

# RAINMAN D.T3.5.3 - RISK MAPS FOR THE CITY OF ZAGREB AND FOR A COASTAL LOCATION IN ISTRIA

Alan Cibilić<sup>1</sup>, Ana Jelka Graf<sup>2</sup>

<sup>1</sup>) Hrvatske vode, Zagreb, <sup>2</sup>) VPB d.d., Zagreb



---

## Risk maps for the city of Zagreb and for a coastal location in Istria

Version 1            15.6.2020.

Authors            Alan Cibilić<sup>1</sup>, Ana Jelka Graf<sup>2</sup>

<sup>1)</sup> Hrvatske vode, Zagreb, <sup>2)</sup> VPB d.d., Zagreb

---

## Contents

<b>1. CONTEXT AND GOALS OF THIS STUDY</b>	<b>4</b>
1.1. Project context	4
1.2. Goals	4
1.3. Approach and structure	4
<b>2. CHARACTERISTICS AND REPRESENTATIVENESS OF SELECTED AREAS</b>	<b>5</b>
2.1. Zagreb pilot area	5
2.2. Umag pilot area	6
<b>3. APPROACH APPLIED</b>	<b>7</b>
<b>4. RESULTS OF ANALYSIS</b>	<b>9</b>

# 1. Context and goals of this study

## 1.1. Project context

Over the last decades, accelerated construction as well as additional value of urban facilities and growing population have significantly increased the socio-economic value of space, including its exposure to individual forms of risk. In the context of climate change these problems are becoming even more pronounced, since heavy rain events cause floods that occur very quickly and their forecasts face high uncertainties.

Unlike river (fluvial) floods, no risk calculation and mapping methods have been developed for pluvial floods. Therefore, as part of the main objective of the RAINMAN Project, the implementation of activities was planned in the pilot areas of Croatia, with Hrvatske vode (Croatian Waters) as a Project Partner giving its contribution to the joint results and objectives of the Project. In the context of the activities planned in Croatia, that implies the mapping of short-lasting heavy rain risks in the pilot areas of Zagreb and the wider Umag area in Istria, with the implementation of hydrological and hydraulic modelling.

## 1.2. Goals

This activity included the assessment of the representativeness of the selected areas, the assessment of the availability of data relevant for the Project, and in line with that analysis of the existing methods and approaches to the development of heavy rain flood hazard and risk maps. In that process, the areas of the City of Zagreb and the Umaški potok basin were selected as representatives of urban and rural areas, respectively. The purpose of the analysis is to provide insight into the issue of the mapping of pluvial floods in different areas, which is the consequence not only of different topographic conditions, but also of the different level of quality of data available in the selected areas.

## 1.3. Approach and structure

Under the RAINMAN Project, different approaches to the identification and mapping of areas at potential pluvial flood risk were proposed, depending on the available data and purpose of the maps. That said, it has to be stressed that even the most sophisticated models have certain errors, related primarily to the imprecision of certain input parameters such as the spatial and/or temporal distribution of rainfall, climate change, soil moisture, dynamics of spatial development, changes to runoff coefficients and a number of other factors affecting runoff. Consequently, not a single map can be fully reliable. That is why one of the objectives of the Project's working group was to identify which level of detail is acceptable for which purpose. The sections that follow present an outline of the selected pilot areas, the main challenges during analyses, and finally the proposed approach to the mapping of risks in the selected areas.

## 2. Characteristics and representativeness of selected areas

### 2.1. Zagreb pilot area

The Zagreb pilot area covers app. 132 km<sup>2</sup> on the territory of the City of Zagreb, bordered by the watershed running along the highest ridges of Mt Medvednica on the north, the Krapina river basin on the west, the Sava River on the south, and the Bukovački potok basin and Radnička St. on the east. The area has the characteristics of the moderate continental climate. The mean annual temperature ranges between 9 and 11°C, with the minimum in January (-2-0°C) and the maximum in July (18-20°C). The mean annual rainfall ranges between 900 and 1100 mm; in the summer months it amounts to 200-300 mm, and in the winter months 100-300 mm. The largest quantities of 1- to 5-day rainfall were measured in the autumn months (on average 59-104 mm). This is a highly urbanized area, with a high share of impermeable surfaces, man-made flow paths and depressions (e.g. underpasses, underground garages, basements, etc.), a reduced number of natural retention areas, and a number of structures that have significantly altered the natural flow of water.

Pluvial flood risks are as a rule very pronounced for two main reasons. The first reason is a high share of water impermeable or poorly permeable surfaces, resulting in reduced infiltration and evapotranspiration and increased runoff volume and velocity. The second reason is a usually huge gap between intensive construction and development or implementation of appropriate sewer systems. Sewer systems are dimensioned mostly for rainfall with a return period of 2-5 years, whereas the possibilities of heavy rainfall occurrence and management are most often not considered.

The specific feature of the selected pilot area is its terrain configuration in terms of a sudden shift from the hilly terrain to the lowland terrain, exactly in the highly urbanized zone. It thus follows that the biggest problems can be expected precisely in the zones where the torrential streams from Mt Medvednica enter the city's sewerage. Since the sewer system is of a limited capacity, and the inlet facilities are subject to occasional clogging, it is to be expected (as confirmed by the collected flood reports) that only a certain volume of water from the Medvednica slopes is discharged into the sewerage, with the remaining volume flowing towards the lower-lying parts of the city.

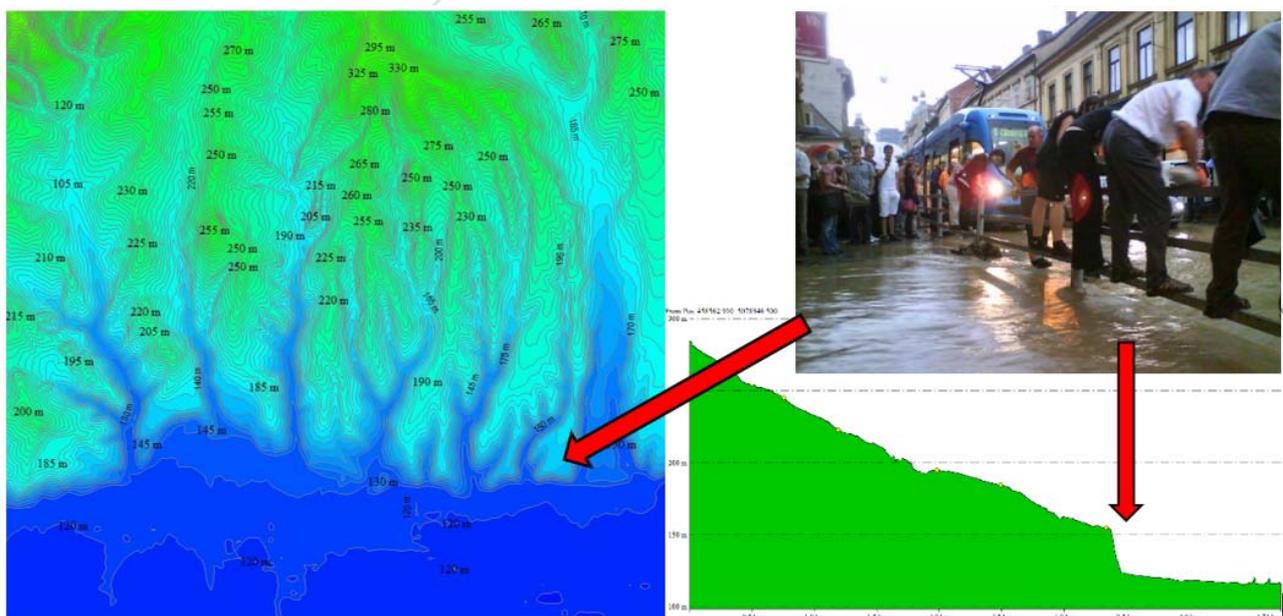


Figure 2.1: Zagreb pilot area

## 2.2. Umag pilot area

The pilot area of the Umaški potok basin was selected as a representative of a rural area. In such areas, heavy rain events most frequently do not represent a major problem since the main functions of the ecosystem are retained. However, in case of a rural area with developed agriculture and the associated soil amelioration systems, then adverse consequences can be even bigger since the majority of the current soil amelioration systems has been designed and built with a dominant role of linear drainage facilities (canals, dikes, etc.), with a very small number and a low retention capacity of the drainage systems themselves. The whole area has a large number of natural depressions with no possibility for gravity surface drainage, which is why lakes form naturally there during heavier rain events. It is also assumed that high groundwater levels in certain depressions could have had certain indirect contribution to the flooding events, since they reduce the possibility of infiltration and accumulation of a certain rainfall volume in the underground.

The two key characteristics of this pilot area are the karst phenomena, which cause a significantly more complex runoff system, and the presence of a complex impact of seawater level fluctuations on the runoff, both on a daily scale and on a scale of several years. Extremely high water events in urban areas as the result of intensive rainfall are not specific only for Umag; it is a problem that has recently been observed more and more frequently in other urban coastal areas as well. Even though in terms of heavy rainfall they don't differ significantly from other areas, the adverse consequences are becoming more and more marked since the capacities of sewer systems also depend on the boundary conditions which are defined by the sea level position. In the context of climate change and a trend of rising seawater level, the problem of pluvial floods in areas like this carries additional weight.

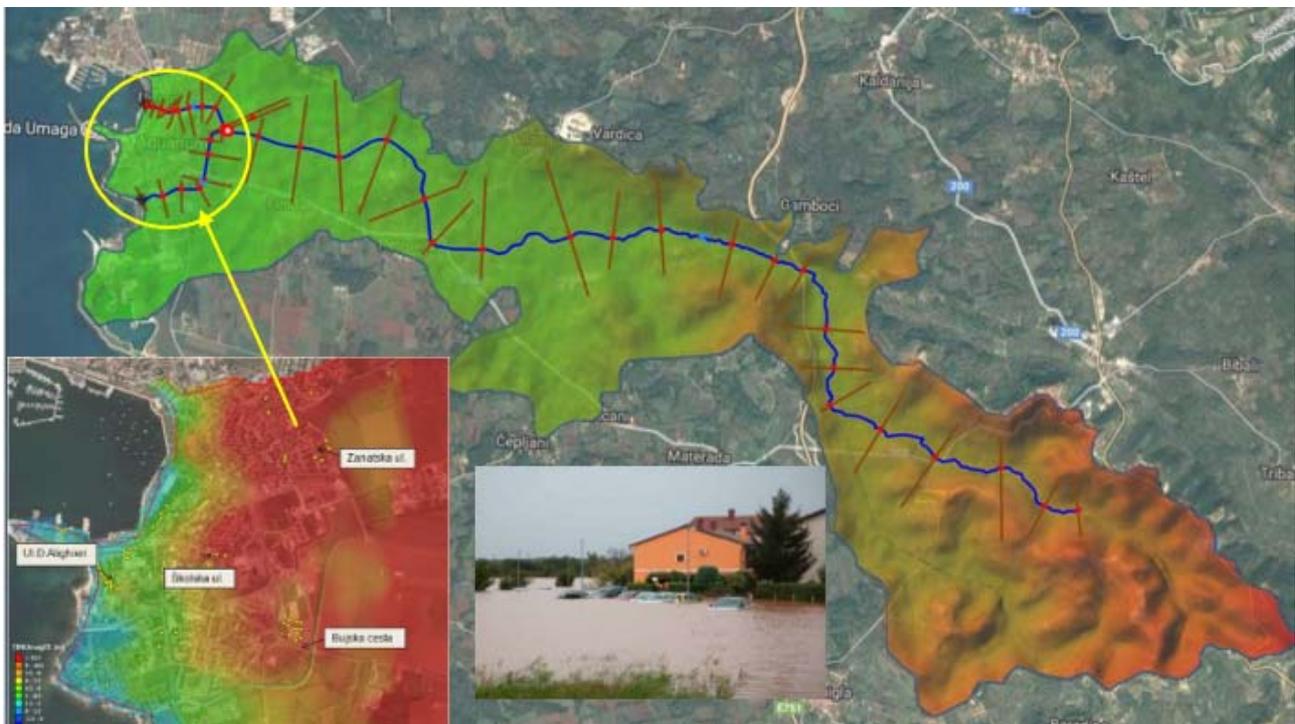


Figure 2.2: Umag pilot area

### 3. Approach applied

The risks in the selected pilot areas were analysed in two phases. In Phase I, using GIS tools based on the recorded firefighting interventions associated with technical interventions due to heavy rain events, the hot spots were defined for which in Phase II a detailed analysis was made using hydrological-hydraulic models.

Data available for the implementation of Phase I was data about the extent and firefighting interventions. In that process, a big difference was observed in the scope and quality of data for the two areas: whereas data for the 2012-2019 period is available for the Zagreb pilot area, data for Umag is available for the 2014-2018 period, with no data about the flood cause (technical failure, pipeline burst, heavy rain, fluvial flood, sea flood or the like). Therefore, the most important step in such an analysis is the selection of a representative set of data, since data can come from different sources (public firefighting departments, voluntary firefighting departments, utility services, etc.), it can be developed at different platforms (a series of different types of records: .txt, .shp, .xls, etc.), it can contain contradictory or insufficiently precise data. Errors can also be generated during data aggregation if its spatial coordinates are not comparable, with the situation additionally aggravated if spatial coordinate systems have experienced independent change over time (updates and redefinitions). Having in mind that there is no procedure for systematic and efficient correction of potential spatial errors in the data, this part of the assignment is generally painstaking, long-lasting and costly. Following the systematization of collected reports using the GIS tool, an intervention density map indicating the hot spots was obtained.

However, the analysis made doesn't provide information about the resulting water depth and velocity or a forecast of the future state, which is a major weakness if the maps are intended for example for the spatial planning authorities, town planners, investors, etc. The preliminary assessment was therefore supplemented with a hydrological-hydraulic model of a broader level, trying to achieve a match between the flooded areas and the locations of interventions.

Open source software HEC-RAS was selected which provides customer support, has a wide user base and is constantly upgraded. Its major weaknesses are the inability to simulate spatially variable rainfall and the inability to integrate the sewer systems. As for supporting data, the software requires a digital elevation model, land cover and use maps, and rainfall data in the form of a hyetograph. The area was discretised to a 25x25 m grid, with defined rainfall of constant intensity, evenly distributed throughout the basin. The results show a relatively good match between the areas with higher depths and the intervention locations.

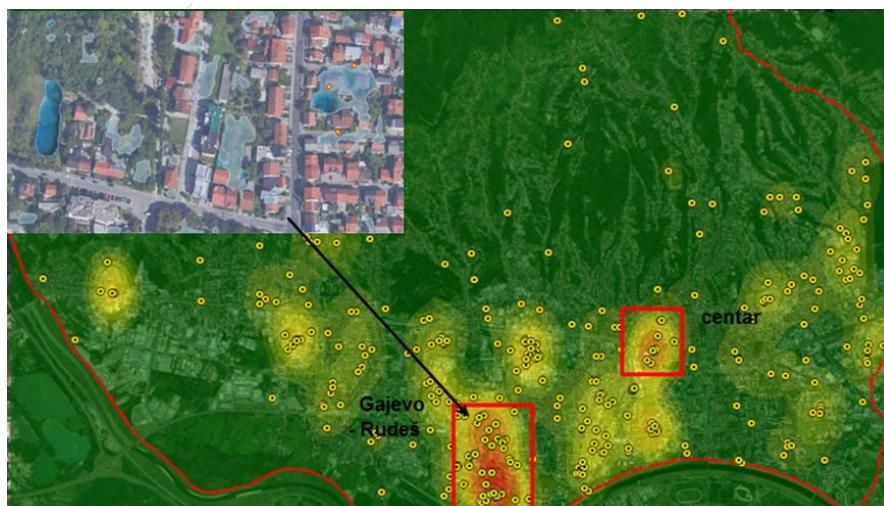


Figure 3.1: The density of interventions can indicate the hot spots

Overlapping of the results of the preliminary analysis with infrastructure, primarily community facilities with a large number of users potentially at risk (nursing homes, facilities for handicapped people, kindergartens, etc.), emergency service facilities (hospitals, firefighting and police stations, etc.), and facilities with cultural and historical value (museums, churches, archives, etc.), has given guidelines for the selection of the hot spots. For the Zagreb pilot area part of the old town centre was selected, and for the Umag pilot area part of the town bordered by the Umaški potok watercourse, its southern branch and the sea.

A more detailed hydrological-hydraulic model was developed for the selected hot spots. Even though there are several software packages enabling the simulation of an interaction between surface flow and pipe flow, which would give the most realistic results, due to the lack of data about the operation of the sewer system the pre-defined HEC-RAS 2D unsteady flow model was retained, with the simulation of the surface flow done by reducing the rainfall hyetograph based on the data about the sewer system capacity, reduced to the duration of the simulated rain event. The elevation model was improved with the knowledge obtained from field insights and from inspection of available studies and spatial planning documents. The size of the calculation cell was selected so as to faithfully present the flow dynamics (5-10 m), and calculations were done for return periods of 5, 20 and 100 years. An extreme scenario was defined as a low probability scenario with a simultaneous failure in the functioning of the sewer system or an event with extremely high seawater levels.

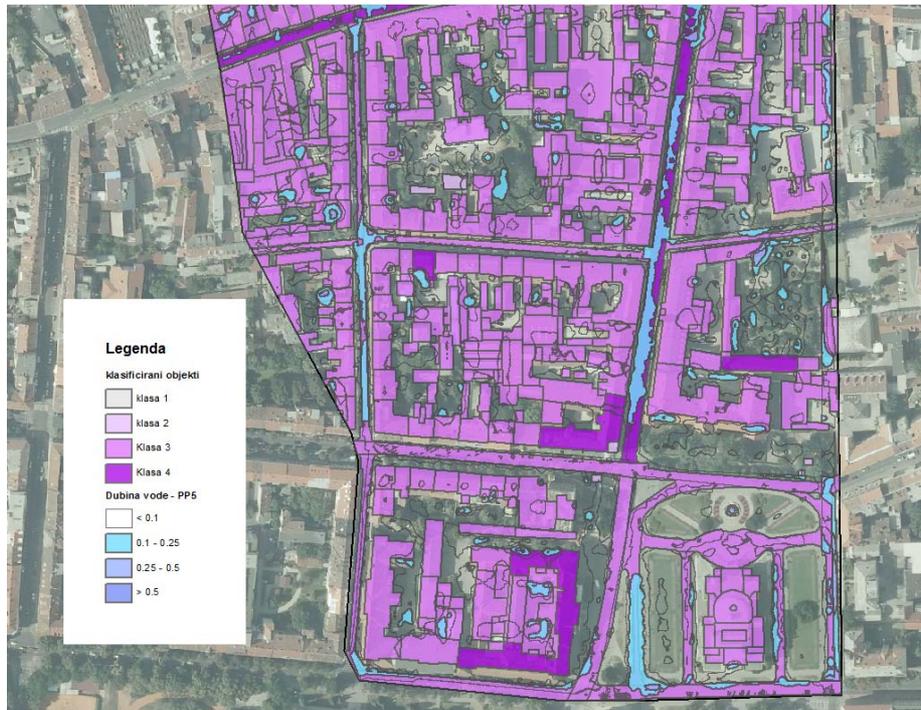


Figure 3.2: Calculation grid in the Umag pilot area

As part of the preliminary RAINMAN activities, “Analysis of Rainfall in the Istria and Zagreb Pilot Areas” was made, including a recommendation to use rainfall defined in the form of a design storm. For the selected locations in the pilot areas, non-dimensional forms of design storms were adopted for the Pula station (representative of the Istrian coastal region) and the Zagreb-Grič station (representative of the western and central parts of Zagreb). In order to be able to use these hyetographs to calculate runoff, they have to be assigned with corresponding duration and average rainfall intensity. For specific rainfall duration and return period, the corresponding intensity is defined from HTP/ITP curves. It is important to note that rainfall duration doesn’t have to be predefined; instead, it is necessary to simulate a series of rainfall events of different duration, and to select as relevant the duration that gives the least favourable case based on which the alarm thresholds are then defined. For the needs of this study, in order to define the guidelines for the development of flood hazard and risk maps, simplifications were adopted, with rainfall duration fixed at 120 minutes. The procedure (model) results in flood hazard maps, with the water depth shown as an envelope of maximum depths achieved.

## 4. Results of analysis

The results of the hydrological-hydraulic model are usually presented on the depth and velocity maps, which can using additional GIS tools be processed so as to obtain other interesting parameters (e.g. a map of their multiplication expressed in  $m^2/s$ ).



Legenda = Legend, Klasificirani objekti = Classified facilities, Klasa = Class, Dubina vode - PP5 - Water depth - RP5

Figure 4.1: Depth map for a 5-year return period

In order to develop flood risk maps, the facilities were classified in terms of their sensitivity to floods. The assessment of sensitivity (S) is usually done with regard to a number of variables (e.g. heavy rain, soil erosion, landslides, traffic interruptions, etc.). However, in accordance with the Terms of Reference, the assessment was made exclusively for heavy rain events and harmful consequences for human health, economic activities, cultural heritage and the environment.

Under this analysis, the facilities were classified in such a way that Class 1 represents negligible, Class 2 low, Class 3 medium, and Class 4 high sensitivity of a facility to a heavy rain event.

Table 4.1: Classification of facilities with regard to their sensitivity to floods

Klasa objekta	element	osjetljivost	ocjena
1	parkovi, šume, livade i slično	zanemariva	1
2	pomoćni objekti (kiosci, terase, vrtne sjenice, nadstrešnice, sportski tereni i sl.)	mala	2
3	stambeni objekti, javne ustanove, gospodarski objekti, škole i fakulteti, lokalne i županijske prometnice	srednja	3
4	vrtići, domovi za starije i nemoćne, objekti hitnih službi, podzemne garaže i podvoznjaci, ključna infrastruktura i prometnice, kulturna baština	velika	4

Klasa objekta = Facility class, Element = Element, Osjetljivost = Sensitivity, Ocjena = Score  
Zanemariva = Negligible, Mala = Low, Srednja = Medium, Velika = High  
Parkovi, šume, livade i slično = Parks, forests, meadows and the like

Pomoćni objekti (kiosci, terase, vrtne sjenice, nadstrešnice, sportski tereni i sl.) = Auxiliary facilities (kiosks, terraces, gazebos, canopies, sports grounds, etc.)

## RISK MAPS FOR THE CITY OF ZAGREB AND FOR A COASTAL LOCATION IN ISTRIA

*Stambeni objekti, javne ustanove, gospodarski objekti, škole i fakulteti, lokalne i županijske prometnice = Residential facilities, public institutions, industrial facilities, schools and universities, local and county roads*  
*Vrtići, domovi za starije i nemoćne, objekti hitnih službi, podzemne garaže i podvožnjaci, ključna infrastruktura i prometnice, kulturna baština = Kindergartens, senior citizen homes, emergency service facilities, underground garages and underpasses, key infrastructure and roads, cultural heritage*

The classification of depths was done in such a way to be coordinated with the PFRA depth classes, whereas for the classification of velocities instead of the PFRA classification the value of the product of multiplication of depth and velocity is used as a critical parameter - if it is higher than 0.8 m<sup>2</sup>/s, all the affected Class 1 or 2 facilities are automatically assigned the highest damage value (16).

Table 4.2: Classification of depths and velocities

Klasa dubina RAINMAN	Max. dubina vode RAINMAN (m)	opasnost	ocjena	Klasa brzine	Max.brzina vode (m/s)	opasnost	ocjena
1	< 0.1	zanemariva	1	1	< 0.5	zanemariva	1
2	0.1 - 0.25	mala	2	2	0.5 - 1	mala	2
3	0.25 – 0.5	srednja	3	3	1 - 2	srednja	3
4	> 0.5	velika	4	4	> 2	velika	4

*Klasa dubina RAINMAN = RAINMAN depth class, Max. dubina vode RAINMAN = RAINMAN max. water depth, Opasnost = Hazard, Ocjena = Score*

*Zanemariva = Negligible, Mala = Low, Srednja = Medium, Velika = High*

*Klasa brzine = Velocity class, Max. brzina vode (m/s) = Max. water velocity (m/s), Opasnost = Hazard, Ocjena = Score*

*Zanemariva = Negligible, Mala = Low, Srednja = Medium, Velika = High*

Table 4.3: Flood damage matrix

šteta				ocjena
4	8	12	16	3
3	6	9	12	2
2	4	6	8	1
1	2	3	4	0

*Šteta = Damage, Ocjena = Score*

Damages are then distributed into classes 0 through 3 and are overlapped with the likelihood of occurrence in order to obtain the flood risk.

Table 4.4: Flood risk matrix

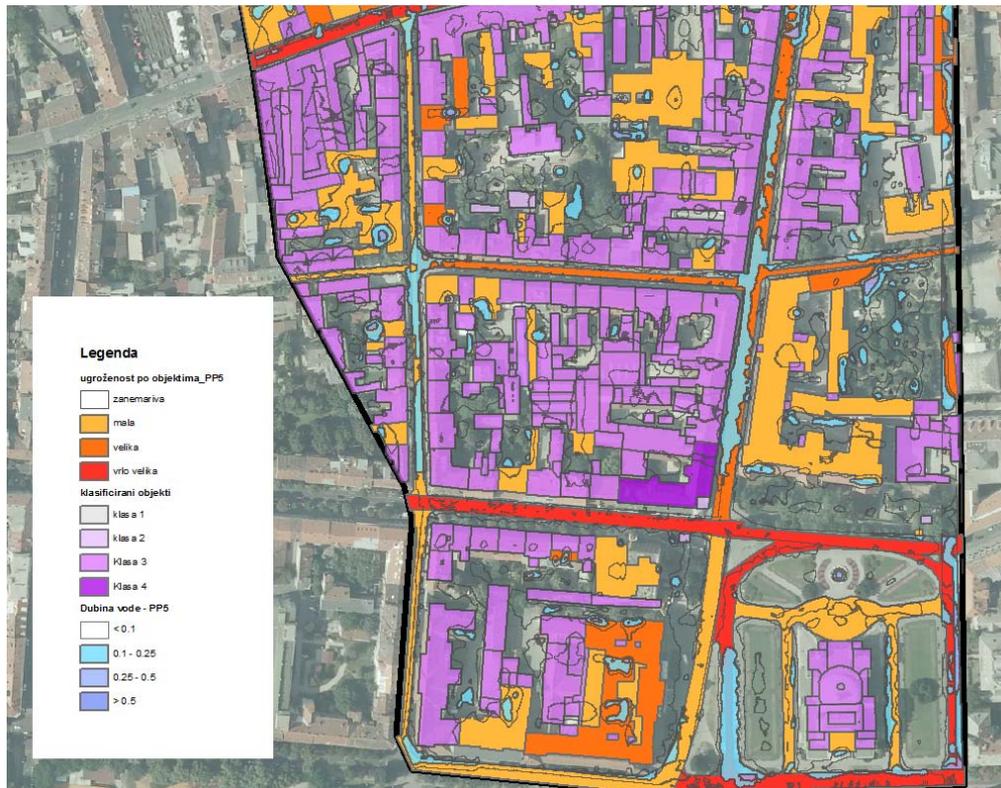
Povratno razdoblje T (god)	Vjerojatnost p (-)	intenzitet	ocjena	rizik				ocjena
				0	3	6	9	
*	*	zanemariva	0	0	2	4	6	visok
100	0.01	mala	1	0	1	2	3	umjeren
20	0.05	srednja	2	0	0	0	0	nizak
5	0.2	velika	3	0	0	0	0	nizak

*Povratno razdoblje T (god) = Return period T (years), Vjerojatnost p (-) = Probability p (-), Intenzitet = Intensity, Ocjena = = Score*

*Zanemariva = Negligible, Mala = Low, Srednja = Medium, Velika = High*

*Rizik = Risk, Ocjena = Score*

*Vrlo = Very high, Visok = High, Umjeren = Moderate, Nizak = Low*



Legenda = Legend, Ugroženost po objektima\_PP5 = Risk by facilities\_PP5, Klasificirani objekti = Classified facilities, Klasa = Class, Dubina vode - PP5 - Water depth - PP5

Figure 4.2: Extract from a pluvial flood risk map for a high probability of occurrence

## Conclusions and recommendations

During work on this activity, it was identified that the results largely depended on the availability and interpretation of inputs. This primarily refers to the data for the development of adequate elevation models, which often have to be checked in detail and improved based on field knowledge. It was also identified that spatial databases often don't contain the key data for modelling (e.g. coastal walls, underpasses, different passages, etc.). In order to make this process easier and faster, it is recommended on the one hand to develop LiDAR images for the entire territory of the Republic of Croatia as the main basis for the development of elevation models of uniform quality, and on the other hand to establish or regularly maintain a register of infrastructure for all the settlements. This particularly refers to the data about sewer infrastructure which to a large extent affects the runoff.

As for the available flood reports or reports on firefighting interventions as the basis for the preliminary risk analysis, their extent is less important than their content since space is exposed to constant change, which means that the problems associated with pluvial flood events constantly change as well. However, the establishment of a standard operating procedure (SOP) for a forecasted heavy rain event would make sure that all the included actors implement the same procedure in the same way, thus forming a basis for easier decision-making in terms of the implementation of certain measures, procurement of equipment, provision of human resources, education and control. The SOP shall as its integral part have an instruction about centralized, continuous and systematized collection of flood reports from the public and voluntary firefighting departments and other competent authorities, with clearly defined data to be collected. Based on such data it is possible to calibrate the hydrological-hydraulic models in different phases of spatial development.

The level of detail of the data used for model development is in a direct correlation with the selection of a calculation domain. A smaller domain enables more precise modelling and the input of data that has a significant impact on the results (e.g. details about how to build a fence, height of walls, roof construction method, etc.), which cannot even be realistically analysed in bigger models. The mere selection of the risk definition methodology depends on its purpose or the target users (local, regional, national level), available software (open source or licensed) and its possibilities (is it possible to simulate different types of flow, integrate LID solutions, etc.). Concerning the selection of representative rainfall, it is recommended to use, whenever possible, the “design storm” instead of the uniform rainfall intensity derived from the intensity-duration-frequency (ITP) curve, in order to demonstrate the actual rainfall as realistically as possible (Dietz, 2007). The methodology for the definition of the design storm is described in detail in Chapter 3 of the “Analysis of Rainfall in the Istria and Zagreb Pilot Areas”.

Based on the results of this phase of the Project, the measures to reduce risks in the selected areas have been proposed, as well as the improvement of pluvial flood risk management.

## RAINMAN Key Facts

Project duration: 07.2017 – 06.2020

Project budget: 3,045,287 €

ERDF funding: 2,488,510 €

RAINMAN website &  
newsletter registration: [www.interreg-central.eu/rainman](http://www.interreg-central.eu/rainman)



## Lead Partner



Saxon State Office for Environment,  
Agriculture and Geology

✉ [rainman.lfulg@smul.sachsen.de](mailto:rainman.lfulg@smul.sachsen.de)

## Project Partner



## Project support



INFRASTRUKTUR & UMWELT  
Professor Böhm und Partner

✉ [RAINMAN@iu-info.de](mailto:RAINMAN@iu-info.de)