drainage system, etc.), vulnerability of the study area, etc.

The use of F-N curves enables the comparison of the current situation of the urban area with other situations from the consideration of non-structural measures.

Also, it should be emphasized that this method considers the study of total risk evaluation (from the analysis of flood scenarios in case of flood defence failure and non-failures) differing from risk evaluation on dam and levee safety, where typically incremental risk is analysed (from the difference between damages due to the dam or levee failure and the situation with non-failure).

Uncertainty on the results will depend on available data and the level of detail of hydrologic and hydraulic models or calculations. However, SUFRI methodology provides a scheme that can be applied for different levels of information: from basic evaluations on flood risk to highly detailed estimations.

In addition, it should be emphasized that risk evaluations from low levels of information require assumptions and should be more conservative. Consequently, uncertainty in the results is high, particularly in the number of people who will be exposed to a flood and hydraulic characteristics of the flood event. However, it should be kept in mind that people can be very resilient during floods and the number of deaths is often less than expected.

APPENDIX

APPENDIX 1

SCHEME OF INPUT DATA FOR CONSEQUENCES IN CASE OF RIVER FLOODING

Appendix 1 includes the overall scheme to assist SUFRI methodology to obtain input data for the risk model within the analysis of flood risk in case of river flooding. This appendix contains three additional sheets:

1A – Flow chart

1B – Tables and definition of additional parameters

1C – Notes

APPENDIX 2

SCHEME OF INPUT DATA FOR CONSEQUENCES IN CASE OF PLUVIAL FLOODING

Appendix 2 includes the overall scheme of SUFRI methodology to obtain input data for the risk model in case of pluvial flooding. This appendix contains two additional sheets:

2A – Flow chart

2B – Tables, definition of additional parameters and notes

APPENDIX 3

VULNERABILITY CRITERIA IN PLUVIAL FLOODING

In this appendix, all vulnerability criteria used for the definition of flood severity levels in pluvial flooding are included. They are classified in terms of the main parameter of each criterion:

Criteria regarding maximum flood depth (ymax)

Denver

A flood water depth of 0.45 m is defined as a threshold level. Above this level, it is considered that water floods buildings and households.

Mendoza

This criterion establishes the previous threshold for a flood depth of 0.30 m.

Témez

A threshold of a flood depth of 1 m is considered to establish risk zones. Flooded zones with water depths below this level are established as non-risk areas.

Criteria regarding maximum velocity (Vmax)

Témez (1992)

A maximum velocity of 1 m/s is established as a threshold value for the definition of risk areas. Flooded zones with velocities below this value are established as non-risk areas.

Gómez and Russo (2009)

In 2009, Gómez and Russo [23] performed an experimental study of a scale model to obtain risk criteria in urban areas. From the analysis and conclusion of their tests, three thresholds were defined from the velocity characteristics:

- Low risk[3] (1.51 m/s < v < 1.56 m/s): People have problems to stand in floodwater with these characteristics.
- Medium risk (1.56 m/s < v < 1.88 m/s): High loss of stability and manoeuvrability.
- High risk (v > 1.88 m/s): People are unable to stand with these characteristics and they are swept away.

Table A.3.1 includes the velocity ranges for these three categories.

Category	v (m/s)
Non-risk area	$v < 1.51$
Low risk	$1.51 < v < 1.56$
Medium risk	$1.56 < v < 1.88$
High risk	$v > 1.88$

Table A.3.1. Velocity ranges from Gómez and Russo, 2009 [23].

Criteria regarding dragging parameter (V·Ymax)

Témez (1992)

A maximum value of the parameter v·y equals to 0.50 m²/s is considered. Above this threshold, flood characteristics are considered within the risk zone.

FEMA (1979)

A maximum rate of 0.56 m²/s is considered as a threshold value for analysing loss of stability of an adult being exposed to a flood.

Reiter (2001)

This criteria provides a classification on flood severity levels from the v·y parameter of the flood. Five categories are defined:

Category	v·y (m²/s)
Low severity. People expected to survive	0-0.5
High severity. People in danger, cars floating	0.5-1
Low severity for buildings. High risk for people outside in floodwater	1.0-3.0
Medium severity for buildings (damages)	3.0-7.0
High severity for buildings (destruction)	>7.0

Table A.3.2. Flood severity levels from Reiter, 2001 [46]

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[3] The study defines three levels of risk, but they attend to flood characteristics. Probability aspects are not considered.

Criteria regarding SLIDING stability ($V^2 \cdot Ymax$)

Nanía (2002)

This study evaluates the capability of an adult to stand in floodwater before being swept away due to sliding. This theoretical analysis defines a reference value of v·y equals to 1.23 m^3/s^2 [43]. This value is established for an adult of 60 kg. This value is affected by the weight and height of the considered person.

Other criteria

DGOHCA (Ministry of Environment, Spain) (From Oleagordia et al)

Three categories are established for the classification of the river flood plane on risk zones:

- Low risk area: areas with flood depths lower than 0.40m for return periods of 500 years.
- Medium risk area: areas with flood characteristics between low and high risks.
- High risk area: areas with flood depths higher than 0.40m for return periods of 50 years.

PATRICOVA (2002, Spain)

This Plan for Flood Risk Prevention in the Valencian Region [13] classifies the magnitude of the flood event in terms of the flood depth (with a threshold value of 0.80 m) and their frequency in terms of annual probability of occurrence. This Plan provides six levels of flood characterization (from 1, High, to 6, Low):

Flood depth	*Low frequency T=100 - 500 years*	*Medium frequency T=25 - 100 years*	*High frequency T<25 years*
Low (<0.80m)	6 (LOW)	4 (MEDIUM)	3 (MEDIUM)
High (>0.80m)	5 (LOW)	2 (HIGH)	1 (HIGH)

Table A.3.3. Risk categories from PATRICOVA, 2002 [13].

APPENDIX 4

ESTIMATION OF FATALITY RATES IN PLUVIAL FLOODING

Introduction

For the estimation of fatality rates in pluvial flooding, the methodology described in Penning-Rowsell et al [45] has been used. This method is based on defining zones of different flood hazard and estimating the total number of people located in the flooded zones, the proportion that are likely to be exposed and who are likely to be injured or killed.

Fatality rates for pluvial flooding are obtained from the combination of SUFRI methodology with the aforementioned method. This appendix presents an outline of the process, including the main factors and parameters.

Thus, for each level of flood severity (S0 to S4), fatality rates are obtained from the abovementioned framework by Penning-Rowsell et al [45].

Procedure

The method evaluates the number of deaths/injuries from the following parameters:

- Flood depth: y
- Velocity of the floodwater: v
- Hazard rating, HR: $HR=y\cdot(v+1.5)$
- Area vulnerability, AV: $AV=FW+SO+NA$

  where FW denotes flood warning, SO represents the speed of onset and NA is used to identify the nature of the area (building typology) .

- Exposure, X (percentage of people exposed to risk): $X(\%)=AV\cdot HR$
- Population at the flooded area: $N(Z)$
- People exposed: $N(ZE)=X\cdot N(Z)$
- P1 factor (people older than 75 years): $P1$
- P2 factor (disabled and long-term sick): $P2$
- People vulnerability, Y: $Y(\%)=P1+P2$
- Number of injuries: $N(ZE)\cdot Y$
- Number of deaths: $2\cdot HR\cdot N(ZE)\cdot Y$

From the given parameters, the estimation of fatality rates for SUFRI methodology in case of pluvial flooding is based on the following assumptions:

- Area vulnerability

  Mean values for the characterization of speed of onset (SO=2) and building typology (NA=2) are established. The existence of flood warning is considered from the three described categories in SUFRI methodology. The FW parameter is defined from FW=1 (category C_{p3}, warning systems) to FW=3 (category C_{p1}, no warning systems are available). Consequently, three different values of area vulnerability (AV) are studied to develop three categories of fatality rates (one for each category C_{p1} to C_{p3}).

- People vulnerability

  Mean values are used for Y (Y=0.50), regarding the presence of very old people and those who are at risk due to disabilities or sickness. If other characteristics of the population are considered, then Y can be modified and fatality rates should be corrected.

The resultant number of fatalities is estimated by:

$$\text{Fatalities} = 2\cdot HR\cdot N(ZE)\cdot Y = 2\cdot HR\cdot[N(Z)\cdot AV\cdot HR]\cdot Y$$

If Y=0.50 is considered and the fatality rate (FR) is defined as the ratio between the number of fatalities and the population at risk, N(Z):

$$FR = 2\cdot HR^2\cdot AV\cdot Y = 2\cdot(y\cdot(v+1.5))^2\cdot AV\cdot 0.5\cdot 10^{-4} = (y\cdot(v+1.5))^2\cdot AV\cdot 10^{-4}$$

The procedure includes two parameters that should be considered as a percentage (2·HR and N(ZE)), consequently, a factor 10^{-4} should be used to obtain fatality rates if flood depth (y) and (v) are expressed in m and m/s. As it was described above, AV ranges from 5 to 7 (depending on the category of the case study, C_p).

Once the previous expression is defined, fatality rates are obtained for mean values of flood depth and velocity (Table A.4.1) for each flood severity level established in SUFRI methodology (S0 to S4).

	y(m)	*v (m/s)*	*y·v (m^2/s)*
S0	0.3	0.8	0.24
S1	0.65	1.15	0.75
S2	0.9	1.1	0.99
S3	1.25	1.6	2
S4	2	2.5	5

Table A.4.1. Mean values of flood characteristics for each flood severity level.

Minimum and maximum values of the fatality rates for each category of flood severity are obtained from the given situations:

- Maximum flood depth for each flood severity category, with a velocity of the flood water of 1 m/s.
- Maximum velocity for each flood severity category, with a flood depth of 0.45 m.

Table A.4.2 shows the associated values of flood characteristics for each flood severity category to analyze the effect of their variation on the results.

Severity	*y(m)*	*v (m/s)*	*y·v* (m^2/s)	Severity	*y(m)*	*v (m/s)*	*y·v* (m^2/s)
S0	0.44	1	0.44	*S0*	0.45	1	0.45
S1	0.79	1	0.79	*S1*	0.45	1.59	0.72
S2	0.99	1	0.99	*S2*	0.45	1.87	0.84
S3	2.99	1	2.99	*S3*	0.45	5	2.25
S4	5	1	5	*S4*	0.45	8	3.6

Table A.4.2. Flood characteristics for estimating maximum and minimum fatality rates.

After applying the flood characteristics presented in Tables A.4.1 and A.4.2 to the previous expression and analysing the results, the following fatality rates are established for each C_p category (depending on the existent warning system):

Category	Flood severity	Fatality rate, FR (Proposed value)	Fatality rate, FR (Range)
C_{p1}	*S0*	0.0003	0 - 0.0009
	S1	0.0021	0.001 - 0.003
	S2	0.0038	0.0015 - 0.0045
	S3	0.0105	0.006 - 0.04
	S4	0.0448	0.01 - 0.11
C_{p2}	*S0*	0.0003	0 - 0.0008
	S1	0.0018	0.0012 - 0.0024
	S2	0.0033	0.0014 - 0.0037
	S3	0.0090	0.005 - 0.035
	S4	0.0384	0.01 - 0.095
C_{p3}	*S0*	0.0002	0 - 0.00065
	S1	0.0015	0.001 - 0.002
	S2	0.0027	0.001 - 0.003
	S3	0.0075	0.004 - 0.028
	S4	0.0320	0.009 - 0.08

Table A.4.3. Fatality rates established in SUFRI methodology.

APPENDIX 5

REFERENCE COSTS AND DEPTH-DAMAGE CURVES FOR ESTIMATION OF ECONOMIC LOSSES

REFERENCE COST

The definition of the reference cost for each land use category can be based on national statistics, insurances, aids, economic studies and market prices, etc.

In this appendix two examples are included as a reference for estimating reference cost. On one hand, Table A.5.1 shows values for different land uses from a regional Plan in Spain, PATRICOVA [13] (Action Plan on Flood Risk of the Valencian Region). On the other hand, rates from International Commission for the protection of the Rhine (IKSR 2001, from [37]) are shown in Table A.5.2.

These values should be adapted to each case study, depending on the area of study.

Code	Land use	Rate (€/m²)	
		High	Low
00	Residential	68.7	22.9
01	Residential. Low density.	68.7	22.9
02	Residential. Medium density.	56.3	18.8
03	Residential. Medium-high density.	75.0	25.0
04	Residential. High density.	100.0	33.3
05	Campsites, caravans, etc.	68.7	22.9
00 a 04	Commercial uses in residential areas	51.8	17.3
06	Industrial use.	16.9	5.6
07	Industrial use. Low density.	16.9	5.6
08	Industrial use. High density.	23.7	7.9
09	Equipments, infrastructures, etc.	51.8	17.3
10	Tertiary sector	51.8	17.3
11	Combined	51.8	17.3
12	Others. Undefined.	0	0
20	Agricultural use. Fruits.	0.89	
21	Agricultural use. Cereal.	0.34	
22	Agricultural use. Rice.	0.34	
23	Agricultural use. Fruits.	0.56	
24	Agricultural use Citrus fruits.	0.86	
25	Others	0.34	
36-40	Dry lands. Herbaceous.	0.34	
	Dry lands (vineyards, olives, etc.)	0.56	
Others		0	

Table A.5.1. Reference costs from PATRICOVA, 2002 [13].

Land use category	Real state and fix (€/m^2)	Mobile goods (€/m^2)	Total (€/m^2)
Residential areas	231	59	289
Industrial areas	231	80	311
Urban infrastructures	263	2	265
Agricultural areas	-	-	9
Forest areas	-	-	1

Table A.5.2. Reference costs from IKSR 2001 [37].

DEPTH-DAMAGE CURVES

Depth-damage curves or functions are distributions that represent flood depth and the percentage of damage in assets, from the land use of the flooded area, building typology and/or their content. In this section several depth-damage curves found in the literature are described.

General depth-damage curves

This type of depth-damage curves do not distinguish between land uses or building typologies. For example, depth-damage curves from PATRICOVA [13] do not consider structural damages or destruction of their content. Rates are defined for a generic land use. Land use distinctions are included in the definition of the reference cost.

Table A.5.3 includes the depth-damage relationships proposed in PATRICOVA [13] and Figure A.5.1 shows the depth-damage curve.

Flood depth (m)	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
Damage (%)	1%	2.5%	5%	14%	40%	60%	67%	71%	75%	77%

Table A.5.3. Rates of damage from different flood depth conditions [13].

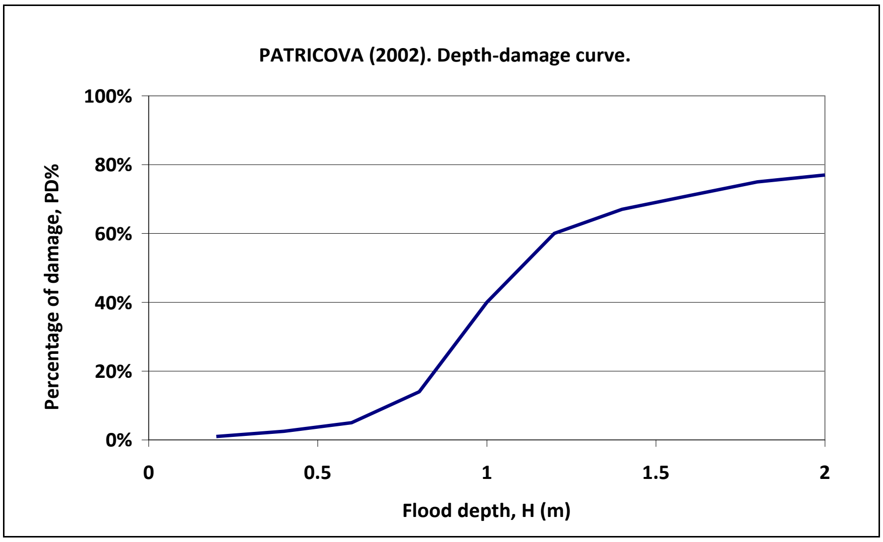

Figure A.5.1. Depth-damage curve. PATRICOVA, 2002 [13].

Depth-damage curves for buildings

There are several depth-damage curves proposed by USACE [6] [14] that define the percentage of damage in case of flooding from the following concepts:

- Structure value. Preliminary data for estimating the value of the content.
- Depth-damage function. Damage of the structure or building as a percentage of the structure value. It depends on the number of floors (one-story or multi-story buildings) and the existence of basement.
- Content-damage relationships. As a function of content valuations (estimation of the economic value of the content). A structure occupancy type is assigned.
- Content depth-damage relationships. The content depth-damage relationship provides the estimate of content flood damage as a percentage of content value.

Depth-damage curves from USACE [14] consider the first floor (ground floor) as a reference level for the definition of flood water depth.

Table A.5.4 shows depth-damage relationships in case of buildings without basement, where SD denotes standard deviation from the mean value of the percentage of damage. Figure A.5.2 shows the depth-damage curves from the given values in Table A.5.4.

		No basement							
		Structure				**Content**			
		One story		**Two or more stories**		**One story**		**Two or more stories**	
Depth (ft)	**Depth (m)**	**Damage Mean (%)**	**SD**	**Damage Mean (%)**	**SD**	**Damage Mean (%)**	**SD**	**Damage Mean (%)**	**SD**
-2	-0.7	0%	0.00%	0%	0.00%	0%	0.00%	0%	0.00%
-1	-0.3	2.50%	2.70%	3.00%	4.10%	2.40%	2.10%	1.00%	3.50%
0	0.0	13.40%	2.00%	9.30%	3.40%	8.10%	1.50%	5.00%	2.90%
1	0.3	23.30%	1.60%	15.20%	3.00%	13.30%	1.20%	8.70%	2.60%
2	0.7	32.10%	1.60%	20.90%	2.80%	17.90%	1.20%	12.20%	2.50%
3	1.0	40.10%	1.80%	26.30%	2.90%	22.00%	1.40%	15.50%	2.50%
4	1.3	47.10%	1.90%	31.40%	3.20%	25.70%	1.50%	18.50%	2.70%
5	1.7	53.20%	2.00%	36.20%	3.40%	28.80%	1.60%	21.30%	3.00%
6	2.0	58.60%	2.10%	40.70%	3.70%	31.50%	1.60%	23.90%	3.20%
7	2.3	63.20%	2.20%	44.90%	3.90%	33.80%	1.70%	26.30%	3.30%
8	2.6	67.20%	2.30%	48.80%	4.00%	35.70%	1.80%	28.40%	3.40%
9	3.0	70.50%	2.40%	52.40%	4.10%	37.20%	1.90%	30.30%	3.50%
10	3.3	73.20%	2.70%	55.70%	4.20%	38.40%	2.10%	32.00%	3.50%
11	3.6	75.40%	3.00%	58.70%	4.20%	39.20%	2.30%	33.40%	3.50%
12	4.0	77.20%	3.30%	61.40%	4.20%	39.70%	2.60%	34.70%	3.50%
13	4.3	78.50%	3.70%	63.80%	4.20%	40.00%	2.90%	35.60%	3.50%
14	4.6	79.50%	4.10%	65.90%	4.30%	40.00%	3.20%	36.40%	3.60%
15	5.0	80.20%	4.50%	67.70%	4.60%	40.00%	3.50%	36.90%	3.80%
16	5.3	80.70%	4.90%	69.20%	5.00%	40.00%	3.80%	37.20%	4.20%

Table A.5.4. Depth-damage relationships. No basement. USACE (2000) [14].

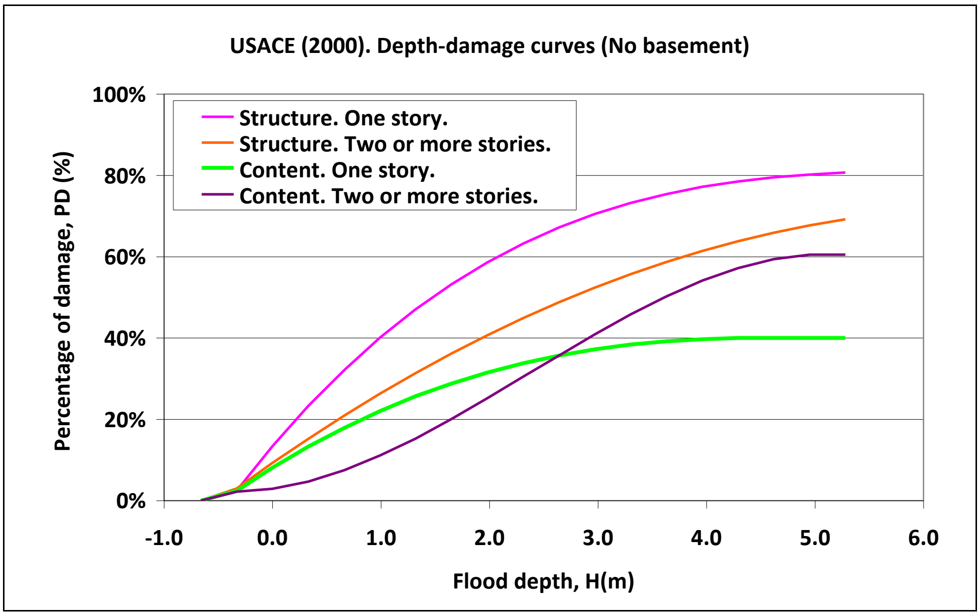

Figure A.5.2. Depth-damage curves. No basement. USACE (2000) [14].

Table A.5.5 and Figure A.5.3 include depth-damage relationships for buildings with basement.

		Basement							
		Structure				Content			
		One story		Two or more stories		One story		Two or more stories	
Depth (ft)	**Depth (m)**	**Damage Mean (%)**	**SD**	**Damage Mean (%)**	**SD**	**Damage Mean (%)**	**SD**	**Damage Mean (%)**	**SD**
-8	-2.6	0%	0.00	2%	2.70	0%	1.60	0%	0.00
-7	-2.3	0.70%	1.34	1.70%	2.70	0.80%	1.16	1.00%	2.27
-6	-2.0	0.80%	1.06	1.90%	2.11	2.10%	0.92	2.30%	1.76
-5	-1.7	2.40%	0.94	2.90%	1.80	3.70%	0.81	3.70%	1.49
-4	-1.3	5.20%	0.91	4.70%	1.66	5.70%	0.78	5.20%	1.37
-3	-1.0	9.00%	0.88	7.20%	1.56	8.00%	0.76	6.80%	1.29
-2	-0.7	13.80%	0.85	10.20%	1.47	10.50%	0.74	8.40%	1.21
-1	-0.3	19.40%	0.83	13.90%	1.37	13.20%	0.72	10.10%	1.13
0	0.0	25.50%	0.85	17.90%	1.32	16.00%	0.74	11.90%	1.09
1	0.3	32.00%	0.96	22.30%	1.35	18.90%	0.83	13.80%	1.11
2	0.7	38.70%	1.14	27.00%	1.50	21.80%	0.98	15.70%	1.23
3	1.0	45.50%	1.37	31.90%	1.75	24.70%	1.17	17.70%	1.43
4	1.3	52.20%	1.63	36.90%	2.04	27.40%	1.39	19.80%	1.67
5	1.7	58.60%	1.89	41.90%	2.34	30.00%	1.60	22.00%	1.92
6	2.0	64.50%	2.14	46.90%	2.63	32.40%	1.81	24.30%	2.15
7	2.3	69.80%	2.35	51.80%	2.89	34.50%	1.99	26.70%	2.36
8	2.6	74.20%	2.52	56.40%	3.13	36.30%	2.13	29.10%	2.56
9	3.0	77.70%	2.66	60.80%	3.38	37.70%	2.25	31.70%	2.76
10	3.3	80.10%	2.77	64.80%	3.71	38.60%	2.35	34.40%	3.04
11	3.6	81.10%	2.88	68.40%	4.22	39.10%	2.45	37.20%	3.46
12	4.0	81.10%	2.88	71.40%	5.02	39.10%	2.45	40.00%	4.12
13	4.3	81.10%	2.88	73.70%	6.19	39.10%	2.45	43.00%	5.08
14	4.6	81.10%	2.88	75.40%	7.79	39.10%	2.45	46.10%	6.39
15	5.0	81.10%	2.88	76.40%	9.84	39.10%	2.45	49.30%	8.08
16	5.3	81.10%	2.88	76.40%	12.36	39.10%	2.45	52.60%	10.15

Table A.5.5. Depth-damage relationships. Basement. USACE (2003) [14].

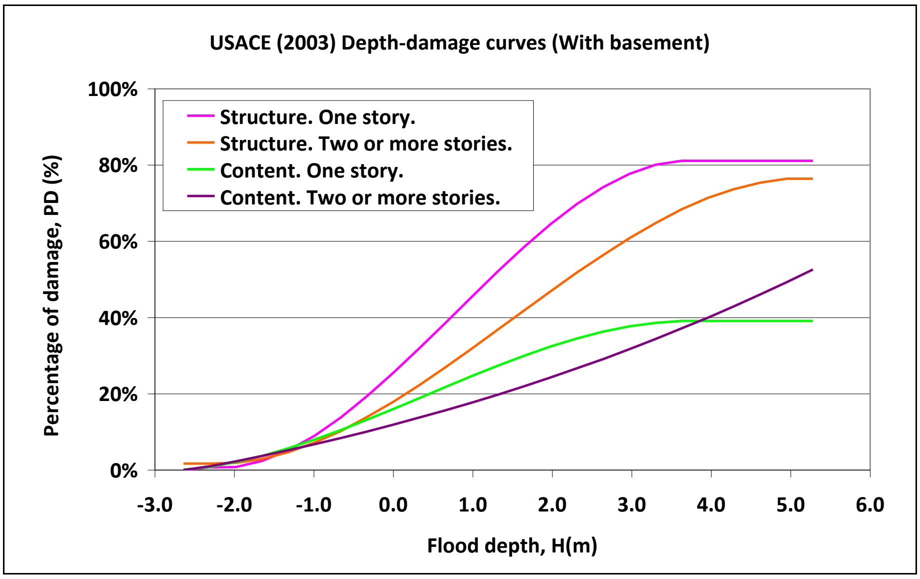

Figure A.5.3. Depth-damage curves. Basement. USACE (2003) [14].

Depth-damage curves for multiple categories

Several dept-damage relationships can be found in the literature for the estimation of economic losses due to a flood event. In this section, an example of depth-damage curves for different land use categories and assets is shown in Figure A.5.4 (Elsner et al, 2003 [19], based on Klaus and Schmitdke, 1990).

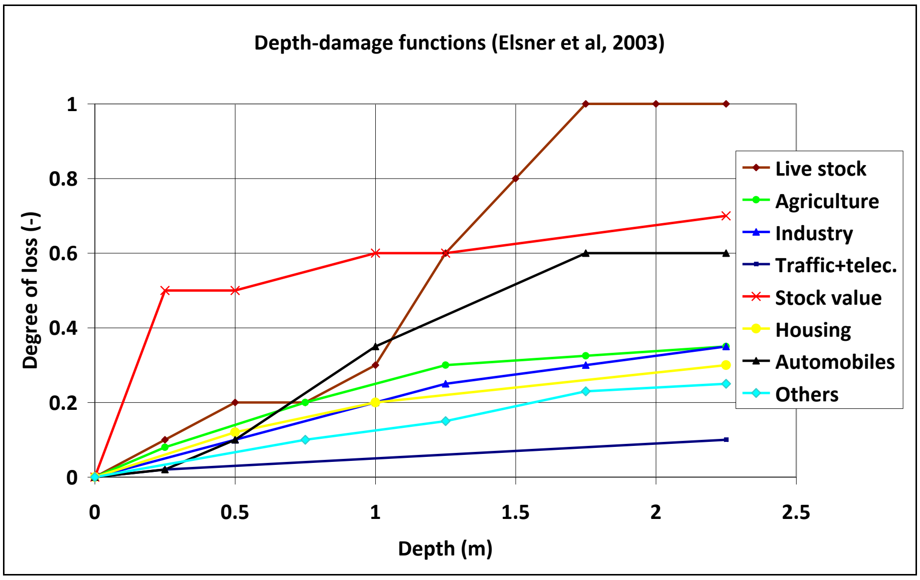

Figure A.5.4. Depth-damage curves for multiple land uses. Elsner et al (2003) [19].

Depth-damage curves for road networks

If damage estimation of road networks is considered, a reference flood depth can be established as a threshold. Streets with flood depths above this reference level are considered as damage areas, obtaining the total length of affected roads. This threshold is often determined at a level of 0.30 m of flood depth in the literature (INUNCAT, 2009 [2]).

Depth-damage curves for vehicles

There are also depth-damage criteria for the estimate of economic costs from damages on vehicles (Scawthorn et al, 2006 [47]). Figure A.5.5 shows an example of depth-damage functions for three categories of vehicles: cars, light trucks and heavy trucks.

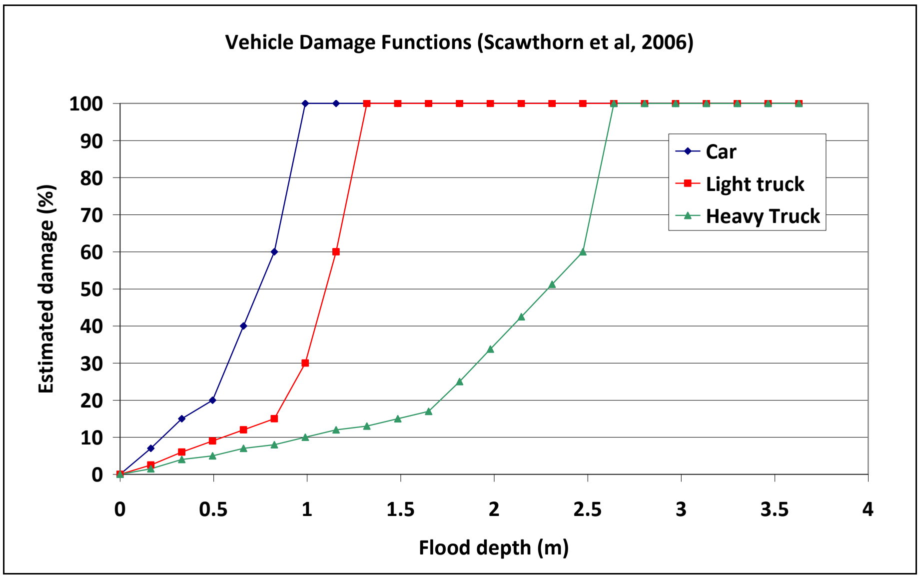

Figure A.5.5. Depth-damage curves for vehicles. Scawthorn et al, 2006 [47].

APPENDIX 6

TEMPLATES FOR CALCULATIONS

(Templates are provided within a Excel file with calculations of the case example described in Appendix 9)

APPENDIX 7

RISK MODEL SCHEMES

As it has been described in SUFRI methodology, the risk model scheme can be generally divided into three blocks of nodes: loads, system response and consequences.

The risk model scheme depends on the characteristics of each case study and the existing structural measures. Their architecture requires a more complex scheme if several infrastructures should be analyzed (i.e. large dams, levees, detention basins, embankments, etc.)

In this appendix, several schemes of different risk models are presented as an example for the risk model architecture.

Natural flow regime. River flooding

This section includes the example of a risk model for the analysis of the natural flow regime of a river. Figure A.7.1 shows the sequence of nodes for the construction of the risk model from iPresas software [48].

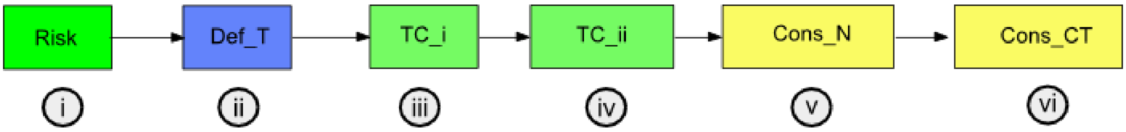

Figure A.7.1. Generic scheme for the study of the natural flow regime of the river.

Each node corresponds with the following information:

i. Risk. This fist node is included for the estimate of total risk. It requires the definition of a variable with one option or category (i.e. variable='risk'), which probability is 1 (probability of being in this category is 100%).

ii. Def_T. This node includes the established return periods for the definition of flood scenarios and their annual probabilities of exceedance. Each return period is related to a maximum peak discharge of the hydrograph.

iii. TC_i. This node is related to information on seasonal variability of the population in the study area (i.e. probabilities of being during summer, winter, special events, etc.).

iv. TC_ii. This node includes information concerning daily variability of the population in the study area (i.e. probabilities of being during the day or at night).

v. Cons_N. This node is associated with files that contain data from the estimation of consequences in terms of life-loss (T-N relationships: number of potential fatalities, denoted by N or 'lives', for each flood scenario).

vi. Cons_CT. This node includes input data from the estimation of consequences in terms of economic losses (T-CT relationships: level of economic losses, denoted by CT or 'costs', for each flood scenario).

Structural measures (dam). River flooding

In this section, the risk model scheme for a base-case with a dam located upstream the urban area is studied.

Figure A.7.2 shows the overall scheme of a risk model that includes the existence of a dam upstream the urban area. This scheme represents a dam with two failure modes in hydrologic scenario [48].

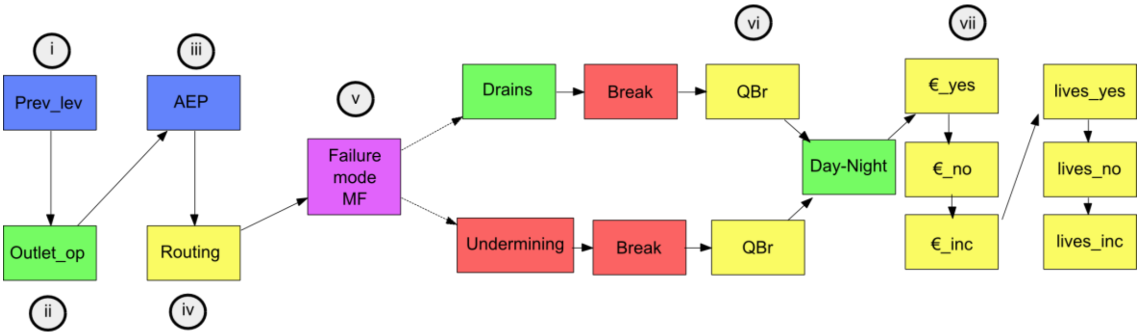

Figure A.7.2. Risk model scheme of a dam with two failure modes.

Information related to these nodes is summarised as follows:

i. Prev_Lev. This node includes the probability of exceedance of a certain water pool level, that is, the probability of being in a certain level when the flood occurs.

ii. Outlet_op. In this node, functionality of outlet works (spillway) is described.

iii. AEP. This node is used to generate several branches with the probability of a certain flood event occurring.

iv. Routing. This node includes the results of the flood routing process, and provides maximum water pool levels, flow discharges and overtopping characteristics.

v. MF. This is an artificial node which introduces the failure modes of the dam. Two failure modes are considered in this scheme.

vi. Qbr. This node represents the dam break peak discharge associated to each failure mode.

vii. €_yes, €_no and E_inc. These nodes include data from potential consequences in terms of economic losses in three different cases: costs due to floods from dam break, costs due to floods from flood routing and incremental costs. If loss of life is analysed, then nodes denoted by 'lives_yes, lives_no and lives_inc' include data from potential consequences in terms of loss of life in the same previous cases: life-loss due to dam break, flood routing and incremental values.

Non-structural measures. River flooding

In this point, differences on the risk model are described from the study of non-structural measures. If the effect of non-structural measures should be analyzed, the risk-model for the base-case is used as a reference scheme.

Figure A.7.3 shows the base-case scheme of the previous section and indicates which nodes should be modified (with new input data) for risk evaluation with non-structural measures (these nodes are shown in Figure A.7.3 within a box, related to point 'vii').

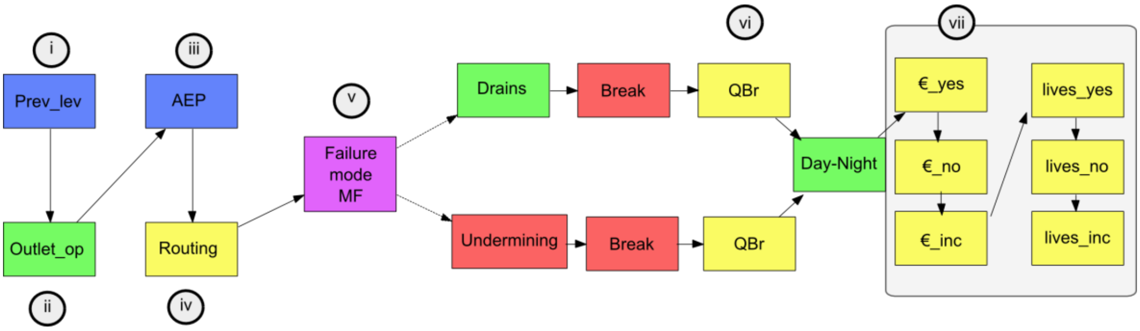

Figure A.7.3. Risk model scheme for non-structural measures.

The effect of non-structural measures includes variations on potential consequences of the established flood scenarios. Consequently, new input data is required for nodes related to the third block of the risk model scheme, identified by a grey area in Figure A.7.3 and described above in paragraph 'vii'.

Pluvial flooding

In this case, the risk model scheme is similar to the previous example for the study of the natural flow regime of a river. The risk model requires the definition of nodes that include information on flood scenarios, system response and potential consequences.

Figure A.7.4 shows the overall risk model scheme for pluvial flooding.

Figure A.7.4. Risk model scheme for pluvial flooding.

Despite the similarities between both risk model schemes (Figures A.7.1 and A.7.4), differences rely on the content of each node.

i. PF. This node is set at the beginning of the risk model for the estimate of total risk. It requires the definition of a variable (i.e. 'risk') and just one option with probability equal to 1.

ii. TC_i. This node includes information on seasonal variability of the population in the study area (i.e. probabilities of being during summer, winter, special events, etc.).

iii. TC_ii. This node includes information concerning daily variability of the population in the study area (i.e. probabilities of being during the day or at night).

iv. Flood. This node includes the established flood scenarios for the analysis. Each flood scenario is defined by a return period.

v. Runoff. This node relates each flood scenario to a reference runoff rate (Q_{pf}). This reference value is used to associate each flood scenario with potential consequences.

vi. Cons_N. This node contains data from the estimation of consequences in terms of loss of life (Q_{pf} -N relationships: number of potential fatalities, denoted by N or 'lives', for each flood scenario).

vii. Cons_CT. This node includes input data from the estimation of consequences in terms of economic losses (Q_{pf} -CT relationships: level of economic losses, denoted by CT or 'costs', for each flood scenario).

F-N curve

Finally, representation of F-N curves is described in this point, from results of the risk model developed by means of iPresas software [48].

Once the risk model is ready for the analysis (all input data is linked to the corresponding node) and results are obtained, then the following command should be applied:

File → Export F-N…

From these commands, a dialogue box gives two options: societal or economic risk (identified by the name established in nodes Cons_N and Cons_CT for the variable of consequences: N or lives and CT or costs).

As a result, the iPresas software creates a .txt file that contains two columns of data: level of consequences (in terms of expected number of fatalities or economic costs) and annual probability of exceedance (AEP).

The F-N curve is obtained from the representation of the cumulative annual probability of exceedance (F, years^{-1}) of a certain number of fatalities (N) or economic costs (€).

Figure A.7.5 shows an example of a F-N curve, where both axes are generally displayed in logarithmic scale.

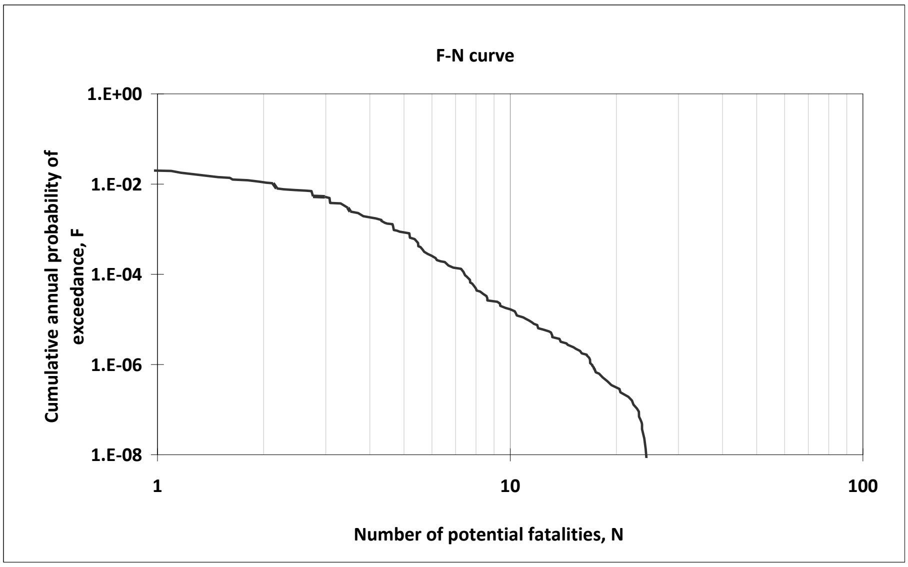

Figure A.7.5. F-N curve. Generic example.

APPENDIX 8

EXISTING TOLERABILITY CRITERIA FOR FLOOD RISK

Tolerability criteria for flood risk are the basis for a proper risk management, with the aim of improving the decision process for implementation of measures for risk mitigation. Therefore, the concept of tolerable risk is fundamental to risk-informed decision making [42]. These tolerability criteria must be mainly referred to human loss of life, as it is the main consequence of flood, but also based on economical consequences.

Figure A.8.1 shows the three general ranges for risk tolerability. The first range is the unacceptable region, where risk can only be justified in extraordinary circumstances. The second region is the range of tolerability, where the risk is under the tolerability risk limit. In this region the analysis of risk is crucial because this risk is accepted by the society if it cannot be lowered in an economically efficient way. The third region is the broadly acceptable region, where risk can be defined as insignificant and can be controlled adequately.

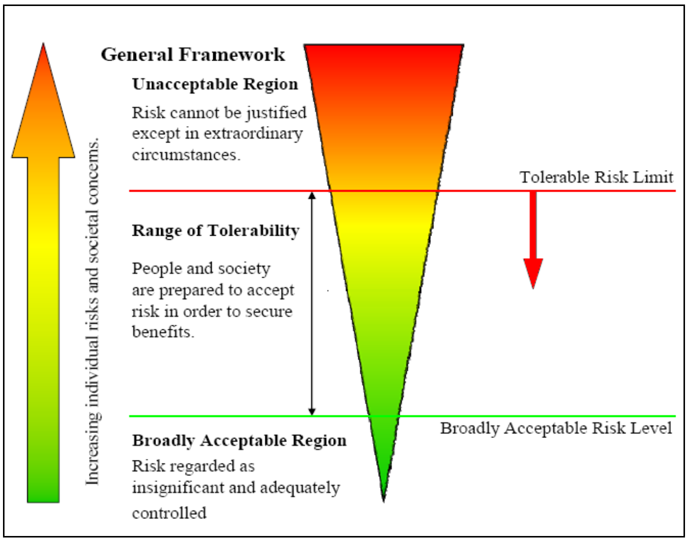

Figure A.8.1. Generalized tolerability of risk framework [25].

In general, in the range of tolerability, the ALARP principle (As Low As Reasonably Practicable) must be followed. This concept considers that risks lower than the tolerable risk limit are only tolerable if further risk reduction is impracticable or the cost is grossly disproportional to risk reduction.

Risk tolerability criteria cannot be only decided by legislators or technicians, since risk tolerability must be known and shared with all the affected population.

In most countries, flood risk tolerability criteria have not been developed yet, as the inexistence of completely developed tools for societal flood risk quantification restricts such development, these criteria must be developed to ensure a proper management of flood risks measures. The current acceptability criteria for risk can be classified in two groups: tolerability guidelines for individual risk and for societal risk.

Tolerability criteria for individual risk

Individual risk is based on the probability part of the risk and, in the case of flood risk, it includes two components: the probability of inundation and the probability of death of an exposed person to the flood. Therefore, individual risk depends on the characteristics of the inundation, hazard, and not on the vulnerability. Their units are number of fatalities per unit of time, as a consequence of the combination of these two probabilities.

The most relevant tolerability criteria with legal importance for acceptability of general individual risk have been developed by the Dutch Ministry of Housing, Urban Planning and Environment (VROM), which limits individual risk in urban areas to 10^{-6}. In addition, limitation of individual risk proposed by the Dutch Technical Committee for Advising in Defence Constructions (TAW) is [53]:

$$IR < \beta \cdot 10^{-4}$$

Where β is the policy factor, which varies accordingly to the degree to which participation in the activity is voluntary and with the perceived benefit. Proposed values for this factor are between 0.01 for involuntary activities and 10 for voluntary activity for personal benefit. Typical values of this factor are shown in Figure A.8.2. In the case of dikes that protect from flooding urban areas, the β factor usually used is between 1 and 0.1.

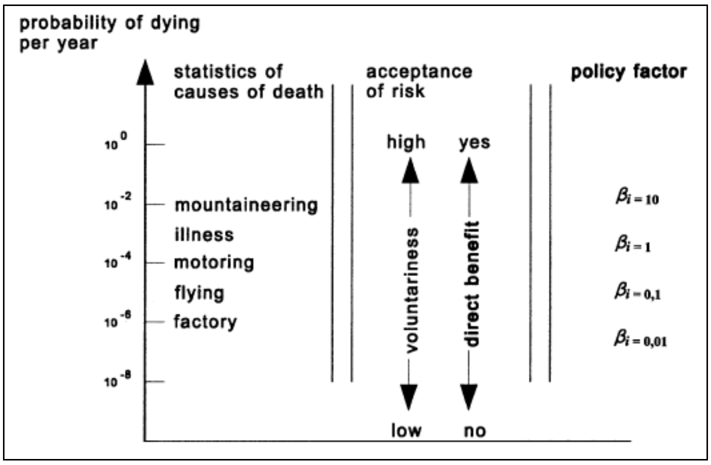

Figure A.8.2. Personal risks in western countries, deduced from the statistics of causes of death and the number of participants per activity [53].

The most common acceptability criteria for flood risk are based on the limitations of the probability of occurrence of a flood in a certain urban area. This limit is also a measure of the hazard flood component, like the individual risk, although this probability does not include the probability of loss of lives. In general, limits for individual risks are important to avoid high risks related with damage to one person, they must be accompanied with societal risk limits [27].

Tolerability criteria for societal risk

It is generally accepted that individual risk criteria must be accompanied with societal risk limits [27].

Societal risk is the relationship between frequency and the number of victims in a given population from the realization of specified hazards, consequently it is more complete than individual risk because it includes vulnerability, not only hazard characteristics.

This risk is normally evaluated with F-N curves that represent the relation between the probability of occurrence of the hazard and the number of victims produced by the hazard. The area under a F-N curve is the total societal risk. These curves are limited by different lines, expressing the acceptability risk criteria. These criteria have not been developed for flood risk, although there are different standards for hazardous industries, as it is shown in Figure A.8.3.

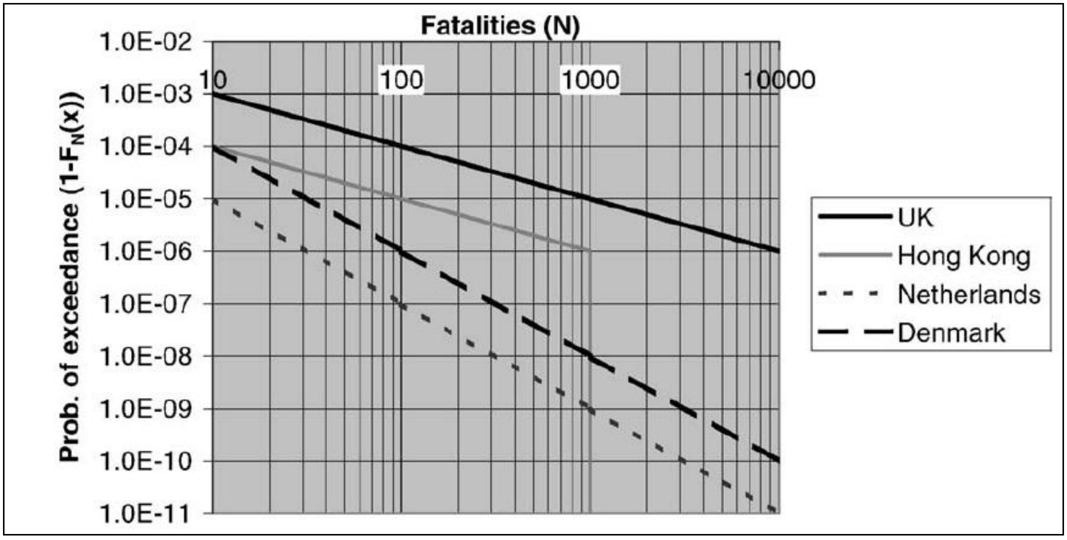

Figure A.8.3. Some international standards for hazardous industry in F-N format [29].

The best known criterion for evaluating societal risk has been formulated in terms of F-N curves by Vrijling [53], establishing the tolerable risk by means of the following equation:

$$1-F_N(n) < C_N / n^{\alpha}$$

Where F_N is the flood probability of occurrence, C_N is a constant that determine the vertical position of the F-N limit line, n is the number of fatalities and α is the risk aversion coefficient that determines the steepness of the F-N limit curve (more usual value is 2).

The coefficient α reflects risk aversion toward large accidents. A standard value of α=1 is called risk neutral. For instance, if α=2, then larger accidents with many fatalities are accepted with a relatively smaller probability than smaller accidents.

The value of C_N can be derived from the following formula, proposed by Vrijling et al [53]:

$$C_N = \left(\frac{\beta \cdot 100}{k} \right)^2$$

where k=3 (proposed value in Vrijling [53]) and β is the aforementioned policy factor, ranging from 0.01 (for involuntary activities) to 10 (voluntary activity for personal benefit). The policy factor, β, is used for the limit of the individual risk and the population at risk.

This criterion can be applied for single installations, not only for a national scale. In that case, C_N is denoted by C_I.

The results of the application of these limits for the societal flood risk in the province of South Holland with different values of C_i are shown in Figure A.8.4.

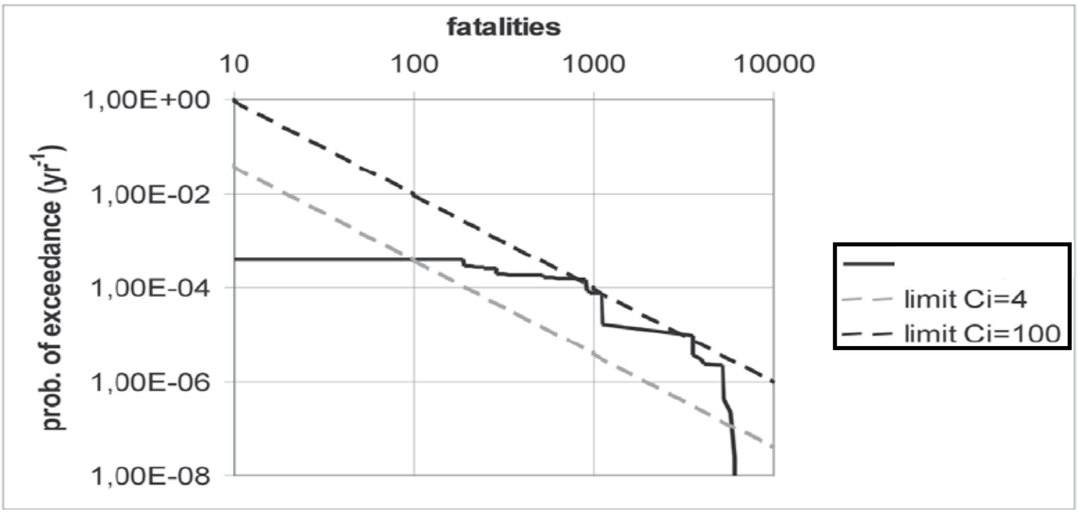

Figure A.8.4. F-N curve for dike ring South Holland and two limit lines for different values of C_i [53].

Furthermore, some tolerability criteria of flood risk have been developed for incremental societal flood risk produced by the existence of large dams. These criteria are also usually drawn in F-N curves, as the criteria proposed by ANCOLD [4]. These criteria have been developed for incremental risk, thus they cannot be used to evaluate the total societal flood risk as the criterion proposed by Vrijling [53].

In conclusion, F-N curves can be a useful tool to evaluate societal flood risk, although different criteria for each country must be developed and accepted by the society. In addition, economical tolerability criteria for floods of a higher probability of occurrence could be developed in cases of high economical consequences but low loss of life.

APPENDIX 9

Case example

SUFRI methodology is here applied in a hypothetical case example. This case example is based on information of a real location in Spain, but some simplifications have been assumed in this initial application of SUFRI methodology to enable a better understanding of this example.

INTRODUCTION

The case example is based on a village located in the north of Spain, crossed by a river course, with a dam located 8 Km upstream the town (Figure A.9.1). The urban area is mainly composed of residential areas. Also, there is an industrial area located at the south-east part of the urban area (Figure A.9.2).

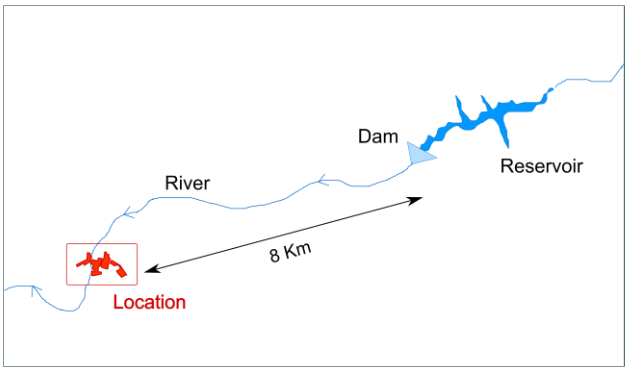

Figure A.9.1. Scheme of location of the urban area.

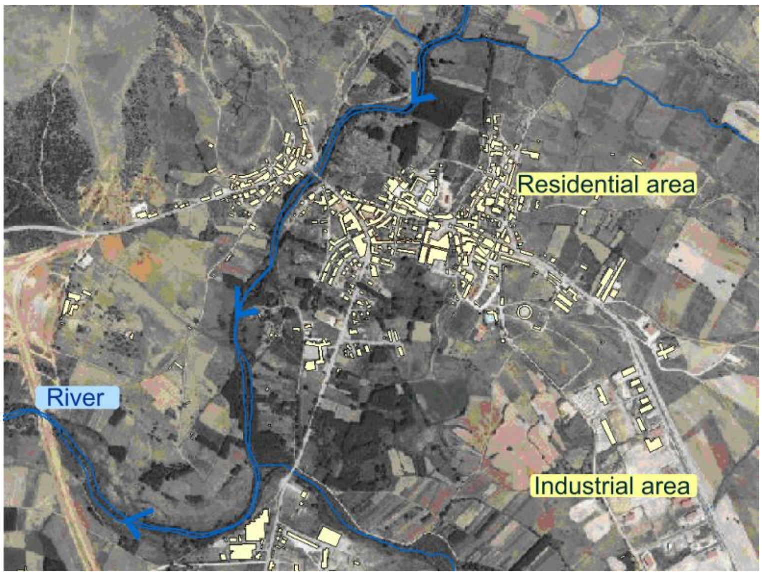

Figure A.9.2. View of the urban area for this case example.

Firstly, risk analysis for river and pluvial flooding are analysed separately. Secondly, the overall analysis of the case example is described from the combination of all results.

RIVER FLOODING

PHASE I. SCOPE OF THE CASE STUDY

In this case example, three different situations from river flooding are considered:

- Current situation (existence of river embankment and dam, denoted as Base-case),
- Situation with non-structural measures (effect of a Public Education Program on Flood Risk, denoted as PFR-case), and,
- Natural flow regime of the river (for comparison purposes, denoted as RN-case).

The aim is the analysis of the existent flood risk in this location and the effect on flood risk reduction that can be achieved through the application of non-structural measures.

PHASE II. REVIEW OF AVAILABLE DATA

Once the aim of the case example is established, it is necessary to obtain all necessary data and information of this location to perform the risk model for the base-case.

Some examples of documents and information obtained after data-collection are:

- Overall information of past flood events.
- Digital Elevation Model of the area.
- Land use maps.
  - Residential and industrial areas.
- Statistics of demography.
  - Total population: 1986 inhabitants.
  - Daily variability: 256 inhabitants.
  - Seasonal variability: 800 inhabitants.

- Building typologies, number of households, etc.
    - Average number of storeys: 2.1 floors/household.
- Identification of vulnerable areas or sectors: campsites, hospitals, schools, etc.
    - No vulnerable areas are identified.
- Economic statistics and value of assets.
    - Reference cost: Residential, 49.29 €/m^2 and industrial, 14.3 €/m^2.
- Information of river characteristics:
    - Hydrographs of the natural flow regime of the river: from return periods that range from 2 to 10,000 years.
    - Mean annual peak discharge: $Q_{2.33}$=29.3 m^3/s.
    - Peak discharge that reaches the capacity of the river embankment at the urban area: Q=150 m^3/s.
    - Peak discharge that reaches the first households at the urban area: Q=200 m^3/s.
- Dam characteristics, analysis and study of gate functionality, expected water pool levels, flood routing, potential failure modes, dam break hydrographs, etc.
    - Peak discharges from flood routing, Q_{nbr}: 121.5 m^3/s, 244.6 m^3/s, 351.6 m^3/s, 632.7 m^3/s and 782.6 m^3/s.
    - Peak discharges from dam failure cases, Q_{br}: 15,034 m^3/s, 37,629 m^3/s, 56,878 m^3/s, 81,039 m^3/s, 107,162 m^3/s, 116,871 m^3/s and 121,323 m^3/s.
- Dam Emergency Action Plan.
- Hydraulic model of the river course.
- Flood maps from dam failure cases, non-failure cases and floods from the natural flow regime of the river.

Definition of time categories

TC Four time categories are defined from daily and seasonal variability of the number of people located at the urban area.

Total population is equal to 1988 inhabitants, and this value increases during the day in 256 persons due to labour reasons. In summer, population increases an amount of 800 people due to the existence of secondary residences (during summer holiday).

Thus, four time categories are distinguished as follows (Table A.9.1):

Time category	Summer/day (TC_1)	Summer/Night (TC_2)	Winter/day (TC_3)	Winter/night (TC_4)
Inhabitants	3,044	2,788	2,244	1,988
Range Summer/winter	Summer: From July 1st to September 15th Winter: Rest of the year			
Range Day/night	Day: 8:00 a.m. - 10:30 p.m. Night: 10:30 p.m. - 8:00 a.m.			

Table A.9.1. Time categories.

Definition of land use categories

CU Two land use categories area proposed in this example: residential areas (land use category CU_1) and industrial areas (land use category CU_2).

PHASE III. STUDY OF THE SYSTEM SITUATION. DEFINITION OF BASE-CASE

The base-case is defined as the current situation: existence of a dam upstream the urban area and the Emergency Action Plan (EAP) of such dam has already been implemented.

Then, risk analysis for this case example starts with the risk model for the base-case, following the different phases of SUFRI methodology.

Risk model "1". River flooding: Base-case.

PHASE IV. FLOOD SCENARIOS

Flood scenarios are defined from the study of dam-break hydrographs and flow discharges from the reservoir due to flood routing. Then, two types of flood scenarios are needed: flood scenarios from dam failure cases and flood scenarios due to peak discharges from flood routing.

Thus, two series of maximum peak discharges are determined (as there are two ranges of values that represent probable flood situations). In general, the same number of flood scenarios can be defined for both ranges, based on a maximum peak flow of the hydrograph (denoted by Q_{br} for dam failure and Q_{nbr} for non-failure cases).

In this hypothetical example, five flood scenarios represent flood events due to peak discharges from flood routing (Table A.9.2). In addition, seven flood scenarios in dam failure cases are provided, from different water pool levels at the reservoir (Table A.9.3).

Flood scenarios (non-failure cases)	Q_{nbr} (m^3/s)
Q_{nbr1}	121.5
Q_{nbr2}	244.6
Q_{nbr3}	351.6
Q_{nbr4}	632.7
Q_{nbr5}	782.6

Table A.9.2. Peak discharges from hydrographs in non-failure cases.

Flood scenarios (failure cases)	Q_{br} (m^3/s)
Q_{br1}	15,034
Q_{br2}	37,629
Q_{br3}	56,878
Q_{br4}	81,039
Q_{br5}	107,162
Q_{br6}	116,871
Q_{br7}	121,323

Table A.9.3. Peak discharges from hydrographs in dam failure cases.

The above flood scenarios are the basis for estimating potential consequences in case of river flooding in this case example.

PHASE V. RISK MODEL ARCHITECTURE

The risk model for the base-case is developed to represent the current situation of the urban area in case of river flooding. It is divided into three main parts: (a) loads, (b) system response and (c) consequences.

Loads and system response provide probabilities of exceedance of each flood scenario from input data of probable flood events, gate functionality, flood routing and feasible failure modes of the flood defence infrastructure (dam). The block of consequences within the risk model includes potential damages in terms of loss of life and economic losses of each flood scenario and time category.

The scheme of the risk model for the base-case is presented in Figure A.9.3. The influence diagram of the base-case risk model performed with iPresas software has different nodes according to the aforementioned parts of the scheme: loads, system response and consequences. Table A.9.4 lists the name of each node, description of necessary input data, name of the input data file and parameters for data identification within the risk model.

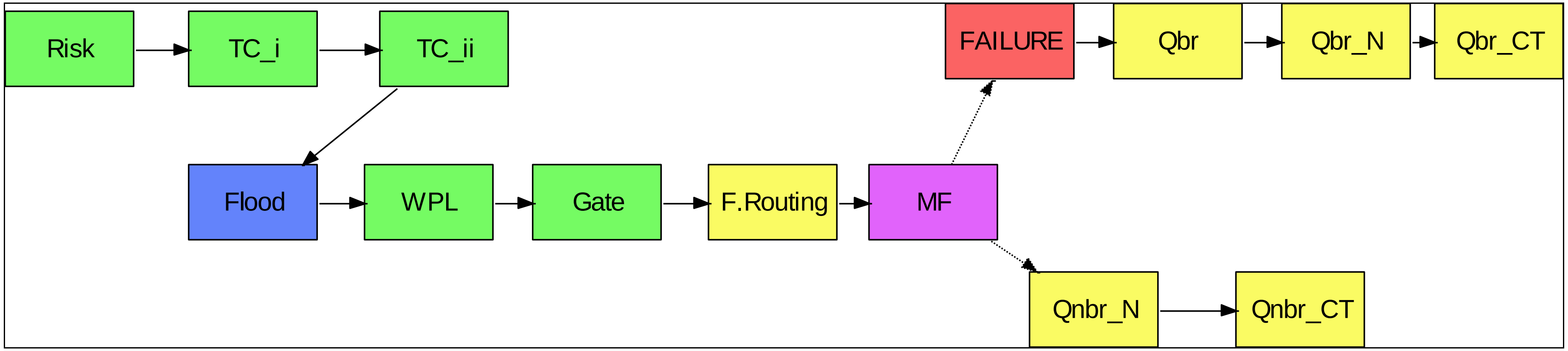

Figure A.9.3. Risk model scheme of the base-case.

Node	Block	Description	Input data file	Descriptor
Risk	-	First node for risk calculation of societal and economic risk	risk.txt	prob (probability=1)
TC_i	-	Defines probabilities of each season: summer or winter. i.e. summer=0.2084; winter=0.7916 (rest of the year)	season.txt	moment
TC_ii	-	Defines probabilities of being during the day or at night. i.e. day=0.6; night=0.4	daynight.txt	day, night (identifies time category)
Flood	a	Annual probability of exceedance of each flood scenario.	flood.txt	AEP (annual probability of exceedance)
WPL	a	Distribution of water pool levels at the reservoir and associated probability.	wpl.txt	NP (previous water pool level)
Gate	a	Probabilities related to functionality of outlet works.	gate.txt	Op_gate (if outlet works do not act Op_gate is 0)
F.Routing	a	This node relates each combination of the aforementioned parameters with a maximum water pool level, peak discharge, overtopping flow and time.	floodrouting.xls	NMax (maximum water pool level), Qnbr (flood routing discharge)
MF	b	It links 'F.Routing' node with two branches: failure and non-failure options.	-	-
Failure	b	Node that contains probability of dam failure for each water pool level.	prob_br.xls	prob_br (probability value)
Qbr	b	These nodes give the peak discharge of the hydrograph for dam failure cases for each water pool level.	Qbr.txt	NMax, Qbr (dam failure flow discharge)
Qbr_N, Qbr_CT	c	Consequences in terms of loss of life or economic losses for each flood scenario and time category for non-failure cases (identified by the peak discharge from flood routing, Q_{nbr})	Qbr_lives.xls Qbr_euros.txt	Qbr, N or Qbr, euros
Qnbr_N, Qnbr_CT	c	Consequences in terms of loss of life or economic losses for each flood scenario and time category in failure cases (identified by the peak discharge from dam failure, Q_{br})	Qnbr_lives.xls Qnbr_euros.txt	Qnbr, N or Qnbr, euros

Table A.9.4. Nodes of the risk model scheme of the base-case.

PHASE VI. INPUT DATA FOR THE RISK MODEL

Input data for performing the risk model is classified in three blocks according to the three aforementioned parts of the model: loads, system response and consequences.

a) LOADS

Input data for nodes of the risk model related to *loads* are based on hydrological studies. It is necessary to obtain information of the river basin upstream the reservoir and hydrographs from dam failure cases and flood routing. Historical records of previous water pool levels are obtained from hydrological studies (see wpl.txt). The analysis of flood routing from these previous pool levels and gate functionality provide a series of maximum water pool levels at the reservoir and associated probabilities of being in each level (see floodrouting.xls).

b) SYSTEM RESPONSE

From the study of potential failure modes of the dam (expert judgement, monitoring, site visit, etc.), conditional probabilities are estimated for each maximum water pool level (see prob_br.xls).

Flood routing analysis provides maximum water levels and peak discharges for non-failure cases. Peak discharges presented in Table A.9.2 are used for hydraulic modelling (flooding maps from non-failure cases) and estimation of input data of potential consequences from flooding events due to non-failure cases.

Dam break hydrographs provide values of the peak discharge for each water pool level at the reservoir (see Qbr.txt). Peak discharges presented in Table A.9.3 are used for hydraulic modelling (flooding maps from failure cases) and estimation of input data of potential consequences in case of failure.

Hydraulic study

Hydraulic simulations of flood scenarios defined in phase IV are performed in MIKE11 from the Digital Elevation Model of the study area, including cross sections of the river embankment and dam geometry. Dam-break hydrographs and breach development are included to analyse floods from dam failure cases.

Simulations provide hydraulic characteristics of each flood scenario, and data of water depth, velocity and arrival times are obtained in the urban area of this case example. From GIS software, flooded areas are obtained to estimate loss of life and economic losses.

c) CONSEQUENCES

Estimation of input data for quantifying consequences associated with the above flood scenarios (Tables A.9.2 and A.9.3) is necessary to obtain societal and economic risk.

Thus, estimation of loss of life and economic losses is required to include potential damages in the risk model. This information, together with probabilities of occurrence of the flood events (from loads and system response nodes), allows the analysis of the base-case.

As it was described in SUFRI methodology, the process to obtain input data for consequences is divided into two parts: loss of life and economic losses.

c.1. LOSS OF LIFE

c.1.1. Category for the base-case to define reference fatality rates (C and RFR)

From Table A.1.1 (Appendix 1) of SUFRI methodology, the base-case corresponds to category C4 (there is a Dam Emergency Action Plan). Consequently, reference fatality rates (RFR) in this case example are the values presented in Table A.9.5.

Warning time TW (h)	Flood severity, Sv		
	High (3)	Medium (2)	Low (1)
0	0.9	0.3	0.02
0.25	0.85	0.2	0.015
0.625	0.6	0.07	0.012
1	-	0.05	0.0005
1.5	-	0.0002	0.0002
24	-	0.0002	0.0001

Table A.9.5. Reference fatality rates (RFR). Category C4.

These reference fatality rates (RFR) are below multiplied by the number of people at risk (population at risk) for estimating loss of life.

c.1.2. Population at risk (PR)

Flooded areas are obtained from comparison of land use and flooding maps. For a certain flood scenario, population at risk for each time and land use category is obtained from multiplying total population in the urban area by the ratio between the resultant flooded area (A_f) and the total area of the urban site (A_T).

	Total area, A_T (m^2)	588,358	Population at risk, PR			
			Time category, TC			
Q_{nbr} (m^3/s)	Flooded area, A_f (m^2)	A_f/A_T (%)	TC_1	TC_2	TC_3	TC_4
121.5	0	0.00%	0	0	0	0
244.6	12500	2.12%	65	59	48	42
351.6	17656	3.00%	91	84	67	60
632.7	63097	10.72%	326	299	241	213
782.6	77325	13.14%	400	366	295	261

Table A.9.6. Population at risk. River flooding. Non-failure cases.

	Total area, A_T (m^2)	588,358	Population at risk, PR			
Q_{br} (m^3/s)	Flooded area, A_f (m^2)	A_f/A_T (%)	TC_1	TC_2	TC_3	TC_4
15,034	73,580	12.51%	381	349	281	249
37,629	151,566	25.76%	784	718	578	512
56,878	349,273	59.36%	1,807	1,655	1,332	1,180
81,039	469,472	79.79%	2,429	2,224	1,790	1,586
107,162	514,569	87.46%	2,662	2,438	1,962	1,738
116,871	525,001	89.23%	2,716	2,487	2,002	1,774
121,323	544,303	92.51%	2,816	2,579	2,076	1,839

Table A.9.7. Population at risk. River flooding. Failure cases.

c.1.3. Warning times (TW)

From Table A.1.4 (Appendix 1), warning times in non-failure cases are defined as the time difference (TD) from the first-notice flow and first-damage flow. In this case example, these values are 150 m^3/s (flow that reaches the river capacity at the urban area) and 200 m^3/s (the flood includes first buildings and households).

Table A.9.8 shows the estimated warning times for non-failure cases.

Q_{nbr} (m^3/s)	TC_1, TC_3 (Day) TW=TD (hours)	TC_2, TC_4 (Night) TW=TD-0.25 (hours)
121.5	NO FLOOD[4]	NO FLOOD
244.6	3.25	3
351.6	1.4	1.15
632.7	1.3	1.05
782.6	1.25	1

Table A.9.8. Warning times. River flooding. Non-failure cases.

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[4] If Q_{nbr} < 150 m/s, no flooded areas are produced from the peak discharge.

Warning times (TW) in failure cases in this hypothetical example are estimated using Table A.1.4 (Appendix 1), with fast breach development and hydrologic scenario, and the existence of a Dam Emergency Action Plan. Thus, the expression of warning time is given as follows:

$TW = T_{wv} + TBR – FMF$

where T_{wv} is the arrival time of the flood wave, TBR is the breach development factor (0.25 hours), and FMF is the failure mode factor (depends on day, FMF = 0, or night scenarios, FMF = 0.25 hours).

Warning times for flood scenarios from failure cases are listed in Table A.9.9.

Q_{br} (m^3/s)	TC_1, TC_3 (Day) $TW=T_{wv} + 0.25$ (hours)	TC_2, TC_4 (Night) $TW=T_{wv}$ (hours)
15,034	0.750	0.500
37,629	0.650	0.400
56,878	0.600	0.350
81,039	0.580	0.330
107,162	0.550	0.300
116,871	0.537	0.287
121,323	0.537	0.287

Table A.9.9. Warning times. River flooding. Failure cases.

Warning times shown in Tables A.9.8 and A.9.9 are used below to obtain fatality rates for each flood scenario.

c.1.4. Flood severity (Sv)

Flood severity of each flood scenario is obtained from the DV parameter (Table A.1.3, Appendix 1). There are three flood severity categories: low (1), medium (2) and high (3). Each flood severity category is related to reference fatality rates in Table A.9.5 for different warning times.

The case example is located 8 Km downstream a dam, then high severity is not considered. Low severity is suggested when DV is lower than 4.6 m^2/s, as defined in Table A.1.3 (Appendix 1). Otherwise, medium severity is established. The mean annual flow discharge, $Q_{2.33}$, of 29.3 m^3/s is used to provide an estimate of DV for each flood scenario.

Tables A.9.10 and A.9.11 include the estimated flood severity levels for each flood scenario in non-failure (Q_{nbr}) and failure cases (Q_{br}).

c.1.5. Fatality rates (FR)

Fatality rates (FR) are obtained by interpolating reference fatality rates of category C4 (Table A.9.5) from the above warning times (with different values for day and night) and flood severity categories. Tables A.9.10 and A.9.11 include the estimated fatality rates for each flood scenario in non-failure (Q_{nbr}) and failure cases (Q_{br}).

c.1.6. Number of potential fatalities(N)

The number of potential fatalities for each flood scenario is estimated by multiplying the number of people at risk (PR from each time category) by the estimated fatality rate (FR) from reference values in Table A.9.5.

Tables A.9.10 and A.9.11 present all results for the estimation of the number of potential fatalities for each flood scenario.

							Number of potential fatalities, N			
Q_{nbr} (m^3/s)	Warning time, TW day (h)	Warning time, TW night (h)	DV	Flood severity, Sv	Fatality rate, FR day	Fatality rate, FR night	Time category			
							TC_1	TC_2	TC_3	TC_4
121.5	-	-	0.00	1	-	-	-	-	-	-
244.6	3.25	3	1.99	1	0.00019	0.00019	0.01	0.01	0.01	0.01
351.6	1.4	1.15	2.69	1	0.00022	0.00027	0.02	0.02	0.01	0.02
632.7	1.3	1.05	3.77	1	0.00024	0.00029	0.08	0.09	0.06	0.06
782.6	1.25	1	3.97	1	0.00025	0.00030	0.10	0.11	0.07	0.08

Table A.9.10. Number of potential fatalities, N. River flooding. Non-failure cases. Base-case.

							Number of potential fatalities, N			
Q_{br} (m^3/s)	Warning time, TW day (h)	Warning time, TW night (h)	DV	Flood severity, Sv	Fatality rate, FR day	Fatality rate, FR night	Time category			
							TC_1	TC_2	TC_3	TC_4
15,034	0.750	0.500	18.77	2	0.037	0.077	13.96	26.73	-	-
37,629	0.650	0.400	38.81	2	0.039	0.106	30.84	76.12	10.29	19.06
56,878	0.600	0.350	45.53	2	0.047	0.121	85.52	199.69	22.73	54.28
81,039	0.580	0.330	59.41	2	0.053	0.127	129.20	281.46	63.04	142.38
107,162	0.550	0.300	74.77	2	0.062	0.135	165.04	329.95	95.24	200.68
116,871	0.537	0.287	80.71	2	0.066	0.139	178.74	346.12	121.66	235.26
121,323	0.537	0.287	83.32	2	0.066	0.139	185.31	358.85	131.76	246.79

Table A.9.11. Number of potential fatalities, N. River flooding.Failure cases. Base-case.

From the previous tables, Q_{nbr}-N and Q_{br}-N relationships are included in two Excel files. These files are used as input data for nodes of the risk model (see Table A.9.4).

c.2. ECONOMIC LOSSES

In this section, potential economic losses are estimated for each flood scenario to create input data files for nodes of the risk model regarding potential consequences.

c.2.1. Land use categories (CU)

In this case example, two land use categories are established for the urban area. In river flooding, all flooded areas correspond with residential areas (land use category CU_1).

c.2.2. Reference costs for each land use category (CR)

The reference cost of the aforementioned land use category is defined from Table A.5.1 (Appendix 5). Residential use, with medium density, is defined for this case example and it corresponds with a rate of 42 €/m² (from the 75% of the highest rate for medium density, 56.3 €/m²). The present value is equal to 49.29 €/m², obtained from the national retail price index in 2009 (RPI).

c.2.3. Percentage of damages (PD)

The percentage of damage is obtained from water depth levels of each flood scenario and the depth-damage curve in Table A.5.3 (Appendix 5). Flood scenarios for failure and non-failure cases are related to the following water depths given in Table A.9.12.

Q_{nbr} (m^3/s)	Flood depth H (m)	Q_{br} (m^3/s)	Flood depth H (m)
121.5	0.000	15,033.7	6.9
244.6	0.530	37,628.9	11.9
351.6	0.975	56,878.4	14.7
632.7	1.850	81,038.8	17.5
		107,161.7	20.5
782.6	2.030	116,870.6	21.4
		121,323.1	21.8

Table A.9.12 . Average water depth for each flood scenario.

c.2.4. Cost estimation: Direct, indirect and total (CD, CI, CT)

Applying the above considerations, direct costs are obtained by multiplying reference cost, flooded area and percentage of damage for each flood scenario.

It is assumed that a percentage of 27% (mean value between 0% and 55%) may be proposed for f_C as a factor to obtain indirect costs.

Tables A.9.13 and A.9.14 include the resultant economic losses obtained for failure and non-failure cases.

Q_{nbr} (m³/s)	Flood depth H (m)	Reference cost CR (€/m²)	Percentage of damage, PD (%)	Direct costs CD (€)	Indirect costs CI (€)	Total costs CT (€)
121.5	0.000	49.29	0.00%	0	0	0
244.6	0.530	49.29	4.12%	25,415	6,862	32,277
351.6	0.975	49.29	36.75%	319,822	86,352	406,174
632.7	1.850	49.29	75.50%	2,348,089	633,984	2,982,073
782.6	2.030	49.29	77.00%	2,934,739	792,380	3,727,118

Table A.9.13. Economic losses. River flooding. Non-failure cases. Base-case.

Q_{br} (m³/s)	Flood depth H (m)	Reference cost CR (€/m²)	Percentage of damage, PD (%)	Direct costs CD (€)	Indirect costs CI (€)	Total costs CT (€)
15,034	6.9	49.29	77.00%	2,792,604	754,003	3,546,607
37,629	11.9	49.29	77.00%	5,752,430	1,553,156	7,305,586
56,878	14.7	49.29	77.00%	13,256,063	3,579,137	16,835,200
81,039	17.5	49.29	77.00%	17,818,012	4,810,863	22,628,875
107,162	20.5	49.29	77.00%	19,529,592	5,272,990	24,802,581
116,871	21.4	49.29	77.00%	19,925,520	5,379,891	25,305,411
121,323	21.8	49.29	77.00%	20,658,095	5,577,686	26,235,781

Table A.9.14. Economic losses. River flooding. Failure cases. Base-case.

PHASE VII. RISK CALCULATION

Nodes of the risk model for the base-case are linked to files with input data in terms of loads, system response and consequences (loss of life and economic losses) and, then, the model is run (Figure A.9.4).

Analysis→ Run analysis…

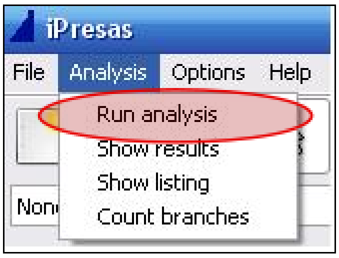

Figure A.9.4. Figure from iPresas software (User guide [48]).

Values of societal risk (or economic risk) and annual probability of exceedance are obtained from the *Analysis→ Show results…* option or from the menu presented in Figure A.9.5.

Figure A.9.5. Option from the iPresas menu to show results.

PHASE VIII. F-N AND F-D CURVES

The next phase consists of the development of F-N and F-D curves for the base-case.

Results in terms of potential fatalities and economic losses are obtained from the *File→ Export F-N…* option. Then, the user should choose one of these two options: ‘lives’ or ‘euros’ (where the given words identify societal and economic risk).

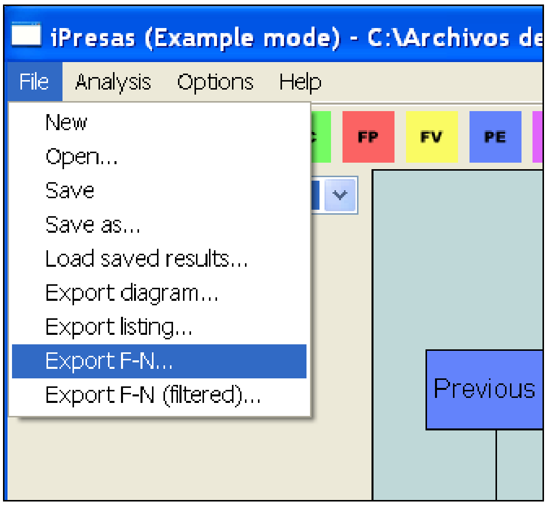

Figure A.9.6. Option to obtain F-N list.

Then, a .txt file is obtained and each level of potential fatalities (N) or economic losses (€) is related to an annual probability of exceedance (f).

The F-N curve shown in Figure A.9.7 represents the annual probability of exceedance (cumulative) of a certain level of potential fatalities for the base-case. If economic losses are considered, the curve is denoted by F-D (Figure A.9.8).

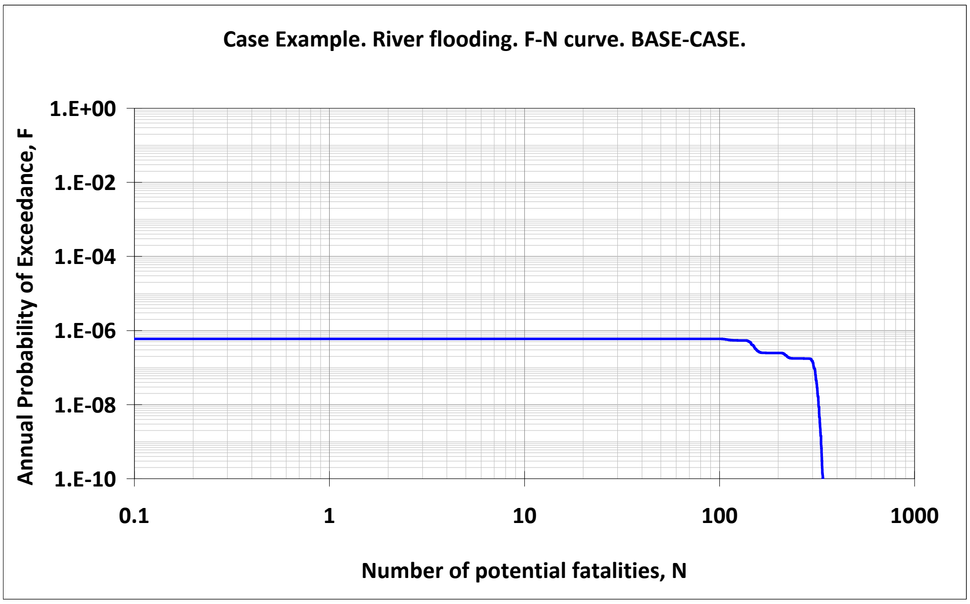

Figure A.9.7. F-N curve. River flooding. Base-case.

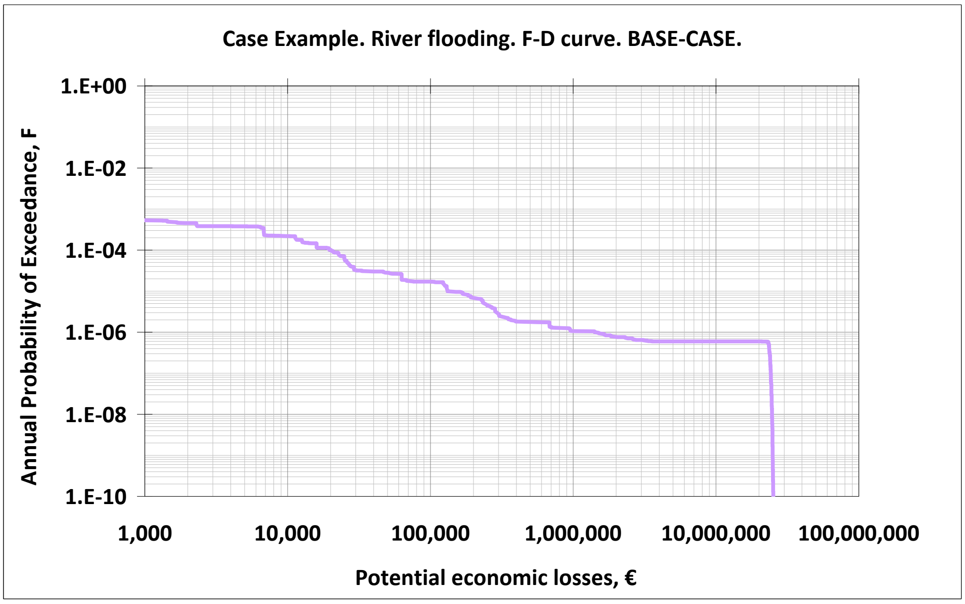

Figure A.9.8. F-D curve. River flooding. Base-case.

The above figures illustrate how the base-case can be represented in terms of societal and economic risk from the established risk model with iPresas software.

PHASE IX. FLOOD RISK EVALUATION

Dam failure cases produce an amount of 304 potential fatalities for an annual probability of exceedance equal to $1 \cdot 10^{-7}$, approximately. Potential economic losses reach a value of 1,409,378 € for an annual probability of exceedance around $1 \cdot 10^{-6}$. A maximum amount of 25,688,517 € in case of dam failure is obtained.

PHASE X. INCORPORATING NON-STRUCTURAL MEASURES

After the base-case analysis, two additional situations are considered:

- Situation with non-structural measures (effect of a Public Education Program on Flood Risk, denoted as PFR-case), and,
- Natural flow regime of the river (for comparison purposes, denoted as RN-case).

First, the effect of a Public Education Program on Flood Risk is evaluated, as it is based on the base-case risk model scheme and it only requires variations on input data for consequences (see section PFR-case). However, a different risk model for the natural flow regime of the river should be established, but it requires a risk model scheme more simple than the base-case (see section RN-case).

PFR CASE

Non-structural measures do not modify the established flood scenarios for the base-case. In addition, flood characteristics remain as in the base-case. However, in phase VI, input data for consequences vary from the base-case due to the application of non-structural measures.

In this hypothetical example, the existence of a Public Education Program on Flood Risk is proposed as a non-structural measures to reduce flood risk from river flooding.

The aim of this program is focus on improving the knowledge of population on flood risk, giving guidance on evacuation and shelter in case of flood emergency, etc.

This non-structural measure is studied from the following variations on the base-case:

- LOSS OF LIFE
  - ○ Definition of the category for the case example.

If a PFR is implemented, it can be considered that the case example belongs to category C10 (best scenario from categories proposed by SUFRI methodology). Consequently, reference fatality rates differ from the base-case.

Warning time, TW (h)	Flood severity, Sv		
	High (3)	Medium (2)	Low (1)
0	0.9	0.3	0.02
0.25	0.5	0.03	0.005
0.625	0.3	0.005	0.001
1	-	0.002	0.0001
1.5	-	0.0002	0.0001
24	-	0.0002	0.0001

Table A.9.15. Reference fatality rates (RFR). PFR-case. Category C10.

Values from the base-case regarding population at risk, warning times and flood severity categories has been adopted for this PFR-case.

- ECONOMIC LOSSES
  - ○ Reduction on damages.

If a PFR is implemented, it is assumed in this example that people will be able to install temporary waterstops to avoid water entrance in their households. In SUFRI methodology, it is proposed that the existence of a PFR is analysed from a percentage of reduction on potential damages. In this case example, a percentage of 25% of reduction on damages due to the flood event is proposed as a result of installation of temporary waterstops from the existence of the PFR program [44]. However, this consideration is only possible if water depths are lower than 1.2 m [44] (water depths in failure cases are above this value).

Values for the PFR-case regarding reference costs, flooded areas and f_c factor remain as the base-case.

Applying these new considerations, the estimation of potential number of fatalities and economic losses results in the values given in Tables A.9.16 to A.9.19 (variations from the base-case are denoted in green).

The risk model scheme of the base-case is used for this PFR case. Figures A.9.9 and A.9.10 illustrate the F-N and F-D curves for this case with non-structural measures.

Q_{nbr} (m³/s)	Warning time, TW day (h)	Warning time, TW night (h)	DV	Flood severity, Sv	Fatality rate, FR day	Fatality rate, FR night	Number of potential fatalities, N			
							Time categories			
							TC_1	TC_2	TC_3	TC_4
121.5	-	-	0.000	-	-	-	-	-	-	-
244.6	3.25	3	1.994	1	0.0001	0.0001	0.01	0.01	0.00	0.00
351.6	1.4	1.15	2.686	1	0.0001	0.0001	0.01	0.01	0.01	0.01
632.7	1.3	1.05	3.771	1	0.0001	0.0001	0.03	0.03	0.02	0.02
782.6	1.25	1	3.965	1	0.0001	0.0001	0.04	0.04	0.03	0.03

Table A.9.16. Number of potential fatalities, N. River flooding. Non-failure cases. PFR-case.

Q_{br} (m³/s)	Warning time, TW day (h)	Warning time, TW night (h)	DV	Flood severity, Sv	Fatality rate, FR day	Fatality rate, FR night	Number of potential fatalities, N			
							Time categories			
							TC_1	TC_2	TC_3	TC_4
15,034	0.750	0.500	18.77	2	0.004	0.013	1.52	4.65	1.12	3.31
37,629	0.650	0.400	38.81	2	0.005	0.020	3.76	14.36	2.77	10.24
56,878	0.600	0.350	45.53	2	0.007	0.023	12.05	38.61	8.88	27.53
81,039	0.580	0.330	59.41	2	0.008	0.025	19.43	54.87	14.32	39.12
107,162	0.550	0.300	74.77	2	0.010	0.027	26.62	65.01	19.62	46.36
116,871	0.537	0.287	80.71	2	0.011	0.028	29.51	68.49	21.76	48.83
121,323	0.537	0.287	83.32	2	0.011	0.028	30.60	71.01	22.56	50.63

Table A.9.17. Number of potential fatalities, N. River flooding. Failure cases. PFR-case.

Q_{nbr} (m³/s)	Flood depth H (m)	Reference cost CR (€/m²)	Percentage of damage, PD (%)	Direct costs CD (€)	Indirect costs CI (€)	Total costs CT (€)
121.5	0.00	49.29	0.00%	0	0	0
244.6	0.53	49.29	3.09%	19,061	5,147	24,208
351.6	0.98	49.29	27.56%	239,867	64,764	304,631
632.7	1.85	49.29	56.63%	1,761,066	475,488	2,236,554
782.6	2.03	49.29	57.75%	2,201,054	594,285	2,795,339

Table A.9.18. Economic losses. River flooding. Non-failure cases. PFR-case.

Q_{br} (m³/s)	Flood depth H (m)	Reference cost CR (€/m²)	Percentage of damage, PD (%)	Direct costs CD (€)	Indirect costs CI (€)	Total costs CT (€)
15,034	6.9	49.29	77.00%	2,792,604	754,003	3,546,607
37,629	11.9	49.29	77.00%	5,752,430	1,553,156	7,305,586
56,878	14.7	49.29	77.00%	13,256,063	3,579,137	16,835,200
81,039	17.5	49.29	77.00%	17,818,012	4,810,863	22,628,875
107,162	20.5	49.29	77.00%	19,529,592	5,272,990	24,802,581
116,871	21.4	49.29	77.00%	19,925,520	5,379,891	25,305,411

Table A.9.19. Economic losses. River flooding. Failure cases. PFR-case.

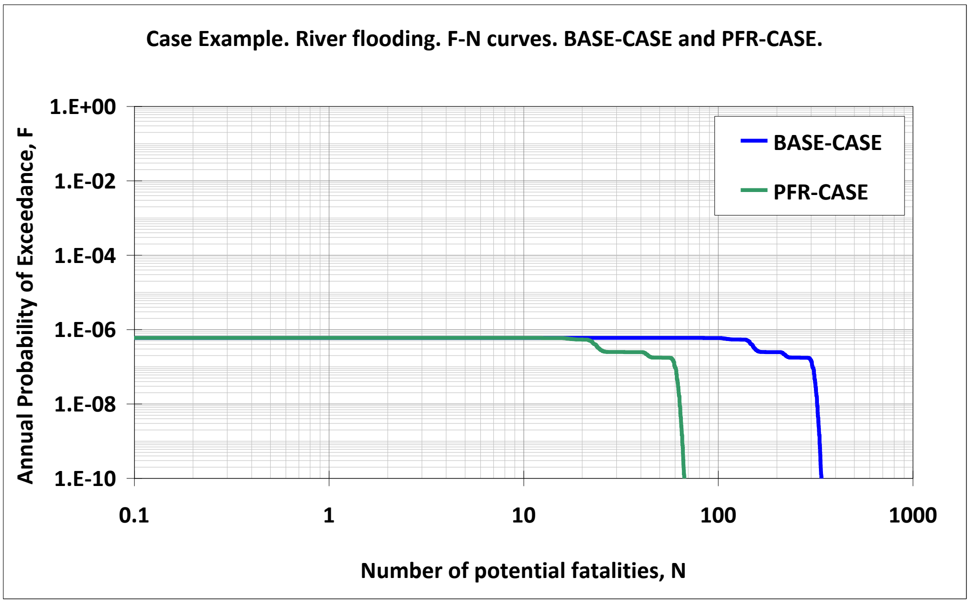

Figure A.9.9. F-N curves. River flooding. Base-case and PFR-case.

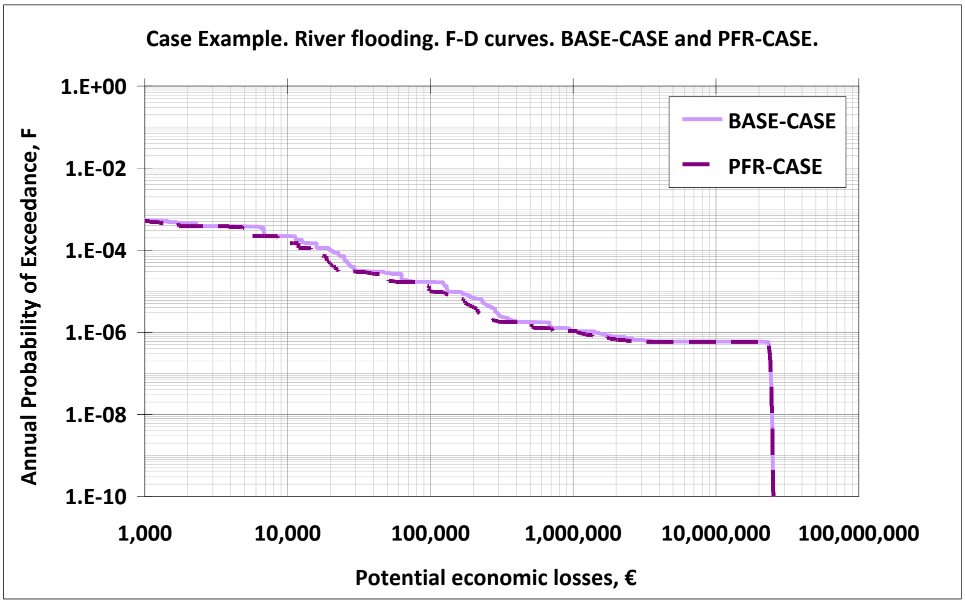

Figure A.9.10. F-D curves. River flooding. Base-case and PFR-case.

RN CASE – Natural flow regime of the river

The study of the natural flow regime of the river requires the evaluation of the overall procedure from phase IV to phase IX. For this RN-case, a different risk model scheme should be performed and new flood scenarios are defined. Thus, flood characteristics and potential consequences vary from the base-case.

PHASE IV.   FLOOD SCENARIOS

Flood scenarios are defined from hydrological studies of the river basin. A series of return periods should be established for defining flood scenarios related to the natural flow regime of the river.

In this case example, flood scenarios for return periods from 2 to 10,000 years are obtained from hydrological studies. A GEV function is proposed to obtain maximum peak discharges for higher return periods. This function provides values for comparison of these flood scenarios with dam failure cases (related to probabilities of exceedance lower than 10^{-6}). Maximum peak discharges for each return period are presented in Table A.9.20.

T (years) from hydrological studies	2	5	10	25	50	100	500	1,000	5,000	10,000
Q_{max} (m^3/s)	94	166	214	274	319	364	466	511	613	658
T (years) from GEV function	50,000		100,000		500,000		1,000,000		10,000,000	
Q_{max} (m^3/s)	759		803		905		950		1,097	

Table A.9.20. Peak discharges from hydrographs and GEV function. River flooding. RN-case.

These flood scenarios are the basis for estimating potential consequences from the natural flow regime of the river.

PHASE V.   RISK MODEL ARCHITECTURE

The risk model for the RN-case is designed to represent the situation before the existence of structural and non-structural measures. It is also divided into three main parts: (a) loads, (b) system response and (c) consequences.

Figure A.9.11 shows the scheme of the RN-case risk model, and, Table A.9.21 includes the name of each node, description of input data requirements, file name and parameters for identifying flood scenarios and potential consequences .

Risk model "2". RN-case: Natural Flow Regime of the River.

Figure A.9.11. Risk model scheme of the RN-case.

Node	Block	Description	Input data file	Parameter
Risk	-	Defines a parameter 'risk' to obtain overall results of total risk	totalrisk.txt	risk
Flood	a	Return periods and annual probabilities of exceedance	flood.txt	T, AEP (annual probability of exceedance)
Qmax	b	Peak discharges for each return period	Qmax.txt	T, Qmax
TC (i)	-	Defines probabilities of each season (summer or winter) to identify time categories. i.e. summer=0.2084; winter=0.7916 (rest of the year)	tc_i.txt	season = summer, winter (identifies time category)
TC (ii)	-	Defines probabilities of moment of the day to identify time categories. i.e. day=0.42; night=0.58 (summer); day=0.625, night=0.375 (winter)	tc_ii.txt	moment = day, night (identifies time category)
Cons_N	c	Consequences in terms of loss of life for each flood scenario (identified by the maximum peak discharge of the hydrograph) and time category	RN_lives.xls	Qmax, lives
Cons_CT	c	Consequences in terms of economic losses for each flood scenario (identified by the maximum peak discharge of the hydrograph) and time category	RN_euros.txt	Qmax, euros

Table A.9.21. Nodes of the risk model scheme of the RN-case.

PHASE VI. INPUT DATA FOR THE RISK MODEL

a) LOADS

Flood scenarios from the above return periods (Table A.9.20) are established as loads for the risk model scheme in the RN-case.

b) SYSTEM RESPONSE

System response corresponds with flood characteristics and flooded areas from the maximum peak discharges presented in Table A.9.20. Hydraulic simulations are performed in MIKE11 from the Digital Elevation Model of the case example.

c) CONSEQUENCES

As it was described for the base-case, the process to obtain input data for consequences is divided into two parts: loss of life and economic losses.

c.1. LOSS OF LIFE

c.1.1. Category for the RN-case to define reference fatality rates (C and RFR)

From Table A.1.1 (Appendix 1) of SUFRI methodology, the RN-case corresponds to category C1. Thus, reference fatality rates (RFR) are the values included in Table A.9.22.

Warning time TW (h)	Flood severity, Sv		
	High (3)	Medium (2)	Low (1)
0	0.9	0.3	0.02
0.25	0.9	0.3	0.02
0.625	0.7	0.08	0.015
1	-	0.06	0.0006
1.5	-	0.0002	0.0002
24	-	0.0002	0.0001

Table A.9.22. Reference fatality rates (RFR). River flooding. RN-case. Category C1.

c.1.2. Population at risk (PR)

Flooded areas are obtained from comparison of land use and flooding maps from hydraulic simulations. For each flood scenario, population at risk for each time category is obtained by multiplying total population by the ratio between flooded area (A_f) and total area of the urban site (A_T).

	Total area, A_T (m^2)	588,358	Population at risk, PR			
Q_{max} (m^3/s)	Flooded area, A_f (m^2)	% total	Time category			
			TC_1	TC_2	TC_3	TC_4
94	2,949	0.50%	15	14	11	10
166	11,693	1.99%	60	55	45	39
214	13,783	2.34%	71	65	53	47
274	21,366	3.63%	110	101	81	72
319	39,032	6.63%	202	185	149	132
364	51,236	8.70%	265	243	195	173
466	70,390	11.96%	364	333	268	238
511	88,745	15.07%	459	420	338	300
613	97,817	16.61%	506	463	373	330
658	102,313	17.38%	529	484	390	345
759	126,530	21.49%	654	599	482	427
803	142,497	24.20%	737	675	543	481
950	241,571	41.03%	1,249	1,144	921	816
1,097	258,919	43.98%	1,338	1,226	987	874

Table A.9.23. Population at risk. River flooding. RN-case.

c.1.3. Warning times (TW)

From Table A.1.4 (Appendix 1) of SUFRI methodology, warning times are defined as the time difference from the first-notice flow, 150 m^3/s, and first-damage flow, 200 m^3/s.

Q_{max} (m^3/s)	TC_1, TC_3 (Day) TW=TD (hours)	TC_2, TC_4 (Night) TW=TD-0.25 (hours)
94	-	-
166	-	-
214	3.00	2.75
274	1.75	1.50
319	1.50	1.25
364	1.25	1.00
466	1.25	1.00
511	1.10	0.85
613	1.10	0.85
658	1.00	0.75
759	0.90	0.65
803	0.90	0.65
950	0.85	0.60
1,097	0.80	0.55

Table A.9.24. Warning times. River flooding. RN-case.

c.1.4. Flood severity (Sv)

Flood severity of each flood scenario is obtained from the DV parameter (Table A.1.3, Appendix 1). All flood scenarios are within the category of low flood severity. Table A.9.25 includes results of the DV parameter for all flood scenarios.

c.1.5. Fatality rates (FR)

Fatality rates (FR) are obtained by interpolating reference fatality rates of category C1 from the above warning times (Table A.9.24) and flood severity categories. Table A.9.25 shows the estimated fatality rates for all flood scenarios.

c.1.6. Number of potential fatalities(N)

The number of potential fatalities for each flood scenario is estimated from population at risk (from each time category), multiplied by the estimated fatality rate (FR).

Table A.9.25 includes all estimated parameters to obtain the resultant number of potential fatalities for the RN-case.

							Number of potential fatalities, N			
Q_{max} (m³/s)	Warning time, TW day (h)	Warning time, TW night (h)	DV	Flood severity, Sv	Fatality rate, FR day	Fatality rate, FR night	Time category			
							TC_1	TC_2	TC_3	TC_4
94	-	-	1.43	1	-	-	-	-	-	-
166	-	-	2.28	1	-	-	-	-	-	-
214	3.00	2.75	2.17	1	5.73E-04	5.78E-04	0.0	0.0	0.0	0.0
274	1.75	1.50	2.22	1	5.96E-04	6.00E-04	0.1	0.1	0.0	0.0
319	1.50	1.25	2.32	1	6.00E-04	7.80E-03	0.1	1.4	0.1	1.0
364	1.25	1.00	2.31	1	7.80E-03	1.50E-02	2.1	3.6	1.5	2.6
466	1.25	1.00	2.43	1	7.80E-03	1.50E-02	2.8	5.0	2.1	3.6
511	1.10	0.85	2.19	1	1.21E-02	1.70E-02	5.6	7.1	4.1	5.1
613	1.10	0.85	2.12	1	1.21E-02	1.70E-02	6.1	7.9	4.5	5.6
658	1.00	0.75	1.93	1	1.50E-02	1.83E-02	7.9	8.9	5.8	6.3
759	0.90	0.65	1.85	1	1.63E-02	1.97E-02	10.7	11.8	7.9	8.4
803	0.90	0.65	1.82	1	1.63E-02	1.97E-02	12.0	13.3	8.9	9.5
950	0.85	0.60	1.90	1	1.70E-02	2.00E-02	21.2	22.9	15.6	16.3
1,097	0.80	0.55	2.09	1	1.77E-02	2.00E-02	23.6	24.5	17.4	17.5

Table A.9.25. Number of potential fatalities, N. River flooding. RN-case.

c.2. ECONOMIC LOSSES

As it was described for the base-case, economic losses are obtained from the definition of a reference cost for the flooded area and a percentage of damages from depth-damage curves.

The same reference cost (49.29 €/m²) is set and results are included in Table A.9.26.

Q_{max} (m^3/s)	Flood depth H (m)	Reference cost CR (€/m^2)	Percentage of damage, PD (%)	Direct costs CD (€)	Indirect costs CI (€)	Total costs CT (€)
94	0	49.29	0.00%	0	0	0
166	0	49.29	0.00%	0	0	0
214	1.6	49.29	71.48%	485,609	131,115	616,724
274	1.8	49.29	74.74%	787,109	212,520	999,629
319	1.8	49.29	74.94%	1,441,761	389,276	1,831,037
364	1.8	49.29	75.09%	1,896,340	512,012	2,408,351
466	2.0	49.29	76.87%	2,667,022	720,096	3,387,118
511	2.1	49.29	77.00%	3,368,166	909,405	4,277,570
613	2.2	49.29	77.00%	3,712,478	1,002,369	4,714,847
658	2.2	49.29	77.00%	3,883,116	1,048,441	4,931,557
759	2.3	49.29	77.00%	4,802,231	1,296,602	6,098,833
803	2.4	49.29	77.00%	5,408,231	1,460,222	6,868,454
950	2.5	49.29	77.00%	9,168,417	2,475,472	11,643,889
1,097	2.6	49.29	77.00%	9,826,830	2,653,244	12,480,075

Table A.9.26. Economic losses. River flooding. RN-case.

PHASE VII. RISK CALCULATION

The new risk model scheme (Figure A.9.11) for the natural flow regime of the river is computed, from input data in terms of loss of life (Table A.9.25) and economic losses (Table A.9.26).

PHASE VIII. F-N AND F-D CURVES

From risk model results, F-N and F-D curves for the RN-case can be performed to represent the resultant number of potential fatalities or economic losses and the related probability of exceedance.

Summary: River Flooding

Finally, the F-N curve of the RN-case is shown in Figure A.9.12, together with results from the base-case and PFR-case (situation with non-structural measures). Figure A.9.13 provides the F-D curve of the three studied situations in this case example.

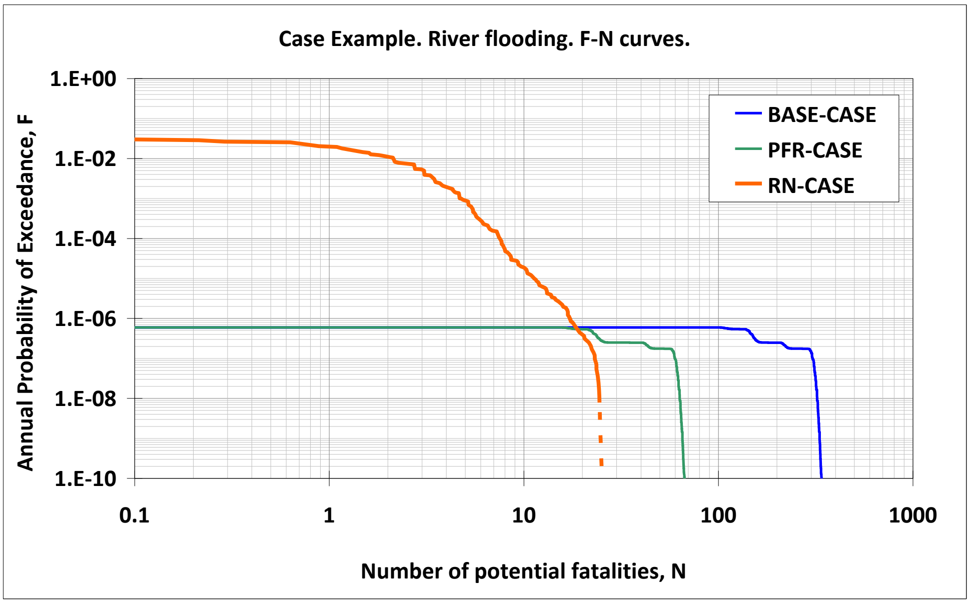

Figure A.9.12. F-N curves for the case example.

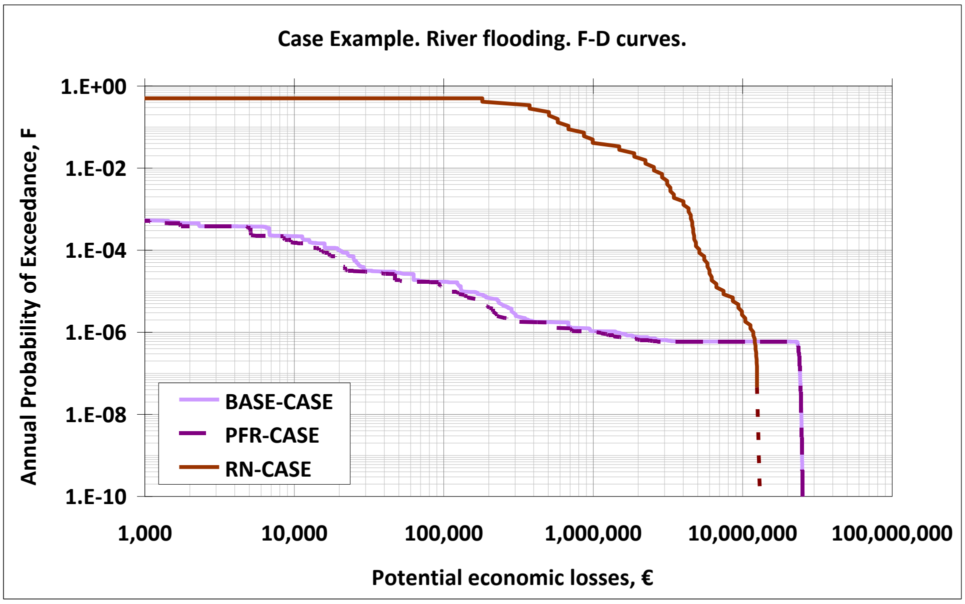

Figure A.9.13. F-D curves for the case example.

The above figures illustrate how the existence of structural measures for low return periods (values of the annual probability of exceedance higher than 10^{-6}) has effect on on risk reduction. However, a dam failure, related to an annual probability of exceedance equal to $2\cdot10^{-7}$, would produce higher consequences than the situation for the natural flow regime of the river.

The effect of non-structural measures, as a Public Education Program on Flood Risk, can be observed from the reduction on potential fatalities in Figure A.9.12. The F-N curve for the base-case yields a maximum value of 351 fatalities. For the situation with non-structural measures, the F-N curve indicates a maximum amount of 70 fatalities. The effect on economic benefits from the existence of a PFR is only reflected in non-failure cases.

Table A.9.27 includes numerical results of the main points of the F-N curve for river flooding.

Number of potential fatalities, N			
F	BASE-CASE	PFR-CASE	RN-CASE
2.00E-02	-	-	1
6.00E-07	9	1	18
1.00E-08	321	63	25

Table A.9.27. Summary of results in river flooding.

PLUVIAL FLOODING

In this section, flood risk from heavy rainfall events is analysed for this hypothetical case example. Phases of SUFRI methodology (Figure 1.5.6) are applied for risk calculation and evaluation as it was described in river flooding.

PHASE I. SCOPE OF THE CASE STUDY

The scope of this analysis is focused on the study of the current situation of the example in case of pluvial flooding and the effect of non-structural measures regarding a Public Education Program on Flood Risk and the existence of a warning system.

PHASE II. REVIEW OF AVAILABLE DATA

As it was described for river flooding, data should be collected with regard to demography, building typologies, land uses, drainage system, hydrological studies, economic rates, etc. From this information, time and land use categories can be established.

Two land use categories are proposed: residential and industrial (Table A.9.28).

Land use category	Type	Total area (m²)
CU_1	Residential	517,755
CU_2	Industrial	70,603

Table A.9.28. Land use categories.

Thus, population at the study area should be divided into these two categories, from data of daily and seasonal variability of population, as it is shown in Table A.9.29.

People located at the study area	Summer/day (TC_1)	Summer/Night (TC_2)	Winter/day (TC_3)	Winter/night (TC_4)
CU_1	2,839	2,788	2,039	1,988
CU_2	205	0	205	0
TOTAL	3,044	2,788	2,244	1,988
Range Summer/winter	Summer: From July 1st to September 15th Winter: Rest of the year			
Range Day/night	Day: 8:00 a.m. - 10:30 p.m. Night: 10:30 p.m. - 8:00 a.m.			

Table A.9.29. Time categories.

PHASE III. STUDY OF THE SYSTEM SITUATION. DEFINITION OF BASE-CASE

The current situation of the case example is based on the existent drainage system: design, characteristics and flow capacity.

The base-case should represent the current situation of the case example from pluvial flooding due to extreme rainfall events and the system response of the existent drainage system.

PHASE IV. FLOOD SCENARIOS

Five flood scenarios are defined from a series of return periods. These return periods are related to rainfall rates of the likely extreme events. These flood scenarios are presented in Table A.9.30.

ID	Return period, T (years)	Rainfall rates (mm)
T1	5	70.8
T2	10	84.1
T3	25	101.0
T4	50	113.4
T5	100	125.8

Table A.9.30. Rainfall rates.

PHASE V. RISK MODEL ARCHITECTURE

The risk model scheme for pluvial flooding is based on the example given in Appendix 7 (Figure A.7.4). Table A.9.31 describes each node and its function within the risk model scheme.

Risk model "3". Base-case: Current situation: Drainage system.

Figure A.9.14. Risk model scheme. Pluvial flooding.

Node	Block	Description	Parameter
PF	-	Defines a parameter 'risk' to obtain results of total risk	risk
TC_i	-	Defines probabilities of each season (summer or winter) to identify time categories. i.e. summer=0.2084; winter=0.7916 (rest of the year)	season = summer, winter (identifies time category)
TC_ii	-	Defines probabilities of moment of the day to identify time categories. i.e. day=0.42; night=0.58 (summer) ; day=0.625, night=0.375 (winter)	moment = day, night (identifies time category)
Flood	a	Return periods and annual probability of exceedance.	T, AEP (annual probability of exceedance)
Runoff	b	Runoff rate for each flood scenario, identified by T.	Q_{pf}
Cons_N	c	Consequences in terms of loss of life for each flood scenario (identified by the runoff flow) and time category	Q_{pf}, N
Cons_CT	c	Consequences in terms of economic losses for each flood scenario (identified by the runoff flow) and time category	Q_{pf}, CT

Table A.9.31. Nodes of the risk model scheme. Pluvial flooding.

PHASE VI. INPUT DATA FOR THE RISK MODEL

The aforementioned nodes of the risk model scheme should be related to files with input data for risk calculation. These requirements of input data are divided into three blocks: loads, system response and consequences.

a) LOADS

In pluvial flooding, loads are defined as the established return periods that identify the series of extreme rainfall events. These return periods are associated to the rainfall rates of the flood scenarios used for the analysis.

b) SYSTEM RESPONSE

Runoff rates should be obtained from rainfall rates of the previous flood scenarios, from characteristics and geometry of the urban area.

Hydraulic calculations or modelling should be performed to estimate runoff rates at the urban area. If hydraulic models are not available, then the area can be divided into several homogenous zones with similar characteristics (i.e. width and slope of streets).

In this case example, it is assumed that the urban area can be divided into four homogenous zones: three areas are distinguished within the land use category CU_1

(areas Ar_1, Ar_2 and Ar_3) and an additional zone is determined from land use category CU_2 (denoted by Ai_1). These areas differ from urban characteristics (typology of streets and buildings), and, thus, the same rainfall rate will produce different flood characteristics in each area.

	ID Area	Width, b (m)	Slope, I(m/m)	Total area (m²)
CU_1	Ar1	7	0.0434	103,551
	Ar2	7	0.0060	232,990
	Ar3	5	0.0556	181,214
CU_2	Ai1	10	0.0050	70,603

Table A.9.32. Characteristics of homogenous areas.

In this initial example of SUFRI methodology, it is assumed that flooded areas for each homogenous zone will correspond to the total area given in Table A.9.32 for all flood scenarios.

SUFRI methodology summarises several methods for rainfall-runoff transformation. In this case example, the Rational Method [50] is used.

		Return periods, T (years)				
		5	10	25	50	100
Maximum daily rainfall rate (mm/day)	Pd	70.8	84.1	101	113.4	125.8
Runoff threshold (mm)	Po	4				
Average daily intensity (mm/h)	Id	2.95	3.50	4.21	4.73	5.24
Factor	I_1/I_d	9				
Average storm intensity (mm/h)	I	66.05	78.46	94.23	105.80	117.37
Runoff coefficient	C	0.39	0.43	0.48	0.52	0.54
Temporal uniformity coefficient	K	1.80				

Table A.9.33. Variables of the Rational Method for runoff calculations.

From the above characteristics and parameters from the Rational Method, the following runoff rates (Table A.9.34) are obtained in each homogenous zone:

ID Area	Basin (km²)	t_c (min)	Runoff rates from Rational Method, Q_{runoff} (m³/s) Return periods, T (years) 5	10	25	50	100
Ar1	0.7	6	8.94	11.89	15.95	19.09	22.36
Ar2	0.85	7.1	10.86	14.44	19.36	23.18	27.15
Ar3	0.55	5	7.03	9.34	12.53	15.00	17.56
Ai1	0.6	6.2	7.66	10.19	13.67	16.37	19.16

Table A.9.34. Runoff rates from flood scenarios (T=5 to 100 years).

The drainage system is capable to drain runoff water from rainfall events with return periods up to 5 years. Thus, the previous runoff rates should be modified from subtracting runoff rates of a return period of 5 years. Table A.9.35 includes runoff rates for estimating potential consequences due to the flood for the base-case.

ID Area	Q_{pf} (m³/s) Return periods, T (years) 5	10	25	50	100
Ar1	-	2.95	7.00	10.15	13.41
Ar2	-	3.58	8.50	12.33	16.29
Ar3	-	2.32	5.50	7.98	10.54
Ai1	-	2.53	6.00	8.701	11.50

Table A.9.35. Runoff rates from flood scenarios (T=5 to 100 years).

These values are used for estimating flood characteristics (water depth and velocity) in each area. Water depths and velocities are obtained from the consideration of the geometric characteristics of each area (width and slope of streets) and the previous runoff rates (Table A.9.35).

Results on water depth and velocity for each flood scenario (from return periods, T1 to T5) are included in Table A.9.36.

	v (m/s)					y (m)				
	Flood scenario					Flood scenario				
Area	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Ar1	-	3.87	5.43	6.27	6.98	-	0.11	0.18	0.23	0.27
Ar2	-	2.28	3.17	3.65	4.04	-	0.22	0.38	0.48	0.58
Ar3	-	4.31	6.03	6.95	7.72	-	0.11	0.18	0.23	0.27
Ai1	-	1.68	2.32	2.67	2.97	-	0.15	0.26	0.33	0.39

Table A.9.36. Flood characteristics for each flood scenario and area.

c) CONSEQUENCES

c.1. LOSS OF LIFE

As it is proposed in SUFRI methodology, estimation of life-loss is based on the scheme given in Appendix 2.

c.1.1. Category for the base-case to define fatality rates (C_p and FRp)

The definition of the category C_p is based on the existence of warning systems. In this case example, no warning systems are available or used, then, category C_{p1} is set for the base-case in pluvial flooding (see Table A.2.1). Fatality rates for the base-case are given in Table A.9.37.

	C_{p1}				
Flood severity	S0	S1	S2	S3	S4
Fatality rates, FRp	0.0003	0.0021	0.0038	0.0105	0.0448

Table A.9.37. Fatality rates for category C_{p1}. Pluvial flooding. Base-case.

As it was described in SUFRI methodology, fatality rates for each category C_p are obtained from a factor, Y, that is a function of two parameters that depend on age and health condition of people located at the flooded area (Table 1.5.12).

In this case example, a value of Y=0.5 has been used as the percentages of very old an infirm people are not likely to be significantly different from the national average. Thus, fatality rates given in Appendix 2 (Table A.2.1) are used for calculations.

c.1.4. Flood severity (S)

Flood severity categories are obtained in SUFRI methodology from Table 1.5.10 or Figure 1.5.7 (see also Table A.2.2, Appendix 2).

From the above flood characteristics (velocity, v and water depth, y) of each flood scenario (given in Table A.9.36), all flood severity categories result in level S3, except for one flood case (for T=10 years, T2, at the industrial area).

	Severity levels				
ID	T1	T2	T3	T4	T5
Ar1	-	S3	S3	S3	S3
Ar2	-	S3	S3	S3	S3
Ar3	-	S3	S3	S3	S3
Ai1	-	S2	S3	S3	S3

Table A.9.38. Flood severity levels. Pluvial flooding.

c.1.2. People exposed to the flood (PRout/PR_{in})

Population at risk is obtained from time and land use categories established in phase II. Each homogenous area is related to a number of people at risk, from the total area given in Table A.9.32.

Once population at risk is estimated, people exposed to the flood outside their households should be obtained from a percentage of the number of people at risk (PR). This percentage should represent the percentage of people that is expected to be outside their households or other buildings.

In this case example, percentages of 10% during the day and 1% at night are considered to estimate PR_{out} (for simplification, no fatalities are considered in people that remains indoors). The resultant values are shown in Table A.9.39.

	ID area	Population exposed to the flood, PR_{out}			
		Time category			
		TC_1	TC_2	TC_3	TC_4
CU_1	Ar1	57	6	41	4
	Ar2	128	13	92	9
	Ar3	99	10	71	7
	TOTAL CU_1	284	28	204	20
CU_2	Ai1	21	0	21	0

Table A.9.39. People exposed to the flood. Pluvial flooding. Base-case.

c.1.6. Number of potential fatalities(N)

The number of potential fatalities in case of pluvial flooding from the established flood scenarios is obtained by multiplying the number of people exposed in each area (PR_{out}) by the fatality rate (FR_p) related to the flood severity category of each flood scenario and area (Table A.9.38).

	Number of potential fatalities, N[5]															
	TC_1				TC_2				TC_3				TC_4			
	T2	T3	T4	T5	T2	T3	T4	T5	T2	T3	T4	T5	T2	T3	T4	T5
CU_1	3.0	3.0	3.0	3.0	0.3	0.3	0.3	0.3	2.1	2.1	2.1	2.1	0.2	0.2	0.2	0.2
CU_2	0.1	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.0	0.0	0.0	0.0
TOTAL	3.1	3.2	3.2	3.2	0.3	0.3	0.3	0.3	2.2	2.4	2.4	2.4	0.2	0.2	0.2	0.2

Table A.9.40. Number of potential fatalities. Pluvial flooding. Base-case.

All areas of land use category CU_1 have the same fatality rate, consequently, the number of potential fatalities can be obtained as $PR_{out} \cdot FR_p$ from the consideration of the whole area for CU_1 (Table A.9.28).

The previous results are included in a .xls file in which each row indicates the number of potential fatalities (N) for each time category (TC) and runoff rate (Q_{pf}).

c.2. ECONOMIC LOSSES

c.2.1. Reference costs for each land use category (CR)

Reference costs are established from Appendix 5. Rates of 49.29 €/m² and 14.23 €/m² are set for land use categories CU_1 and CU_2.

c.2.2. Percentage of damages (PD)

Percentage of damage is estimated from water depth for each flood scenario and area, based on the depth-damage curve presented in Appendix 5 (Figure A.5.1).

---

[5] TC=time category, T=return period.

c.2.3. Cost estimation: Direct, indirect and total costs (CD, CI, CT)

Direct, indirect and total costs are obtained from the procedure described in river flooding.

Tables A.9.41 and A.9.42 include results from estimation of potential economic losses as the product of each reference cost, percentage of damage and flooded area. Applying a factor of f_c=27%, indirect costs are obtained from direct costs.

Potential economic losses are included in a .txt file that relates each value of total costs to the runoff rate or return period that identifies the flood scenario (i.e. identified by the runoff rate of area Ar1 or the value of the return period, T).

		Flood depth, y (m)				Percentage of damage, PD (%)			
ID	Area, A_f (m²)	T2	T3	T4	T5	T2	T3	T4	T5
Ar1	103,551	0.11	0.18	0.23	0.27	0.5%	0.9%	1.2%	1.6%
Ar2	232,990	0.22	0.38	0.48	0.58	1.2%	2.4%	3.5%	4.7%
Ar3	181,214	0.11	0.18	0.23	0.27	0.5%	0.9%	1.2%	1.5%
Ai1	70,603	0.15	0.26	0.33	0.39	0.8%	1.4%	1.9%	2.4%

Table A.9.41. Percentage of damages for each flood scenario. Base-case.

		Direct costs, CD (€)			
ID	Area, A_f (m²)	T2	T3	T4	T5
Ar1	103,551	27,737	47,008	63,029	79,632
Ar2	232,990	135,415	272,152	406,248	540,068
Ar3	181,214	47,947	81,508	109,169	138,321
Ai1	70,603	7,641	14,710	19,774	24,435
Total costs CT (€), CT = (1+fc)·CD		277,800	527,531	759,740	993,719

Table A.9.42. Total costs for each flood scenario. Base-case.

PHASE VII. FLOOD RISK CALCULATION

The risk model is performed with iPresas software and results are obtained for both risk categories: societal and economic risk.

PHASE VIII. F-N AND F-D CURVES

From risk model results, F-N and F-D curves are provided for the base-case, as it is illustrated in Figures A.9.15 and A.9.16.

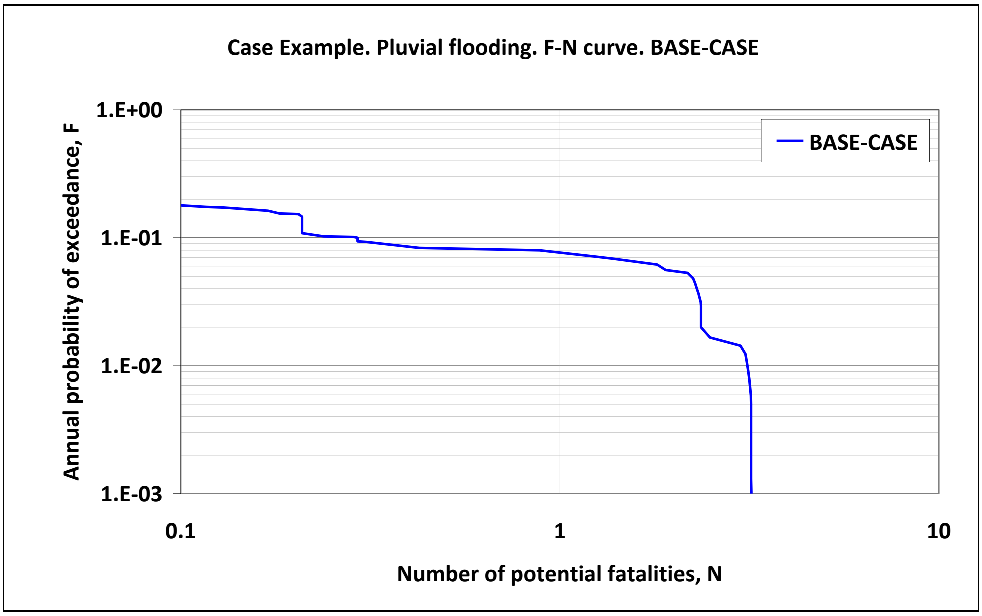

Figure A.9.15. F-N curve. Pluvial flooding. Base-case.

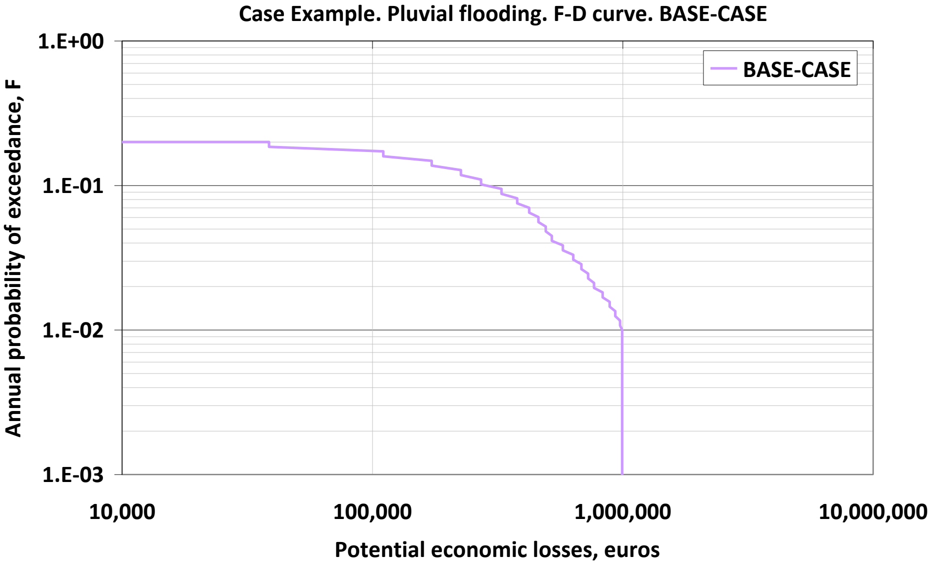

Figure A.9.16. F-D curve. Pluvial flooding. Base-case.

PHASE X. INCORPORATING NON-STRUCTURAL MEASURES

For comparison purposes, an alternative to the base-case is now described to analyse the effect of a public education program on flood risk and a new warning system at the case study. This alternative is denoted as PRF+WS-case.

Also, the situation without structural measures (no existence of the current drainage system) is studied and denoted as NDS-case (No Drainage System).

PFR+WS-case

The risk model scheme of the base-case is used, but variations on input data should be applied to obtain potential consequences for this alternative.

Several modifications are included in the process for estimating input data for the risk model in terms of consequences:

- LOSS OF LIFE
  - Definition of the category for the case example.

If a warning system is installed and used for the urban area, in SUFRI methodology, the category C_p varies from C_{p1} to C_{p3}. Thus, fatality rates vary from the base-case.

	C_{p3}				
Flood severity	S0	S1	S2	S3	S4
Fatality rates, FR_p	0.0002	0.0015	0.0027	0.0075	0.0320

Table A.9.43. Fatality rates for category C_{p3}. Pluvial flooding. PFR+WS-case.

- Population exposed to the flood event (PR_{out}).

If a public education program is applied, it can be considered that population located at the area will remain at home and a lower percentage of people will be exposed to the flood. Then, percentages of PR_{out} are reduced by a 50% from the base-case (Table A.9.44).

ID area		Population exposed to the flood, PR_{OUT}			
		Time category			
		TC_1	TC_2	TC_3	TC_4
CU_1	Ar1	29	3	21	2
	Ar2	64	7	46	5
	Ar3	50	5	36	4
	TOTAL CU_1	143	15	103	11
CU_2	Ai1	11	0	11	0

Table A.9.44. People exposed to the flood. Pluvial flooding. PFR+WS-case.

The number of potential fatalities for the PFR+WS-case is estimated by multiplying fatality rates for category C_{p3} by the above values of people exposed to the flood (PR_{out}), from flood severity categories of each flood scenario and land use area.

	Number of potential fatalities, N															
	Time category															
	TC_1				TC_2				TC_3				TC_4			
Land use category	T2	T3	T4	T5	T2	T3	T4	T5	T2	T3	T4	T5	T2	T3	T4	T5
CU_1	1.1	1.1	1.1	1.1	0.1	0.1	0.1	0.1	0.8	0.8	0.8	0.8	0.1	0.1	0.1	0.1
CU_2	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0
TOTAL	1.1	1.1	1.1	1.1	0.1	0.1	0.1	0.1	0.8	0.8	0.8	0.8	0.1	0.1	0.1	0.1

Table A.9.45. Number of potential fatalities. Pluvial flooding. PFR+WS-case.

- ECONOMIC LOSSES
  - Reduction on damages.

If a public education program is applied and the warning system provides a certain warning lead time, it can be assumed that people will act in case of an impending heavy rainfall event and the installation of temporary waterstops would reduce damages on households.

Economic losses for the PFR+WS-case are obtained from results for the base-case. In SUFRI methodology, two factors are proposed for new calculations: RD and K_{TC}. RD is the percentage of reduction on damages due to the installation of temporary waterstops (from the existence of a certain warning lead time and public education). In this case example, 25% of reduction on damages is considered. In addition, it is suggested that this value should be multiplied by a factor, K_{TC}, that depends on seasonal variability of the population in the area, as secondary residences cannot be protected in winter. Thus, economic losses from the application of non-structural measures are estimated as follows:

$$CT_{PFR+WR-case} = CT_{base-case} \cdot (1 - K_{TC} \cdot RD) \qquad \text{(eq. A.9.1.)}$$

Finally, economic losses are obtained for each flood scenario in the situation with non-structural measures (Table A.9.46) from the previous equation.

Total costs, CT (€)	Flood scenario			
	T2	T3	T4	T5
Base-case	277,800	527,531	759,740	993,719
PFR+WS-case (TC_1, TC_2)	208,350	395,648	569,805	745,289
PFR+WS-case (TC_3, TC_4)	227,921	432,811	623,327	815,294

Table A.9.46. Total costs for each flood scenario. Pluvial flooding. PFR+WS-case.

- RISK CALCULATION

  From new potential fatalities and economic losses, new input data is set for the risk model and results with iPresas software are obtained for the PFR+WS-case.

From risk model results for the new situation with non-structural measures, F-N and F-D curves are provided, as it is illustrated in Figures A.9.17 and A.9.18.

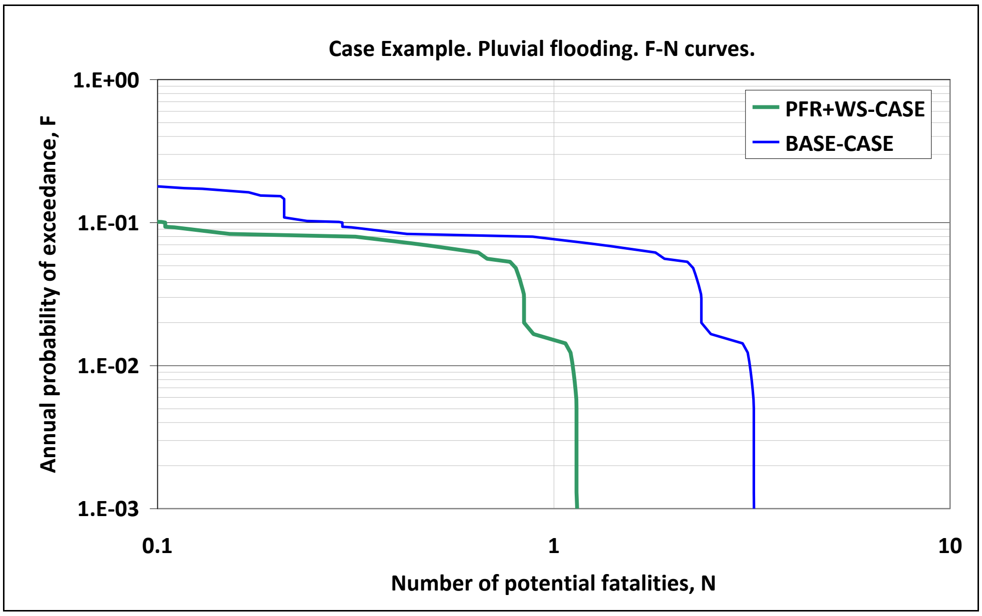

Figure A.9.17. F-N curve. Pluvial flooding. PFR+WS-case.

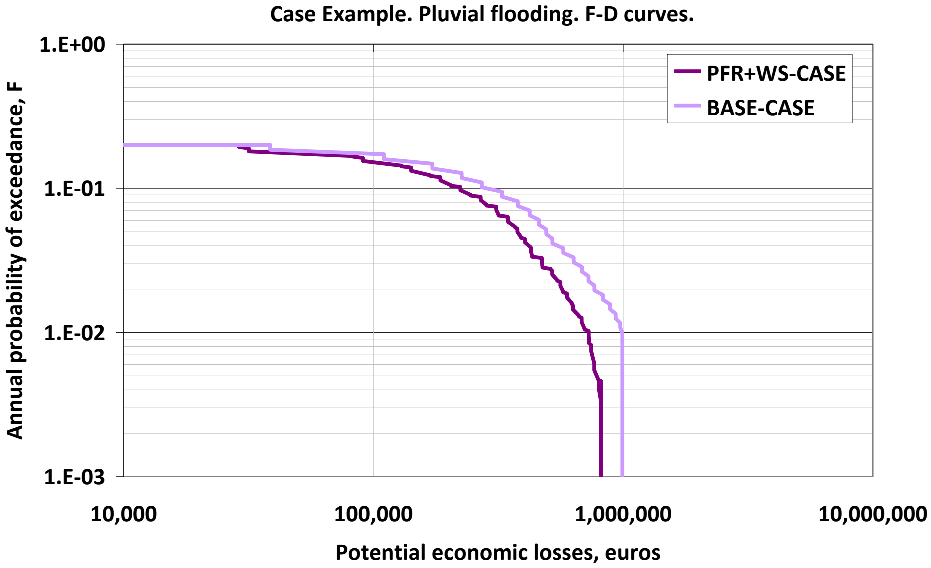

Figure A.9.18. F-D curve. Pluvial flooding. PFR+WS-case.

NDS-case

The same risk model scheme of the base-case is used for this case, but runoff rates without the existence of drainage system are obtained and new input data for consequences are estimated.

If the situation without drainage system is considered, then rainfall events related to the studied flood scenarios will produce flood water in the urban area from T=5 years (first scenario). Thus, resultant runoff rates are the estimated values from the Rational Method (Table A.9.47).

			Runoff rates from Rational Method				
			Return periods, T (years)				
ID area	Basin (km^2)	t_c (min)	5	10	25	50	100
Ar1	0.7	6	8.94	11.89	15.95	19.09	22.36
Ar2	0.85	7.1	10.86	14.44	19.36	23.18	27.15
Ar3	0.55	5	7.03	9.34	12.53	15.00	17.56
Ai1	0.6	6.2	7.66	10.19	13.67	16.37	19.16

Table A.9.47. Runoff rates from flood scenarios (T=5 to 100 years). NDS-case.

These new runoff rates (Table A.9.47) produce different flood characteristics in each area, and different flood severity categories are defined (Table A.9.48).

	Flood severity categories, S				
ID area	T1	T2	T3	T4	T5
Ar1	S3	S3	S3	S3	S3
Ar2	S3	S3	S3	S4	S4
Ar3	S3	S3	S4	S4	S4
Ai1	S3	S3	S3	S3	S3

Table A.9.48. Flood severity levels. Pluvial flooding. NDS-case.

From the flood severity categories given in Table A.9.48, fatality rates for category C_{p1} (Table A.9.37) are used for estimating the number of potential fatalities for each flood scenario (T) and time category (TC).

	Number of potential fatalities, N																			
	Time category																			
	TC_1					TC_2					TC_3					TC_4				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
CU_1	3.0	3.0	12.7	12.7	12.7	0.3	0.3	1.2	1.2	1.2	2.1	2.1	9.1	9.1	9.1	0.2	0.2	0.9	0.9	0.9
CU_2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0
TOTAL	3.2	3.2	12.9	12.9	12.9	0.3	0.3	1.2	1.2	1.2	2.4	2.4	9.3	9.3	9.3	0.2	0.2	0.9	0.9	0.9

Table A.9.49. Number of potential fatalities. Pluvial flooding. NDS-case.

Economic losses are obtained from flood characteristics of these new runoff rates related to the situation without drainage systems. Thus, new percentages of damage are estimated for each flood scenario and area.

		Flood depth, y (m)					Percentage of damage, PD (%)				
ID area	Area, A_f (m^2)	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Ar1	103,551	0.21	0.25	0.31	0.34	0.38	1.1%	1.4%	1.8%	2.1%	2.3%
Ar2	232,990	0.45	0.53	0.64	0.72	0.80	3.1%	4.2%	7.0%	10.5%	14.0%
Ar3	181,214	0.21	0.25	0.30	0.34	0.38	1.1%	1.4%	1.8%	2.1%	2.3%
Ai1	70,603	0.30	0.36	0.43	0.48	0.53	1.8%	2.2%	2.9%	3.5%	4.1%

Table A.9.50. Percentage of damages for each flood scenario. NDS-case.

Finally, total costs for this NDS-case are obtained from direct and indirect costs, as the product of each flooded area, reference cost and percentage of damage (Table A.9.50).

		Direct costs, CD (€)				
ID area	Area, A_f (m²)	T1	T2	T3	T4	T5
Ar1	103,551	56,392	72,089	91,511	105,364	118,885
Ar2	232,990	353,072	479,123	798,551	1,206,137	1,606,662
Ar3	181,214	97,539	125,064	159,238	183,690	207,618
Ai1	70,603	17,911	22,318	29,302	35,782	42,107
Total costs CT (€), CT = (1+fc)·CD		666,641	887,215	1,369,825	1,944,337	2,508,596

Table A.9.51. Total costs for each flood scenario. NDS-case.

In the next section, all cases regarding pluvial flooding (base-case, non-structural measures and situation without drainage system) are analysed.

Summary: Pluvial Flooding

F-N and F-D curves for all cases after analysing pluvial flooding are shown in Figures A.9.19 and A.9.20.

Table A.9.52 includes numerical results of potential fatalities in several points of the F-N curve in case of pluvial flooding.

	Number of potential fatalities, N		
F	BASE-CASE	PFR+WS-CASE	NDS-CASE
1.00E-01	0	0	1
1.00E-02	3	1	9
1.00E-03	3	1	13

Table A.9.52. Summary of results in pluvial flooding.

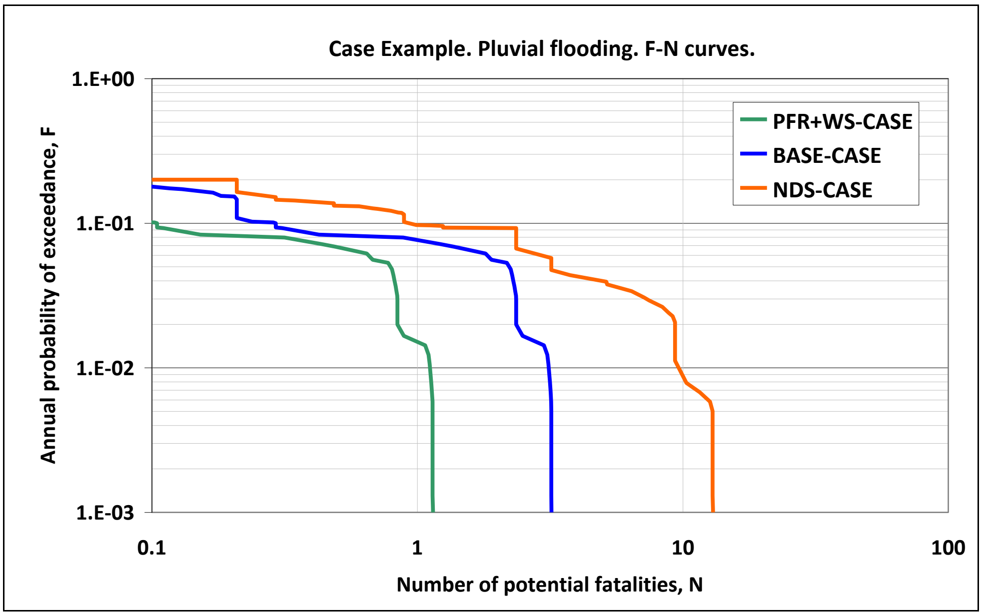

Figure A.9.19. F-N curves. Pluvial flooding.

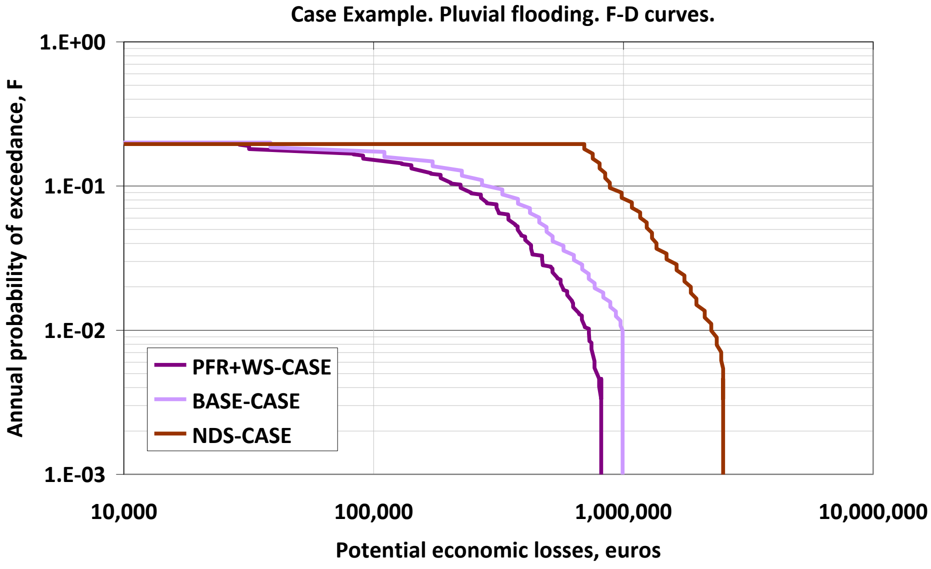

Figure A.9.20. F-D curves. Pluvial flooding.

TOTAL RISK: RIVER PLUS PLUVIAL FLOODING

Finally, flood risk from river and pluvial flooding should be analysed together.

First, risk calculations for the situation without any measures (RN-case in river flooding and NDS-case in pluvial flooding) should be carried out in the same risk model scheme to obtain an overall F-N curve of the situation without structural and non-structural measures. Then, from T=5 years to T=100 years, the potential number of fatalities and economic losses in river and pluvial flooding are added to the same file as input data for the risk model scheme of the natural flow regime of the river (Risk model "2"), that is, the RN-case is evaluated again, but using potential consequences of river and pluvial flooding for each flood scenario.

For this purpose, a new input data file is created from the following relation:

From T=5 years to T=100 years→ $N = N_{\text{RN-case}} + N_{\text{NDS-case}}$

$$CT = CT_{\text{RN-case}} + CT_{\text{NDS-case}}$$

In addition, an overall risk model scheme is performed for analysing river plus pluvial flooding simultaneously. Figure A.9.21 includes the scheme for this new risk model that combines river with pluvial flooding.

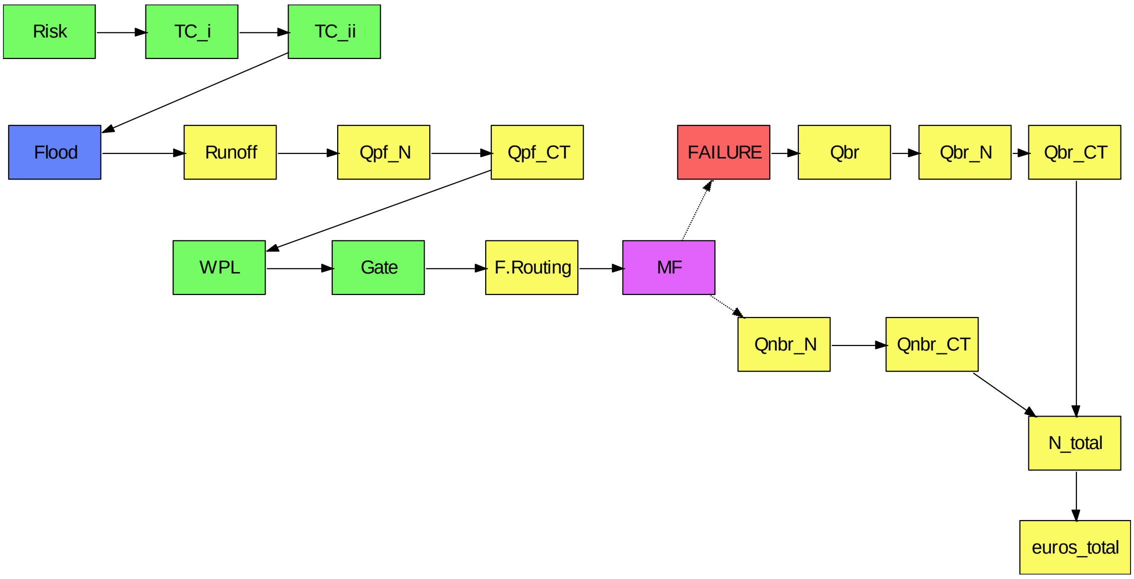

Figure A.9.21. Overall risk model scheme.

Once results from the overall risk model are obtained, F-N and F-D curves for this case example can be represented for flood risk evaluation in case of river and pluvial flooding.

Figures A.9.22 and A.9.23 illustrate results from all analysed cases for this hypothetical example.

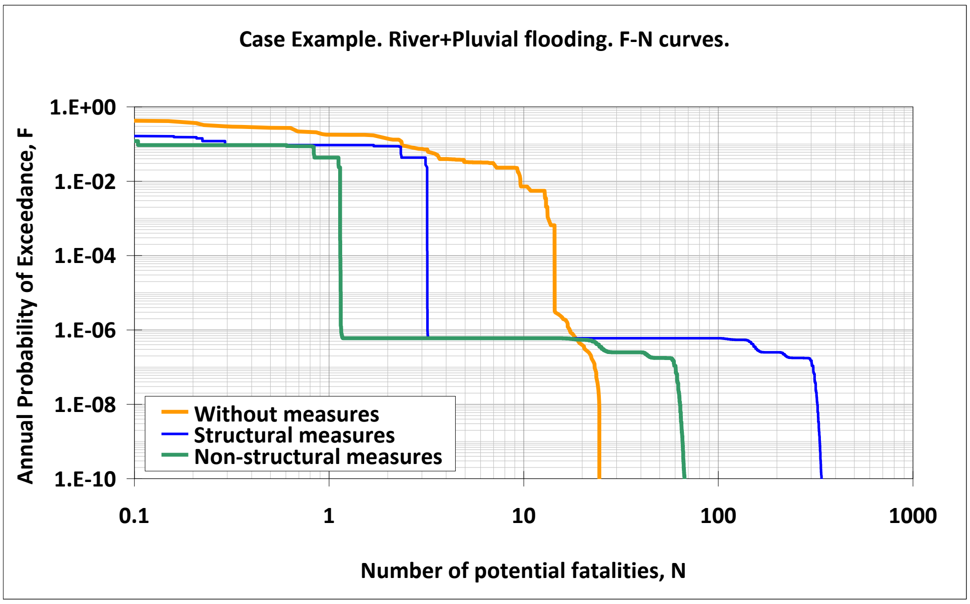

Figure A.9.22. F-N curves case example.

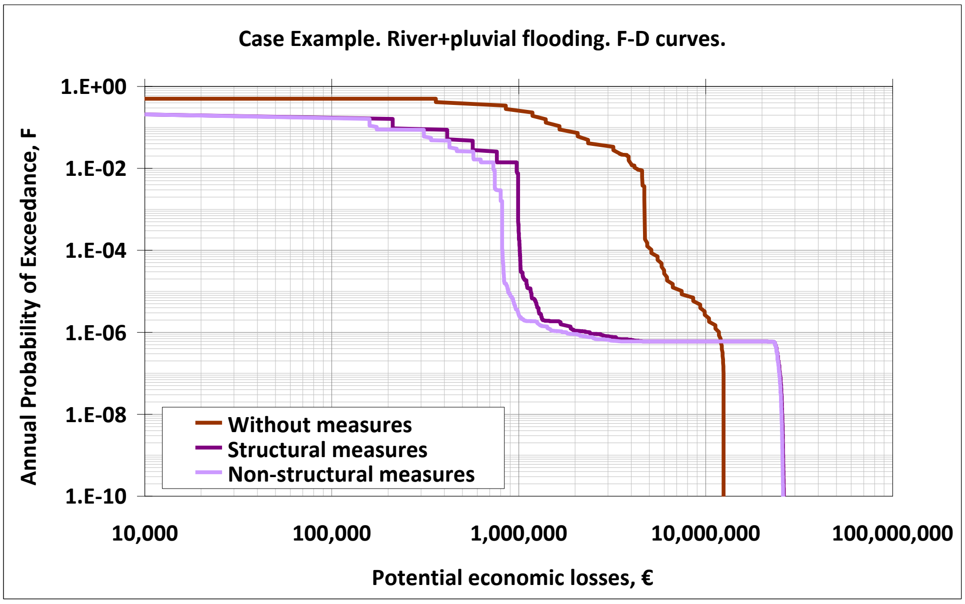

Figure A.9.23. F-D curves case example.

Tables A.9.53 and A.9.54 include several points of F-N and F-D curves after the combination of results from river and pluvial flooding.

	Number of potential fatalities, N		
F	Without any measures	Structural measures	Non-structural measures
1.00E-01	2	0	0
1.00E-02	10	3	1
1.00E-04	14	3	1
1.00E-08	25	321	63

Table A.9.53. Summary of results. River and pluvial flooding. Number of potential fatalities.

	Potential economic losses, €		
F	Without any measures	Structural measures	Non-structural measures
1.00E-01	1,654,634	212,068	174,241
1.00E-02	4,019,919	975,811	732,039
1.00E-07	12,477,470	24,758,006	24,758,006

Table A.9.54. Summary of results. River and pluvial flooding. Potential economic losses.

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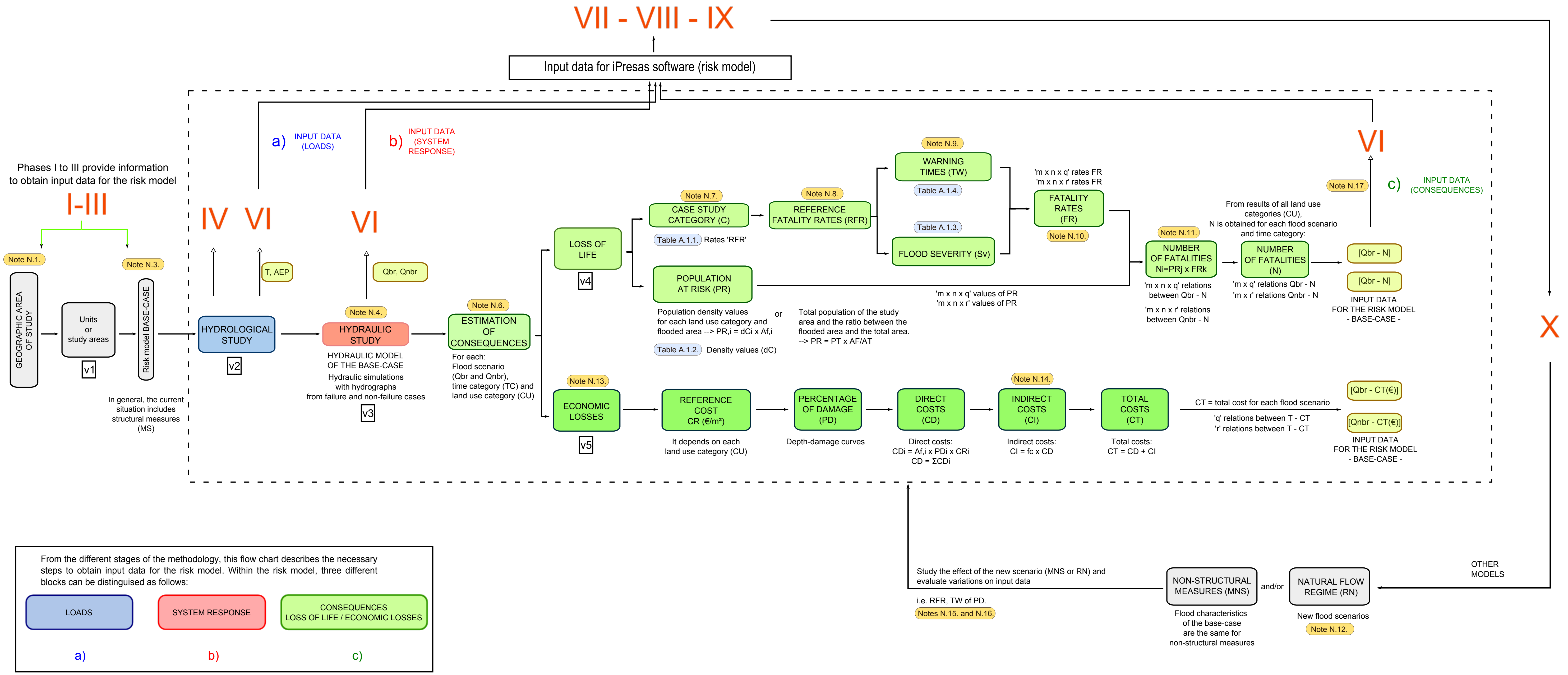


VII - VIII - IX

Input data for iPresas software (risk model)

X

Phases I to III provide information to obtain input data for the risk model

I-III

Note N.1.

GEOGRAPHIC AREA OF STUDY

Units or study areas

v1

Note N.3.

Risk model BASE-CASE

In general, the current situation includes structural measures (MS)

IV VI

a) INPUT DATA (LOADS)

T, AEP

HYDROLOGICAL STUDY

v2

b) INPUT DATA (SYSTEM RESPONSE)

VI

Qbr, Qnbr

Note N.4.

HYDRAULIC STUDY

HYDRAULIC MODEL OF THE BASE-CASE

Hydraulic simulations with hydrographs from failure and non-failure cases

v3

Note N.6.

ESTIMATION OF CONSEQUENCES

For each:
Flood scenario (Qbr and Qnbr),
time category (TC) and land use category (CU)

LOSS OF LIFE

v4

Note N.7.

CASE STUDY CATEGORY (C)

Table A.1.1. Rates 'RFR'

Note N.8.

REFERENCE FATALITY RATES (RFR)

Note N.9.

WARNING TIMES (TW)

Table A.1.4.

Table A.1.3.

FLOOD SEVERITY (Sv)

'm x n x q' rates FR
'm x n x r' rates FR

FATALITY RATES (FR)

Note N.10.

POPULATION AT RISK (PR)

Population density values for each land use category and flooded area --> PR,i = dCi x Af,i

or

Total population of the study area and the ratio between the flooded area and the total area.
--> PR = PT x AF/AT

Table A.1.2. Density values (dC)

'm x n x q' values of PR
'm x n x r' values of PR

Note N.11.

NUMBER OF FATALITIES Ni=PRj x FRk

'm x n x q' relations between Qbr - N

'm x n x r' relations between Qnbr - N

From results of all land use categories (CU), N is obtained for each flood scenario and time category:

NUMBER OF FATALITIES (N)

'm x q' relations Qbr - N
'm x r' relations Qnbr - N

Note N.17.

VI

c) INPUT DATA (CONSEQUENCES)

[Qbr - N]

[Qbr - N]

INPUT DATA FOR THE RISK MODEL - BASE-CASE -

Note N.13.

ECONOMIC LOSSES

v5

REFERENCE COST CR (€/m²)

It depends on each land use category (CU)

PERCENTAGE OF DAMAGE (PD)

Depth-damage curves

DIRECT COSTS (CD)

Direct costs:
CDi = Af,i x PDi x CRi
CD = ΣCDi

Note N.14.

INDIRECT COSTS (CI)

Indirect costs:
CI = fc x CD

TOTAL COSTS (CT)

Total costs:
CT = CD + CI

CT = total cost for each flood scenario

'q' relations between T - CT
'r' relations between T - CT

[Qbr - CT(€)]

[Qnbr - CT(€)]

INPUT DATA FOR THE RISK MODEL - BASE-CASE -

Study the effect of the new scenario (MNS or RN) and evaluate variations on input data

i.e. RFR, TW of PD.

Notes N.15. and N.16.

NON-STRUCTURAL MEASURES (MNS)

Flood characteristics of the base-case are the same for non-structural measures

and/or

NATURAL FLOW REGIME (RN)

New flood scenarios

Note N.12.

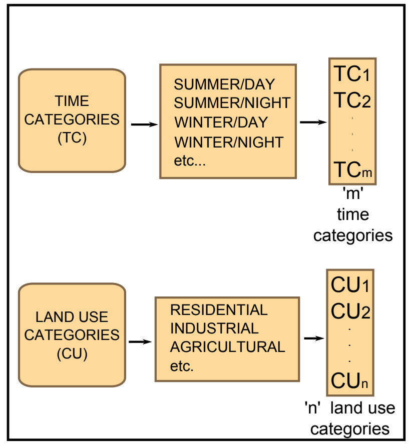
OTHER MODELS

From the different stages of the methodology, this flow chart describes the necessary steps to obtain input data for the risk model. Within the risk model, three different blocks can be distinguished as follows:

LOADS	SYSTEM RESPONSE	CONSEQUENCES LOSS OF LIFE / ECONOMIC LOSSES
a)	b)	c)

VARIABLES OF SUFRI METHODOLOGY

v1 CATEGORIES



TIME CATEGORIES (TC)

SUMMER/DAY
SUMMER/NIGHT
WINTER/DAY
WINTER/NIGHT
etc...

TC_1
TC_2
TC_m

'm' time categories

LAND USE CATEGORIES (CU)

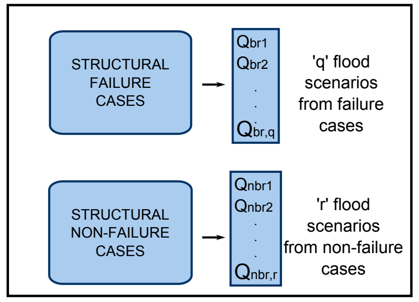
RESIDENTIAL
INDUSTRIAL
AGRICULTURAL
etc.

CU_1
CU_2
CU_n

'n' land use categories

Note N.2.

v2 FLOOD SCENARIOS



STRUCTURAL FAILURE CASES

Q_{br1}
Q_{br2}
$Q_{br,q}$

'q' flood scenarios from failure cases

STRUCTURAL NON-FAILURE CASES

Q_{nbr1}
Q_{nbr2}
$Q_{nbr,r}$

'r' flood scenarios from non-failure cases

v3 FLOW CHARACTERISTICS

- Maximum peak discharge (Qbr or Qnbr).
At the study site:
- Arrival wave time (Twv), TQ1 and TQ2.
- Water depths (H).
- Velocities (v).
- Width (w).
- Total flooded area (AF), and flooded area for each land use category (Af,i).
- Peak discharge (Qf).

Note N.5.

v4 v5 See next page

LEGEND

Data related to:

🟥	Loads
🟦	System response
🟩	Consequences Life-loss
🟩	Consequences Economic losses
🟨	Input data for the risk model
🟧	Other parameters
⬜	Preliminary stages before risk model architecture

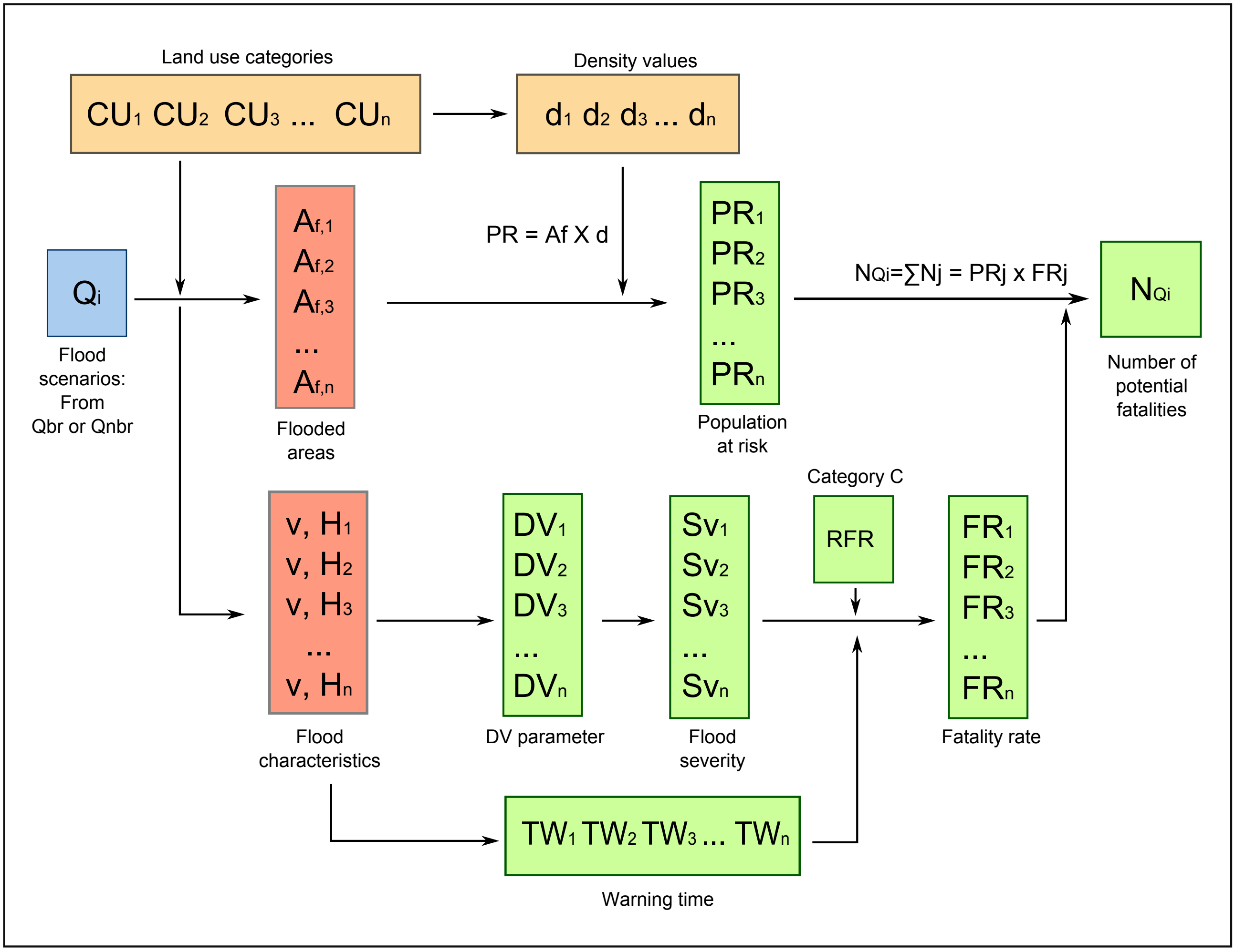
III	Phase of the methodology (process).
↓	Phases I to III of the methodology provide information to establish categories, base-case risk model and flood scenarios.
↑	Hydraulic and hydrological studies, together with estimation of potential consequences provide input data for the risk model in three diferent blocks: loads, system response and consequences (phase VI).
Table A.1.x.	Tables are included in sheet A.1B.
Note N.x.	Notes are included in sheet A.1C.

FLOW CHART TO OBTAIN INPUT DATA FOR THE RISK MODEL
-RIVER FLOODING-

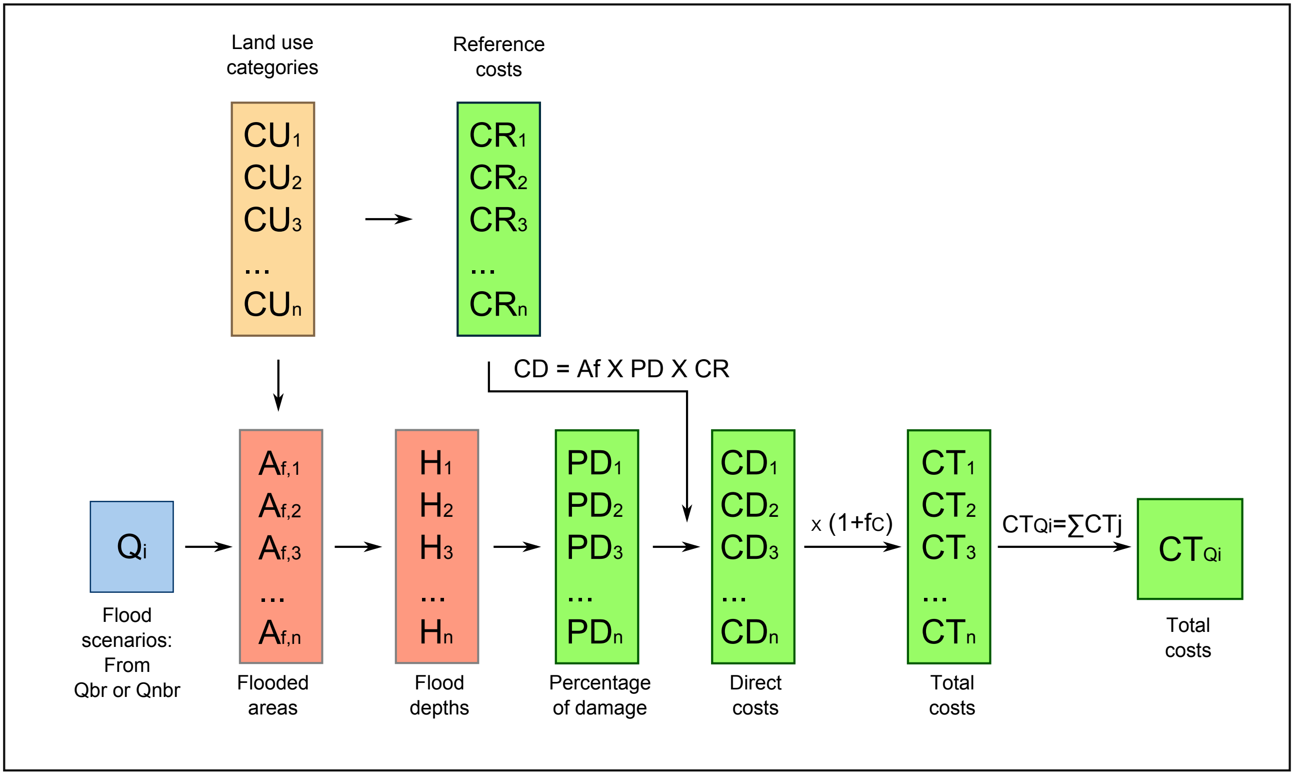
Scheme A.1.
Sheet A.1A.

PHASES

v4 LOSS OF LIFE



v5 ECONOMIC LOSSES



FLOW CHART TO OBTAIN INPUT
DATA FOR THE RISK MODEL
-RIVER FLOODING-

Sheet A.1A*. VARIABLES

A.1.1. DEFINITION OF THE CASE STUDY CATEGORY TO DETERMINE REFERENCE FATALITY RATES (RFR) (Sources: [22])

TABLE A.1.1. REFERENCE FATALITY RATES FOR EACH CASE STUDY CATEGORY.

Category for the case study (C)		Warning time TW (h)	Flood severity (Sv) High (3)	Medium (2)	Low (1)	
C1	- There is no public education on flood risk. - No warning systems, no EAP. - There is no coordination between emergency agencies and authorities. - No communication mechanisms to the public.	***0***	0.9	0.3	0.02	Natural flow regime
		0.25	0.9	0.3	0.02	
		0.625	0.7	0.08	0.015	
		1	-	0.06	0.0006	
		1.5	-	0.0002	0.0002	
		24	-	0.0002	0.0001	
C2	- There is no public education on flood risk. - There is **no EAP,** but there are other warning systems. - There is no coordination between emergency agencies and authorities. - No communication mechanisms to the public.	***0***	0.9	0.3	0.02	
		0.25	0.9	0.3	0.02	
		0.625	0.675	0.075	0.014	
		1	-	0.055	0.00055	
		1.5	-	0.0002	0.0002	
		24	-	0.0002	0.0001	
C3	- There is no public education on flood risk - There is **EAP,** but it has not been applied yet. - Some **coordination** between emergency agencies and authorities (but protocols are not established). - No communication mechanisms to the public.	***0***	0.9	0.3	0.02	
		0.25	0.85	0.2	0.015	
		0.625	0.6	0.07	0.012	
		1	-	0.05	0.0005	
		1.5	-	0.0002	0.0002	
		24	-	0.0002	0.0001	
C4	- There is no public education on flood risk. **- EAP** is already applied. - Coordination between emergency agencies and authorities (there are **protocols**). - No communication mechanisms to the public.	***0***	0.9	0.3	0.02	EAP No public education
		0.25	0.75	0.15	0.01	
		0.625	0.5	0.04	0.007	
		1	-	0.03	0.0003	
		1.5	-	0.0002	0.0002	
		24	-	0.0002	0.0001	
C5	- There is no public education on flood risk - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - **Communication** mechanisms to the public (not checked yet).	***0***	0.9	0.3	0.02	
		0.25	0.75	0.15	0.01	
		0.625	0.5	0.0375	0.0065	
		1	-	0.0275	0.000275	
		1.5	-	0.0002	0.0002	
		24	-	0.0002	0.0001	
C6	- There is no public education on flood risk - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.	***0***	0.9	0.3	0.02	
		0.25	0.75	0.15	0.01	
		0.625	0.475	0.035	0.006	
		1	-	0.025	0.00025	
		1.5	-	0.0002	0.0002	
		24	-	0.0002	0.0001	
C7*	- **Public education.** - EAP is already applied. - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.	***0***	0.9	0.3	0.02	Dam break No hydrologic scen.
		0.25	0.65	0.1	0.0075	
		0.625	0.4	0.02	0.002	
		1	-	0.01	0.0002	
		1.5	-	0.0002	0.0002	
		24	-	0.0002	0.0001	
C8	- Public education - EAP is already applied. It has been proved or used **previously.** - Coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.	***0***	0.9	0.3	0.02	
		0.25	0.55	0.06	0.006	
		0.625	0.35	0.01	0.0015	
		1	-	0.005	0.00015	
		1.5	-	0.0002	0.00015	
		24	-	0.0002	0.0001	
C9	- Public education. - EAP is already applied. It has been proved or used previously. - **High** coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.	***0***	0.9	0.3	0.02	
		0.25	0.55	0.06	0.006	
		0.625	0.35	0.008	0.0015	
		1	-	0.004	0.000125	
		1.5	-	0.0002	0.0001	
		24	-	0.0002	0.0001	
C10	- **Regular** activities and plans for public education. - EAP is already applied. It has been proved or used previously. - High coordination between emergency agencies and authorities (there are protocols). - Communication mechanisms to the public.	***0***	0.9	0.3	0.02	Best scenario
		0.25	0.5	0.03	0.005	
		0.625	0.3	0.005	0.001	
		1	-	0.002	0.0001	
		1.5	-	0.0002	0.0001	
		24	-	0.0002	0.0001	

Variation between categories depending on non-structural measures

*(C7 is used for categories 'C8','C9' and 'C10' if the analysis of a flood defence failure in case of non-hydrologic scenario is considered

A.1.2. REDUCTION ON THE VALUE OF DENSITY OF POPULATION IN AREAS WITH A HIGH PERCENTAGE OF MULTI-STORY BUILDINGS TO OBTAIN POPULATION AT RISK (PR)

Data requirements:
- Density of population for the study area (d) or total number of citizens within the urban area.
- Average height of buildings (hm) or mean value of number of floors (np).
- Water depths due to the flood (H).

This part is considered in urban areas where np >2 or hm>6.6m (urban areas with a high percentage of multi-story buildings).

TABLE A.1.2. Density population for risk calculations (dC)

	Case	dC
Mean value of the number of floors (np)	H < h1p*	dC = d / np
	h1p < H < h2p	dC = d x 2 / np
	H > h2p	dC = d x (H/hn*) / np
Average building heigth (hm)	H < h1p	dC = d x h1p / hm
	h1p < H < h2p	dC = d x h2p / hm
	H > h2p	dC = d x H / hm

*h1p= 3.3m, h2p= 6.6m and hn = height between floors.

(Source: SUFRI)

NOTE: If there are several urban areas in the case study (several villages, towns, etc. of minor importance or low population), it is recommended to obtain 'np' or 'hm' of three units or cities of differente population (entity) and consider the results as a reference number (p.e. if population=x: x<10,000; 10,000<x<100,000 y x>100,000).

A.1.3. DEFINITION OF FLOOD SEVERITY (Sv)

In general, flood severity of each flood scenario is established from the DV parameter.

$$DV = \frac{Qaf - Q2.33}{w}$$

Data requirements:
- Peak discharge at the study site (Qaf).
- Mean annual discharge of the river at the study site ($Q_{2.33}$).
- Maximum width reached by the flood at the study site (w).

If previous information is not available, then the flood severity category can be determined using flood water depths (H).

TABLE A.1.3. FLOOD SEVERITY (Sv)

		DV	H
Severity for each flood scenario (Sv)	Low (1)	< 4.6 m²/s	< 3.3 m
	Medium (2)	> 4.6 m²/s	> 3.3 m
	High (3)	Areas located downstream the dam**	

(Source: [22])

**DSO-99-06 procedure does not include recommendations on how to establish the diference between medium and high severity. Therefore, except for specific cases, high flood severity is established in urban areas located close to the dam, where shelter or evacuation are not feasible and total destruction of the area would occur in case of dam break.

Sources:
[9] Risk Based Profiling System (USBR, 2001)
[12] PATRICOVA (2002)
[22] DSO-99-06 Procedure (Graham, 1999)

A.1.4. INDICATIONS TO OBTAIN WARNING TIME (TW) FOR EACH FLOOD SCENARIO, DEPENDING ON THE ARRIVAL WAVE TIME AND OTHER FACTORS RELATED TO BREACH DEVELOPMENT, FAILURE MODE AND THE EXISTANCE OF AN EMERGENCY ACTION PLAN.

-- WARNING TIME FOR RISK MODELS OF THE NATURAL FLOW REGIME OF THE RIVER (RN) AND STRUCTURAL MEASURES (EXCEPT FOR DAMS)

TW = TD = tQ2 - tQ1

where TD is the diference between the time of the first notice peak discharge at the study site (Q1) and the time of first damages in buildings or households (Q2)

Day: TW = TD = tQ2 - tQ1
Night: TW (h) = TD (h) - 0.25   (TW at night is defined as a time which is 15 minutes lower than TW during the day)

-- WARNING TIMES FOR RISK MODELS WITH DAM UPSTREAM THE STUDY AREA

Breach Development Speed (TBR)

Breach Development	TBR (h)	TBR (min)
Fast	0.25	15
Moderate	0.75	45
Slow	1.25	75

Failure Mode Factor (FMF)

	Average value		Day		Night	
Failure mode	**FMF (h)**	**FMF (min)**	**FMF (h)**	**FMF (min)**	**FMF (h)**	**FMF (min)**
Seismic	0.375	15-30	0.25	15	0.5	30
Internal erosion	0.375	15-30	0.25	15	0.5	30
Hydrologic	0.125	0-30	0	0	0.5	30

(Source: [9])

Warting time (TW)*
TW = Wave arrival time (Twv) + Breach Development Speed (TBR) - Failure Mode Factor (FMF) - FPE

*For cases with no dam-break, the warning time is considered as the diference between the peak flow that reaches the first buildings and the first notice flow. This time is denoted by TD

If there is no Emergency Action Plan, a factor FPE equal to 30min should be considered.

p.e. TBR=0.25h y FPE=0.5h. All time values in hours.

	LOAD SCENARIO		Day	Night
NO EMERGENCY ACTION PLAN	Seismic		TW= Twv - 0.5	TW= Twv -0.75
	Internal erosion		“”	“”
	Hydrologic	No dam-break**	TW= TD	TW= TD - 0.25
		Dam-break	TW= Twv -0.25	TW= Twv -0.5

Warting time (TW)*
TW = Wave arrival time (Twv) + Breach Development Speed (TBR) - Failure Mode Factor (FMF)

**In case of no dam-break, the warning time will be equal to the diference between the first notice peak discharge and the peak flow that reaches the first constructions. This time is denoted by TD.

p.e. TBR=0.25h. All time values in hours.

	LOAD SCENARIO		Day	Night
EMERGENCY ACTION PLAN	Seismic		TW= Twv	TW= Twv - 0.25
	Internal erosion		“”	“”
	Hydrologic	No dam-break**	TW= TD + 0.5	TW= TD + 0.25
		Dam-break	TW= Twv + 0.25	TW= Twv

(Source: SUFRI)

TABLES TO DETERMINE INPUT DATA FOR THE RISK MODEL
-RIVER FLOODING-

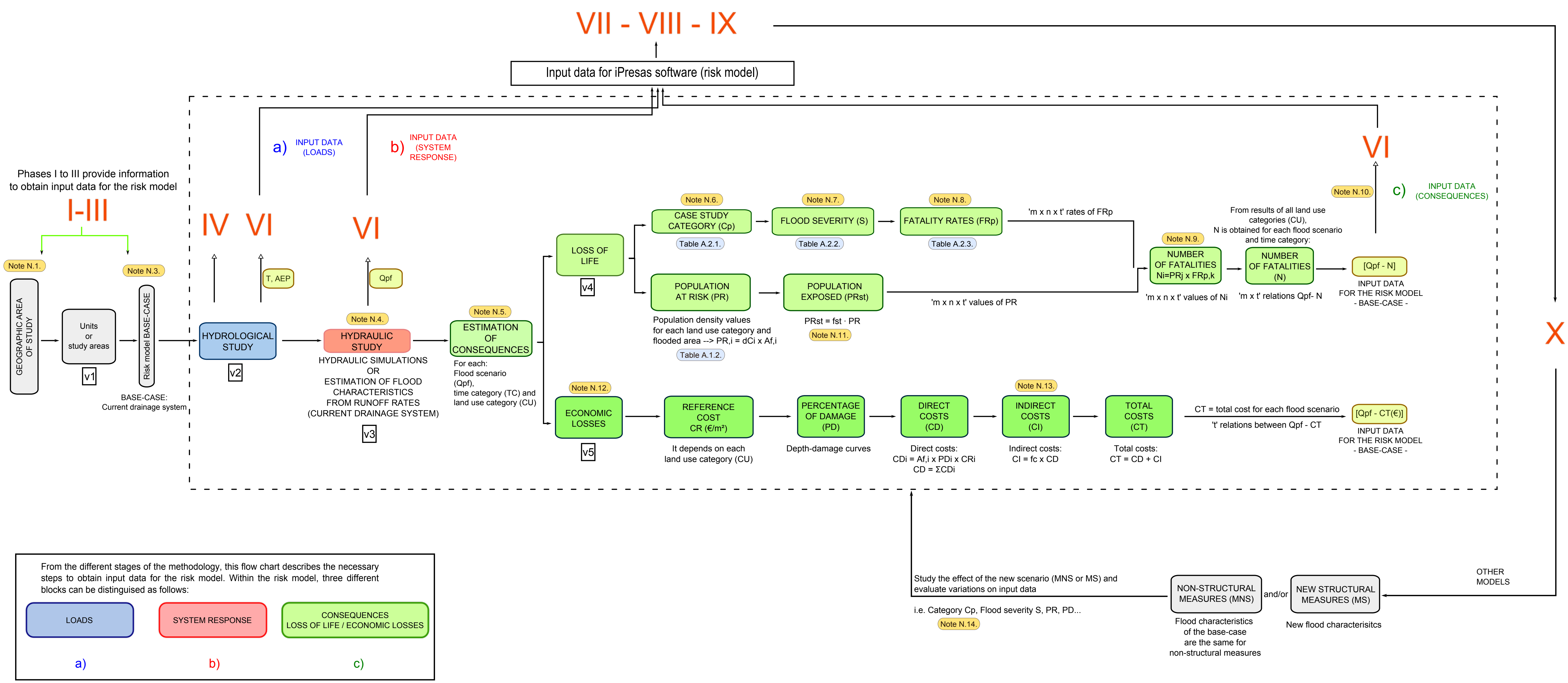
SHEET A.1B. TABLES

CODE	NOTE
N.1.	Analysis of the case study, including residential areas, industrial areas and other units with potential victims in case of flood. Data requirements: demography, land uses, type of buildings, maps, statistics, historical records and information of past events, economic rates, etc.
N.2.	Study of population variability: moment of the day, day of the week, season, special events, etc. i.e. Work conditions, studies, other residence, etc. To reduce the amount of calculations in case studies with a high number of population units, consequences for two time categories can be obtained and then a factor is applied to estimate results for other categories (i.e.Nj=Ni x PRj/PRi)
N.3.	A risk model for the base-case should be implented, including the current structural measures. However, if possible, the risk model to study the natural flow regime of the river should be performed for comparison purposes. Once this base-case is performed, other alternatives can be applied for studying the effect of structural or non-structural measures (MS or MNS).
N.4.	Hydraulic modelling will provide data for each flood scenario. The model should represent the characteristics of the river. It should be hydraulic, complete and dynamic, enable to obtain results in sub-critical and supercritical flow. Uni-dimensional models are maybe more appropiate than bi-dimensional (the first require less amount of data). The model should be capable of modelling unsteady flow regimes in case of structural failure. Some examples are: MIKE 11(DHI), SOBEK (Deltares) o HEC-RAS (USACE).
N.5.	Q, first notice flow, is the peak discharge at the study site that reaches the capacity of the river bank and it is established as a threshold: population is aware of a potential flood event. First-damage flow, Q2, is the peak discharge at the study site that reaches the first buildings or households.
N.6.	Input data for the risk model, related to consequences is divided into two parts: loss of life and economic losses.
N.7.	Category of the case study (C) to obtain reference fatality rates (RFR) is defined taking into account: (Table A.1.1.) - Public education. - Communication. - Coordination between emergency agents and authorities. - Existence of Emergency Action Plans (dams).
N.8.	Once the category is defined, there are 15 reference fatality rates for different flood severity levels and warning times, where: - Severity (Sv): High, medium or low. - Warning time (TW): 0 h, 0.25 h, 0.625 h, 1 h, 1.5 h and 24 h.
N.9.	Warning times (TW) vary depending on the base-case (dams, leeves, dikes, ponds, etc.), also if non-structural measures are applied. If there is a dam usptream the location, warning times depend on breach development, existence of EAP, etc. Warning times are defined differently in 'day' or 'night' time categories. (Table A.1.4.)
N.10.	For each flood scenario, fatality rates (FR) are obtained by interpolating the reference values from warning times obtained from flood characteristics (flood severity and time category). (Table A.1.3.)
N.11.	The number of potencial fatalities (N) is obtained for each flood scenario, time category (TC) and land use category (CU) as the product of the fatality rate (FR) and population at risk (PR): N = PR x FR. In general, results of potential loss of life lower than 1 are rounded up to N=1.
N.12.	For risk models of the natural flow regime, input data includes relations Qmax-N, where Qmax is the peak discharge associated with each return period and N is the number of potential fatalities.
N.13.	Economic losses of each flood scenario (direct and indirect costs) are obtained from the estimation of a reference cost (CR) for each land use category (CU). Economic costs will depend on the percentage of damages (PD) in each flooded area (depth-damage curves).
N.14.	Indirect costs can be estimated as a percentage of direct costs. A factor, fC, is defined for each case study and it will depend on the population, infrastructures, economic relevance of the city, etc. i.e. It will range from 0% to 55% [5].
N.15.	If dam failure is considered in case of non-hydrological scenario (no rainfall event), then values of the Failure Mode Factor for seismic scenario are used to estimate warning times (FMF, Table A.1.4.).
N.16.	The effect of non-structural measures can be included as a reduction of the potential economic losses of the flood. If the estimation of this reduction can be established, then the percentage of reduction will be estimated from 'warning time-damage reduction' curves ([42]), in flood scenarios in which water depths are lower than 1.2 m (low severity levels).
N.17.	The risk model will use input data for estimation of consequences and risk calculation from the list of values Q-N obtained from the steps described in the given flow chart, where Q is the flow that identifies each flood scenario (natural flow regime, flood routing or dam-break) and N is the potential loss of life or number of fatalities for that flood case.

Sources: [9] Risk Based Profiling System (USBR, 2001)
[12] PATRICOVA (2002)
[22] DSO-99-06 Procedure (Graham, 1999)
[42] Parker et al (2005)

NOTES TO OBTAIN INPUT DATA
FOR THE RISK MODEL
-RIVER FLOODING-

Sheet A.1C. NOTES

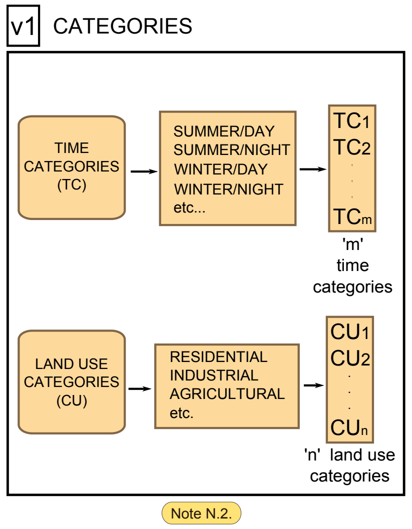


From the different stages of the methodology, this flow chart describes the necessary steps to obtain input data for the risk model. Within the risk model, three different blocks can be distinguished as follows:

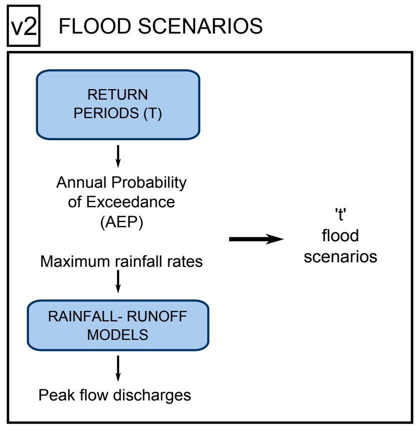
a)	b)	c)
LOADS	SYSTEM RESPONSE	CONSEQUENCES LOSS OF LIFE / ECONOMIC LOSSES

VARIABLES OF SUFRI METHODOLOGY

v1 CATEGORIES



v2 FLOOD SCENARIOS



v4 v5 See next page

v3 FLOW CHARACTERISTICS

For each flood scenario:

- Runoff rates for each area (from land use categories or definition of homogenous zones).
- Water depths (y).
- Velocities (v).
- Flooded areas (AF, Af,i).

Note N.4.

LEGEND

Data related to:

🟥	Loads
🟦	System response
🟩	Consequences. Life-loss
🟩	Consequences. Economic losses
🟨	Input data for the risk model
🟧	Other parameters
⬜	Preliminary stages before risk model architecture

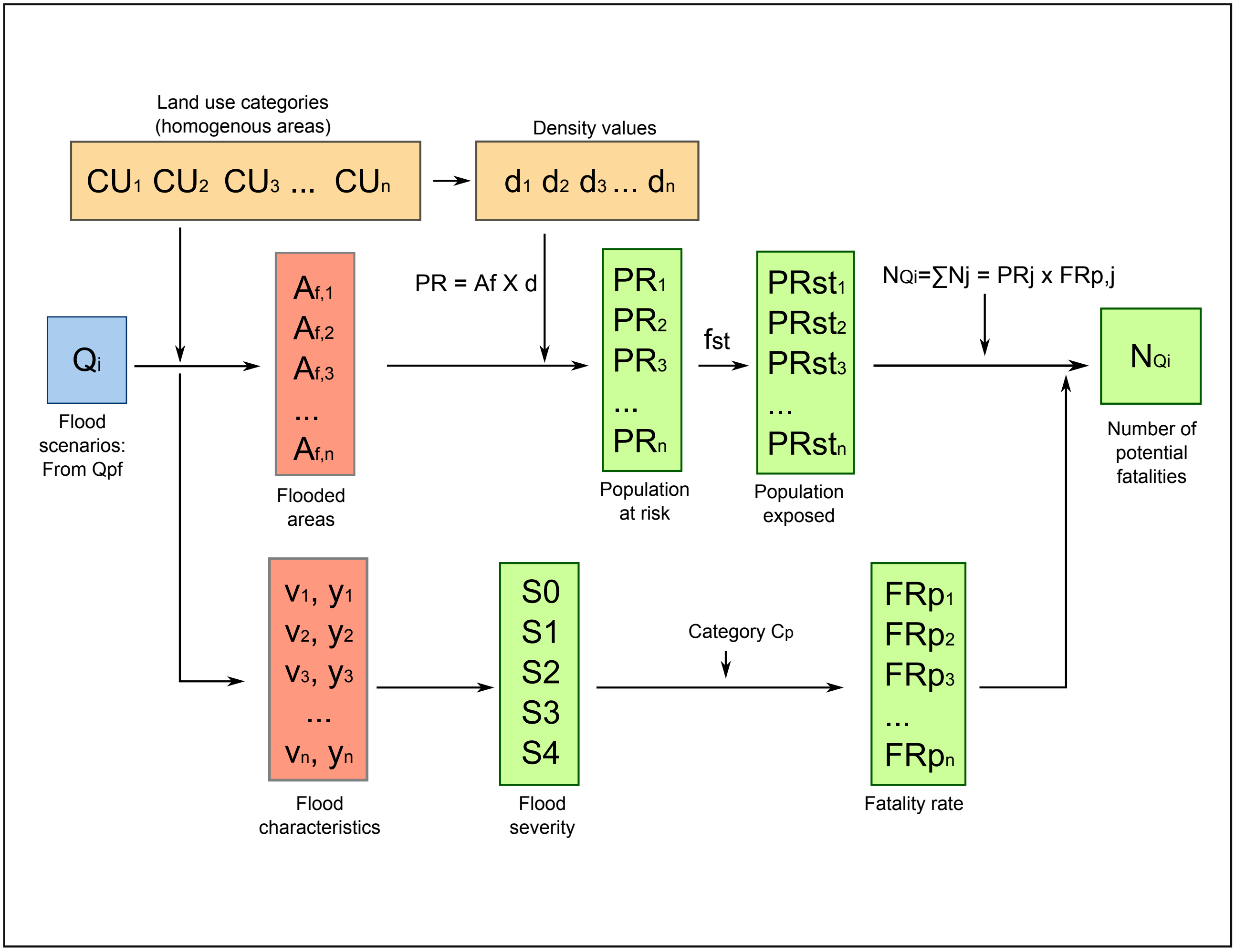
III	Phase of the methodology (process).
↓	Phases I to III of the methodology provide information to establish categories, base-case risk model and flood scenarios.
↑	Hydraulic and hydrological studies, together with estimation of potential consequences provide input data for the risk model in three different blocks: loads, system response and consequences (stage VI).
Table A.2.x.	Tables are included in sheet A.2B.
Note N.x.	Notes are included in sheet A.2B.

FLOW CHART TO OBTAIN INPUT DATA FOR THE RISK MODEL
-PLUVIAL FLOODING-

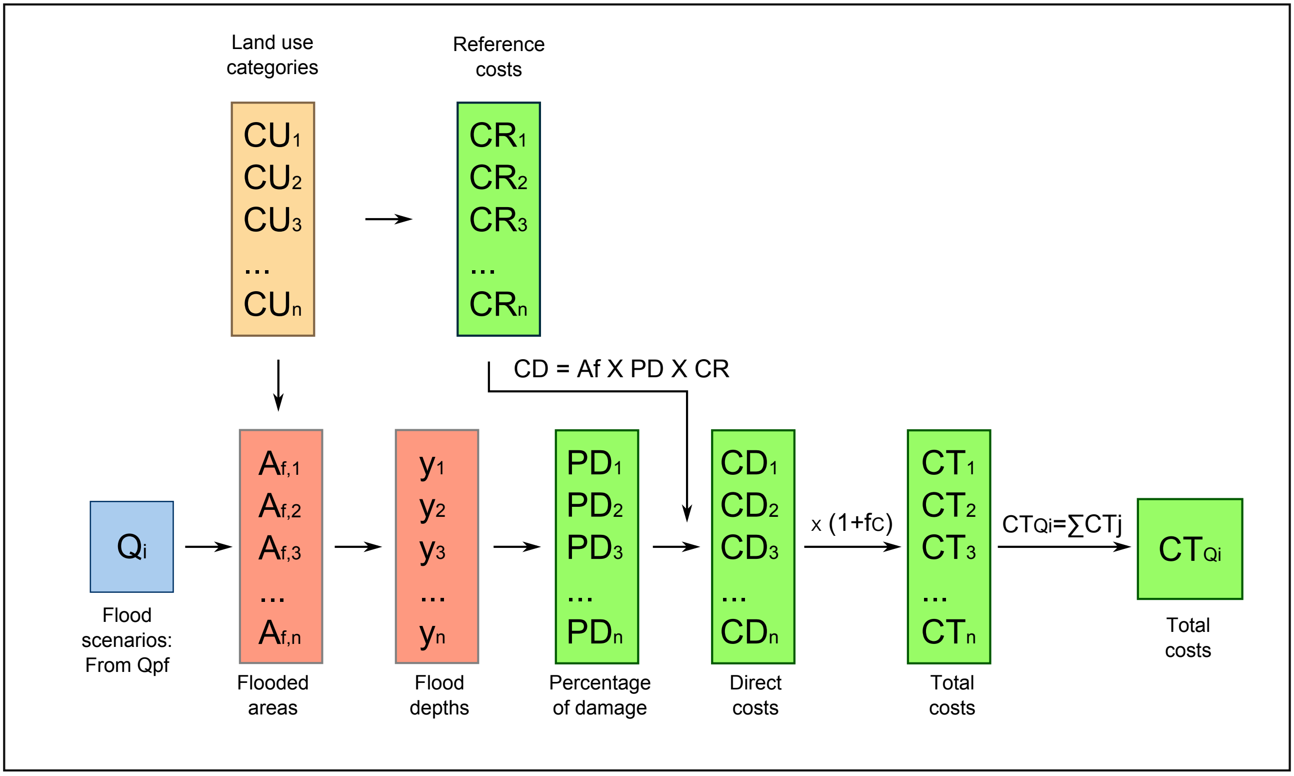
Scheme A.2.
Sheet A.2A.

PHASES

v4 LOSS OF LIFE



v5 ECONOMIC LOSSES



FLOW CHART TO OBTAIN INPUT
DATA FOR THE RISK MODEL
-PLUVIAL FLOODING-

Sheet A.2A*. VARIABLES

TABLE A.2.1. CATEGORY Cp FOR THE CASE STUDY TO OBTAIN FATALITY RATES IN PLUVIAL FLOODING (Source: SUFRI)

Category C_p	**Definition**
C_{p1}	No warning systems
C_{p2}	Existence of warning systems, but not used or protocols are unknown
C_{p3}	Warning systems completely established and proved (drills)

TABLE A.2.2. FLOOD SEVERITY LEVELS (S) (Source: SUFRI and criteria Appendix 3)

Flood severity (S)		Depth y(m)	Velocity v (m/s)	Dragging parameter v·y (m^2/s)	Sliding parameter $v^2 \cdot y$ (m^3/s^2)
S0	No fatalities are expected. People expected to survive.	<0.45	<1.50	<0.50	<1.23
S1	*Low severity* People may suffer loss of stability. People in danger.	<0.80	<1.60	<1.00	<1.23
S2	*Medium severity* Significant loss of stability. Cars can lose roadholding. Floating.	<1.00	<1.88	<1.00	<1.23
S3	*High severity* High risk for people outside Low risk for buildings	>1.00	>1.88	>1.00	>1.23
S4	*Extreme severity* Structural damages on buildings	>1.00	>1.88	>3.00	>1.23

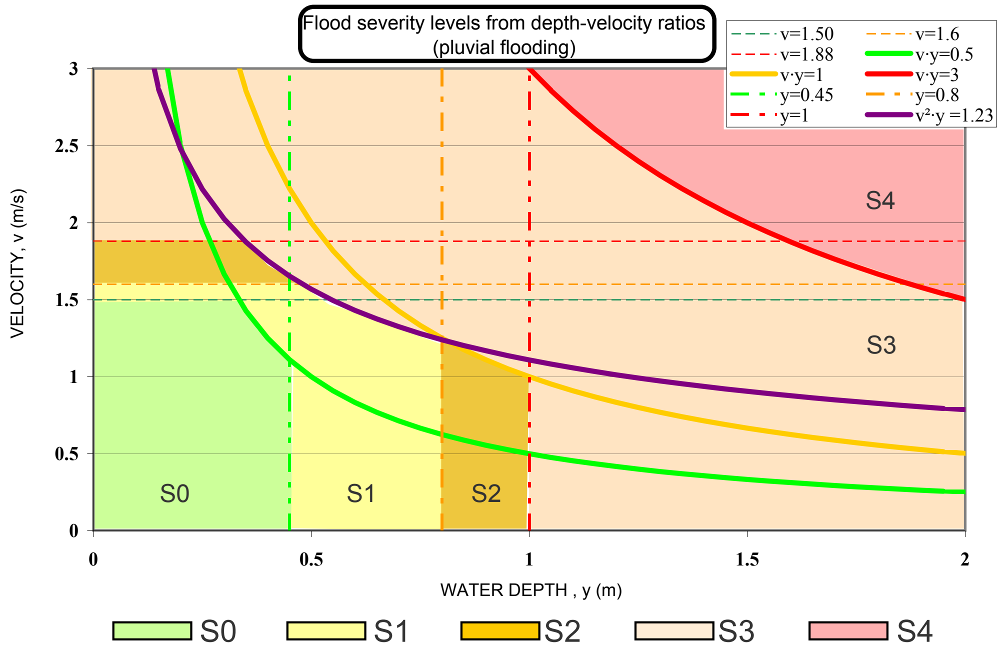

Flood severity levels from depth-velocity ratios (pluvial flooding)

TABLE A.2.3. FATALITY RATES FOR EACH CATEGORY (Cp) AND FLOOD SEVERITY (S). (Source: [36],[45])

Category C_p	Flood severity S	Fatality rate, FRp	Range of values for FRp
C_{p1}	S0	0.0003	0.0000 - 0.0009
	S1	0.0021	0.0010 - 0.0030
	S2	0.0038	0.0015 - 0.0045
	S3	0.0105	0.0060 - 0.0400
	S4	0.0448	0.0100 - 0.1100
C_{p2}	S0	0.0003	0.0000 - 0.0008
	S1	0.0018	0.0012 - 0.0024
	S2	0.0033	0.0014 - 0.0037
	S3	0.0090	0.0050 - 0.0350
	S4	0.0384	0.0100 - 0.0950
C_{p3}	S0	0.0002	0.0000 - 0.0007
	S1	0.0015	0.0010 - 0.0020
	S2	0.0027	0.0010 - 0.0030
	S3	0.0075	0.0040 - 0.0280
	S4	0.0320	0.0090 - 0.0800

CODE	NOTE
N.1.	Analysis of the case study, including residential areas, industrial areas and other units with potential fatalities in case of flood. Data requirements: demography, land uses, type of buildings, maps, statistics, historical records and information of past events, economic rates, etc.
N.2.	Study of population variability: moment of the day, day of the week, season, special events, etc. i.e. Work conditions, studies, other residence, etc. To reduce the amount of calculations in case studies with a high number of population units, consequences for two time categories can be obtained and then a factor is applied to estimate results for other categories (i.e.Nj=Ni x PRj/PRi)
N.3.	A risk model for the base-case should be developed, including the current drainage system. Once this base-case is performed, other alternatives can be applied for studying the effect of structural or non-structural measures (MS or MNS).
N.4.	Hydraulic modelling or other calculations will provide data for each flood scenario, defined by a return period. The model/process should represent the characteristics of the current drainage system.
N.5.	Input data for the risk model, related to consequences is divided into two parts: loss of life and economic losses.
N.6.	The category (Cp) that determines fatality rates (FRp) in case of pluvial flooding, depends on existence of warning systems (Table A.2.1.).
N.7.	Flood severity in pluvial flooding is based on a classification of five levels, from the characteristics of the flood: water depth (y) and velocity (v). These five levels range from S0 to S4.
N.8.	Once the category is established (Cp), fatality rates (FRp) depend on the flood severity level of each flood scenario (S).
N.9.	The number of potencial fatalities (N) is obtained for each flood scenario, time category (TC) and land use category (CU) as the product of the fatality rate (FRp) and population at risk (PR): N = PR x FRp. In general, results of potential loss of life lower than 1 are rounded up to N=1.
N.10.	The risk model uses input data for risk calculation from the list of values Qpf-N obtained from the steps described in the given flow chart, where T is the return period (flood scenario) and N is the potential loss of life or number of fatalities for that flood case.
N.11.	People exposed to the flood (PRst) can be estimated as a percentage (fst) of the population at risk (PR): number of people within the flooded area.
N.12.	Economic losses of each flood scenario (direct and indirect costs) are obtained from the estimation of a reference cost (CR) for each land use category (CU). Economic costs depend on the percentage of damages (PD) in each flooded area (depth-damage curves).
N.13.	Indirect costs can be estimated as a percentage of direct costs. A factor, fc, is defined for each case study and it depends on population, infrastructures, economic relevance of the city, etc. i.e. It can range from 0% to 55% [13].
N.14.	The effect of non-structural measures can be included, for example, as a reduction of the potential economic losses of the flood. A percentage of damage reduction can be estimated from 'warning time-damage reduction' curves ([44]), in flood scenarios with water depths lower than 1.2 m.

Sources:

[13] PATRICOVA (2002)
[36] Defra (UK)
[44] Parker et al (2005)
[45] Penning-Rowsell et al (2005)

TABLES TO OBTAIN INPUT DATA
FOR THE RISK MODEL
-PLUVIAL FLOODING-

Sheet A.2B.

TABLES and NOTES