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Vulnerability assessment of embankments and bridges exposed to flooding hazards

D5.1 Quantification framework for direct and indirect impacts of flooding hazards

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Executive Summary

The risk of floods, a combination of flood hazard and vulnerability, is a risk influencing large areas and causing a chain of cascading cross-border effects. Three partnering countries Croatia, the Netherlands and Slovenia are all exposed to a very high risk of flooding, with different type of threats to critical infrastructure. The Netherlands, with one third of the country below the sea level, is exposed to continuous flooding threat and has one of the most sophisticated flood protection systems in the world. Croatia and Slovenia have joint transboundary river basins, a similar infrastructure and approach regarding flood protection measures, while now facing more frequently new and unknown conditions caused by increasing climate change impacts.

The current systems of civil protection in Croatia and Slovenia are lacking information about flood protection infrastructure, transport infrastructure and its vulnerability. The already well-established civil protection mechanisms could be jeopardized by sudden failures of parts of infrastructure in case of an emergency event. All involved agencies, including the Netherlands, expressed their need for more accurate estimate of vulnerability of critical infrastructure and potential risks which would provide them necessary information for immediate response, as well as long term planning for authorities and infrastructure owners.

In order to develop basis for the development of a tool for rapid risk forecast, all direct and indirect impacts of flooding hazards need to be established. The focus of this report is identification and classification of these impacts followed by their quantification. The quantified impacts will serve as the key performance indicators for risk mapping tool applied on demonstration areas.

Keywords: direct and indirect flood impacts, key performance indicators, risk assessment

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Abbreviations and Acronyms

Abbreviation / Acronym	Description
CPA	Civil Protection Agency
CPDRR	Croatian Platform for Disaster Risk Reduction
DRR	Disaster Risk Reduction
FD	Flood Directive
GIS	Geographic information system
H2020	Horizon 2020
IM	Infrastructure Manager
IMP	Information Management Platform
LBI	Loss of business interruption
MD	Material Damage
UDC	User Delay Cost
VNK2	Veiligheid Nederland in Kaart (Safety of the Netherlands on the map)
WMO	World Meteorological Organization

1 Introduction

Flooding is a significant threat to human-life, ecosystems, cultural heritage and society in general. The Netherlands is the most flood prone country in the EU (EC, 2017). The Great North Sea flood of 1953 caused breaches of the famous levee (embankments and dikes) system leading to 1,835 fatalities, the inundation of 200,000 hectares of land and severe damage to cultural heritage (particularly in the vicinity of failed levees e.g. fortified towns, polder mills and water mills). In response the country built strategic large flood defence schemes and developed a sophisticated flood risk management system called VNK2 (Rijkswaterstaat, 2014) for levees.

Scour erosion of bridge foundations, as a consequence of flooding, is the number one cause of failure for bridges located over waterways (Gavin et al., 2018). In addition to other impacts such failures greatly affect emergency response capability during a flood event. In recent years Europe has experienced some of the largest flood events in its history, as for example in May 2014 extensive flooding affected over 1,5 million people across Croatia, Bosnia and Serbia. While the mean daily rainfall in Southern Eastern Europe has increased only a little since 1950, the intensity of the strongest rainfall events rose by one third (Stadtherr et al., 2016). In May 2014, daily rainfall amounts were higher than at any time since records began. The frequency of such potentially devastating extremes in the region has doubled over the past sixty years. According to IPCC projections (2021) many countries will be exposed to higher peak river discharges in the near future. The three partner countries in the oVERFLOW project are particularly vulnerable to cross-border river flooding in their position near the end of major European river systems.

In order to develop basis for the development of a risk assessment tool, this report is focusing on quantification of direct and indirect impacts of flooding hazards. The methods for quantification of flood impacts are explained in the following chapters and will serve for risk assessment mapping.

2 Quantification methodologies

2.1 Literature review

Flood effects may be both direct, through the immediate interaction of flood water with built, natural and human environments, and indirect, through damage or disruption of transportation and economic activities that impact people's livelihoods. Damage can be further divided into tangible and intangible categories. Categorization of flood losses is presented in Figure 2-1. Direct flood damages cover all varieties of harm which relate to the immediate physical contact of flood water to humans, property and the environment. This includes, for example, damage to buildings, economic assets, loss in agriculture, loss of human life, immediate health impacts and loss of ecological goods. Direct damages are usually measured as damage to stock values. Indirect flood damages are damages caused by disruption of physical and economic linkages of the economy and the extra costs of emergency and other actions taken to prevent flood damage and other losses. This includes, for example, the loss of production of companies affected by the flooding, induced production losses of their suppliers and customers, the costs of traffic disruption or the costs of emergency services. Indirect damages are often measured as loss of flow values (WMO, 2015).

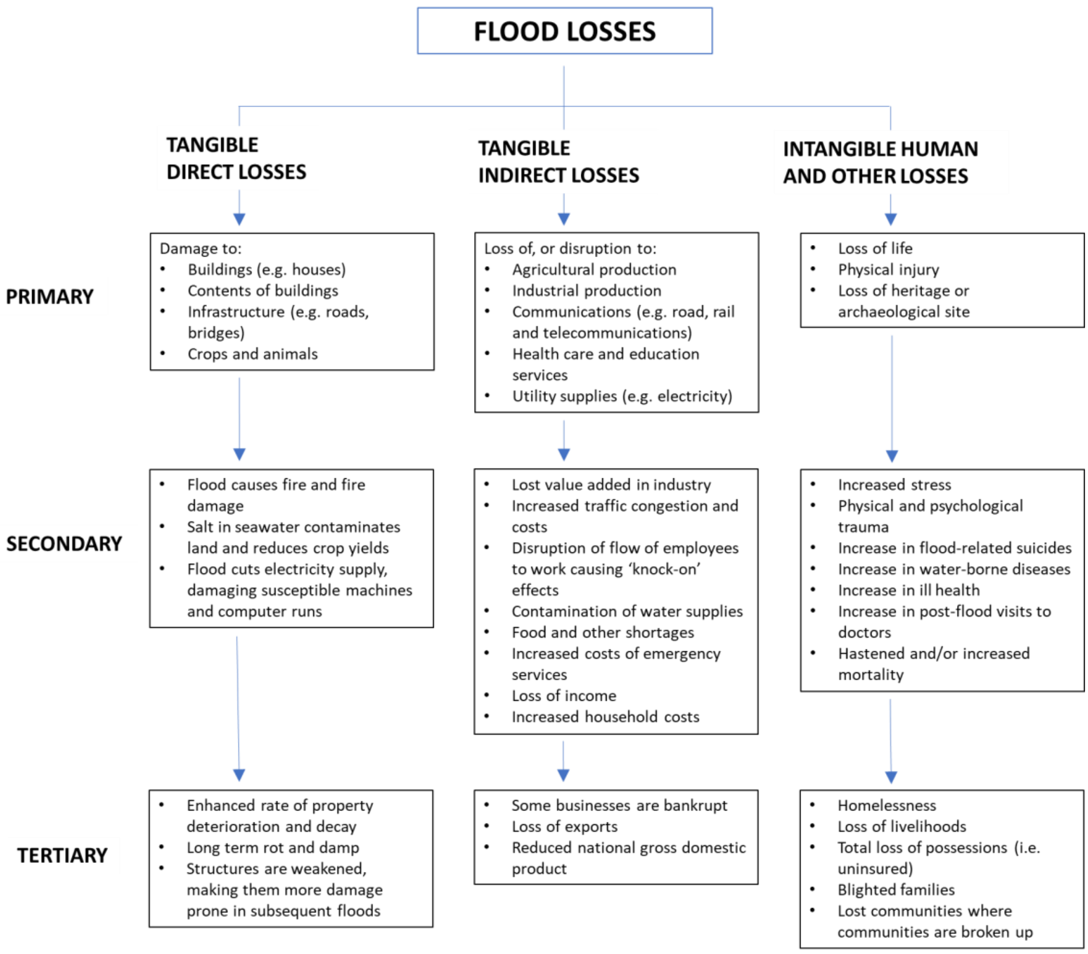

Figure 2-1 Categorization of flood losses (WMO, 2005)

European Flood Directive (EC, 2007) on the assessment and management of flood risks aims at risk reduction especially for human health and life, the environment, cultural heritage, economic activity and infrastructure associated with floods. To determine the impact of a flood event in a certain area, the Flood Directive (FD) indicates how flood exposure should be characterized in order to map potential adverse consequences associated with flood scenarios. Specifically, the following elements of exposure have to be considered (EC, 2007):

a) the indicative number of inhabitants potentially affected;
b) type of economic activity of the area potentially affected;
c) installations which might cause accidental pollution in case of flooding and potentially affected protected areas as by the Water Framework Directive (EC, 2000);
d) areas subject to floods with a high content of transported sediments, or with significant sources of pollution.

Other aspects of exposure that are mentioned by the Flood Directive are critical infrastructure (such as transport and energy networks, hospitals etc.) and cultural heritage buildings (Poljanšek et al. JRC, 2019). General approach to quantifying flood impact is a determination of vulnerability of population, economic activities and the environment (natural and cultural).

Document 'Disaster risk assessment for Republic of Croatia' was developed by the Main working group of the Croatian Platform for Disaster Risk Reduction (CPDRR, 2019). In this document different risks are identified and with each risk a preliminary scenario is associated. Consequences of events are evaluated by impacts on the following three categories: Human Life and Health, Economy and Social Stability and Politics. Some impacts are quantified while others require a qualitative approach. For the purposes of selecting priority risks for processing in the first National Assessment, the categories are developed only as having a small, moderate or large impact and a small, moderate or high probability.

The Dutch project Map of Safety in the Netherlands 2 (in Dutch: Veiligheid Nederland in Kaart 2, or VNK2) is aimed at estimating flood risks for all major levee systems, also called dike rings, by calculating both the probabilities of flooding and the associated consequences. In the VNK2 approach the economic damage resulting from a flood depends on the water depth, the total area inundated, and the use of land or the infrastructure present. The number of fatalities depends on the rise rate and flow velocity of the flood water, as well as the potential for evacuation. The damage and casualty numbers are calculated for each scenario with the aid of the HIS Damage and Fatalities Module software (Rijkswaterstaat VNK, 2012).

These two approaches have been adopted and combined in the oVERFLOw approach to make it applicable with already existing practices and strategies, with the aim to improve the quantification methodologies of each particular category.

2.2 oVERFLOw Methodology

oVERFLOw methodology for quantification of different impact categories includes **two approaches** developed for different types of users:

i) the identification of impacts that can be monetized in a way to show direct monetary value of flood damage to different assets which can then be used by **infrastructure managers, owners or local authorities**. This information can support decisions such as the identification of possible needed interventions and investments for flood protection infrastructure or transport infrastructure, through cost benefit analysis or risk assessment models.

ii) mapping of critical infrastructure gives the insight to **CPAs and first responders** about highly populated areas, areas with low rise buildings or buildings with people without self-sufficiency (preschools, schools, old-people homes etc.) where their immediate attention is needed in case of floods. It also provides them the information about safety routes so they can reach certain areas without delay or endangerment.

Impact categories are adopted from the Croatian disaster risk reduction strategy (2019), developed for the purpose of reducing vulnerability of all categories of social values which are exposed to adverse impacts of different threats. There are three main categories for which consequences are quantified:

i) **economy,**
ii) **human life and health** and
iii) **social stability and politics,**

which are in line with WMO categorization, where the first two belong to direct impacts and the third one into indirect impact category, see Figure 2-2.

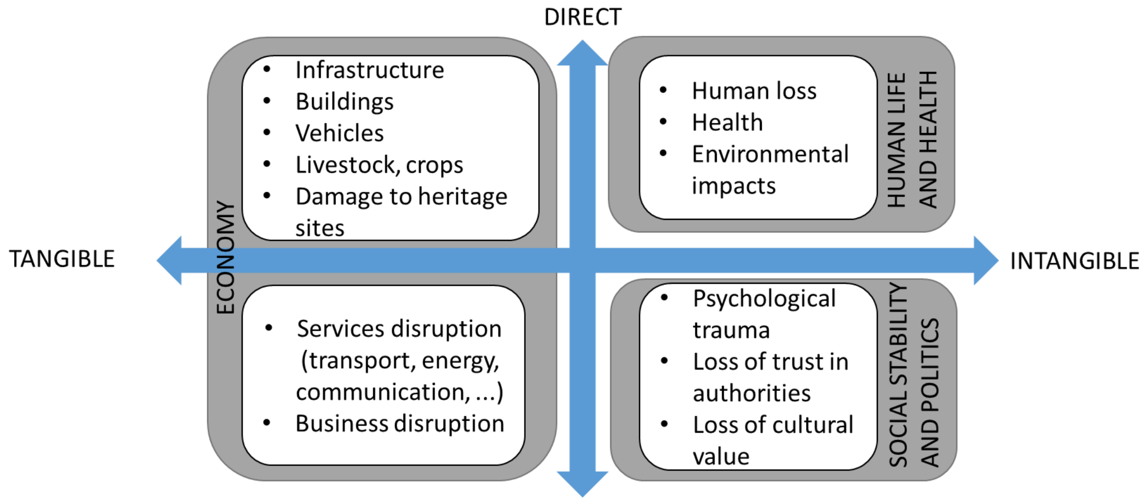

Figure 2-2 Framework to quantify direct and indirect impacts

These three categories are addressed in the oVERFLOw project with different criterions attached to each category. Criterions are defined and the methodology for quantification of each criterion is developed separately. Risk will be calculated with risk matrices with overlapping of consequences and probabilities of different criterions for three main categories.

The main input as a flood parameter for an estimation of the flood damage is the water depth (relevant for certain return period), while other parameters such as water flow or water level rise speed are added where it is relevant. Flow velocity is taken into consideration regarding critical infrastructure bridges and embankments in the vulnerability assessment in WP4. Water level rise rate is a flood parameter which can be used to asses flood fatalities and evacuation.

2.3 Economy

The main parameters for the risk evaluation and calculation of direct economic damage are the value of elements at risk and water depth-damage curves (Moel&Aerts, 2011). The results of the analysis can be presented in different ways such as highlighting of certain high risk areas regarding assets value, valuable cultural heritage or natural protected areas, presence of potential pollutants or calculation of monetary flood risk value. It can also be used to perform cost -benefit analysis for construction of flood protection systems or investments in infrastructure e.g. critical transport infrastructure which is vulnerable to floods. Flood risk managers define the parameters included in the analysis as well as the level of detail depending on the available data, the purpose of the analysis and the users of the results.

In the oVERFLOw methodology damages of industrial and residential buildings, businesses, infrastructure and land per type will be quantified in monetary terms. Special objects and areas including vulnerable objects (critical infrastructure such as transport, healthcare, electricity, water supply), cultural heritage, installations and vulnerable nature areas will be identified and mapped. The flooding of these objects may be of relevance for flood risk managers, infrastructure managers and evacuation services.

There are a lot of studies and various methods developed to assess flood damage with application of depth-damage curves for land use and buildings. In the UK the ‘multi-coloured manual’ (Penning-Rowsell et al., 2005) is used for flood damage modelling. In Germany empirical data on floods and related damages is unified into databases such as HOWAS21 (Merz et al. 2004) which can then be used for different calculations. In the Netherlands the damage per scenario is determined using the ‘HIS Damage and Victims Module’ (HIS-SSM, Huizinga 2004, Kok et al. 2005) to calculate flood damages. Mostly these methods describe the relationship between a flood characteristic (most often water depth) and the economic loss that occurs to the objects, e.g. land or building that is damaged (Wagenaar et al. 2016). In 2017, JRC (Huizinga et al., 2017) Waterbouwkunde. produced a technical report with global depth-damage functions, so called damage curves depicting fractional damage as a function of water depth as well as the relevant maximum damage values for a variety of assets and land use classes across the world, including Europe. This research revealed that for certain types of assets a global depth damage function can be applied. This first of all goes for agriculture and infrastructure-roads since the damage curves for different parts of world (Europe and Asia) were quite similar. It is stated that if the share of these individual damage categories is restricted in the total (recorded) damage, then they can be represented by one global function (Huizinga et al. 2017). Damage factors for other types of assets such as buildings, residential and industrial, and the associated land need to be assessed on a more local level. To calculate the monetary value of the damage, percentages are multiplied by the maximum damage value of properties (Mancusi et al. 2016).

2.3.1 Built environment

2.3.1.1 Land use categories

Direct flood damage for a certain type of land-use class can be calculated providing that there is available data about land value, maximum damage value and depth-damage curve. Land use classes include in general residential areas, industrial areas, agriculture (livestock farming, cultivation, gardening) or forestry,. In the risk assessment tool different types of land will be associated with different total values (€/m2) and damage flood values (€/m2) which in combination with yearly flood probability enables calculation of annual expected value of land flood damage economic loss. Maximum damage value of a certain object presents a percentage of total value of an object which is susceptible to flood.

In Figure 2-5 the depth-damage curves for the Netherlands, Later study (Klijn et al., 2007), a derivative of the HIS-SSM (Kok et al., 2005) method are presented. The method allows use of different types of land use classes in the calculation of economic flood loss and distinguishes 11 damage categories, Figure 2-3.

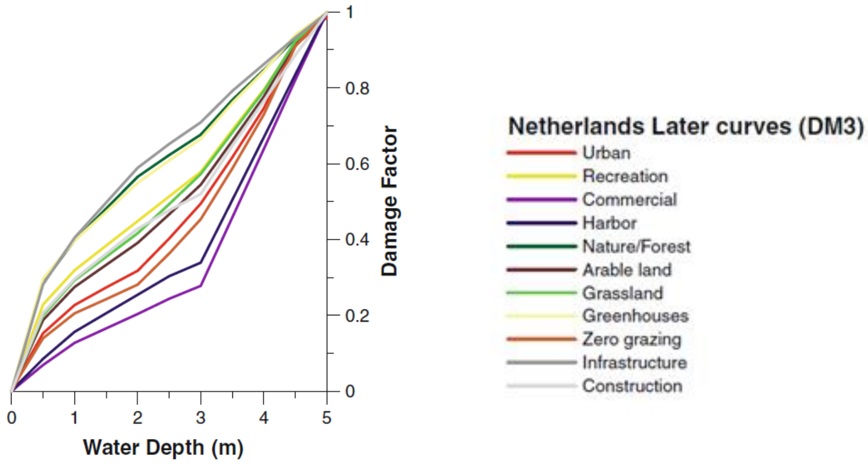

Figure 2-3 Depth-damage curves for the Netherlands Later study (Klijn et al. 2007)

In Table 1 land use classes which are used in general in urban planning in Croatia are presented. These are associated with current market land values per type for the City of Karlovac area. Certain classes, marked orange, are not associated with market value since they are used for special purposes, such as mining or hazardous waste deposition, labelled as high risk areas. Actual value of this type of land is a minor parameter in regards to potential of harmful impacts on air, water and population. It can be included as a long term impact in a more complex analysis.

Table 1 Type of land for different usage purposes for the Karlovac area with current market value of land (PPUG Karlovac-Spatial plan of the city)

Code	Land-use class - description	Market land value (€/m2)
1, 2*	Hazardous waste	
E3*	mineral exploitation areas-brick clay	
E4*	mineral exploration areas-quartz sand	
I	Industry purpose	33.5
K	Business purpose	7
N	Special Purpose	18.5
OK*	Regional center for waste management	
P1	particularly valuable arable land	0.8
P2	valuable arable land	0.8
P3	other arable land	0.8
PK*	Infrastructure for the management of special categories and types of waste	
PS	Other agricultural land, forest and forest land	0.2
R	Sports-recreational purpose	18.5
S1	Commercial forest	0.4
S2	Protective forest	0.4
S3	Special purpose forest	0.4
T1	Hotel	71.0
T3	Camp	71.0
Construction	Building areas of the settlement - Developed	71.0
Construction	Building areas of the settlement - Undeveloped	18.5
*Land value not determined – predominant significance potential source of pollution – area mapped as high risk		

Agricultural areas and forest

Damage to agricultural and forest area is not dependant with the inundation depth because it is not susceptible to flood. For agriculture associated damage is related to the loss of crops and the value that would yield. The average maximum damage value for the damage class 'Agriculture' is 0.77 €/m^2 (2007) in Europe (Huizinga et al, JRC, 2017).

Industrial, commercial and business areas

Direct damage to buildings is calculated in the chapter 2.3.1.2, while here only the damage to the land and built in infrastructure is taken into account.

Damage to land per hectare or m^2 in a context of land type is foreseen as the cost of cleaning and return of the land to its original state prior to flood and repair of damages to parts of infrastructure (communal infrastructure). Maximum damage to this type of area is 1 €/m^2 while damage factors are used based on the values from Kok et al. (2005) in Table 2.

Table 2 Damage factor for industrial areas

Inundation depth	Damage factor
0 m	0
1 m	0.4
2 m	0.8
3 m	0.9
4 m	1

Urban areas

Urban areas include developed and undeveloped construction areas, recreational areas and hotels. In urban areas monetary damage value can be calculated per individual object (house, building…) or per area (hectare, km^2, m^2..) depending on the available data and pixel values. Calculation per objects provides a more accurate analysis result but is complex and requires more data. In the following chapters calculation of different building types is analysed while transport infrastructure is calculated as damage per m' of road or rail. Damage for land per hectare or m^2 is calculated as for the industrial land with a maximum damage value to this type of area of 0.5 €/m^2.

2.3.1.2 Residential and industrial buildings

Total value of residential and industrial buildings are determined from market surveys and construction costs analysis regarding the location of the analysed study area. For a rough estimate standard construction price per m^2 can be used which for example in Croatia amounts to around 800 €/m^2. Other parameters needed for calculation of flood damage of buildings are number of floors, presence of underground floors, projected floor plan area, age, building style etc. Once established value of the built environment can then be converted into flood damage value with damage factor, as presented in Figure 2-4.

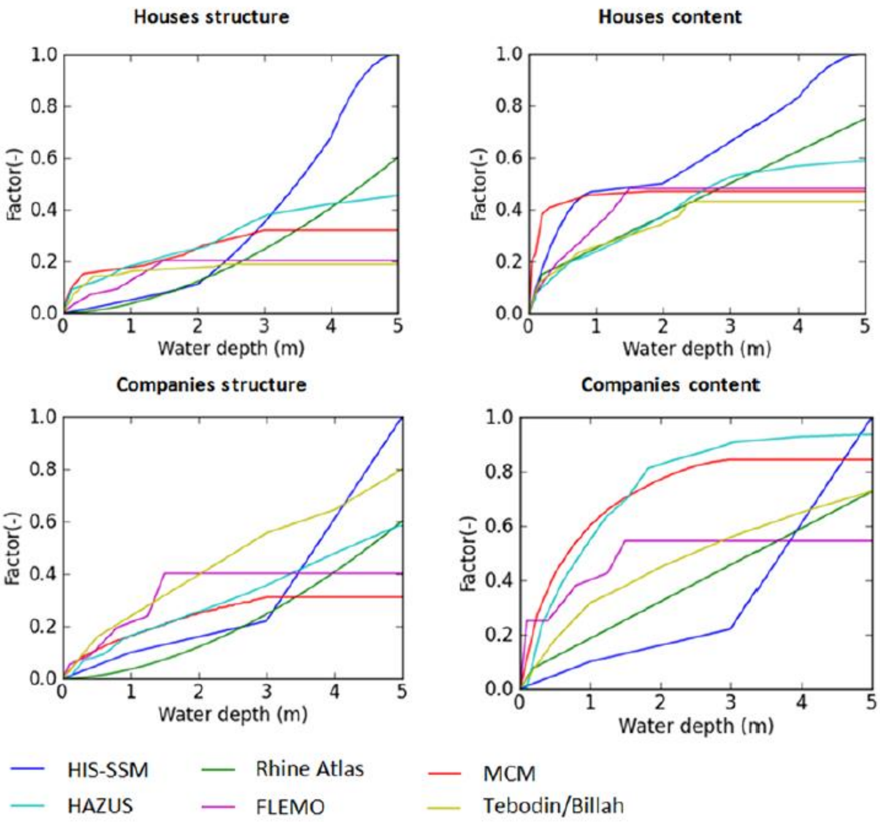

Figure 2-4 Average damage functions for the different flood damage models in the damage function library. Blue: HIS-SSM, green: Rhine Atlas, red: MCM, light blue: FLEMO, pink: HAZUS, yellow: Billah (2007) for houses and Tebodin for companies (Wagenaar et. Al, 2016)

Number of storeys of buildings is a valuable information to evacuation services. Higher buildings mean more space for people to evacuate themselves on higher floors. Mapping buildings per number of storeys provide evacuation service data needed to prioritize certain areas. For the oVERFLow project, mainly for the case study area of the city of Karlovac different categories for residence and industrial buildings are taken into account.

The following **residence buildings** categories are distinguished:

- Low rise buildings (1-2 story buildings)
- Middle rise buildings (3-4 story buildings)
- High rise buildings (>5 story buildings)
- Single family houses
- Outbuildings

The following **industrial buildings** categories are distinguished:

- Industrial halls (prefabricated structures) – shops, warehouses, retail, commerce
- Low rise buildings (1-2 story buildings)
- Middle rise buildings (3-4 story buildings)
- High rise buildings (>5 story buildings)
- Complex industrial production facilities

Each damage category is associated with a different potential maximum damage. Maximum damage combines damage to the building itself, deduction of the appurtenant land value since it is not susceptible to flood and the furnishing for residential buildings, or other type of interior which can vary depending on the usage of the building. For complex industrial production facilities, it can be difficult to generalise the maximum damage value but can be grouped per industry type for simplification of the analysis. The proposed damage values for Croatian case study are given in Table 3 and graphically represented in Figure 2-5.

Table 3 Market values and maximum damage values for typical building stock in the Karlovac area

Type of building	**Total market value/max. damage value (€/m²)**	**Inventory value (€/m²)**	**Percentage of building plain area under water for water depths**				**Damage factor for water depths House/content**			
			0.5 m	**1 m**	**2 m**	**3 m**	**0.5 m**	**1 m**	**2 m**	**3 m**
Residential										
Low rise building	1000/800	200	5	20	40	60	0.02	0.05	0.15	0.35
Middle rise building	1000/800	200	3	7	20	25	0.01	0.03	0.08	0.2
High rise building	1000/800	200	2	3	6	15	0.005	0.01	0.04	0.08
Single family house	650/500	200	10	25	50	70	0.04	0.1	0.3	0.7
Outbuildin gs	300/200	100	10	30	50	80	0.05	0.15	0.4	0.75
Industrial										
Industrial halls	600/500	100-500	4	15	30	50	0.03	0.05	0.20	0.40
Low rise building	1000/800	200	5	20	40	60	0.02	0.05	0.15	0.35
Middle rise building	1000/800	200	3	7	20	25	0.01	0.03	0.08	0.2
High rise building	1000/800	200	2	3	6	15	0.005	0.01	0.04	0.08
Complex industrial production facilities	Individual assessment	Individual assessment								

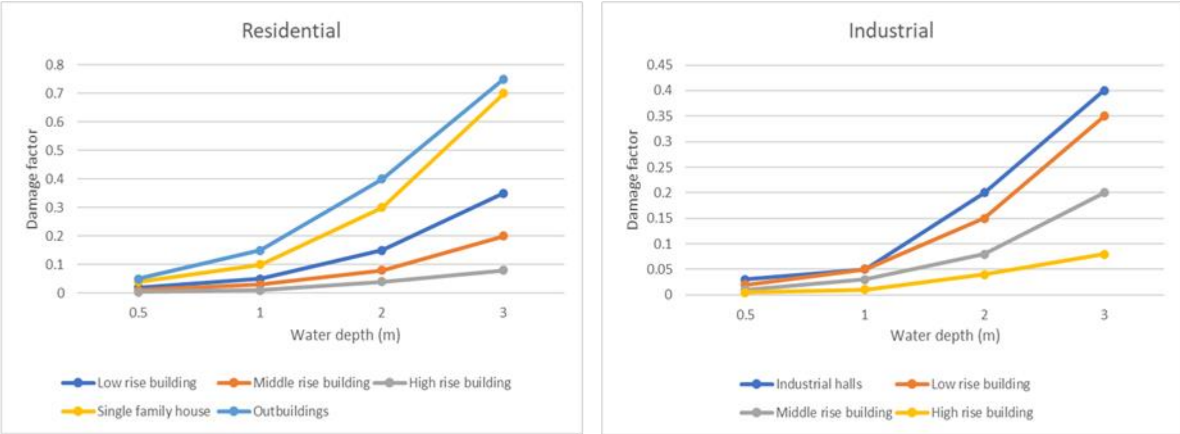

Figure 2-5 Proposed damage values for Croatian case study

2.3.1.3 Infrastructure

Critical infrastructure includes sectors listed in Table 4. Calculation of direct economic loss on structures related to these sectors is similar to any other type of building.

Table 4 List of critical infrastructure (Croatian Platform for DRR, 2019)

Sector	Constituent elements
Energy	Production, including accumulations and damns, transmission, storage, transport of energy and fuels, distribution systems
Communication and information technology	Electronic communications, data transfer, information systems, providing audio and audio visual media services
Transport	Road, rail, air, sea and inland waterway transport
Health care	Health care, production, trade and supervision of medicines
Water management	Regulatory and protective water structures and communal water structures
Food	Food production and supply and food safety system, commodity stocks
Finance	Banking, stock exchanges, investments, insurance and payment systems
Production, storage and transport of harmful substances	Chemical, biological, radiological and nuclear materials
Public services	Ensuring public order and peace, protection and rescue, emergency medical care
National monuments and values	National monuments and values

2.3.1.3.1 Transport infrastructure

The oVERFLOw project specifically addresses critical infrastructure bridges and embankments. A flooding event can cause direct damage to transport systems but can also have an economic impact on a wider area due to the disruption of communication links disabling movement of goods and people. Input from WP4 Vulnerability assessment for embankments and bridges provides the information on behaviour of these types of structures in case of a flooding event dependant on the flood hazard intensity. The data is used to establish safe evacuation routes and for investment planning regarding infrastructure maintenance and development.

a)  b) 

Figure 2-6 Examples of damages to transport infrastructure, a) Road damaged in flood in Zadar (Croatian Waters, 2018); b) flooded road in Karlovac (2019, https://kaportal.net.hr/)

The value of transport infrastructure is based upon the average cost of road or rail infrastructure. In Croatia roads are generally divided into highways, regional roads and local roads. Maximum damage values are based on the construction cost of roads and rails. Indirect damage is calculated for highways and rails due to the loss of traffic which has to be redirected. Construction costs are collected through market survey and present average values for the Republic of Croatia. Maximum direct damage cost is based on the assumption that the potential damage is 5-10% of the construction cost (Bruijn et al., 2015), and the values for Croatia are given in Table 5. Infrastructure managers can take performance indicators such as User Delay Cost (UDC) or general availability of the network to enable informed decision making regarding maintenance and upgrading investments which will increase the reliability and robustness of structures and network in case of flood. These indicators will be then integrated in the risk assessment tool which takes into account multiple attributes.

Table 5 Proposed direct damage values for Croatia for road infrastructure

Transport infrastructure category	Maximum direct damage (€/m)
Highway	1500
Regional road	1000
Local road	700
Rail	8500

2.3.1.3.2 Supply infrastructure

Water management system, energy supply system (electricity, gas, oil) and telecommunication falls into category supply infrastructure. The oVERFLOw project summarizes the damage to all communal infrastructure for urban and industrial areas by calculating damage per m^2 of the flooded area as already described in the previous chapter.

Electrical power supply – Electrical power supply system is very vulnerable to flood events and literature reveals that electricity is interrupted in 100% of the flood events. Damage to certain equipment might be permanent when being in contact with even a small amount of water or mud. Recovery period of the whole system highly depends on the duration of a flood and can take from 24h to few weeks. Shortages or blockage of the electrical power supply causes cascading effects since most systems rely on electric supply. Buried systems are more vulnerable to flood and also more expensive to repair and restore. Damage can be minimized if the power of the electric utilities is shut down when the flood occurs. Early warning system can thus make a big difference regarding prevention for electrical power supply systems (Karagianis et al., JRC, 2017).

Water supply system – system for collection, transmission, treatment, storage and distribution of water. The components include network of water pipes (mostly underground), reservoirs, water tanks, water towers, water treatment facilities etc. Fresh water supply systems are among critical infrastructure and can be severely affected by floods, similar to electrical power supply system.

Telecommunication infrastructure– communication systems are vulnerable to physical damage caused by flood water but also overload or delays when too many users use the same technology at the same time when a disaster event occurs. Mainly three primary categories of communication failures occur during hazard events:

a) Physical destruction of network components,
b) Disruption in supporting network infrastructure,
c) Network congestion (Townsend & Moss, 2005).

All damages to supply infrastructure are taken into account in a damage value of the urban area type of land.

2.3.1.4 Other categories

2.3.1.4.1 Cultural heritage

Cultural heritage may include diverse assets such as archaeological sites, monuments, architectural heritage, museums, spiritual sites and buildings or a landscape significant from the point of view of culture and tradition. Direct monetary value of this type of assets can be evaluated through repair cost of returning the site in its condition prior to the flood. Nevertheless, harmful effects or permanent consequences in case of a flood on these types of assets go far beyond the direct monetary value since they are often considered as priceless. Part of this value should be also assessed through indirect monetary value which can be established in a form of exploitation for tourism, recreation and religion for calculation of long term flood impact.

2.3.1.4.2 Natural environment

Disruption or damage to industrial installations or processes in case of a flood can lead to release of harmful substances into air and water. Quantification of consequences of these effects is often not simple but qualitative approach can be adopted in these cases. Flood event can cause pollution and long term impact on the environment. Mapping of potential sources of hazardous substances such as chemical plants or waste landfills provides valuable information.

The water body status, protected areas, pollution sources and other potential adverse impacts can be assessed taking into account WFD Water Framework Directive, Birds Directive or Habitats Directive. Consequences can occur due to the pollution from different sources (point and diffuse) or due to hydro-morphological effects of floods. The following flood adverse effects can be accounted for and mapped:

- potential groundwater bodies of interest,
- protected areas or water bodies, bathing water or drinking water intake sites,
- sources of potential pollution in the event of a flood, such as IPPC and Seveso plants, or point or scattered sources,
- effects on soil, biodiversity, flora and fauna and similar (protected nature areas).

2.3.2 Business

Losses to any business include loss of value that would have been produced if a flood event did not occur. Production is stopped due to Material Damage (MD) of installations or disrupted supply chains. It could be that other businesses or productions, processes before or after, have also been stopped or delayed due to a hazardous flood event. These are indirect losses, defined as **Loss of Business Interruption (LBI)**, which do not include direct economic losses to a company caused directly by contact with water, described in previous chapters. Direct damage to industrial plants and other buildings and infrastructure is taken into account in the economy category. Loss of business category implies long term monetary effect of a flood due to business interruption. Indirect losses to business are often expressed as a share of the material damage in a flood (Vilier et.al, 2014). In the flood of 1993 in the Netherlands, it was calculated that 75% of the damage to industry was related to the property and 25% was related to the productivity loss (Kok, 2001, Genovese, 2006). Certain historic data reveal different ratios of material damage and LBI, which are dependent on flood parameters and the specifics of the area affected by flood. Flood in Thailand in 2011, the World Bank estimated losses due to business interruption which concluded that these losses were 1.3 of the value of material damage value. This was probably due to long duration of the flood. While the flood in Japan in 2011, caused the losses due to business interruption equal to nearly half the material damage, Table 6 (Vilier et al., 2014).

Table 6 Losses due to business interruption of recent large-scale floods (Vilier et al., 2014)

Event	MD (b$)*	MD (%)	LBI (%)
Flood Japan 2011	205	3.6	47.3
Flood Thailand 2011	21	6.0	125.0
Hurricane Sandy 2012	70	3.7	37.5
Hurricane Katrina 2005	30	15.4	30.0
*The Material Damage (MD) is expressed in billion USD and as a share of the GDP in the year of the flood.			

Two flood parameters, flood depth and flood duration are most influencing factors for calculation of loss of business interruption. The two flood parameters are combined into time (days) needed for return of business to pre-flood conditions. There are different economic parameters describing certain business that can be used for calculation of flood impact. Depending on the available data, descriptive financial performance indicators per employee, per business or per business type that can be used are: **total income, total expenditure, consolidated results**. The analysis includes determination of businesses in the area affected by flood and the appurtenant daily monetary value that is lost due to flood business disruption and loss of income. For a more precise analysis types of businesses can be recognized and the associated financial parameters per business type established. The financial performance indicators for Karlovac area for year 2019 are listed in

Table 7.

Table 7 Financial business results of entrepreneurs in City of Karlovac in 2019 (HGK, 2019)

Financial indicator	**Whole county (mil €)**	**Per employee/day (€/day)**
Total income (I_{tot})	908	237
Total expenditure (E_{tot})	856	224
Number of entrepreneurs	1227	
Number of employees	10.499	

Following the economic scenario that there is no income while the business is interrupted but the expenditures remain, if the business is to be restored after the flood event, the economic loss due to business interruption (LBI) is calculated based on the following:

$$LBI = (I_{tot} + E_{tot}) \times Nr_{emp} \times T$$

Where:

- LBI – loss due to business interruption (€)
- I_{tot} – Total income per employee per day
- E_{tot} – Total expenditure per employee per day
- Nr_{emp} – number of employees in the flood affected area
- T – time for return of business to pre-flood conditions

Based on the analysis of historic events and climate change scenarios development for the Karlovac area matrix was derived for determination of parameter - time needed for return of business to pre-flood conditions, dependant on two flood characteristics water height and flood duration, Table 8 (oVERFLOw, Del 2.1, Del 2.2, 2019).

Table 8 Time which is needed to return business to pre-flood condition in days

Water height	Return of business to pre-flood conditions (days)				
<0.3	2	4	6	8	11
0.3-0.5	3	6	8	10	15
0.5-1.0	5	7	14	17	21
1.0-1.5	10	10	16	21	40
>1.5	15	25	45	60	90
Duration of flood	1	3	5	7	10

2.4 Human life and health

In a case of flood event, people affected by flood may be injured or even have fatal consequences. According to Jonkman (2007) all the individuals that are present in the exposed area before any signs or warnings can be perceived and are referred to as the population affected, or population at risk. Adverse effects on human health, whether as a direct or consequential impact, which may result, for example, from pollution or disruption of water and sanitation services, and would involve human casualties are taken into consideration but in different forms and phases of the analysis. In this chapter direct threat to human life and health due to incoming water is calculated while the influencing factors or criterion such as population density, water height and waterflow are analysed. Other indirect impacts such as pollution and disrupted services, as well as effectiveness and preparedness for evacuation are analysed in the following chapters.

2.4.1 Loss of life or injury

There are different methods for loss of life estimation regarding flood hazard. Flood characteristic such as water depth is an important parameter, while low-lying and densely populated areas are most vulnerable. Different methods take into consideration different parameters, but following are most commonly used parameters:

- Flood related: water depth, water velocity, water level rise speed,
- Population related: preparedness of the population, population density.

These parameters are then combined with flooding area, duration, source of flooding to establish potential significant flood risk. Some methods take into consideration more in-depth analysis and data such as population structure regarding age or gender, water quality and temperature. Nevertheless this data is less frequently available and needs to be collected in a targeted manner.

In the VNK2 approach possible number of fatalities is calculated based on the number of people living in the affected area in combination with flood characteristics, while the effectiveness of evacuation highly influences the overall number of fatalities. oVERFLOw approach is developed as a generic but highly influenced by the case study area in the City of Karlovac and the available data. Criterions chosen to quantify consequences of a flood on human life and health are population density as a parameter describing vulnerability of the area, while water height and water rise speed depict the hazardous event. Water height and water flow are the parameters that are measured in the vicinity of the case study infrastructure and can be linked to the analysed area. Water flow can be linked to water rise speed which is a more suitable parameter to evaluate influence on population in the area regarding the river flood classification. The water rise rate can be derived from the development of water depth over time and is estimated as the average rise rate at a location from initiation of flooding up to a depth of 1,5 metres (Jonkman, 2007).

In Table 9 consequences from negligible to catastrophic level are derived from the interdependence of vulnerability, determined by population density, and flood exposure, determined by two different flood parameters, water height and water rise speed. Consequence matrix is developed, Figure 2-7, with different colouring for consequences category which will be used for GIS mapping.

Table 9 Flood consequences to human life and health for different criterions and their appurtenant values for each category

Human life and health				
Category	Consequence	Vulnerability	Flood exposure	
		Population density (inhabitants/km^2)	Water height (m)	Water rise speed (m/h)
1	Negligible	0	<0.3	0
2	Small	<20	0.3-0.5	<0.1
3	Moderate	20-100	0.5-1.0	0.1-0.2
4	Large	100-500	1.0-1.5	0.2-0.5
5	Catastrophic	>500	>1.5	>0.5

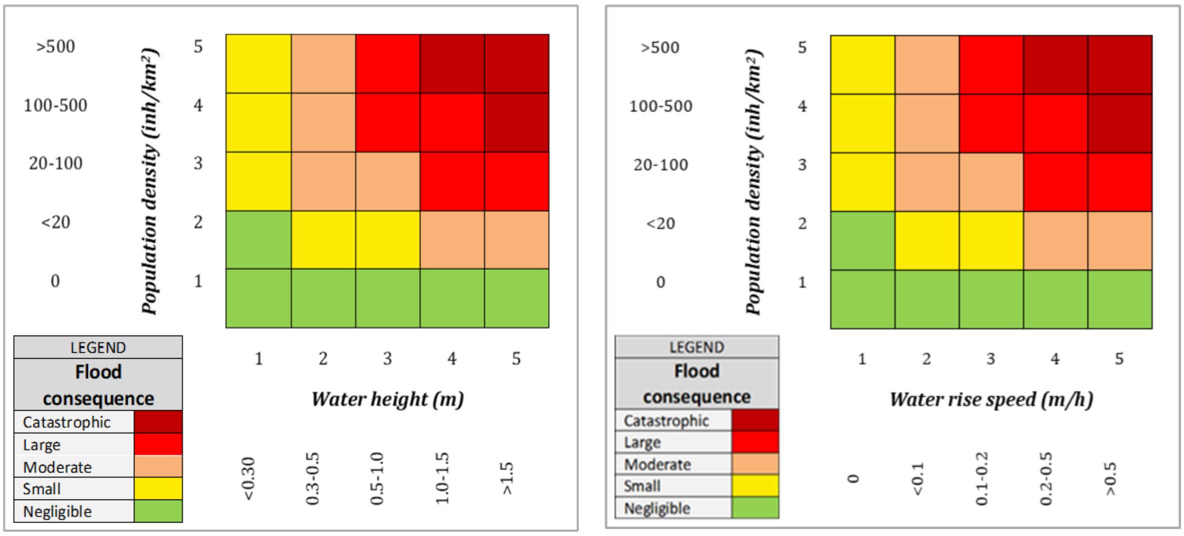

Figure 2-7 Flood consequences matrix from negligible to catastrophic for flood parameters water height and water rise speed

2.4.2 Evacuation routes

Preventive evacuation makes a significant difference regarding individual risk and decreases potential number of fatalities or injuries. On the other hand literature reveals that individual risk in case of a flood event is not very much dependant on the evacuation services and that there is no substantial reduction of the loss of life due to organised rescue actions in the first hours of the flood. The evacuation service and rescuers become much more important evacuating people from the flooded areas hours and days after the event.

The effectiveness of preventive evacuation depends on the predictability of flooding, the capacity of the infrastructure and the circumstances in which the evacuation has to take place, such as weather conditions and general panic. Various scenarios have therefore been developed for the effectiveness of an evacuation. Number of fatalities is highly affected on the evacuation possibilities. Prior evacuation is an effect that is used in the VNK2 approach in a way that each flood scenario is divided into four partial scenarios, depending on if the flood was predicted well in advance or shortly before, and the opportunity from no evacuation to organised evacuation, (Rijkswaterstaat VNK Project Office, 2014). The VNK2 four evacuation scenarios approach is further elaborated to take into account the availability and accessibility of evacuation transport routes combining it with different maintenance strategies, see Figure 2-8. The event tree is developed and applied independently for each analysed safe route on case study area for different scenarios.

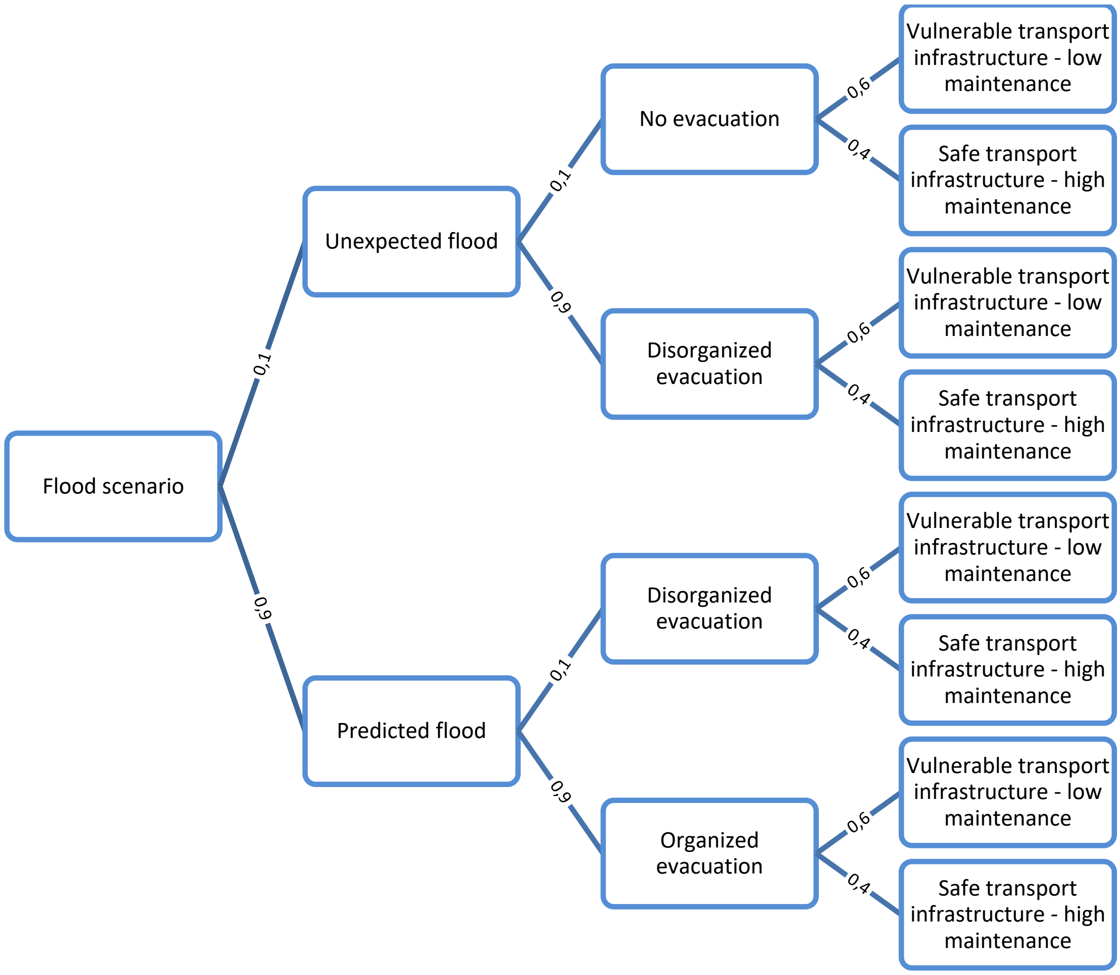

Figure 2-8 Event tree - Four different partial evacuation scenarios and the link to transport infrastructure condition (adjusted from Rijkswaterstaat VNK Project Office, 2014)

Safe evacuation routes and accessibility for first responders are determined by highlighting critical transport infrastructure. The safe evacuation routes are established based on reaching the nearest safe place within buildings, building blocks and city district with areas with higher buildings safer in case of a flood hazard. The main constraints associated with the emergency structural vulnerabilities along escape routes (collapse of bridges or flood protection structures), uncertain road conditions with roads or parts of roads under water, including traffic congestion, road blockage, and other constraints associated with the emergency. Optimal evacuation alternatives in the form of safest and most efficient routes for evacuation of the population from the affected region are determined based on the results of vulnerability assessment of bridges and embankments.

The results of study conducted by Jonkman (2007) to derive representative values for modelling of the first three phases of evacuation (namely prediction & decision making, warning, response) for the situation in the Netherlands and the results are summarized in Table 10.

Table 10 Overview of phases that determine time required for evacuation (Jonkman, 2007)

	Foreseen flood – preventive evacuation	**Unexpected flood – forced evacuation**
Decision time	4 hours	2 hours
Warning time	2 to 3 hours	2 to 3 hours
Fraction of population warned	0.95 to 1	Depends on situational factors (first suggestions: Official warning: 0.8 to 1 No official warning: 0.3 to 0.5
Response time	Mean: 2.5 hours Whole population after 6 hours	Mean: 1 hour Whole population after 2 hours
Fraction of population that complies to warning	0.95	No indicators from literature

There are numerous other criterions that can also be taken into consideration such as average age of population. Large number of old or very young people in a certain area reveal the fact that people cannot evacuate themselves without help making the area a priority for evacuation. Mainly agricultural households in a certain area can indicate that people could be reluctant to evacuate or in danger while trying to secure their farms and livestock. Depending on the availability of data, other parameters and criterions can be added into the analysis.

2.5 Social stability and politics

Finally, the category of social stability and politics focuses on the scope of action of the governing bodies such as county, municipality or state, depending on the analysed area. Governing bodies perform tasks of regional significance, and especially tasks related to education, healthcare, social and cultural institutions and economic development. Consequences for the community include adverse effects on local authorities and public administration, emergency services, education, health and social institutions (such as hospitals). Certain critical infrastructure presents high-risk points, lines or areas for society as a whole, namely social stability and politics. In Table 11 objects of interest with corresponding data that provide information about their significance for the community are listed. These objects and areas will be mapped and highlighted in the oVERFLOw case study analysis.

Table 11 Objects and areas which are mapped and highlighted in case of flood

Critical objects, infrastructure and areas mapped and highlighted in the oVERFLOw project		Data
1	Hospitals, health care institutions, pharmacies	Location, number of employees, accommodation capacity
2	Education institutions (university, school, preschool)	Location, number of children/students, number of employees
3	Family homes for elderly and infirm	Location, number of users, number of employees
4	Social welfare institutions	Location, number of users, number of employees
5	Civil protection agency	Location, number of employees
6	Fire station	Location, number of firefighters
7	Cultural/natural heritage	Location, type
8	Waste management	Location
9	Installations or industry which might cause accidental pollution in case of flooding	Location,

Indirect losses can be following: stress and anxiety (PTSD), disruption of living, loss of community, reduced land values and undermined trust in public authorities.

The indicator *social stability and politics* can be assessed through the share of total material damage of a flood event in the budget of municipality of the area affected. Threshold values are set as a percentage of the budget with criterion from negligible to catastrophic, as presented in Table 12.

Table 12 Flood consequences to social stability and politics and the example of appurtenant values for each category

Social stability and politics		
Category	Consequence	Criterion (% of municipalities budget)
1	Negligible	1-2
2	Small	2 – 9
3	Moderate	9-27
4	Large	27-45
5	Catastrophic	>45

3 Conclusion

A flood is a natural hazard that, due to the intensity and unexpectedness can endanger the health and lives of large population, infrastructure, material goods and the environment. Floods can cause more damage than any other natural hazard, inflicting damage and losses that can last for a very long time period.

Flood management and control play a key role in protecting people, their property, industry and society as a whole. Practice has shown that in most cases it is impossible to completely eliminate the risk of floods, i.e. to avoid the damage they cause. Therefore, efforts should be focused on reduction or mitigation of adverse consequences for people, the environment and property, including natural and cultural heritage, through flood defence measures, evacuation, rescue and disaster relief based on risk quantification methodologies. Targeted data, often already available, can be used to extract valuable information for different users such as CPAs and infrastructure managers. Quantification of consequences of flood impacts leads to vastly improved risk assessments providing decision makers such as CPAs and infrastructure owners the valuable information for decision making process during the prevention and response stages.

The methodology presented in this report is implemented in the risk forecasting tool and applied on the case study areas in oVERFLOw project.

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