University of Split, Faculty of Civil Engineering, Architecture and Geodesy

REPORT ON VULNERABILITY ANALYSIS

Pilot Project on Climate Change Adaptation
Building the Link between Flood Risk Management Planning and Climate Change Assessment in the Sava River Basin

Contracting authority: the International Sava River Basin Commission

November, 2013

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This report has been produced in the framework of the project "Testing of the Guidance document developed under the Water Convention (UNECE) - Building the link between the flood risk management planning and climate change assessment in the Sava River Basin“, implemented in the framework of the Environment and Security Initiative (ENVSEC) by the International Sava Commission (ISRBC) and the United Nations Economic Commission for Europe (UNECE) with funding from Finland. The countries sharing the Sava River Basin, together with the ISRBC (www.savacommision.org), appreciate this successful cooperation and kind support.

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1. Introduction

Developing, testing and implementing indicators to identify and assess vulnerability and coping capacity to floods are an important pre-requisite for effective flood risk reduction. Although strengthening capacities to reduce hazardous events are important (magnitude and frequency of hazardous events), it became evident that we have to live with natural hazards, such as floods. Particularly in view of the on going global warming and the increasing frequency of extreme weather events technical solutions alone, such as dams and dykes, will not be adequate to ensure human security in the long term. Therefore it is important to promote a paradigm shift form the quantification of the hazard and primary focus on technical solutions towards the identification and assessment of the various vulnerabilities of societies, their economy and environment.

Vulnerability is a human condition or process resulting from physical, social, economic, and environmental factors, which determine the likelihood and scale of damage from the impact of a flood event. It is the likelihood of injury, deaths, loss, disruption of livelihood or other harm in an extreme flood event, and/or unusual difficulties in recovering from such effects.

In the Sava River Basin (SRB) there have been past flooding events that have resulted in various dimensions of vulnerability of the river basin shared by Sava riparian countries. Typical dimensions of vulnerability can be summarized in social dimension (vulnerability of different social groups – role of social networks), economic dimension (vulnerability of different economic sectors, such agriculture and residential areas), environmental dimension (environmental degradation – land and groundwater), and institutional dimension (effectiveness and failure of defence structures). Floods in the Sava River Basin usually appear in the spring and in the autumn. Spring floods are the result of snow melting while autumn floods are caused by heavy rainfall. Spring floods last longer and they don’t have large maximum discharges, while autumn floods are of shorter duration and have very high extreme flows, when floods go over the riverbank they last longer periods of time and become more flat. There have been recorded some severe flood events caused by the tributaries from the right riverbank (BiH). Detail information about historical flood events could be found in the Sava River Basin Analysis Report (ISRBC, 2009) and Hydrology Report for the Sava River Basin Analysis (S. Prohaska, 2009).

However, during last six decades lot of dykes and other flood protection structures have been constructed. These structures define completely new condition in the Sava River Basin making historical flood events analysis irrelevant for actual vulnerability assessment.

The intention of this report is to provide some background information regarding hydrological and hydrodynamic studies already conducted in the Sava River Basin with a proposal how to address the issue of assessing the vulnerability to future flooding events. The complexity of the existing flood defence structures and its influence on the future flooding events will be discussed and analysed.

2. Climate and hydrology

2.1 Climate

Sava River Basin is situated within mild climate area. Cold and warm time periods can be clearly distinguished. Climate varies a lot within the catchment area, which is the consequence of the vicinity of the sea and land, as well as of different orographic characteristics. Climate characteristics can be classified within three groups:

- Alpine climate (upper part of the Sava River Basin);
- Moderate continental climate (right tributaries' catchments);
- Moderate continental (mid-European) climate (left tributaries' catchments that belong to the Pannonian Basin).

The most important factors influencing the climate of Sava River Basin are orographic characteristics, especially air temperature and precipitation. Annual average temperature of Sava River Basin is 8.8 °C, monthly average temperature in January is -1.5°C, and monthly average temperature in July is 20°C. The temperature decreases with an increase of elevation. Digital elevation model (DEM) together with Sava river network are shown on Figure 2.1 and Figure 2.2, respectively.

According to Prohaska´s report from year 2009, annual average temperature decreases 5 °C with an increase of elevation of 1000 meters. Amounts and disposition of precipitation varies within the catchment. Annual average precipitation of Sava River Basin is 1067 mm. Average annual runoff, measured at hydrologic station Sremska Mitrovica is 526,6 mm/year.

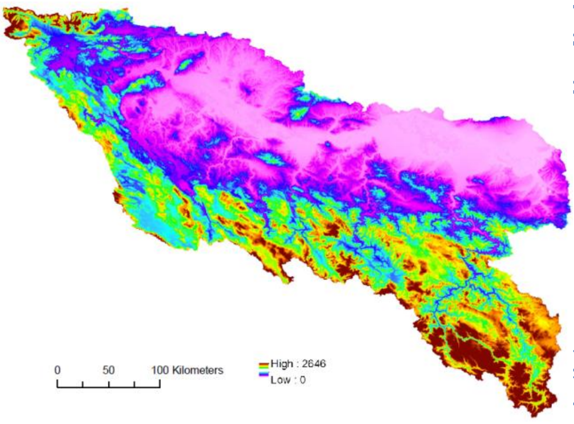


Figure 2.1: DEM of Sava River Basin

Figure 2.2: Digitalized Sava river network

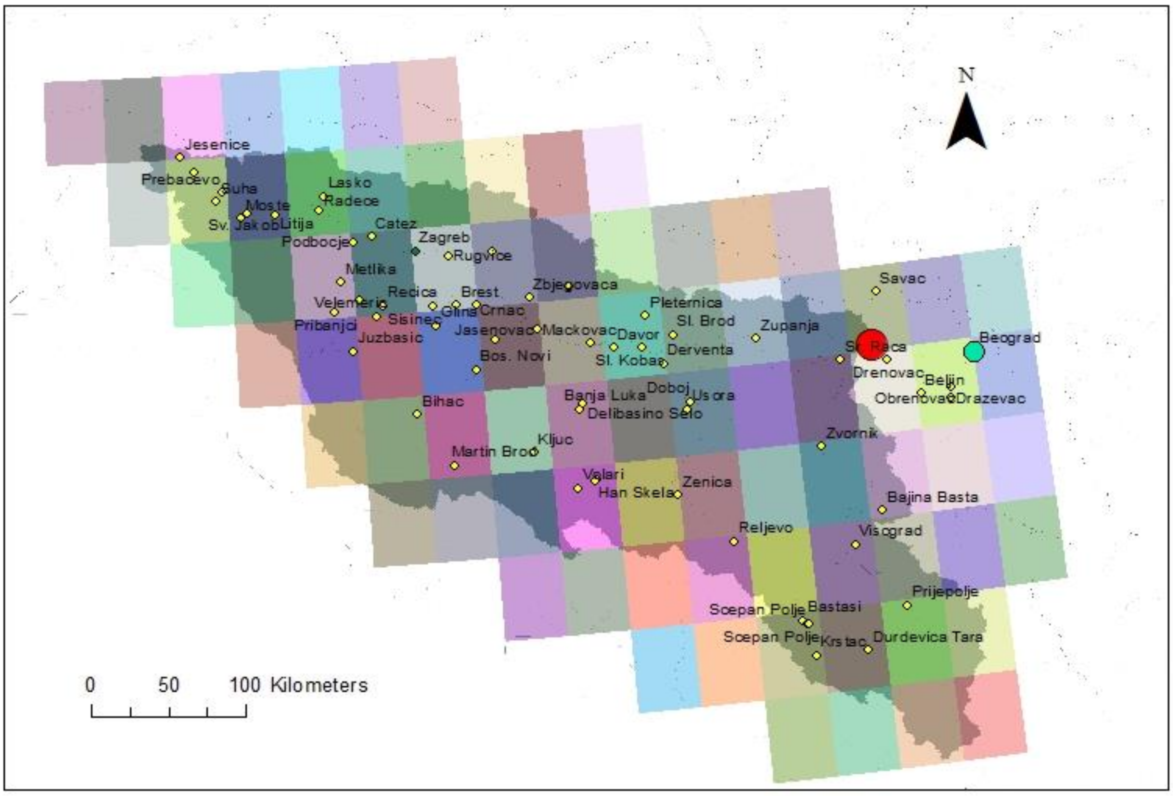


Figure 2.3: Delineated Sava River catchment (marked are hydrologic runoff stations) superimposed with temperature and precipitation layers. Red circle represents hydrologic station of Sremska Mitrovica

2.2 Temperature and precipitation

Temperature and precipitation data (Figure 2.3) were downloaded from free online database of CRU (Climate Research Unit) TS 2.1 Global Climate Database with a spatial resolution of 0.5°. The data are within time period of year 1901 till year 2002. The data were downloaded as a GIS layer of pixels, where each pixel has a unique value of temperature (precipitation) (Mitchell, T.D. and Jones, P.D. 2005).

2.3 Runoff

The data used in this report are runoff data measured on 60 different hydrologic stations within Sava River Basin, taken from “Hidrološke studije reke Save” published by Federal hydrometeorological federation in Belgrade 1969. Part of the data, dating from year 1961 till year 2009 was provided by The Institute Jaroslav Černi from Belgrade. The hydrologic stations were digitalized using GIS Tools in ArcMap. Their location was also coordinated according to a real hydrologic network, after delineating the catchment.

2.4 Results

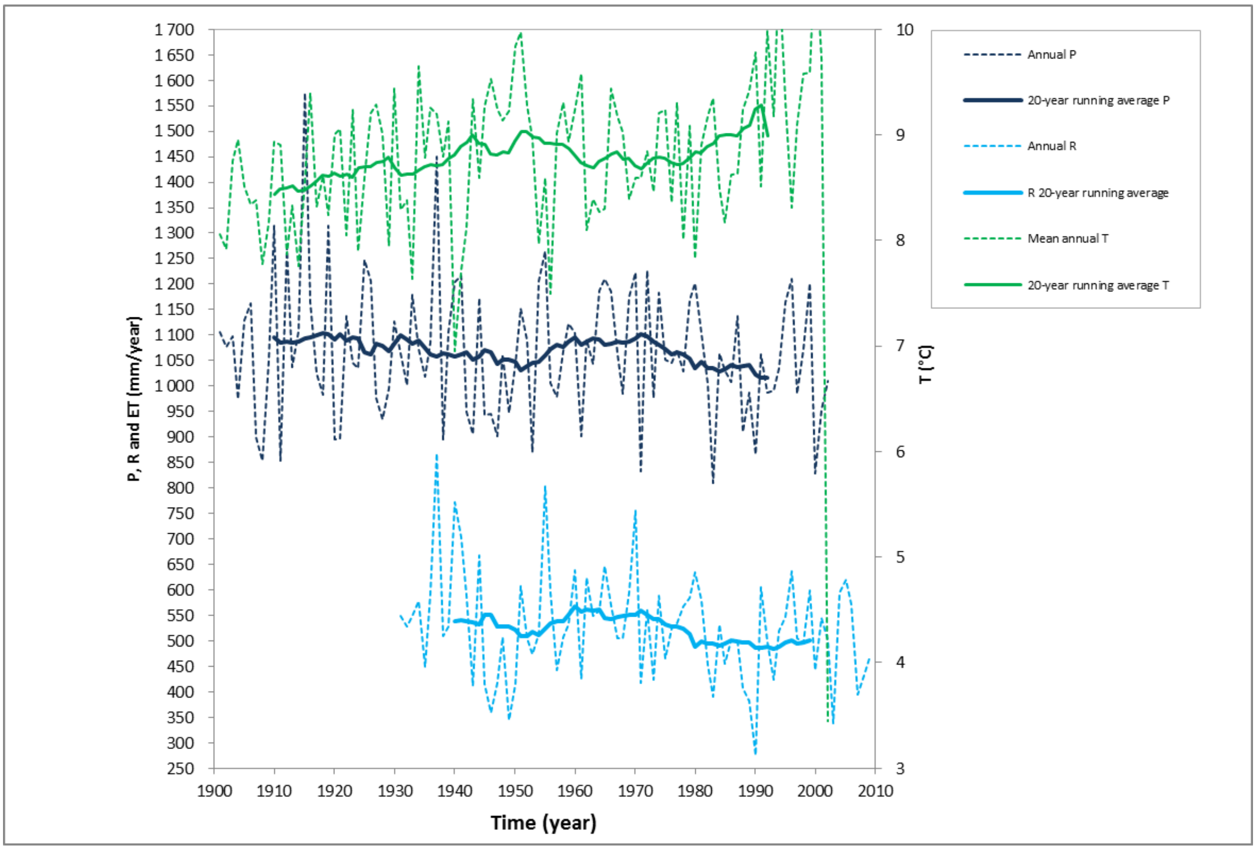


Figure 2.4: T, P and R timechange for Sremska Mitrovica measuring station

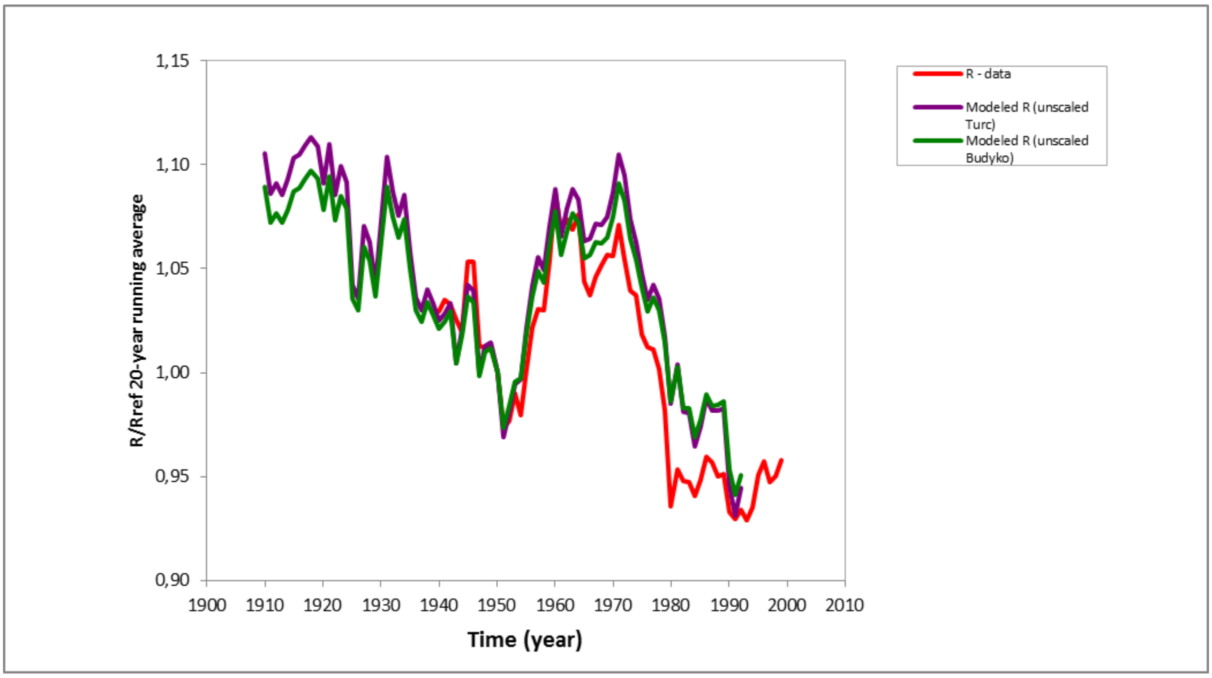


Figure 2.5: R change during 20 year moving average for Sremska Mitrovica measuring station

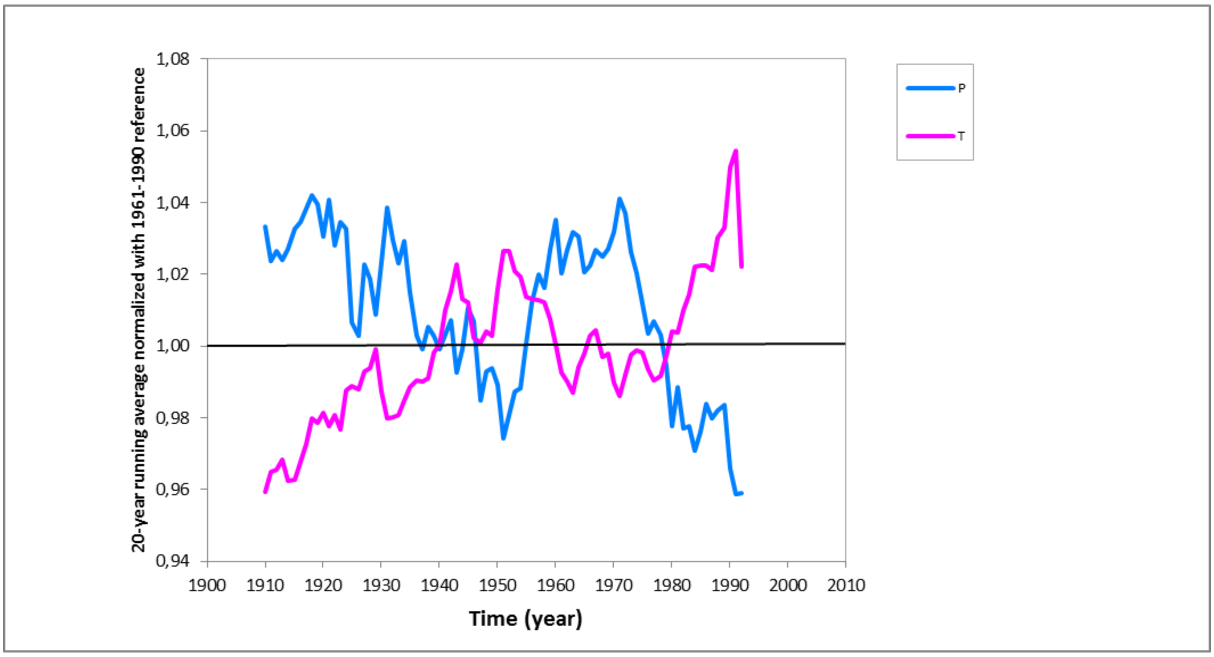


Figure 2.6: P and T for Sremska Mitrovica measuring station normalized with IPCC time reference

Figure 2.4 shows increase and decrease of precipitation during the same time periods in which increase and decrease of runoff is present. A continuous increase of temperature can be seen on the same picture during all time period. There are no higher increases of runoff. There are no bigger differences in runoff trend of CRU data in comparison with the data modelled according to Turc and Budyko (Figure 2.5). Referent runoff (Rref) was modelled as an average change of runoff during 20 years running average within IPCC time period 1961-1991 (Figure 2.6).

2.5 Significant floods in the past

Most likely floods occur in the Sava River Basin in autumn and spring, with approximately same volume and damages. The largest flood was recorded in 1879, when in just 106 days, in the Sava River Basin, there was approximately 1381 mm rainfall. In Slovenia, floods in Sava River Basin have been recorded since the year 1550. In 1707 Sava River damaged the bridge in Medvode and in 1850 there were fatalities during the flood event. The fatalities and evacuation of the people were also recorded during 1960s. On December 19, 1968, large flood of Bosna River was recorded in Sarajevsko polje with depth of 30-40 cm. The most severe recorded flood event in the Sava River Basin happened in October 1964 in Zagreb. In period of 1972-1974, floods have covered entire lowland area in BiH. Entire period from 1981 to 1991 is characterized by flood events with different volume, covering more or less upper Sava River tributary courses. In 1999, a big flood event was recorded in Tuzla, Bosna River Basin, when the small River Jala caused great flooding event. In 2004, Srbac suffered significant damages in the area of Vrbas and Povelić River mouth.

Recently, severe floods in the Sava River Basin occurred in 2010. On the Croatian part of Sava River Basin, the floods were caused predominantly by extreme precipitation in Croatia as well as by large inflow from the upstream parts of the river basin in the neighbouring countries. In Bosnia and Herzegovina the key flood events were registered at the beginning of January 2010 on Una, Sana, Vrbas and Bosna river. Flood waves on Sava River in Serbia occurred in February 2010 due to fast snowmelt and rainfalls, as well as in December 2010 as a result of flood waves on the Drina River and its tributaries. At the end of June a flood event occurred in the Kolubara River (right Sava River tributary), which was caused by the abundant rainfall.

Despite the fact that the severe flood events have occurred in the past, causing damages and casualties, people remain to live and have economic activities on the flood plains. Apparently, residents of the Sava River Basin still find more benefits than losses by living on the flood prone areas. Although the vulnerability could be relatively high in some of these areas it can also be offset by the flood protection system possibly resulting in lower hazard and risk assessments.

3. Hydrodynamic modelling

3.1 Historical modelling efforts

In the Sava River Basin there are two types of flooding flows. One is a typical for high land areas where the flow is over the karstic areas with typical karstic sources and sinks which are temporarily flooded. These are areas with natural flooding conditions without anthropogenic influence. Since the monitoring is rather rare in these areas simplified hydrologic modelling can be applied.

Quite different condition is in the lowland areas along the Sava River. Flooding flow is relatively slow with strong interaction with Sava tributaries. After completion of the flood defence structures, the flooding flow and surface runoff became very complex. To address the hydrodynamic situation in these areas, the non-stationary modelling becomes a necessity.

There have been many studies analysing and simulating flooding flow over different parts of the Sava River Basin. The Table 3.1 provides the list of different models used in modelling of the Sava River and its tributaries. Figure 3.1 shows spatial distribution of both hydrological and hydraulic models applied on the Sava River Basin floodprone areas.

Table 3.1: Hydrologic and hydraulic analysis on Sava River Basins

Country	**River**	**Floodprone area**	**Location (from the river mouth)**		**Methodology used for Hydrologic Analysis**	**Hydraulic Model Used**	**Model No. on Figure 3.3**
			Downstream limit	**Upstream limit**			
SI	KAMNIŠKA BISTRICA	IHANSKO POLJE					
SI	LJUBLJANICA	LJUBLJANSKO BARJE	mouth of tributary IŠČICA	settlement VRHNIKA	Statistical Analysis of Gage Records Precipitation/Runoff Model NASH model - unit hydrogram		1
SI	SORA	GODEŠIČ-RAKOVNIK	settlement GORIČANE	settlement ŠKOFJA LOKA	Statistical Analysis of Gage Records Precipitation/Runoff Model SCS model - unit hydrogram	HEC-2, HEC-RAS	2

SI	SAVINJA	LOWER SAVINJSKA DOLINA	settlement CELJE	cross-country highway near settlement LATKOVA VAS	Statistical Analysis of Gage Records Precipitation/Runoff Model HEC-1	HEC-2, HEC-RAS	3
SI	SAVA	MIDDLE SAVA, DOLSKO-LITIJA	settlement SPODNJI LOG	mouth of KAMNIŠKA BISTRICA- left tributary of SAVA	Statistical Analysis of Gage Records	HEC-RAS, MIKE FLOOD	4
SI	SAVA	MIDDLE SAVA, TACE-ŠENTJAKOB-BERIČEVO	mouth of KAMNIŠKA BISTRICA- left tributary of SAVA	settlement TACEN	Statistical Analysis of Gage Records	HEC-RAS, MIKE FLOOD	5
SI	SAVA	LOWER SAVA, DOBOVSKO FIELD	border with Croatia	settlement MOSTEC	Statistical Analysis of Gage Records	HEC-RAS, MIKE FLOOD	6
SI	SAVA	LOWER SAVA, ČATEŠKO FIELD	border with Croatia	settlement ČATEŽ OB SAVI	Statistical Analysis of Gage Records	HEC-RAS, MIKE FLOOD	7
SI	SAVA	LOWER SAVA, BREŽIŠKO FIELD	settlement BREŽICE	settlement KRŠKO	Statistical Analysis of Gage Records	HEC-RAS, MIKE FLOOD	8
SI	SAVA	LOWER SAVA, KRŠKO FIELD	mouth of KRKA - right tributary of SAVA	settlement KRŠKO	Statistical Analysis of Gage Records	HEC-RAS, MIKE FLOOD	9
SI	SOTLA	MIDDLE SOTLA	ZELENJAK	mouth of tributary MESTINJŠČICA	Statistical Analysis of Gage Records Precipitation/Runoff Model SCS model - unit hydrogram		10
SI	KRKA	LOWER KRKA	settlement KRŠKA VAS	settlement OTOČEC	Statistical Analysis of Gage Records		11
SI	UNICA	PLANINSKO POLJE	Sinkhole - POD STENAMI	karst spring - MALNI			
SI	STRŽEN	CERKNIŠKO POLJE	Sinkhole – JAMA	karst spring - OBRH			
HR	SAVA		213,08	728,542	Statistical Analysis of Gage Records Regional Regression Equations	HEC-2	12
HR	SAVA		599,3	728,542	Statistical Analysis of Gage Records Regional Regression Equations	Mike 11	13
HR	SAVA		213,08	604,7	Statistical Analysis of Gage Records Regional Regression Equations	HEC-RAS	14
HR	SAVA		599,291	728,873	Statistical Analysis of Gage Records Regional Regression Equations	HEC-2	15
HR	SAVA		378,1	714,093	Statistical Analysis of Gage Records Regional Regression Equations	KORSIM	16

HR	DOBRA		0	11,2	Statistical Analysis of Gage Records Regional Regression Equations	KORSIM, Mike 11	17
HR	KRAPINA		0,102	57,9	Statistical Analysis of Gage Records Regional Regression Equations	HEC-RAS	18
HR	KUPA		0	94,4	Statistical Analysis of Gage Records Regional Regression Equations	KORSIM	19
HR	KUPA		66,4	173	Statistical Analysis of Gage Records Regional Regression Equations	KORSIM	20
HR	KUPA		94,4	173	Statistical Analysis of Gage Records Regional Regression Equations	Mike 11	21
HR	OK KUPA-KUPA		0	21,633	Statistical Analysis of Gage Records Regional Regression Equations	KORSIM, Mike 11	22
HR	KORANA		0	19,4	Statistical Analysis of Gage Records Regional Regression Equations	KORSIM, Mike 11	23
HR	MERŽNICA		0	5,1	Statistical Analysis of Gage Records Regional Regression Equations	KORSIM, Mike 11	24
HR	UNA		0	44,2	Statistical Analysis of Gage Records Regional Regression Equations	KORSIM	25
HR	VRBAS		0	71	Statistical Analysis of Gage Records Regional Regression Equations	KORSIM	26
HR	ORLJAVA		10	97	Statistical Analysis of Gage Records Regional Regression Equations	HEC-RAS	27
HR	BOSUT		0,28	109,49	Statistical Analysis of Gage Records Regional Regression Equations	HEC-RAS	28
HR	CESMA				Statistical Analysis of Gage Records Regional Regression Equations	HEC-RAS	29
BiH, FBiH	SAVA	ODŽAČKA POSAVINA	321+000	348+650	Statistical Analysis of Gage Records	Mike 11	30
BiH, FBiH	SAVA	SREDNJA POSAVINA	239+823	319+968	Statistical Analysis of Gage Records	Mike 12	
BiH - RS	VRBAS	VRBAS-1: River section from Municipality Laktasi border to HPP "Banja Luka niska"	66+000	87+700	Statistical Analysis of Gage Records Precipitation/Runoff Model Regional Regression Equations	MIKE 11, MIKE 21	31

BiH - RS	VRBAS	VRBAS-2: River section of urban area of Banja Luka Town	66+000	87+700	Statistical Analysis of Gage Records Precipitation/Runoff Model Regional Regression Equations	DUFLOW	
BiH - RS	BOSNA	BOSNA-1: River section from rm to Modrica Town	0+000	25+150	Statistical Analysis of Gage Records Precipitation/Runoff Model Regional Regression Equations	DUFLOW	32
BiH - RS	BOSNA	BOSNA-2: River Bosna section from river Rudanka bridge to confluence of Usora River	69+500	79+600	Statistical Analysis of Gage Records Precipitation/Runoff Model	HEC-RAS	33
BiH - RS	TINJA	TINJA-1: Section of Tinja River from rm to Cvijanovici	0+000	43+800	Statistical Analysis of Gage Records Precipitation/Runoff Model Regional Regression Equations	HEC-RAS	34
BiH - RS	BRKA	BRKA-2: Section of Brka River from existing regulation to end of Brka Sttlement	1+348	3+516	Statistical Analysis of Gage Records Precipitation/Runoff Model Regional Regression Equations	HEC-RAS	35
RS	DUNAV + SAVA + NOVA GALOVICA	NOVI BEOGRAD			Statistical Analysis of Gage Records	Mike11	36
RS	NOVA GALOVICA + SAVA	DONJI SREM			Statistical Analysis of Gage Records	Mike11	
RS	SAVA	KUPINOVO I			Statistical Analysis of Gage Records	Mike11	
RS	SAVA	KUPINOVO II			Statistical Analysis of Gage Records	Mike11	
RS	SAVA	KUPINOVO-KLENAK			Statistical Analysis of Gage Records	Mike11	
RS	SAVA	KLENAK			Statistical Analysis of Gage Records	Mike11	
RS	SAVA	KLENAK-HRTKOVCI			Statistical Analysis of Gage Records	Mike11	
RS	SAVA	HRTKOVCI			Statistical Analysis of Gage Records	Mike11	
RS	SAVA	HRTKOVCI-SREMSKA MITROVICA			Statistical Analysis of Gage Records	Mike11	
RS	SAVA + ISTOCNI OBODNI KANAL	SREMSKA MITROVICA			Statistical Analysis of Gage Records	Mike11	
RS	SAVA + ISTOCNI OBODNI KANAL	GORNJI SREM			Statistical Analysis of Gage Records	Mike11	
RS	SAVA + TOPCIDERSKA REKA	BEOGRAD			Statistical Analysis of Gage Records	Mike11	

RS	SAVA + OSTRUZNICKA REKA + ZELEZNICKA REKA + TOPCIDERSKA REKA	VELIKI MAKIS-ADA CIGANLIJA			Statistical Analysis of Gage Records	Mike11	
RS	SAVA	MALI MAKIS			Statistical Analysis of Gage Records	Mike11	
RS	SAVA + KOLUBARA + BARICKA REKA	MISLODJIN-BARIC			Statistical Analysis of Gage Records	Mike11	37
RS	SAVA + KOLUBARA + OBODNI GRAVITACIONI KANAL	OBRENOVAC			Statistical Analysis of Gage Records	Mike11	
RS	SAVA	PROVO-ORLACA			Statistical Analysis of Gage Records	Mike11	38
RS	SAVA + DOBRAVA	MRDJENOVAC-LADJENIK			Statistical Analysis of Gage Records	Mike11	
RS	SAVA + DOBRAVA	ORASAC			Statistical Analysis of Gage Records	Mike11	
RS	SAVA + DRINA	MACVA			Statistical Analysis of Gage Records	Mike11	
SI HR BiH, FBiH BiH-RS RS	SAVA RIVER BASIN				HEC-HMS	HEC-RAS	39

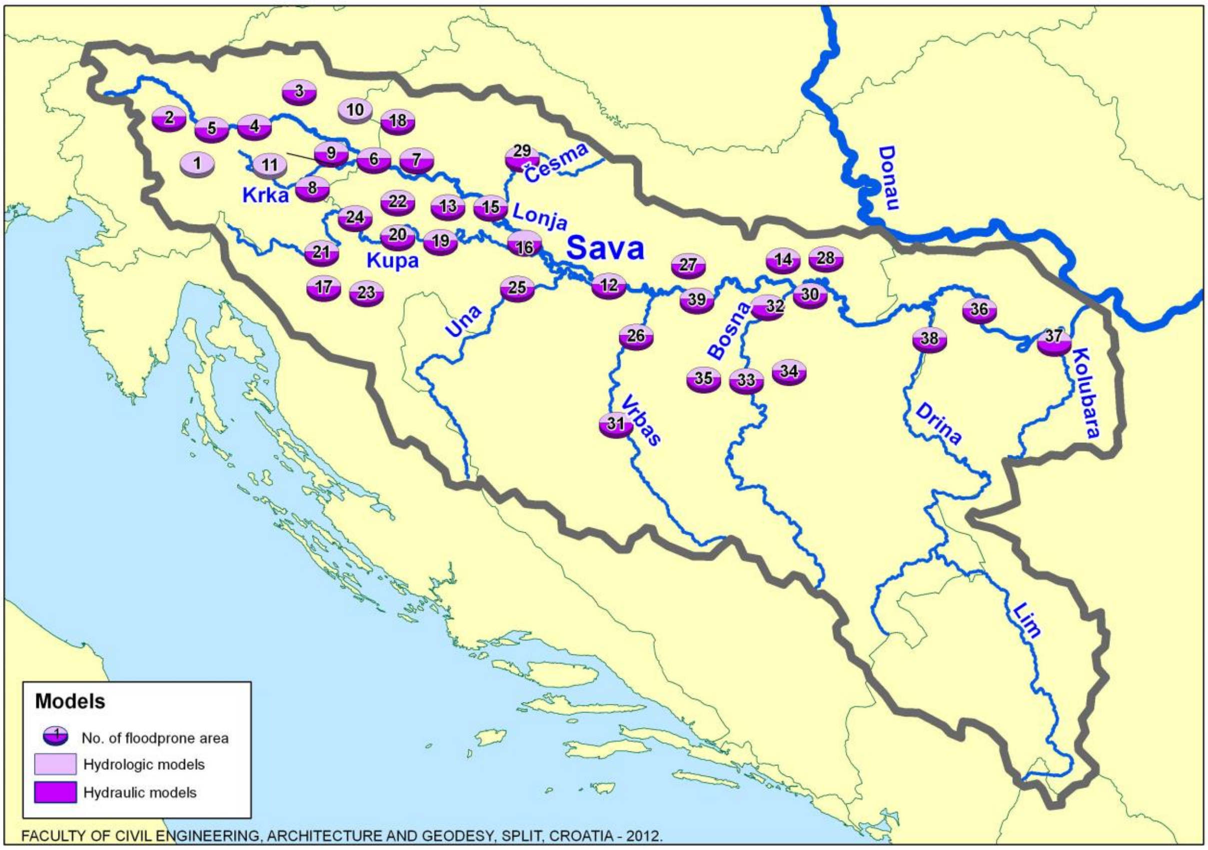


Figure 3.1: Hydrologic and hydraulic models - spatial distribution

3.2 System and state of the flood protection structures

The existing protection systems in the Sava River Basin are very complex and comprise of a large number of regulative and protective water structures. Along national watercourses, there are around 1,600 km of protective dikes, whereas local watercourses are protected by around 200 km of protective structures. The most important protection system for the Sava River Basin has been developed along the watercourse in Croatia, creating new system of water redistribution, particularly during the flood events.

In cooperation with various water and land users, multipurpose reservoirs were constructed with the total volume of 73 hm^3 and mountain retention storages with the total volume of 2,5 hm^3; partially also 5 large lowland retention storages in the Sava River Basin (Lonjsko polje, Mokro polje, Kupčina, Zelenik and Jantak) with the total volume of 1.590 hm^3. Two basic water distribution facilities, Prevlaka and Trebež1 weirs are built. Canal network in the Sava River Basin is rather developed. There are three major relief canals (Odra, Lonja - Strug and Kupa - Kupa) with a total length of about 65 km, connective canals Zelina - Lonja - Glogovnica - Česma and Ilova - Pakra, and a total of about 534 km of lateral canals for collecting mountain waters on the margins of flood protected areas.

The Sava River Basin is asymmetric and dispersed, which is why the occurrence of extreme high waters is slightly reduced. The average annual flow of the Sava River at its entry into Croatia (Jesenice), amounts to ca. 300 m^3/s, and to ca. 1,200 m^3/s at its exit from Croatia. The ratio of absolute extremes at the exit from Croatia is considerably less (around 18). The highest flow of 4,161 m^3/s at the Županja station, was recorded as far back as 1970. The central part of the Sava valley is a depression, which is a particular topographic phenomenon.

The core of the solution was the flood storages in the Kupa and Sava lowlands, of sufficient retention capacity for the relief of excess flood waves. 58,800 ha of flood storages were planned (Lonjsko polje, Mokro polje, Zelenik, Kupčina), which provided the required level of protection. Apart from the flood storages, the system comprised of three relief canals (Odra, Lonja-Strug, Kupa-Kupa), which made up for the limited flow rate on some stretches of the main watercourses and redirection of excess water into flood storages, and about 15 structures for water distribution control under flood conditions. Additionally, there were earlier constructed dikes along the larger watercourses, which had to be continuously rebuilt and reconstructed, if necessary. The system was generally designed to provide protection from the predicted 100-year flood, whereas larger urban centres, i.e. Zagreb, Karlovac and Sisak, were defended from 1000-year flood. The original solution anticipated these areas with full flood control, maximally reduced surfaces and higher depths of retained water. The modified solution proposed the following crucial changes:

- enlargement of floodplains at Lonjsko polje by approx. 7,000 ha;
- free flow of relieved flood water along Mokro polje;
- lowering of maximal water depths in the flood storages.

These changes contribute to a better protection of natural values, and are an important step towards environmentally acceptable flood management. Part of the lowland, with an area of about 50,000 ha, was proclaimed the Nature Park of Lonjsko polje in 1990 and is also recognized as a Wetland of International Importance (Ramsar site) since 1993.

The area along the Sava River, from Zagreb and Karlovac in the west to Gradiška in the east is commonly known as the Central Posavina (Middle Posavlje). Parts of the area are protected in accordance with laws and conventions on nature protection (Nature Park and a Ramsar site of Lonjsko polje, a Ramsar site of Crna Mlaka, ornithological reserves of Rakita and Krapje Đol, etc.).

The floods in Zagreb in 1964 and in Karlovac and Sisak in 1966, prompted the development of an integrated solution for protecting the lowland area along the Sava from floods, i.e. Central Posavina. Reconstruction of the existing dikes and construction of new ones started soon after the 1964 flood. From the mid 1960-ies to the mid 1980-ies, around 40 % of the planned regulation and protection water structures of the Central Posavina flood protection system were constructed. They protect important parts of river valleys, enable certain control of the high water regime of the Sava River and its tributaries, as well as safe use of significant agricultural areas.

The flood protection system in the Central Posavina relies on five large lowland retention areas: Lonjsko Polje, Mokro polje, Kupčina, Zelenik and Jantak, two basic water distribution facilities, Prevlaka and Trebež1 sluices and the three relief canals (Odra, Lonja-Strug and Kupa-Kupa). This flood defence system has not yet been finished. The construction works have been executed just in 40 % of the value of the planned investment, however a large positive impact on the flood regime has been achieved as in Croatia, so in the downstream countries. Generally, the flood protection works helped to reduce the areas potentially flooded by 100-year high water of the Sava River and its tributaries by 65 %. However, the Sava section upstream of Zagreb to the Slovenian border is still unprotected. In Croatia, through the Water Management Strategy, the targets for effective flood protection are determined. As priority of the first order for the flood protection, the larger towns, potentially at risk from the Sava and Kupa River, are set, then other settlements along the Sava, Kupa and Una River. As next goal, reconstruction of dykes and further construction of the Central Posavina flood protection system are foreseen. Status of flood protection in the Sava River Basin in Croatia is shown on Figure 3.2.

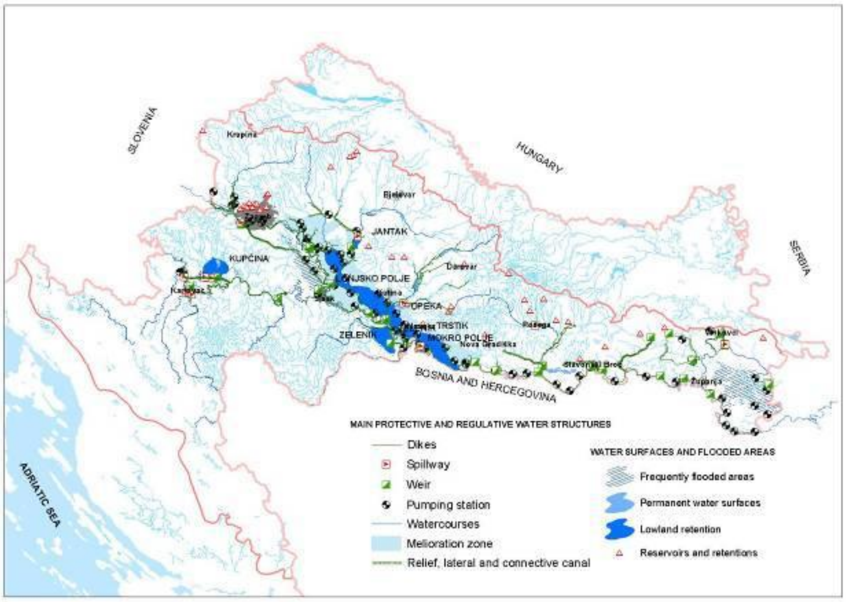


Figure 3.2: Status of flood protection in the Sava River Basin in Croatia

4. Vulnerability analysis

Generally, the vulnerability assessment, among other things, is also related to the awareness and preparedness before and during the floods, as well as resilience capacity during and after the floods. The proposed vulnerability assessment is reached as combination of existing legislation in Slovenia and good practice in other SRB riparian countries taking into account the following:

- Slovenia has legally defined methodology in Rulebook (Pravilnik o metodologiji za določanje območij, ogroženih zaradi poplav in z njimi povezane erozije celinskih voda in morja, ter o načinu razvrščanja zemljišč v razrede ogroženosti, Uradni list RS, št. 60/2007, http://www.uradni-list.si/1/content?id=81148),
- Other SRB riparian countries have not developed officially and legally defined methodologies and procedures.
- results and proposals of on-going project in Serbia, Study of flood prone areas in Serbia, SOFPAS 1st phase, considers development of methodology for risk/potential adverse consequences mapping methodology including vulnerability assessment (http://rdvode.minpolj.gov.rs/sofpas/);
- findings and proposals of IPA project "Support to BiH Water Policy" (http://www.voda.ba/loc/?p=72);
- conclusions of several PFRA projects in Croatia;
- findings and proposals of DANUBE Flood risk project (http://www.danube-floodrisk.eu/).

4.1 Recommendations for common methodology

For the purpose of flood risk management and taking into account definition of flood risk within EU Flood Directive (EFD) vulnerability is defined by five criteria:

- Population density,
- Economic activities,
- Special structures and objects,
- Protected areas – nature,
- Cultural heritage.

Each criterion has three classes/levels defining vulnerability: high, moderate and low. Consequently, an overall vulnerability is classified as:

1. High vulnerability,
2. Moderate vulnerability,
3. Low vulnerability.

Criteria should be presented spatially. Since majority of the data are being derived from CORINE classification the most practical approach to structure criteria values is a grid (for ex. 100 x 100 meters cells). Grid cells are classified according to each criterion, thus having five attributes: C1, C2, C3, C4, C5. For each cell vulnerability is calculated using the following rule:

$$\text{Vulnerability Level} = \text{Max}\,(C1, C2, C3, C4, C5)$$

Where, high > moderate > low.

The cell vulnerability level is the maximum value of the criteria levels. Figure 4.1 shows vulnerability assessment procedure.

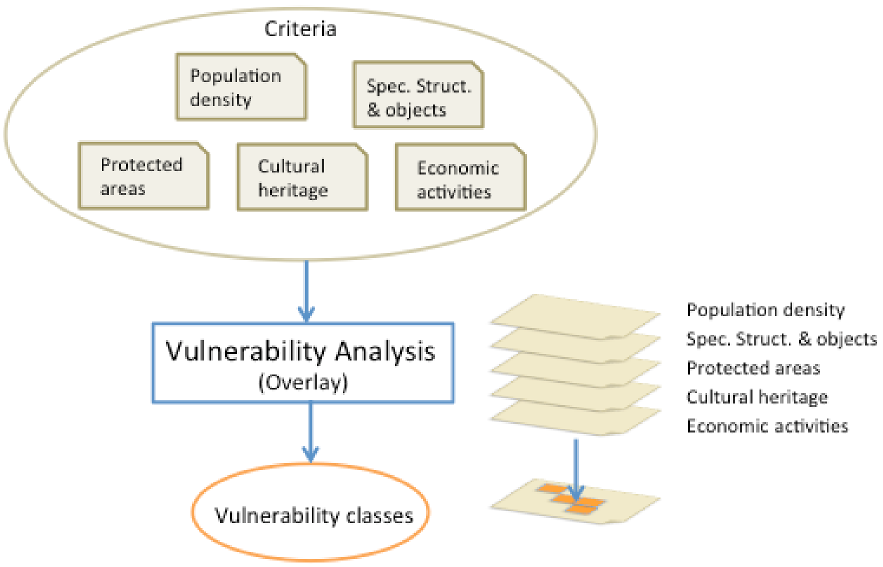


Figure 4.1: Vulnerability assessment procedure

4.1.1 Population density

Population density over 500 inhabitants per square kilometre defines expected density for urban areas in SRB. For low populated areas it is expected to have less than 100 inhabitants per square kilometre. The classes are:

1. High vulnerability - greater than 500 inhabitants per square kilometre,
2. Moderate vulnerability - between 100 and 500 inhabitants per square kilometre,
3. Low vulnerability - less than 100 inhabitants per square kilometre.

4.1.2 Economic activities

This criterion is related to economic activities and their importance to economy: national, regional or local. The criterion has high level of abstraction. Therefore each riparian country is expected to define particular type of activities through land cover/use categorisation and estimate importance to the economy. For transboundary areas a special attention should be given to avoid eventual discrepancy in judgement. The classes are:

1. High vulnerability - areas with importance to national economy,
2. Moderate vulnerability - areas with importance to regional economy,
3. Low vulnerability - areas either without any importance or with importance to local economy.

4.1.3 Special structures and objects

This criterion concerns structures and objects that are either essential for functioning of society or economy especially during floods or could cause pollution and derogate health condition of the population in flooding conditions. Structures and objects that are either essential for functioning of society or economy are known as critical infrastructure (water supply systems, energy networks, telecommunication systems, major roads and railroads, etc.). Structures and objects that could cause pollution are usually dumpsites, water treatment plants, quarries, etc. The classes are:

1. High vulnerability - structures and objects having national or transnational influence,
2. Moderate vulnerability - structures and objects having regional influence,
3. Low vulnerability - structures and objects having local influence.

4.1.4 Protected areas – nature

Categorisation of the protected areas is developed in accordance with definition of protected areas by International Union for Conservation of Nature and Natural Resources. Special attention should be paid to potentially affected protected areas identified in Annex IV(1)(i), (iii) and (v) of EU Water Framework Directive (WFD), i.e. water designate for human consumption, recreation, bathing as well as protected habitats or species. Particular attention should be paid to the wetlands and marshes such that flood maps and above classification should be reported only for a low probability flood event or in the case of potential pollution that could be caused by high probability flood event. The classes are:

1. High vulnerability – strictly protected areas where human visitation and impacts are rigorously controlled and/or limited (for ex. categories Ia, Ib and II, defined by International Union for Conservation of Nature),
2. Moderate vulnerability - protected areas centred on particular natural feature, fragments of ecosystems or habitats (for ex. categories III and IV, defined by International Union for Conservation of Nature),
3. Low vulnerability - protected areas like cultural landscapes altered by humans, natural areas where biodiversity conservation is linked with sustainable use of the natural resources (for ex. categories V and VI, defined by International Union for Conservation of Nature).

4.1.5 Cultural heritage

Cultural heritage includes tangible culture such as buildings, monuments, landscapes, books, works of art, and artefacts, etc. This criterion also comprises the museums and similar facilities that store cultural heritage. The riparian countries shall define importance of their cultural heritage. The classes are:

1. High vulnerability - World heritage (UNESCO) or high national importance,
2. Moderate vulnerability - national or regional importance,
3. Low vulnerability - local importance.

4.2 Flood prone areas mapping – Q_{100} flood scenario

The Project's GIS database has been developed in order to demonstrate vulnerability assessment in Sava River Basin. The vulnerability criteria are represented as GIS data layers, and GIS analyses functions are used for the vulnerability assessment.

So far the database contains several layers with information on population, land cover, protected areas and flood prone areas. The main GIS layers and descriptions of their sources are in the Table 4.1.

Table 4.1: Sava River Basin GIS layers and their sources

GIS layer	Data source
Protected areas – nature	Protected areas in the Sava River Basin ver.3 November 2011, the study together with its GIS database, International SRB Commission.
Population density	Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Population Density Grid, Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI); The World Bank; and Centro Internacional de Agricultura Tropical (CIAT). 2004. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw [date of download: December 2011]
Economic activities	CORINE 2000 (data acquired via ISRBC)
Special structures and objects	CORINE 2000 (data acquired via ISRBC)
Flood prone areas	Data acquired from the SRB countries official agencies (data acquired via ISRBC)
Subbasins	ISRBC
Digital elevation model	Shuttle Radar Topography Mission (SRTM), developed by the NASA/NGA/USGS, available from the CGIAR-CSI SRTM 90m database, http://srtm.csi.cgiar.org [date of download: December 2011]
Water drainage network	Global hydrological database (HydroSHEDS), developed by the Conservation Science Program of World Wildlife Fund (WWF) in partnership with the USGS, CIAT, The Nature Conservancy (TNC), and the Center for Environmental Systems Research (CESR), available from the http://www.worldwildlife.org/hydrosheds [date of download: December 2011]
General topographic data (administrative boundaries, main settlements and roads)	ESRI data
Satellite image	Google Earth

Adequate cultural heritage data has not been available for this demonstration of vulnerability analysis. So far, Slovenia developed a detailed methodology for identification of potential damage of cultural heritage and classification regarding flood vulnerability "Ocena poplavnega škodnega potenciala nepremične kulturne dediščine" (2011).

Data homogenization of classification schemas and geo-reference systems is performed for the whole study area. For the GIS database, the ETRS-LAEA coordinate reference system has been chosen (as recommended by EC JRC, 2001).

For further analysis gridding for all layers is done, so that extent and cell size is same as the original CORINE 2000 grid (cell size 100mx100m).

4.2.1 Vulnerability criteria – affected areas by Q_{100} flood scenario

The first step in vulnerability analysis is to locate the flood areas and then to find out affected population, economy, infrastructure and other objects as previously defined by vulnerability criteria. The results so far obtained are:

- Population affected by Q_{100} flood scenario,
- Land use affected by Q_{100} flood scenario,
- Special structures and objects affected by Q_{100} flood scenario, and
- Protected areas – nature affected by Q_{100} flood scenario.

The vulnerability analysis has solely demonstration character because the assessment of economic activities and cultural heritage information has not been available. Therefore, land use information has been used to evaluate economic activities, and protection of cultural heritage has been omitted from the analysis.

The spatial analyses for the Sava River Basin shown that the total area affected by Q_{100} flood scenario for the whole SRB (area of 98.000 km^2) is 9.400 km^2, and population affected by Q_{100} flood scenario for the whole SRB is 664.504 people. Spatial distribution of affected population is shown on Figure 4.2.

The total affected area by Q_{100} flood scenario for the whole SRB of various land use, special structures and objects, and of protected nature is given in Table 4.1. Spatial distribution of affected areas is shown in Figures 4.3, 4.4 and 4.5.

The tables that follow provide data about the spatial distribution of each of the four groups of results available for the areas affected by floods. The data refer to next four different groups of results: population, land use, special structures and objects and protected areas affected by Q_{100} flood scenario. Groups are indicated in the first column of the table, and the spatial distribution of each is presented with a certain value expressed in ha. All groups are further divided into subgroups, and the division continues up to the third level, which is the case with a group of Land Use. The division into three levels of this group corresponds to the CORINE classification.

Population Group is not divided while two groups of special structures and objects and protected areas have only one level of division. Each table has four corresponding picture displaying the spatial distribution for each group separately. The different groups of the available results are shown in the pictures with appropriate levels of division.

Table 4.2: Sava River Basin Area affected by Q_{100} flood scenario

Population (total number)	664.504				
Land use (ha) Agricultural areas	585.400	Arable land	211.634	Non-irrigated arable land	211.634
		Heterogeneous agricultural areas	304.137	Complex cultivation patterns	228.046
				Land principally occupied by agriculture	76.091
		Pastures	69.200	Pastures	69.200
		Permanent crops	429	Fruit trees and berry plantations	407
				Vineyards	22
Artificial surfaces	45.124	Artificial, non-agricultural vegetated areas	1.956	Green urban areas	1.083
				Sport and leisure facilities	873
		Industrial, commercial and transport units	5.283	Airports	198
				Industrial or commercial units	4.579
				Road and rail networks and associated land	506
		Mine, dump and construction sites	1.691	Construction sites	212
				Dump sites	740
				Mineral extraction sites	739
		Urban fabric	36.194	Continuous urban fabric	277
				Discontinuous urban fabric	35.917
Forest and semi natural areas	280.137	Forests	204.319	Broad-leaved forest	202.370
				Coniferous forest	442
				Mixed forest	1.507
		Scrub and/or herbaceous vegetation associations	75.615	Natural grasslands	90
				Transitional woodland-shrub	75.525
		Open spaces with little or no vegetation	203	Beaches, dunes, sands	195
				Sparsely vegetated areas	8
Water bodies	25.080	Inland waters	25.080	Water bodies	8.574
				Water courses	16.506
Wetlands	3.878	Inland wetlands	3.878	Inland marshes	3.878
Special structures and objects (ha)		Road and rail networks and associated land, Airports, Dump sites, Construction sites			1.656
Protected areas - nature (ha)		Natura 2000 sites important for the protection of avifauna			196.166
		Natura 2000 sites - Community importance for protection - Habitats Directive			68.571
		Natura 2000 sites important for the protection of avifauna and Natura 2000 sites - Community importance for protection - Habitats Directive			43.023

	Natura 2000 sites important for the protection of avifauna , Natura 2000 sites - Community importance for protection - Habitats Directive and “Ramsar sites” - Wetlands of International Importance	10.527
	Natura 2000 sites - Community importance for protection - Habitats Directive and Park of Nature	408
	Natura 2000 sites - Community importance for protection - Habitats Directive and “Ramsar sites” - Wetlands of International Importance	49.715
	Natura 2000 sites - Community importance for protection - Habitats Directive and UNESCO	8
	Park of Nature	687
	“Ramsar sites” - Wetlands of International Importance	7
	“Ramsar sites” - Wetlands of International Importance and other	1.037
	Other	1.209
	∑Areas-Natural	371.358

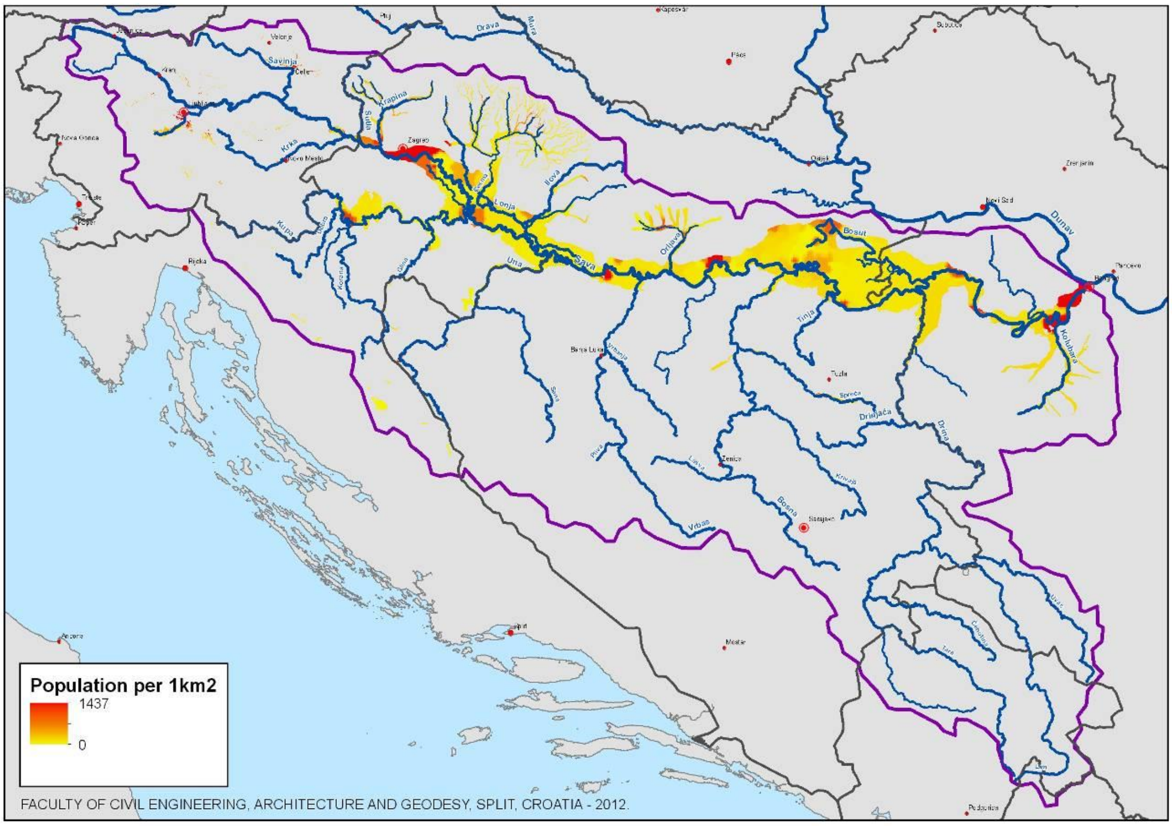


Figure 4.2: Sava River Basin Area - Population affected by Q_{100} flood scenario

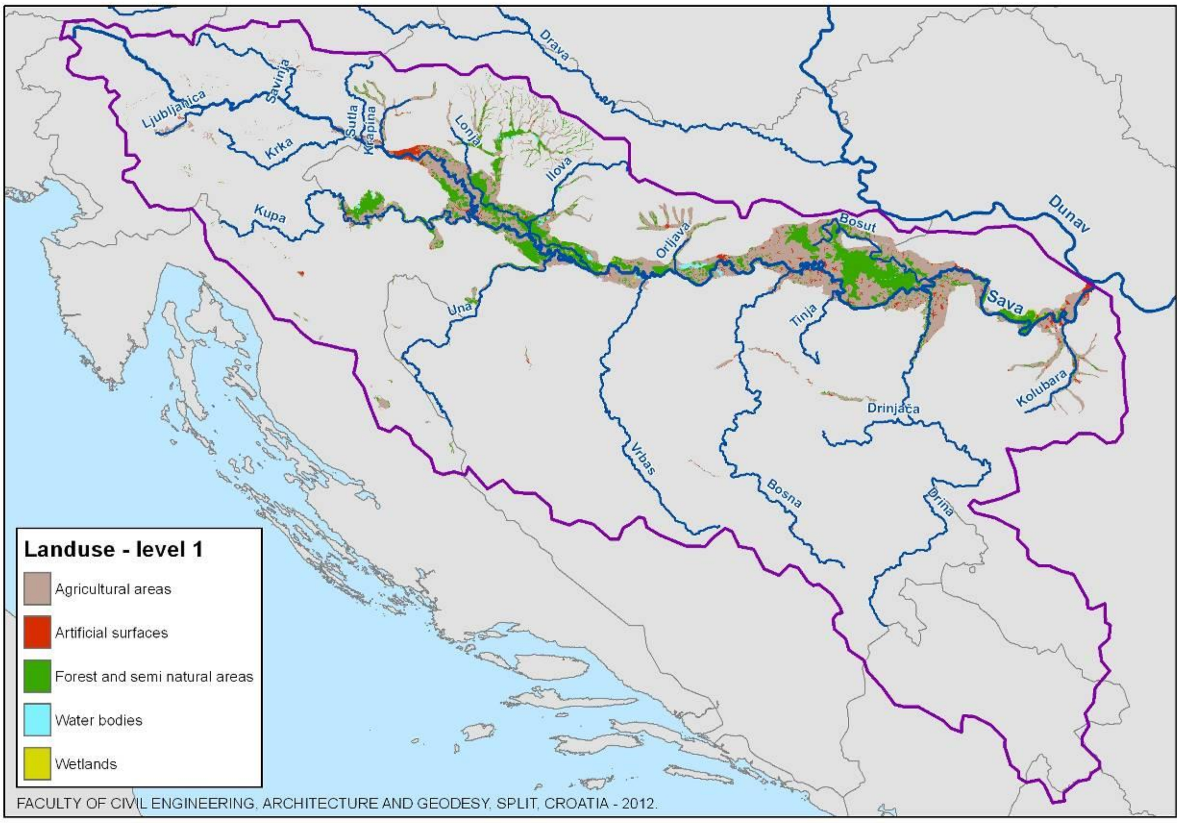


Figure 4.3: Sava River Basin Area - Land use affected by Q_{100} flood scenario

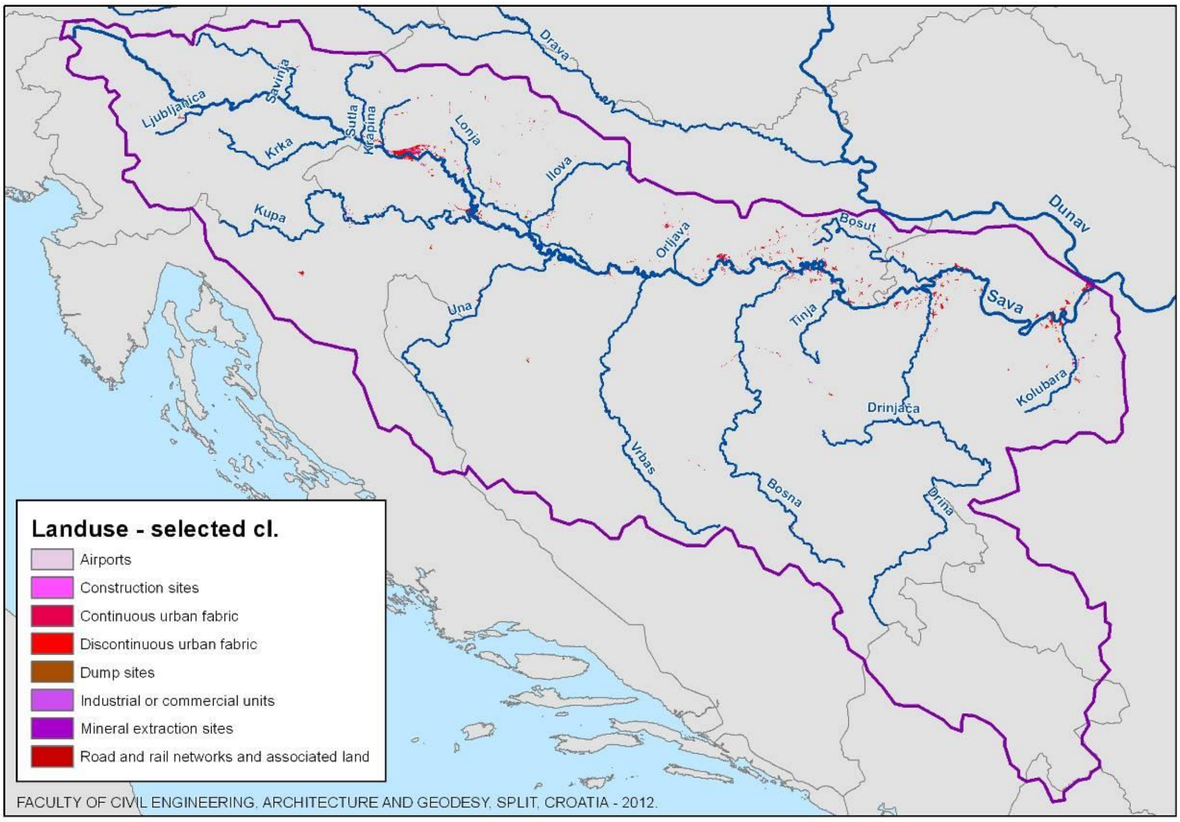


Figure 4.4: Sava River Basin Area - Special structures and objects affected by Q_{100} flood scenario

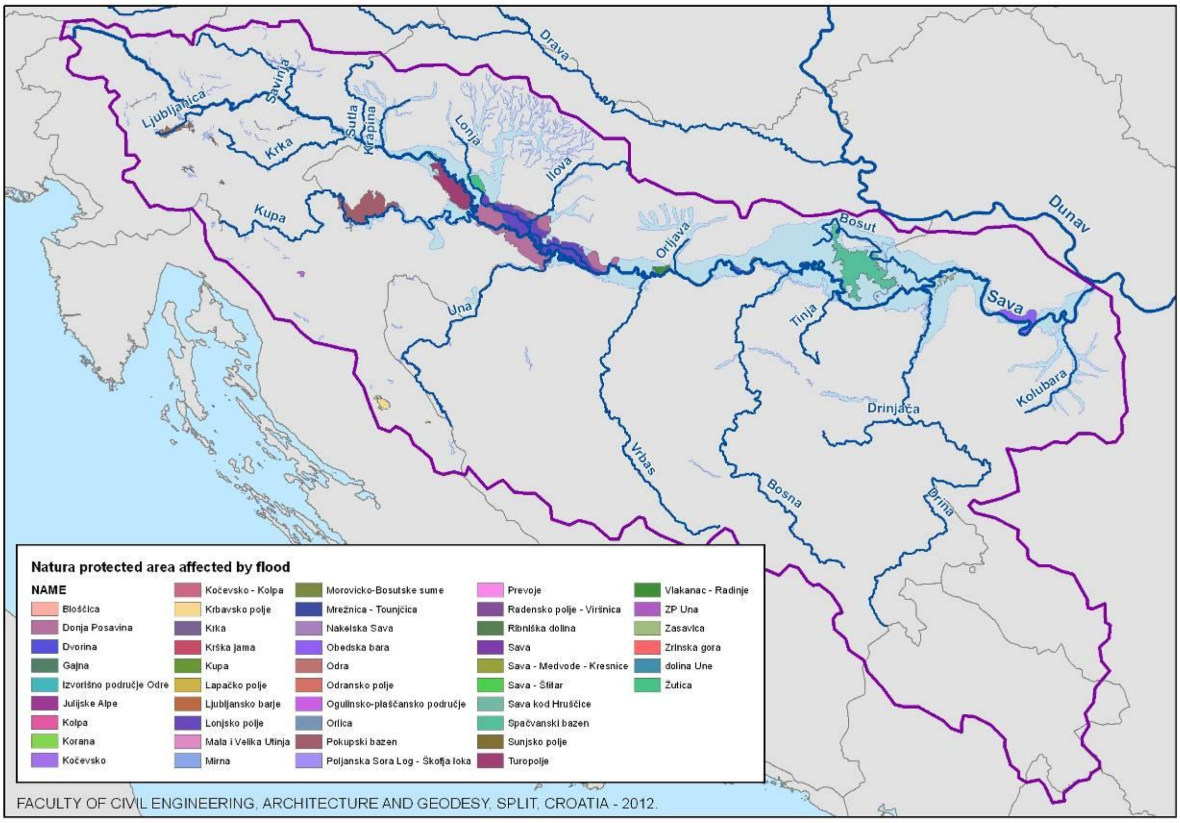


Figure 4.5: Sava River Basin Area - Protected areas – nature affected by Q_{100} flood scenario

4.2.2 The five pilot areas mapping

For the purpose of more detailed analyses and vulnerability criteria demonstration, the five pilot areas are chosen:

1. Wider area of Ljubljana
2. Zagreb and Sisak
3. Slavonski Brod and Bosanski Brod
4. Mouth of river Drina
5. Belgrade and mouth of river Kolubara

Wider area of LJubljana, Zagreb and Sisak, Slavonski Brod and Bosanski Brod, as well as Belgrade are chosen concerning their high population density and economic activities. The river Drina and river Kolubara mouths are selected as important spots regarding hydraulic characteristics.

For every pilot area, the following tables and maps show population, land use, special structures and objects, and protected areas affected by Q_{100} flood scenario.

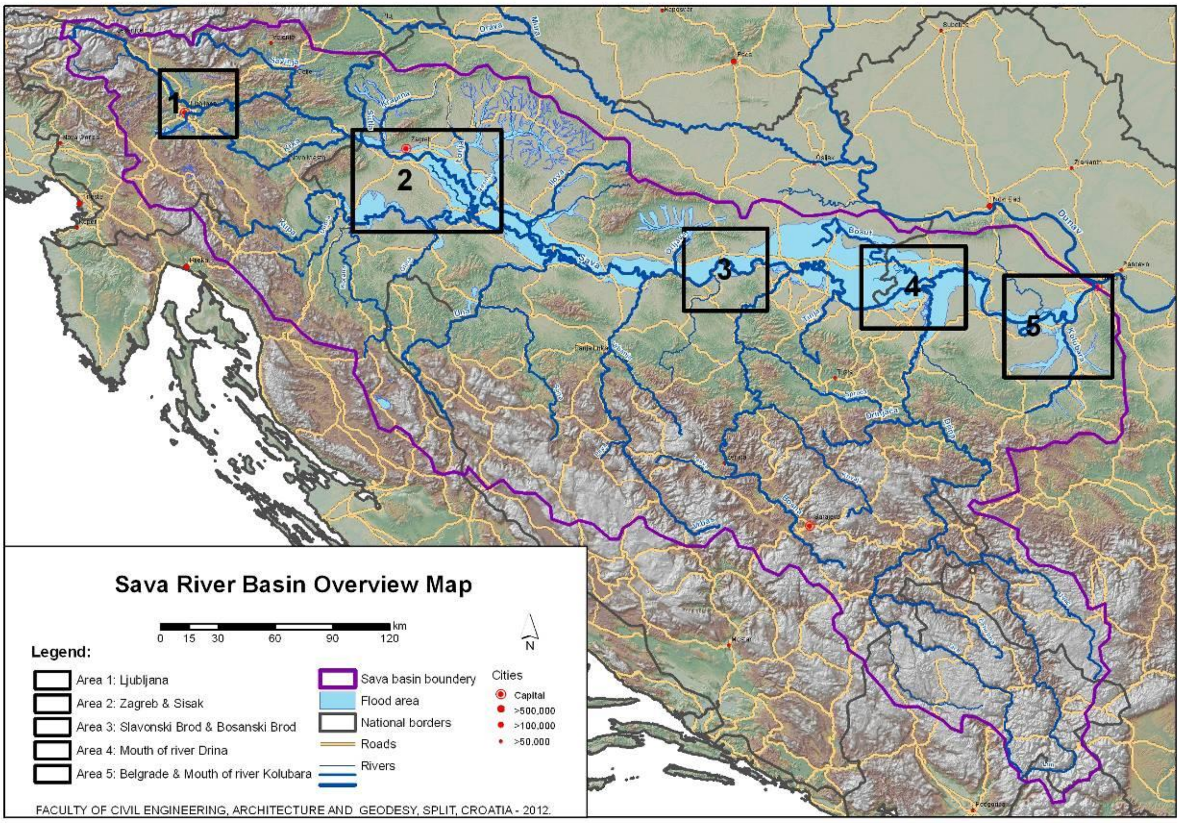
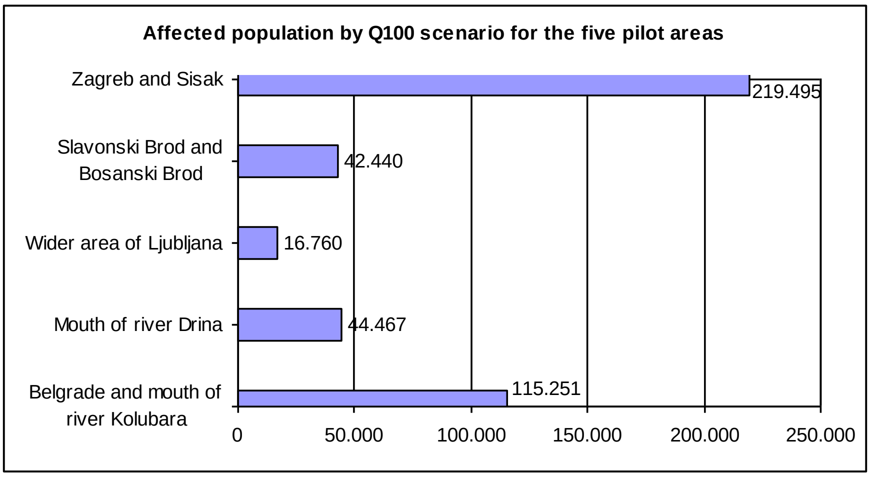


Figure 4.6: The five pilot areas mapping



4.2.2.1 Wider area of Ljubljana

Table 4.3: Area 1 - Ljubljana affected by Q_{100} flood scenario

Population (total number)	16.760				
Land use (ha)					
Agricultural areas	5.582	Arable land	601	Non-irrigated arable land	601
		Heterogeneous agricultural areas	3.788	Complex cultivation patterns	3.280
				Land principally occupied by agriculture	508
		Pastures	1.193	Pastures	1.193
Artificial surfaces	488	Artificial, non-agricultural vegetated areas	14	Sport and leisure facilities	14
		Industrial, commercial and transport units	76	Industrial or commercial units	47
				Road and rail networks and associated land	29
		Mine, dump and construction sites	6	Dump sites	6
		Urban fabric	392	Discontinuous urban fabric	392
Forest and semi natural areas	347	Forests	300	Broad-leaved forest	98
				Coniferous forest	47
				Mixed forest	155
		Scrub and/or herbaceous vegetation associations	47	Transitional woodland-shrub	47
Water bodies	109	Inland waters	109	Water courses	109
Special structures and objects (ha)		Road and rail networks and associated land, dump sites			35
Protected areas - nature (ha)		Natura 2000 sites important for the protection of avifauna			3.731
		Natura 2000 sites - Community importance for protection - Habitats Directive			3.884
		∑Areas-Natural			7.615

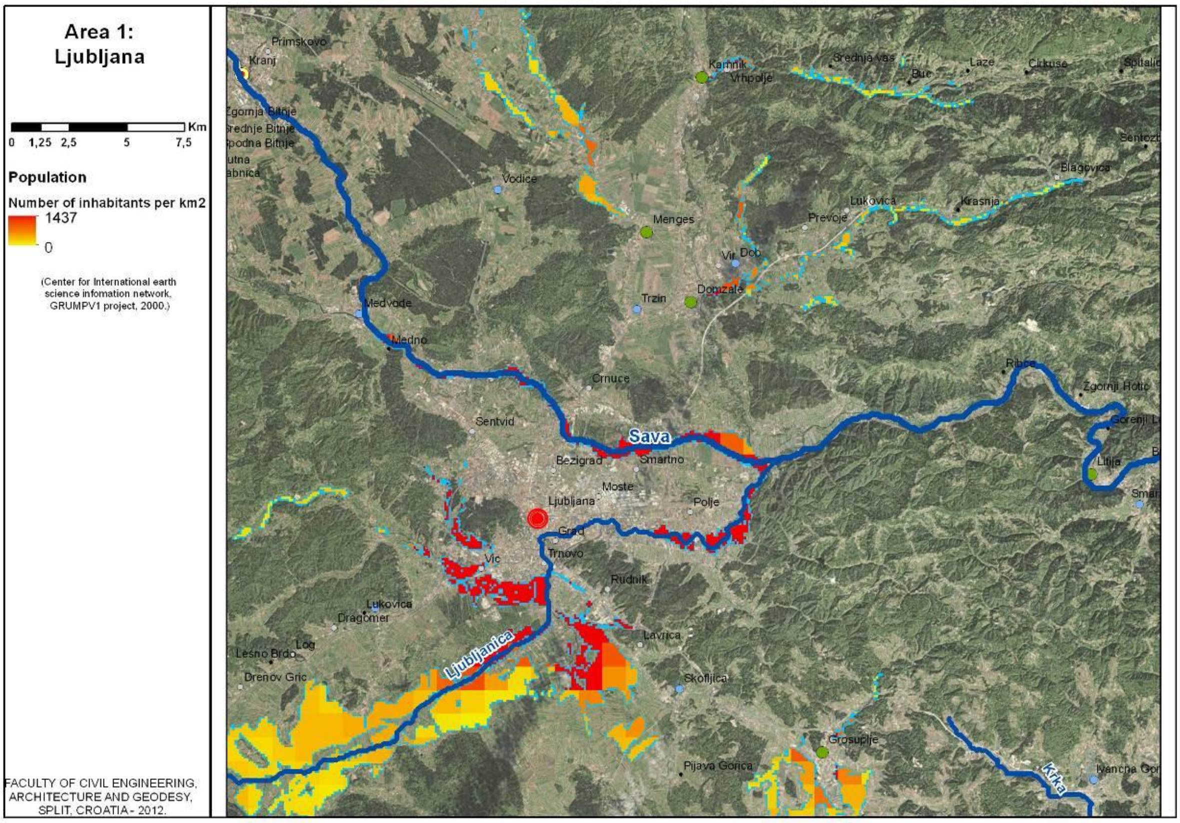


Figure 4.7: Wider area of Ljubljana - Population affected by Q_{100} flood scenario

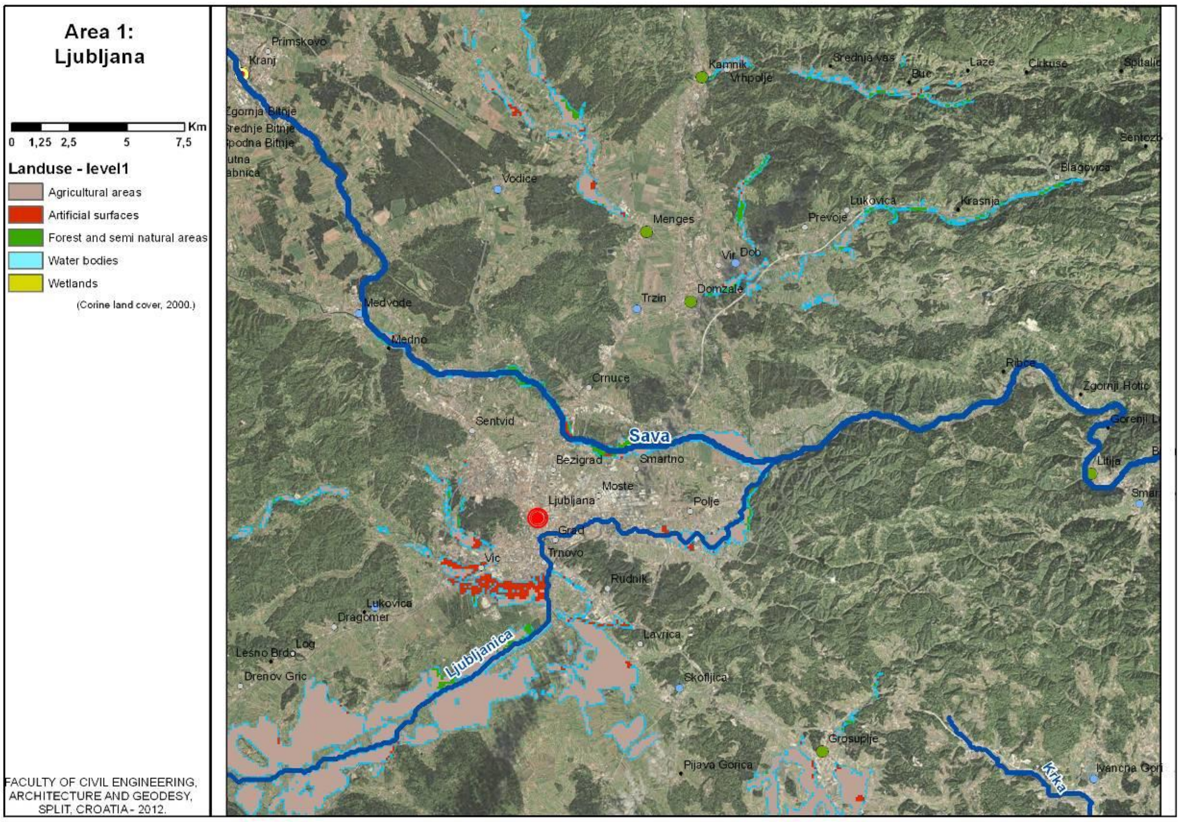


Figure 4.8: Wider area of Ljubljana - Land use affected by Q_{100} flood scenario

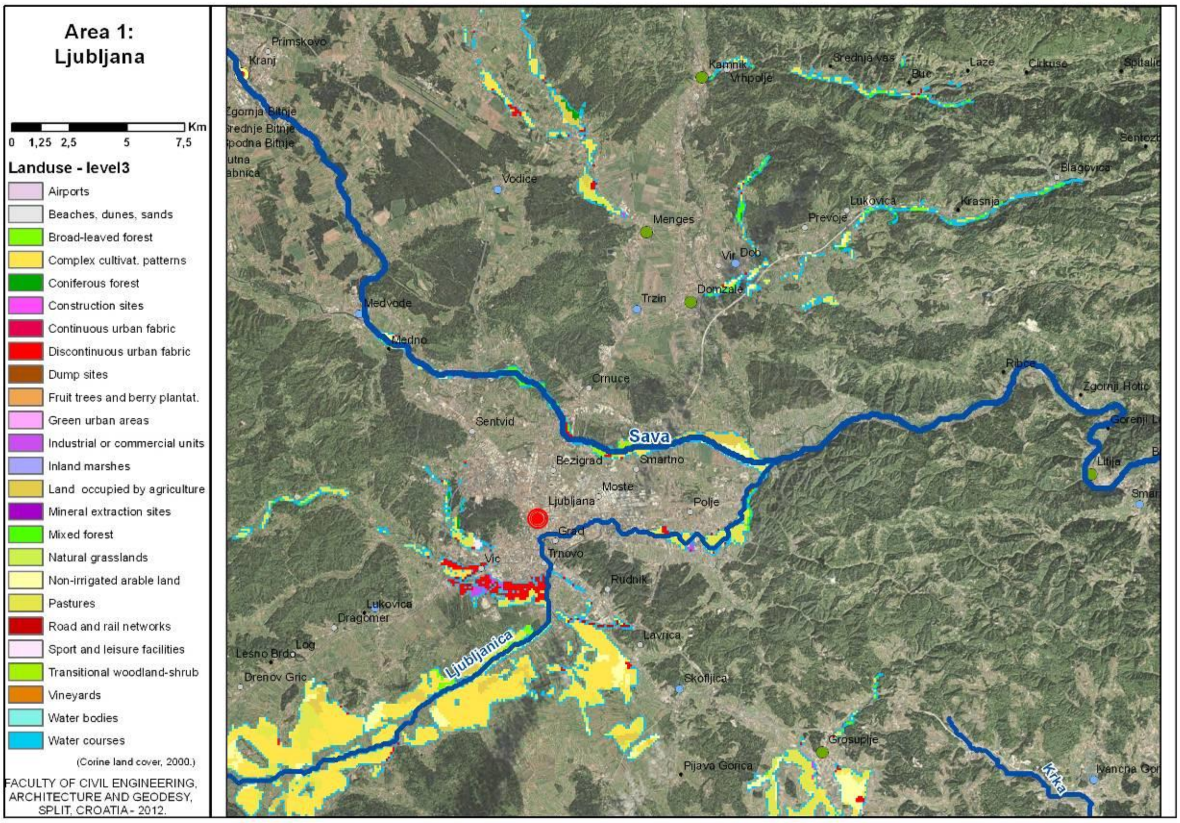


Figure 4.9: Wider area of Ljubljana - Land use affected by Q_{100} flood scenario

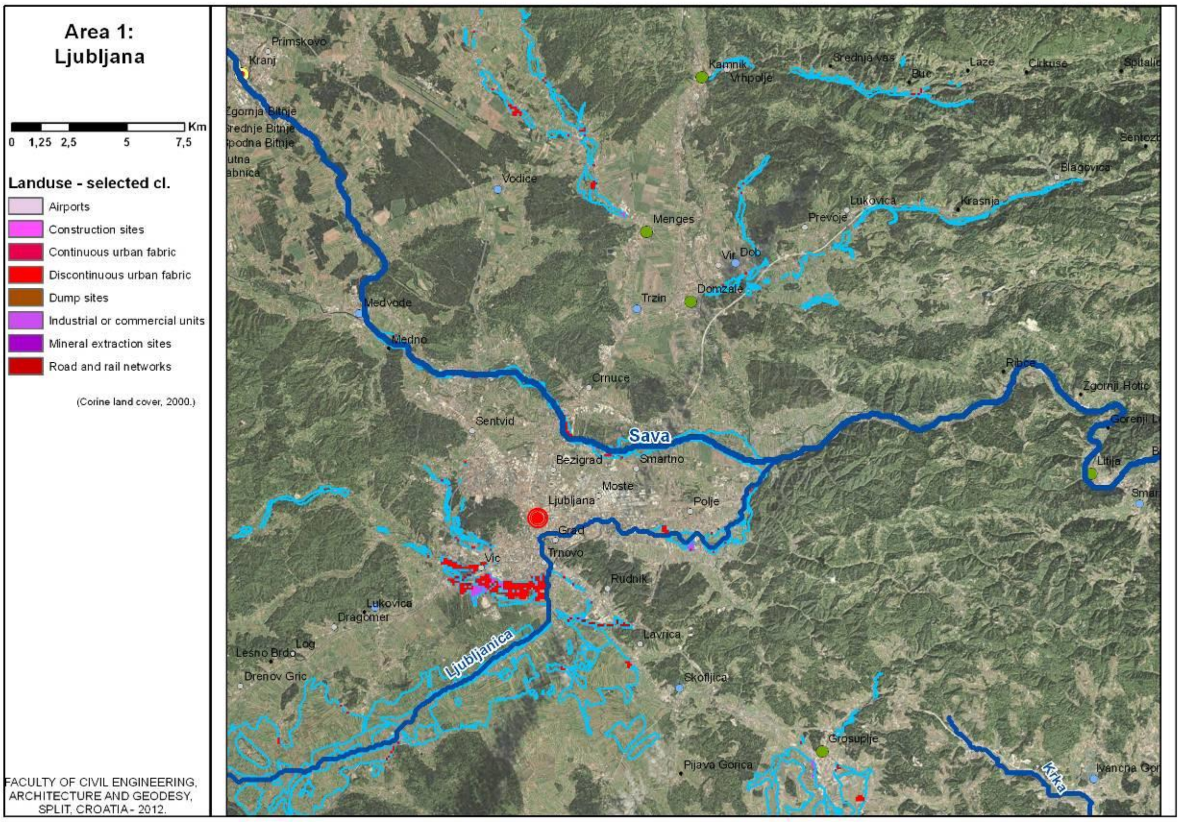


Figure 4.10: Wider area of Ljubljana - Special structures and objects affected by Q_{100} flood scenario

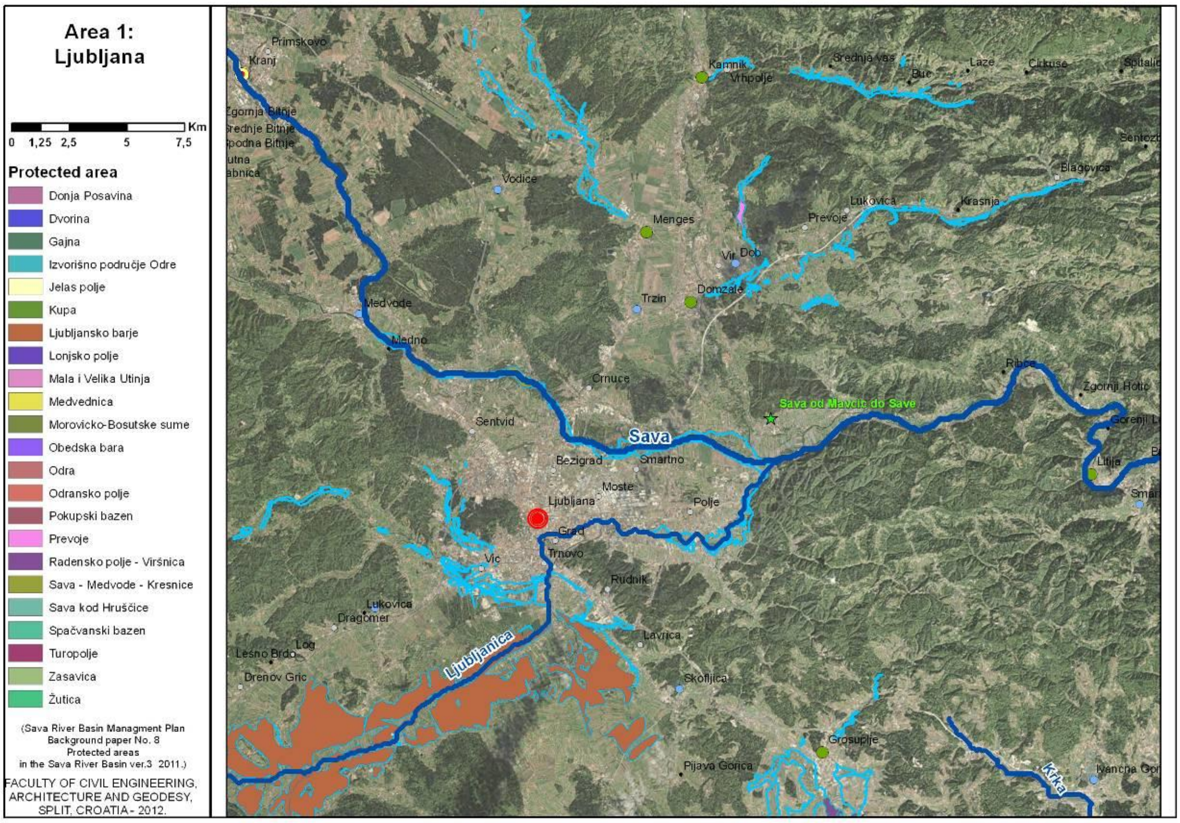


Figure 4.11: Wider area of Ljubljana - Protected areas – nature affected by Q_{100} flood scenario

4.2.2.2 Zagreb and Sisak area

Table 4.4: Area 2 - Zagreb and Sisak area affected by Q_{100} flood scenario

Population (total number)	219.495				
Land use (ha)					
Agricultural areas	100.034	Arable land	17.485	Non-irrigated arable land	17.485
		Heterogeneous agricultural areas	64.908	Complex cultivation patterns	47.913
				Land principally occupied by agriculture	16.995
		Pastures	17.641	Pastures	17.641
Artificial surfaces	13.128	Artificial, non-agricultural vegetated areas	446	Green urban areas	89
				Sport and leisure facilities	357
		Industrial, commercial and transport units	2.213	Airports	198
				Industrial or commercial units	1.857
				Road and rail networks and assoc. land	158
		Mine, dump and construction sites	335	Construction sites	87
				Dump sites	163
				Mineral extraction sites	85
		Urban fabric	10.134	Continuous urban fabric	201
				Discontinuous urban fabric	9.933
Forest and semi natural areas	56.711	Forests	36.945	Broad-leaved forest	36.700
				Coniferous forest	73
				Mixed forest	172
		Scrub and/or herbaceous vegetation associations	19.766	Transitional woodland-shrub	19.766
Water bodies	5.000	Inland waters	5.000	Water bodies	1.248
				Water courses	3.752
Wetlands	427	Inland wetlands	427	Inland marshes	427
Special structures and objects (ha)		Road and rail networks and associated land, airports, construction sites, dump sites			606
Protected areas - nature (ha)		Natura 2000 sites important for the protection of avifauna			63.816
		Natura 2000 sites - Community importance for protection - Habitats Directive			22.303
		Natura 2000 sites important for the protection of avifauna and Community importance for protection - Habitats Directive			136
		Natura 2000 sites - Community importance for protection - Habitats Directive and “Ramsar sites” - Wetlands of Internat. Importance			4.228
		Park of Nature			173
		“Ramsar sites” - Wetlands of Internat. Importance			7
		∑Areas-Natural			90.663

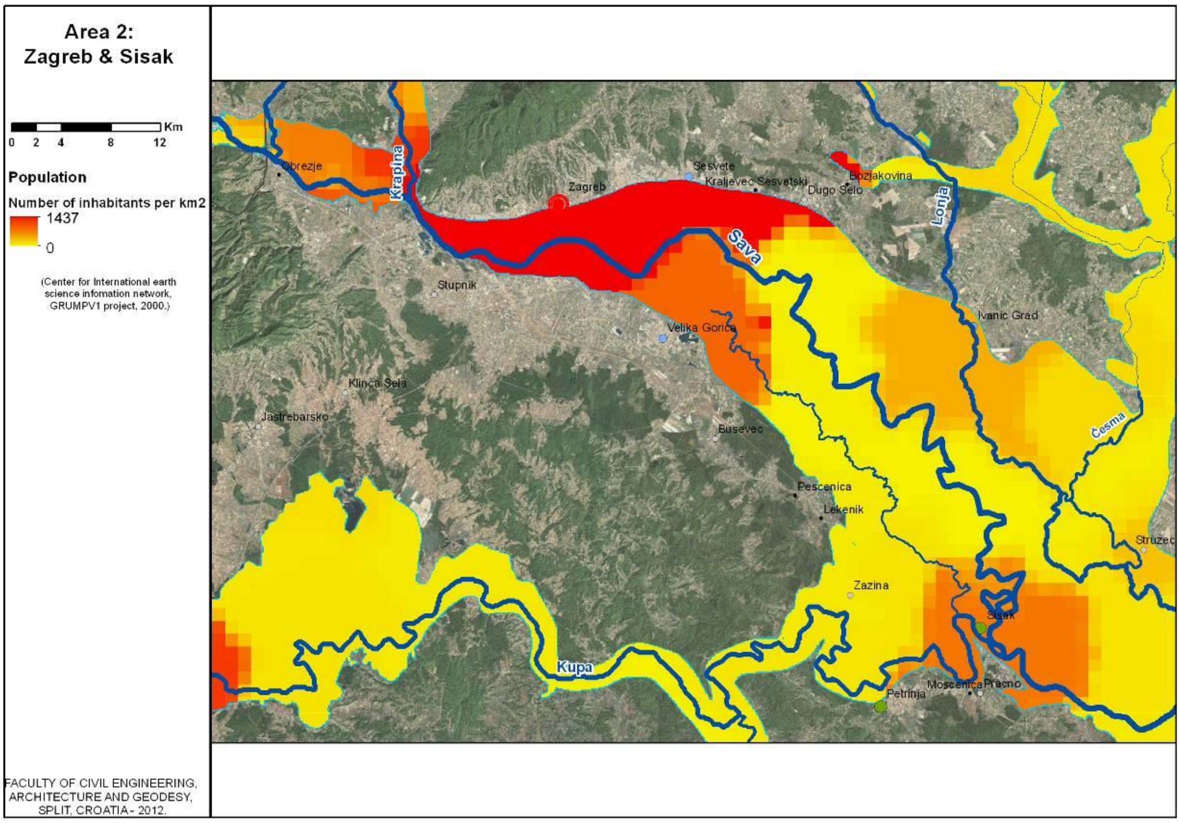


Figure 4.12: Zagreb and Sisak area - Population affected by Q_{100} flood scenario

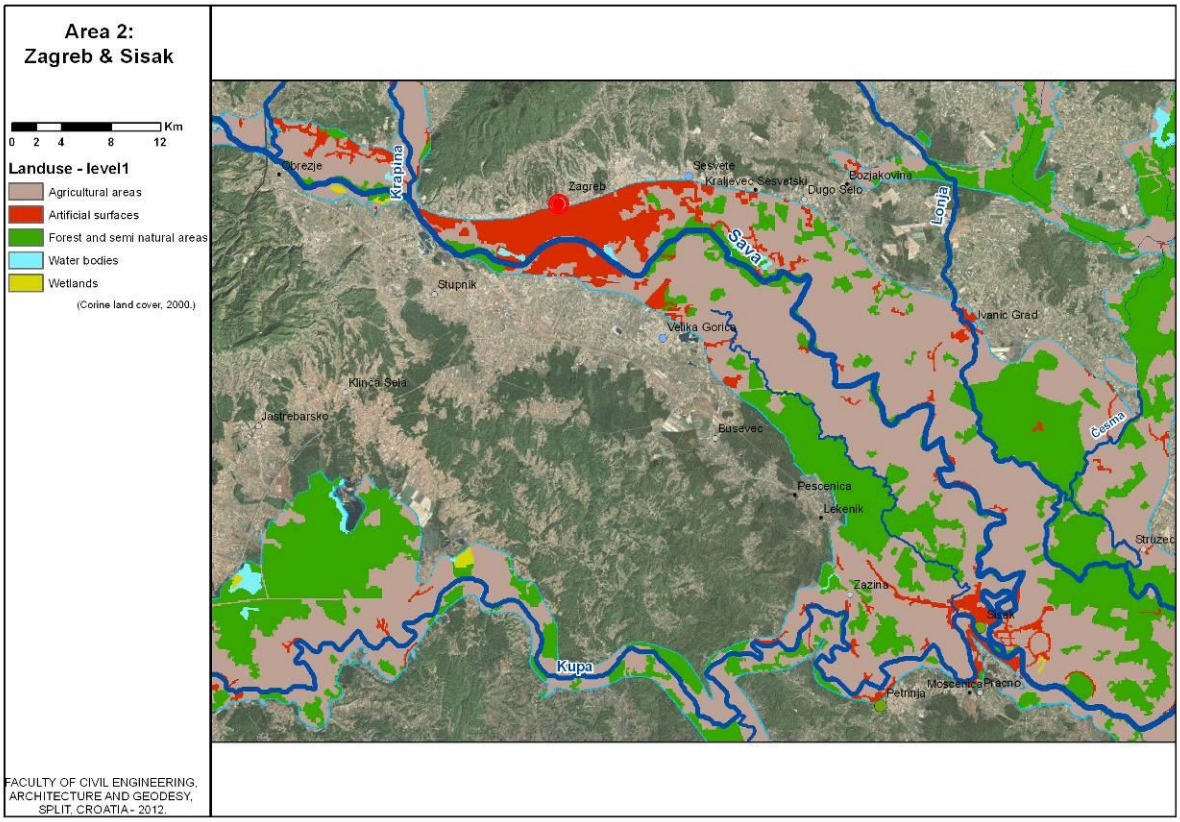


Figure 4.13: Zagreb and Sisak area - Land use affected by Q_{100} flood scenario

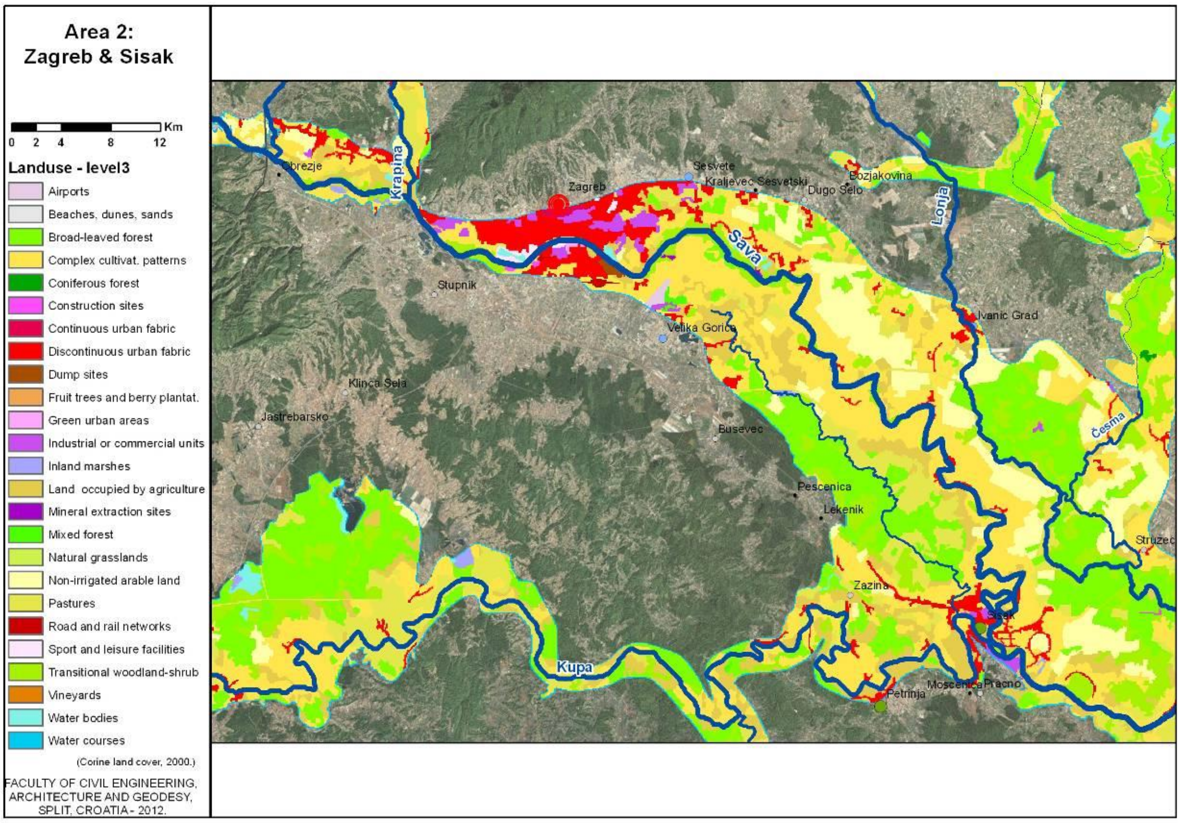


Figure 4.14: Zagreb and Sisak area - Land use affected by Q_{100} flood scenario

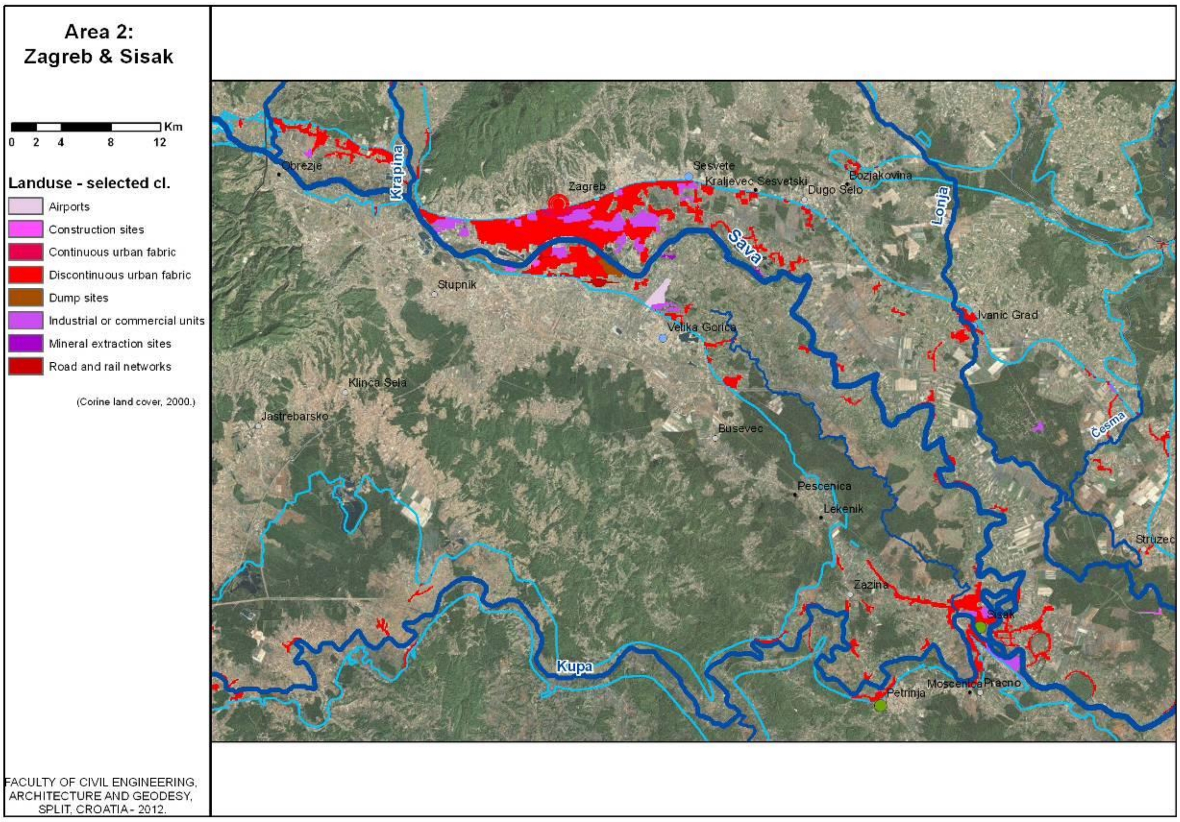


Figure 4.15: Zagreb and Sisak area - Special structures and objects affected by Q_{100} flood scenario

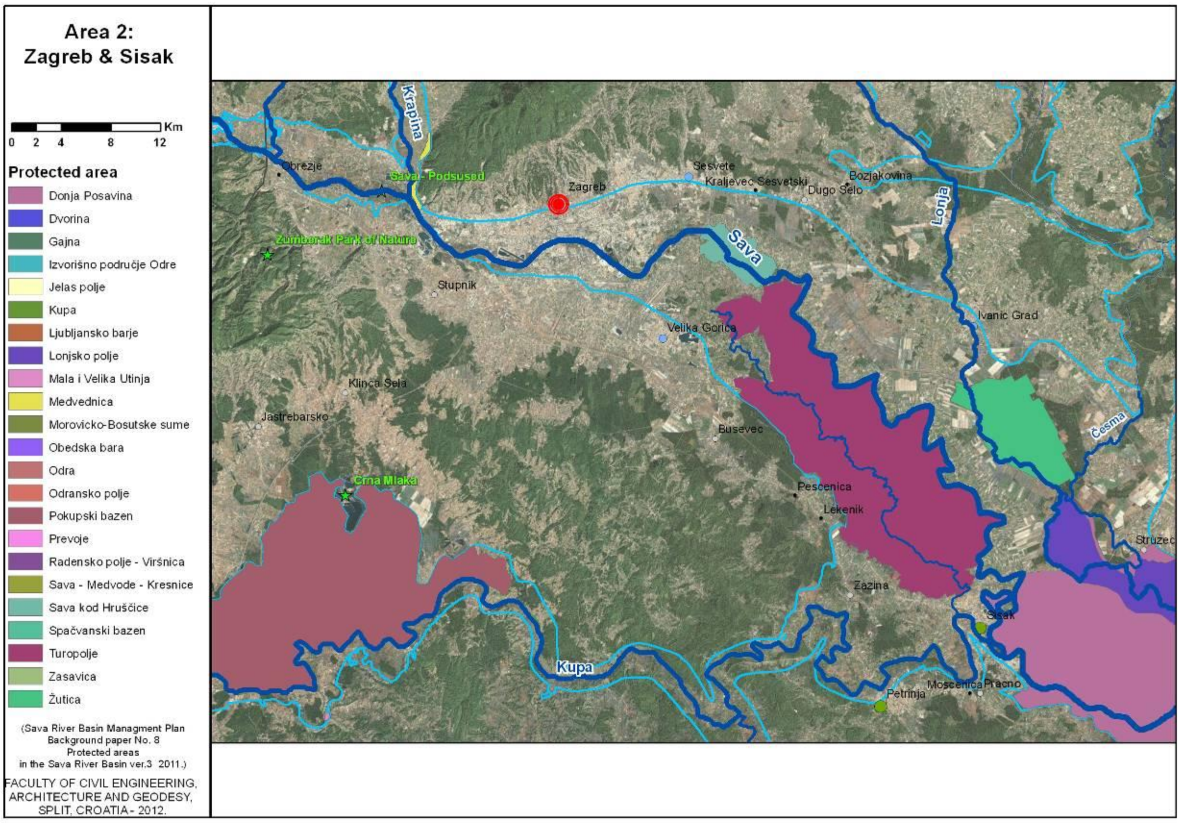


Figure 4.16: Zagreb and Sisak area - Protected areas – nature affected by Q_{100} flood scenario

4.2.2.3 Slavonski Brod and Bosanski Brod area

Table 4.5: Area 3 - Slavonski Brod i Bosanski Brod area affected by Q_{100} flood scenario

Population (total number)	42.440				
Land use (ha)					
Agricultural areas	34.660	Arable land	10.497	Non-irrigated arable land	10.497
		Heterogeneous agricultural areas	20.989	Complex cultivation patterns	17.738
				Land principally occupied by agriculture	3.251
		Pastures	3.174	Pastures	3.174
Artificial surfaces	3.136	Artificial, non-agricultural vegetated areas	62	Green urban areas	37
				Sport and leisure facilities	25
		Industrial, commercial and transport units	386	Industrial or commercial units	342
				Road and rail networks and associated land	44
		Mine, dump and construction sites	22	Mineral extraction sites	22
		Urban fabric	2.666	Continuous urban fabric	41
				Discontinuous urban fabric	2.625
Forest and semi natural areas	9.932	Forests	6.496	Broad-leaved forest	6.496
		Scrub and/or herbaceous vegetation associations	3.436	Transitional woodland-shrub	3.436
Water bodies	4.219	Inland waters	4.219	Water bodies	2.731
				Water courses	1.488
Wetlands	100	Inland wetlands	100	Inland marshes	100
Special structures and objects (ha)		Road and rail networks and associated land			44
Protected areas - nature (ha)		Natura 2000 sites important for the protection of avifauna			26.111
		Natura 2000 sites - Community importance for protection - Habitats Directive			3.351
		∑Areas-Natural			29.462

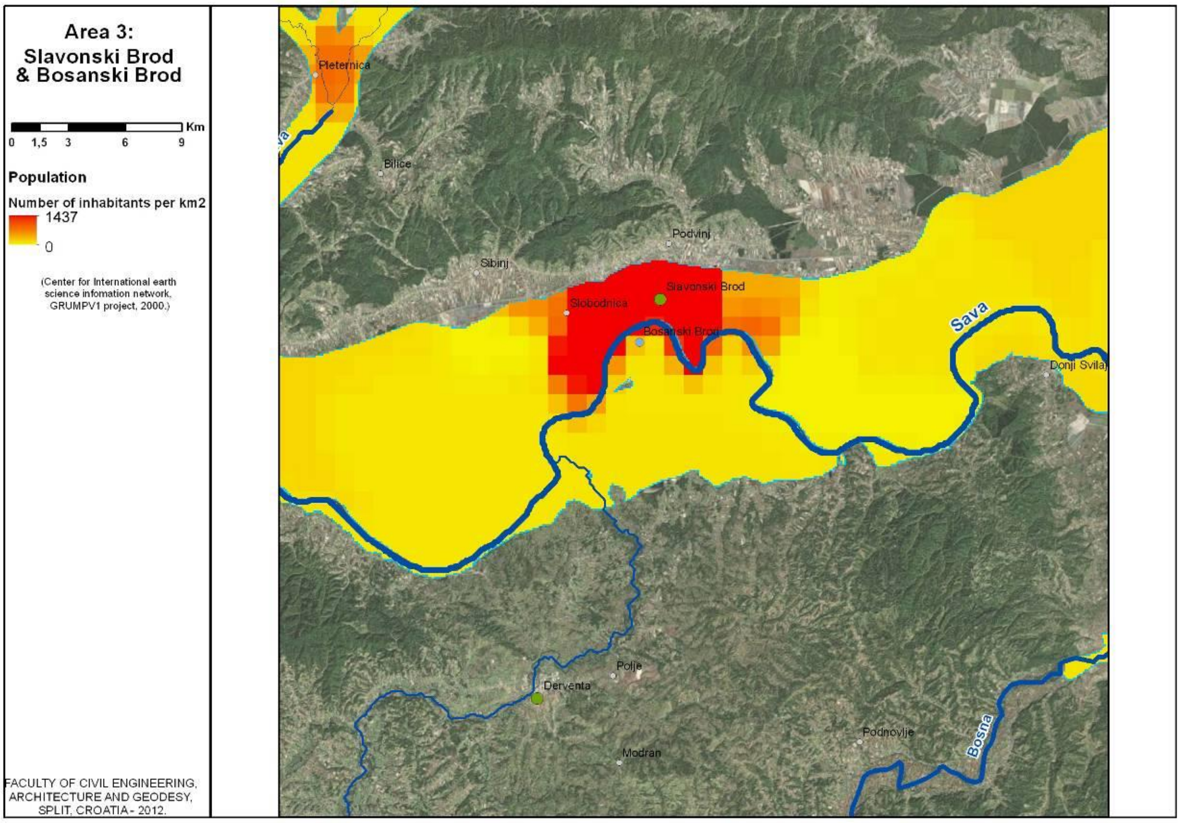


Figure 4.17: Slavonski Brod i Bosanski Brod area - Population affected by Q_{100} flood scenario

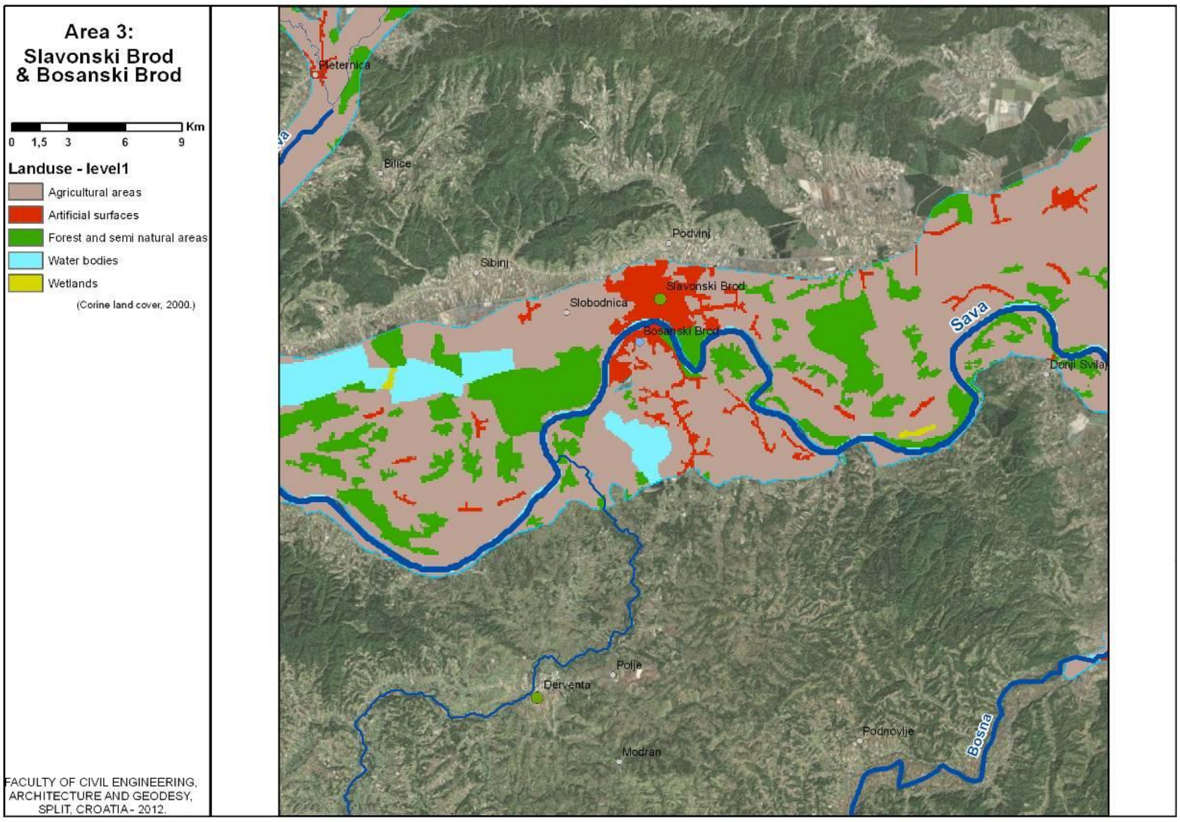


Figure 4.18: Slavonski Brod i Bosanski Brod area - Land use affected by Q_{100} flood scenario

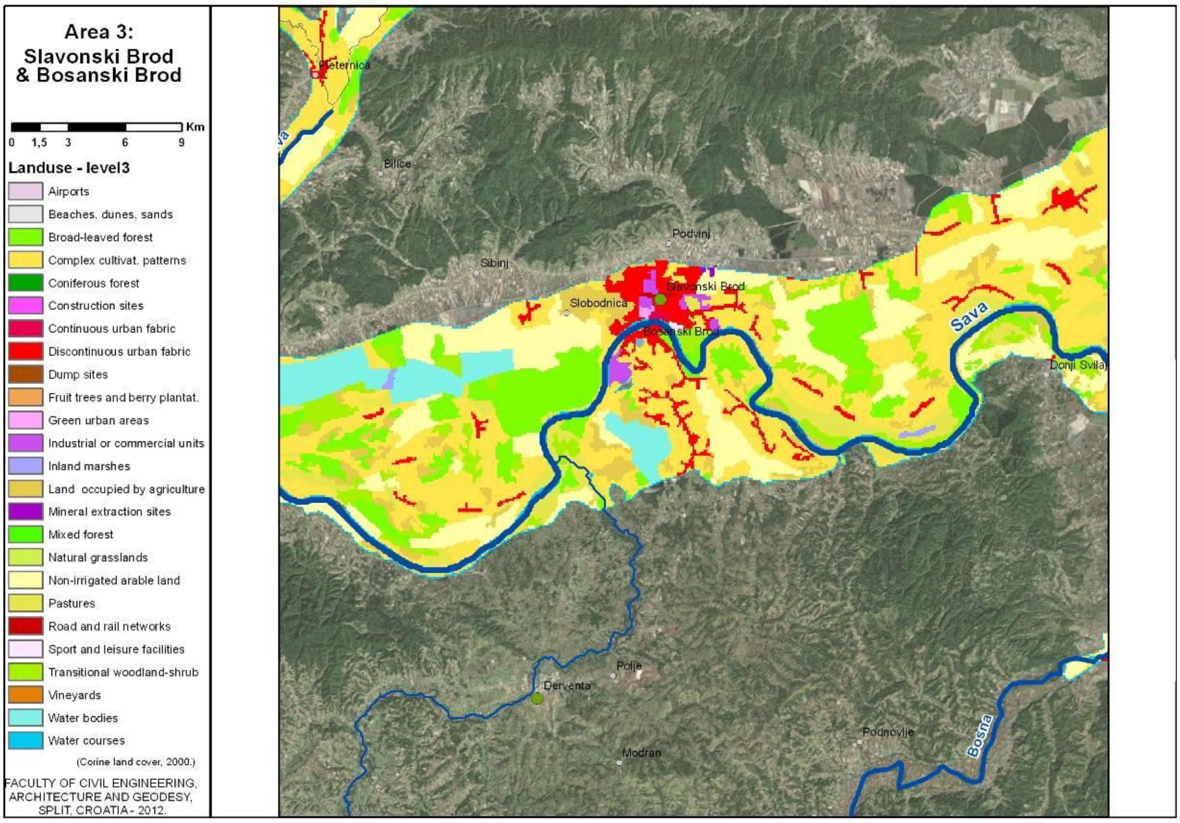


Figure 4.19: Slavonski Brod i Bosanski Brod area - Land use affected by Q_{100} flood scenario

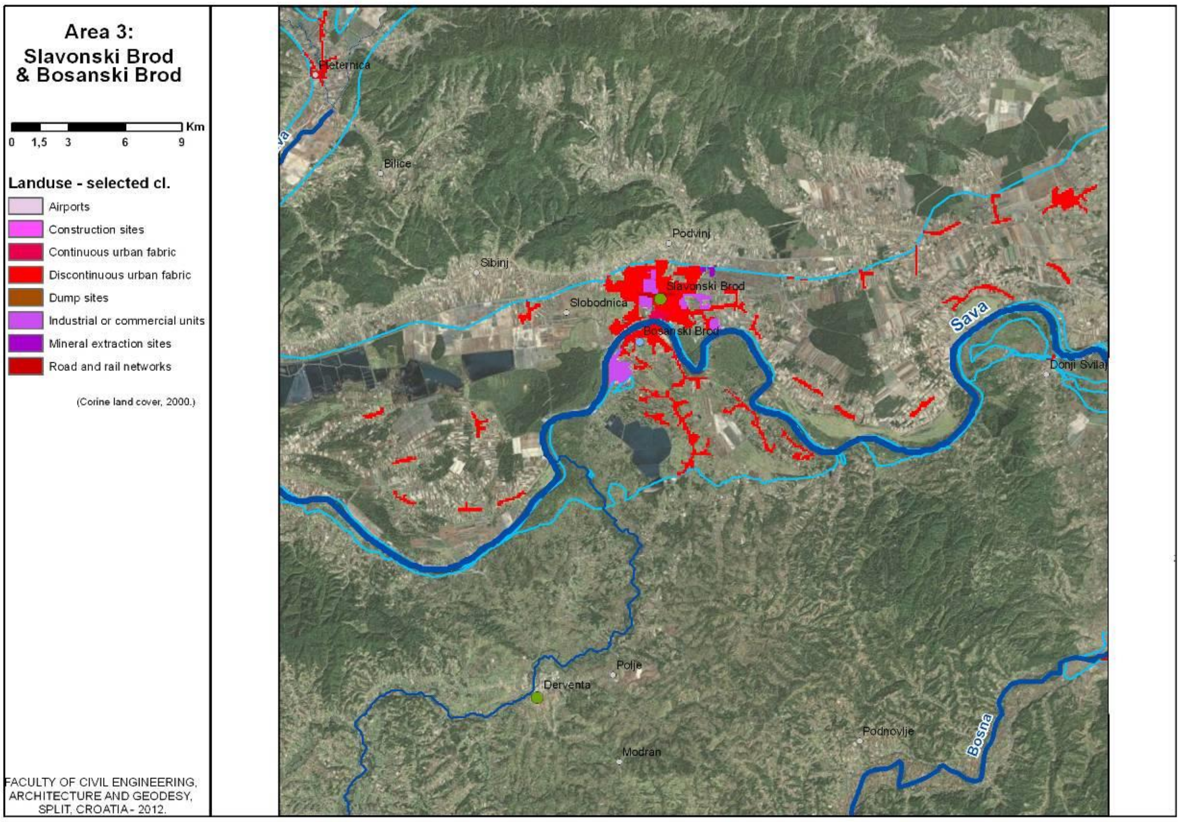


Figure 4.20: Slavonski Brod i Bosanski Brod area - Special structures and objects affected by Q_{100} flood scenario

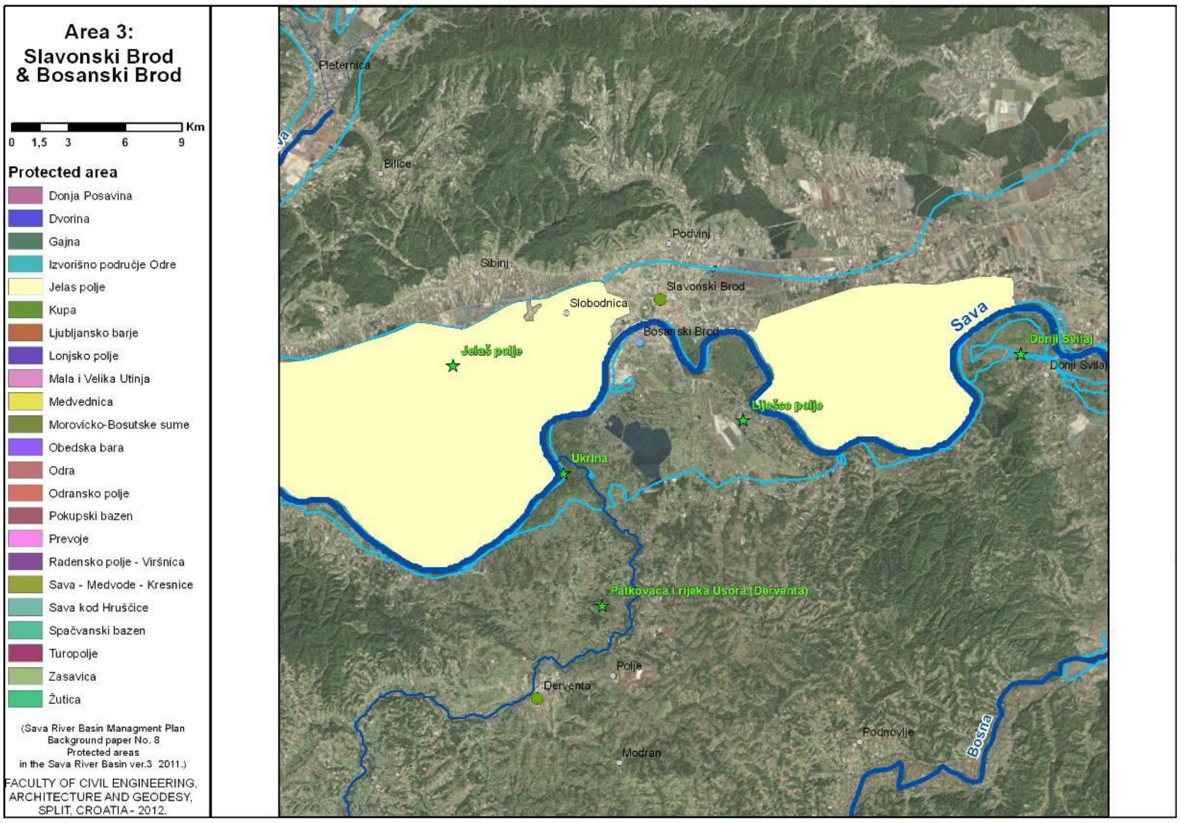


Figure 4.21: Slavonski Brod i Bosanski Brod area - Protected areas – nature affected by Q_{100} flood scenario

4.2.2.4 Mouth of river Drina area

Table 4.6: Area 4 - Mouth of river Drina area affected by Q_{100} flood scenario

Population (total number)	44.467				
Land use (ha)					
Agricultural areas	95.845	Arable land	75.183	Non-irrigated arable land	75.183
		Heterogeneous agricultural areas	20.069	Complex cultivation patterns	15.010
				Land principally occupied by agriculture	5.059
		Pastures	487	Pastures	487
		Permanent crops	106	Fruit trees and berry plantations	106
Artificial surfaces	5.593	Artificial, non-agricultural vegetated areas	86	Green urban areas	54
				Sport and leisure facilities	32
		Industrial, commercial and transport units	81	Industrial or commercial units	81
		Mine, dump and construction sites	27	Mineral extraction sites	27
		Urban fabric	5.399	Discontinuous urban fabric	5.399
Forest and semi natural areas	49.312	Forests	42.985	Broad-leaved forest	42.985
		Open spaces with little or no vegetation	102	Beaches, dunes, sands	102
		Scrub and/or herbaceous vegetation associations	6.225	Transitional woodland-shrub	6.225
Water bodies	2.221	Inland waters	2.221	Water bodies	133
				Water courses	2.088
Wetlands	155	Inland wetlands	155	Inland marshes	140
Protected areas - nature (ha)		Natura 2000 sites important for the protection of avifauna and Natura 2000 sites - Community importance for protection - Habitats Directive			16.888
		Natura 2000 sites - Community importance for protection - Habitats Directive			471
		Natura 2000 sites important for the protection of avifauna , Natura 2000 sites - Community importance for protection - Habitats Directive and “Ramsar sites” - Wetlands of International Importance			832
		∑Areas-Natural			18.191

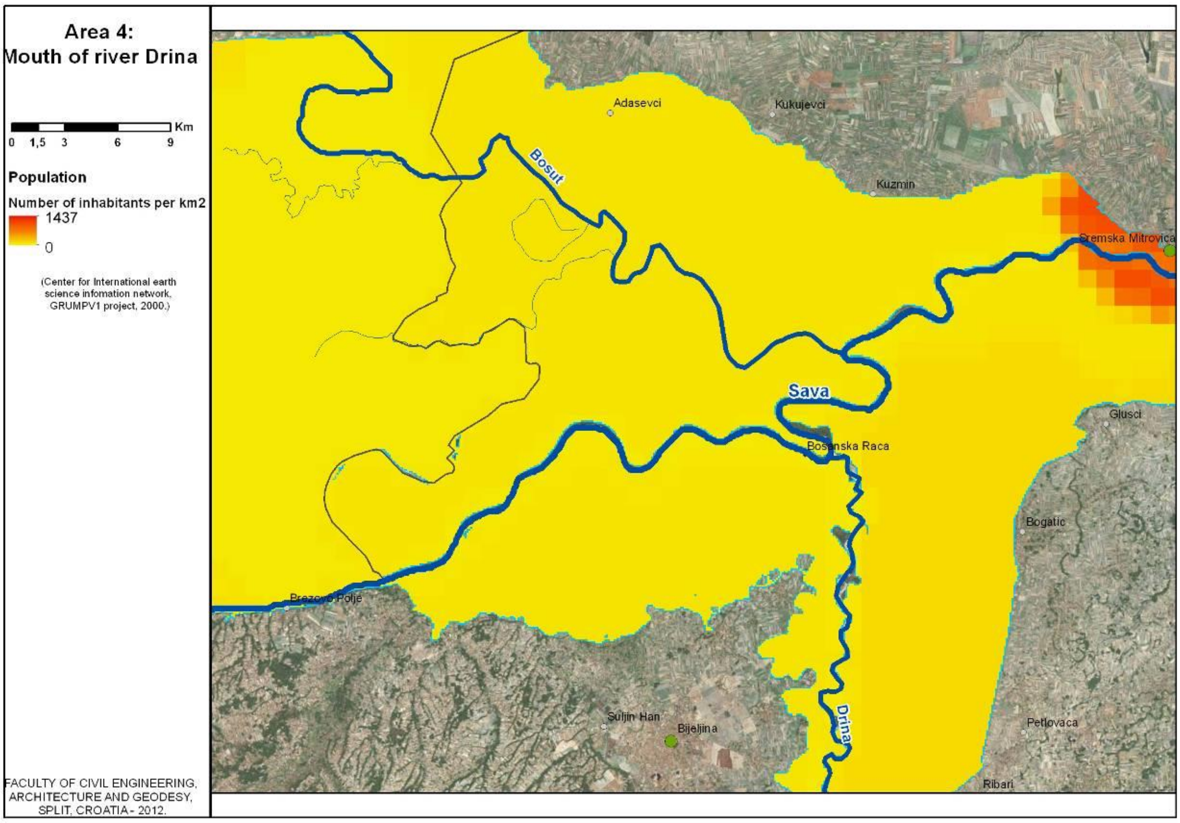


Figure 4.22: Mouth of river Drina area - Population affected by Q_{100} flood scenario

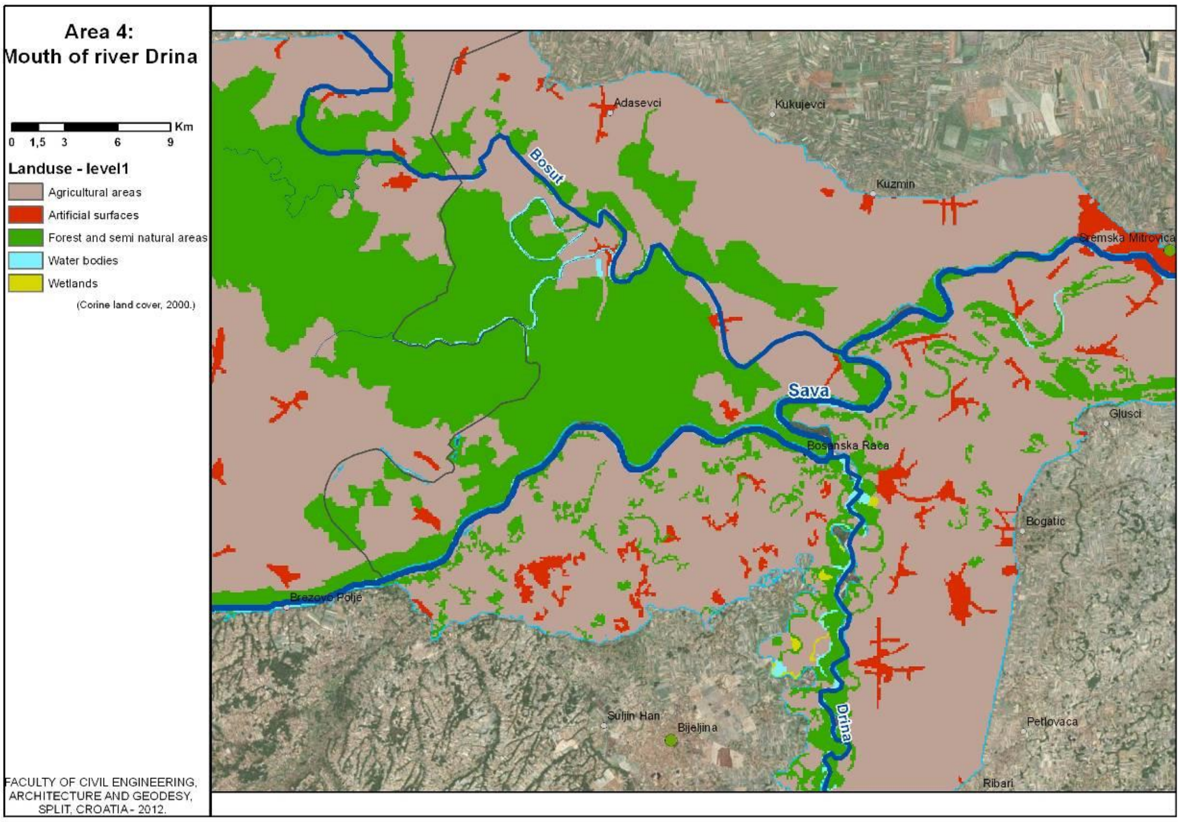


Figure 4.23: Mouth of river Drina area - Land use affected by Q_{100} flood scenario

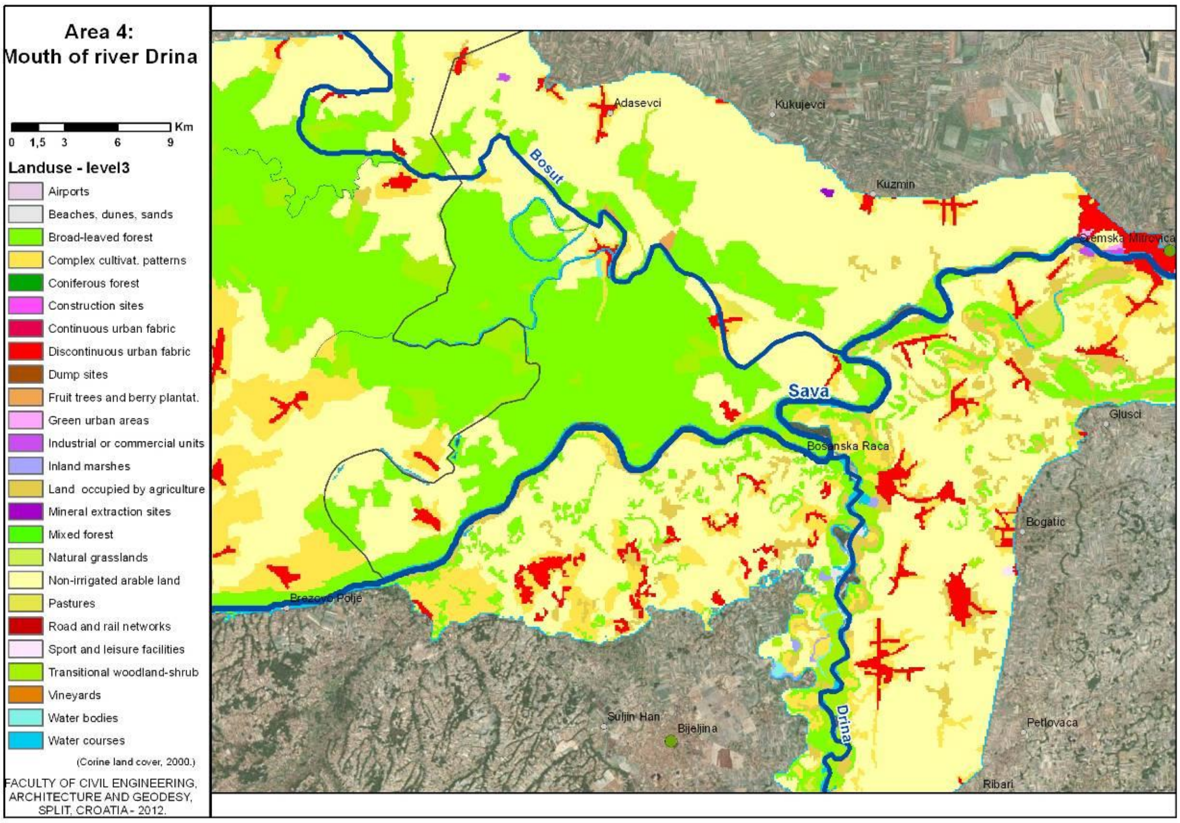


Figure 4.24: Mouth of river Drina area - Land use affected by Q_{100} flood scenario

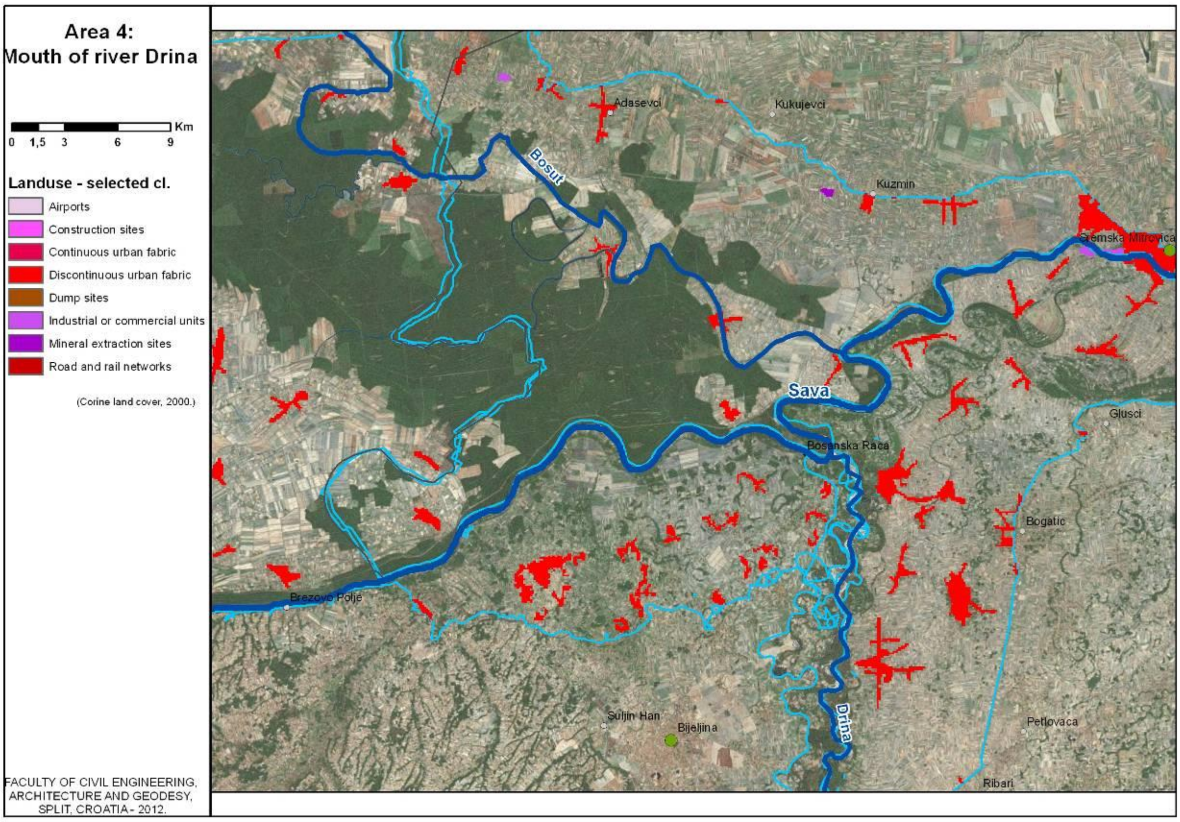


Figure 4.25: Mouth of river Drina area - Special structures and objects affected by Q_{100} flood scenario

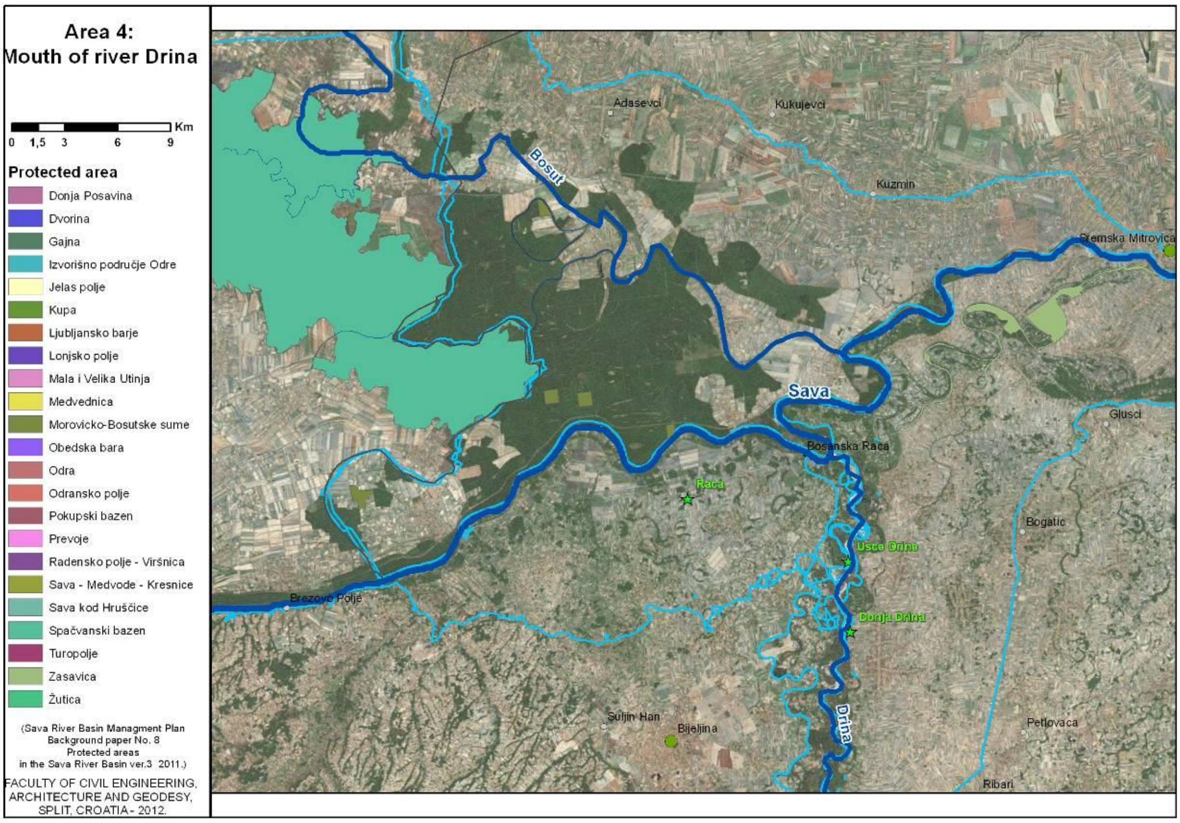


Figure 4.26: Mouth of river Drina area - Protected areas – nature affected by Q_{100} flood scenario

4.2.2.5 Belgrade and mouth of river Kolubara area

Table 4.7: Area 5 - Belgrade and mouth of river Kolubara area affected by Q_{100} flood scenario

Population (total number)	115.251				
Landuse (ha)					
Agricultural areas	39.280	Arable land	19.271	Non-irrigated arable land	19.271
		Heterogeneous agricultural areas	18.930	Complex cultivation patterns	10.724
				Land principally occupied by agriculture	8.206
		Pastures	937	Pastures	937
		Permanent crops	142	Fruit trees and berry plantations	142
Artificial surfaces	7.102	Artificial, non-agricultural vegetated areas	987	Green urban areas	802
				Sport and leisure facilities	185
		Industrial, commercial and transport units	1.010	Industrial or commercial units	840
				Road and rail networks and associated land	170
		Mine, dump and construction sites	851	Construction sites	125
				Dump sites	388
				Mineral extraction sites	338
		Urban fabric	4.254	Discontinuous urban fabric	4.254
Forest and semi natural areas	1.5327	Forests	12.375	Broad-leaved forest	12.375
		Scrub and/or herbaceous vegetation associations	2.952	Transitional woodland-shrub	2.952
Water bodies	668	Inland waters	668	Water bodies	268
				Water courses	400
Wetlands	1.244	Inland wetlands	1.244	Inland marshes	1.244
Special structures and objects (ha)		Road and rail networks and associated land			1.730
Protected areas - nature (ha)		Natura 2000 sites important for the protection of avifauna			1
		Natura 2000 sites - Community importance for protection - Habitats Directive, Natura 2000 sites important for the protection of avifauna and “Ramsar sites” - Wetlands of International Importance			9.106
		Other			1.144
		∑Areas-Natural			10.251

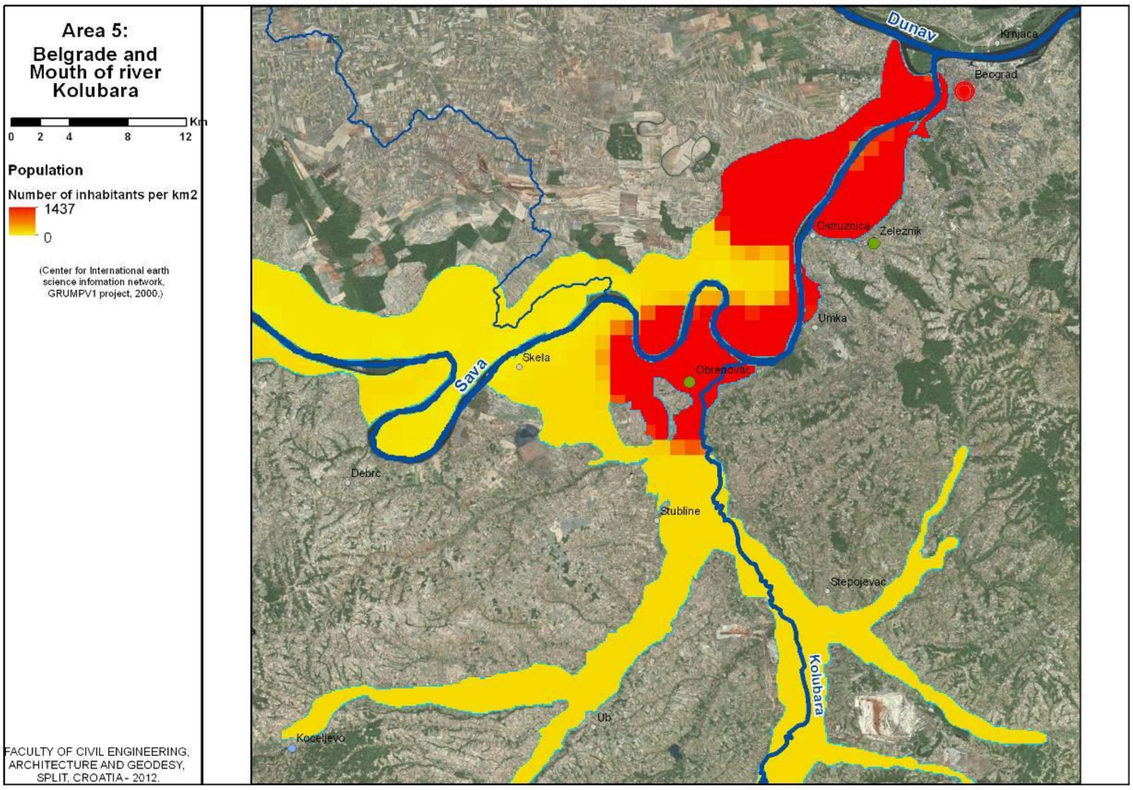


Figure 4.27: Belgrade and mouth of river Kolubara area - Population affected by Q_{100} flood scenario

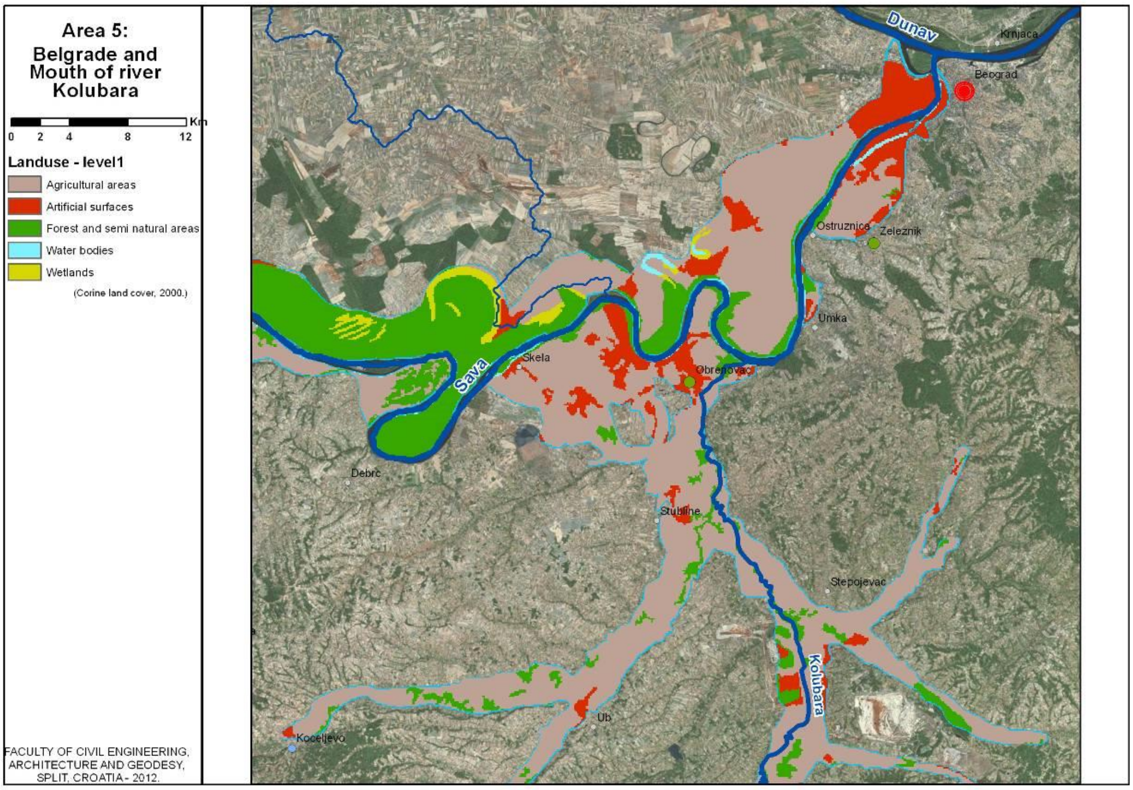


Figure 4.28: Belgrade and mouth of river Kolubara area - Land use affected by Q_{100} flood scenario

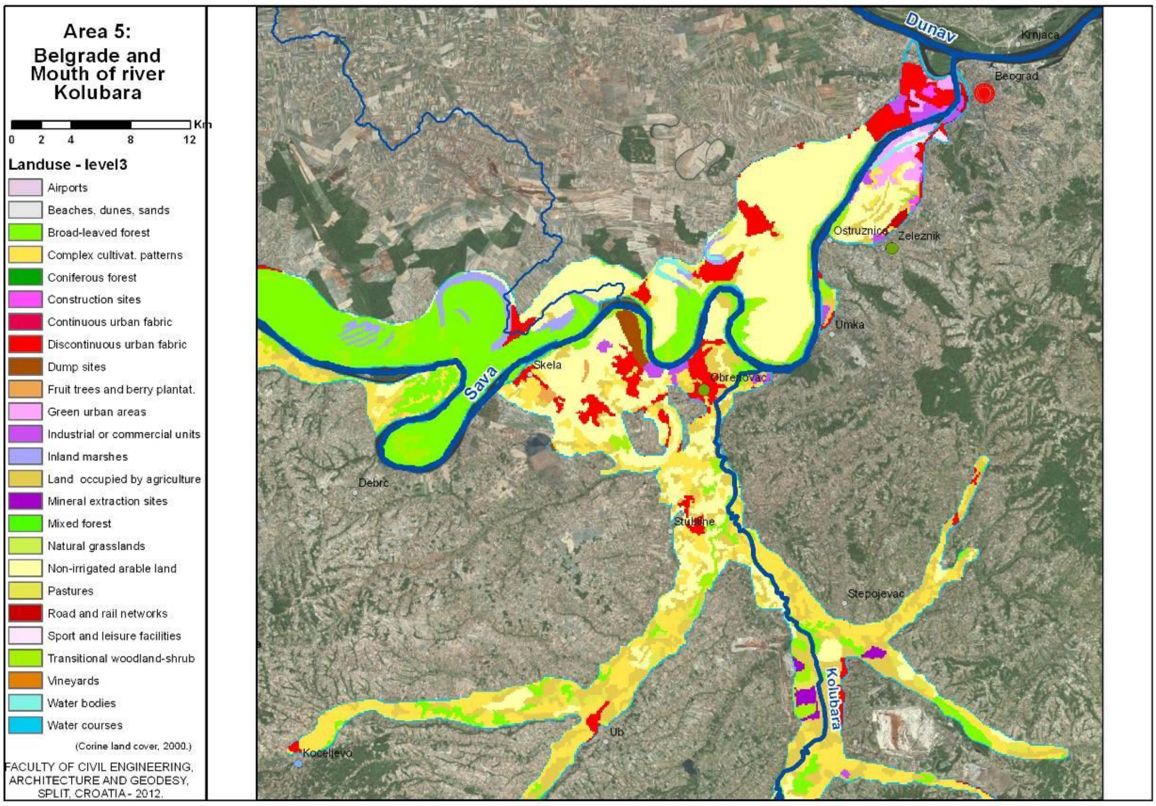


Figure 4.29: Belgrade and mouth of river Kolubara area - Land use affected by Q_{100} flood scenario

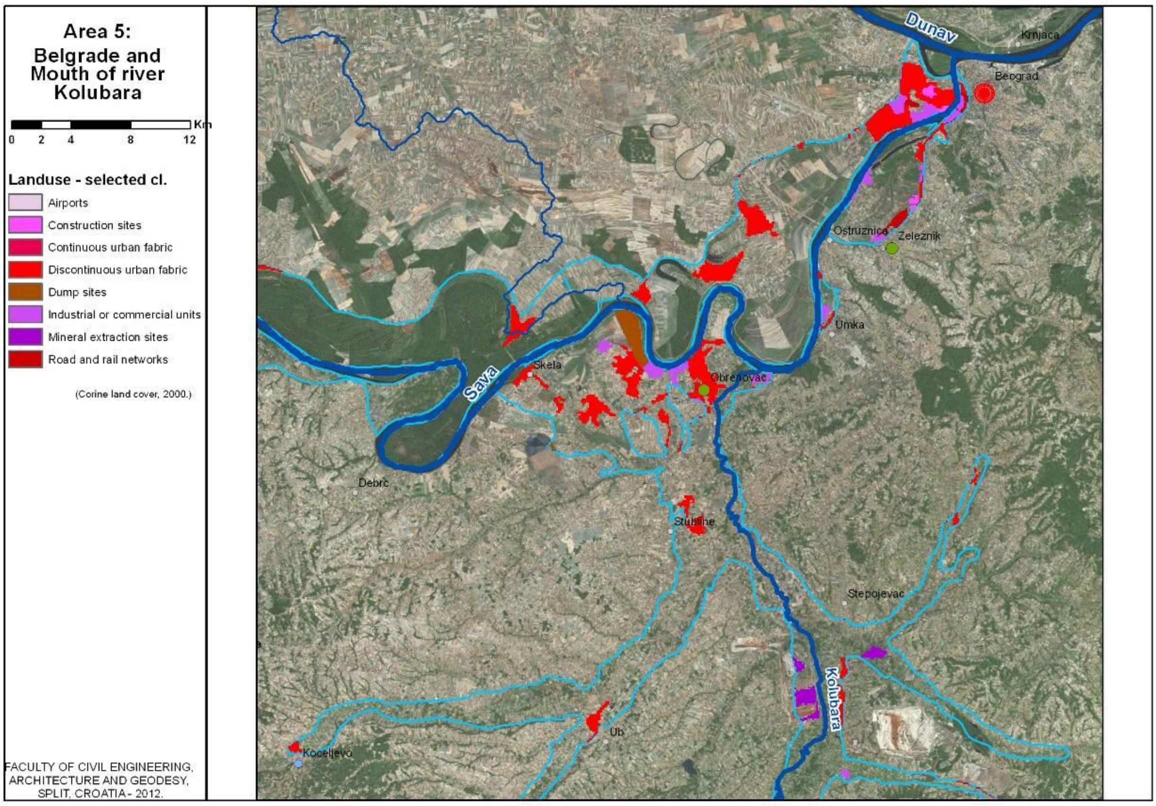


Figure 4.30: Belgrade and mouth of river Kolubara area - Special structures and objects affected by Q_{100} flood scenario

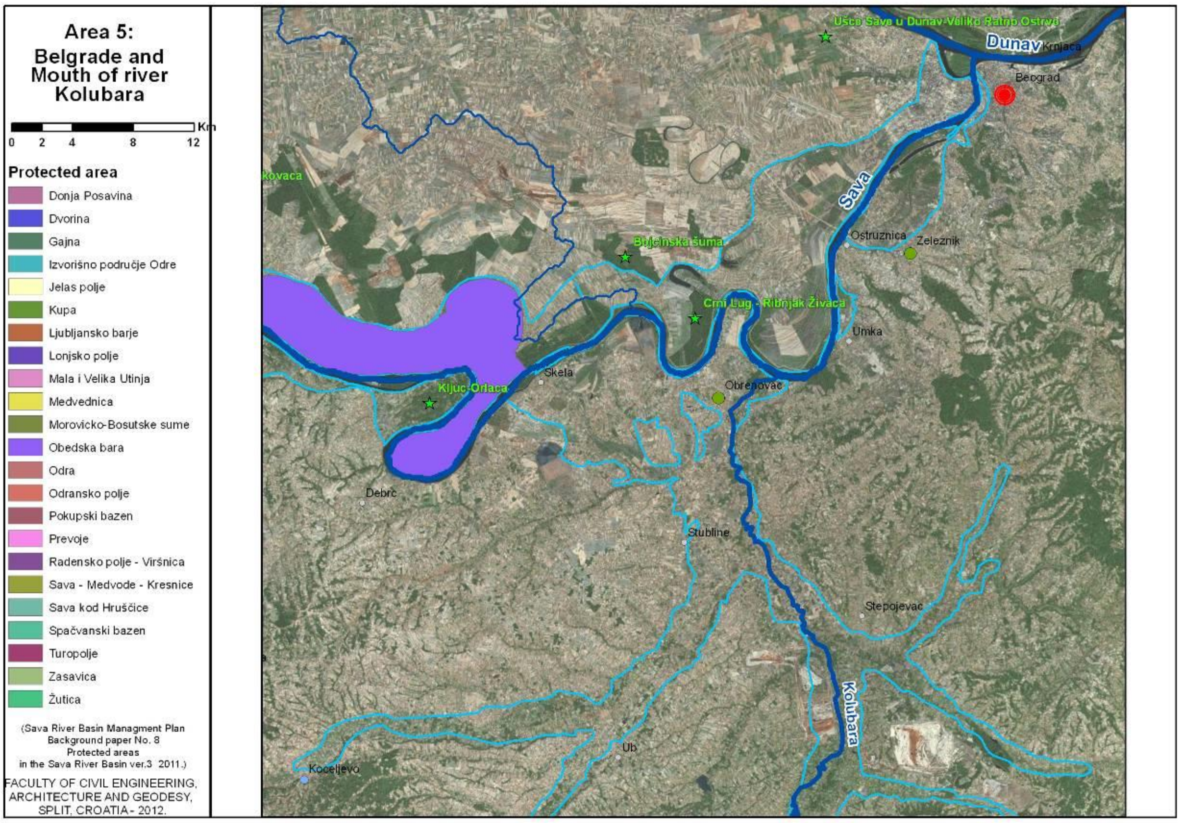


Figure 4.31: Belgrade and mouth of river Kolubara area - Protected areas – nature affected by Q_{100} flood scenario

4.3 Vulnerability analysis demonstration

Once the flood affected population, economy, infrastructure and other objects defined as vulnerability criteria have been estimated, the final vulnerability level can be calculated. The proposed methodology is demonstrated on the flood prone areas (Q_{100}) for the whole SRB, including all tributaries.

Each vulnerability criteria has to be categorized into three classes/levels of vulnerability, and the overall/final vulnerability level is calculated by overlaying all criteria. The final vulnerability level is the maximum value of the criteria levels. Figure 4.32 shows overlay of criteria and final vulnerability calculation.

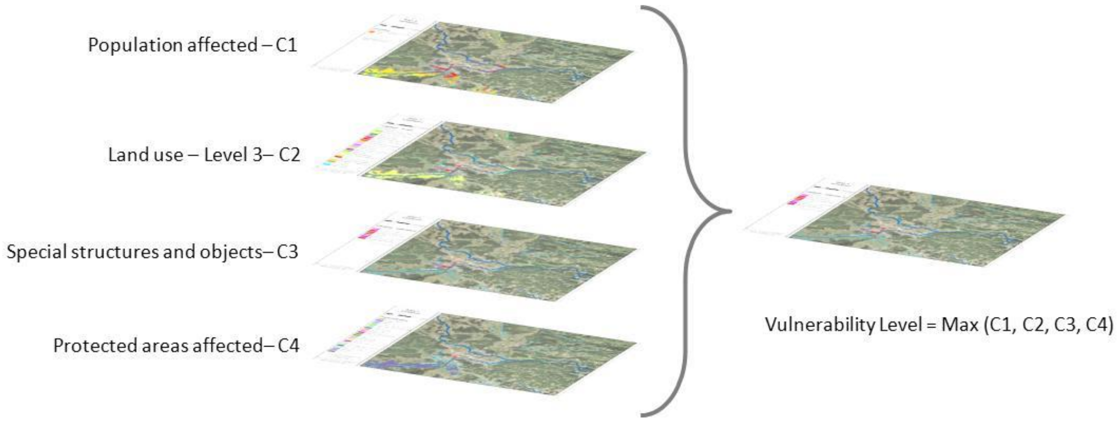


Figure 4.32: Example of vulnerability evaluation

4.3.1 Population density (criterion C1)

Format of source data is ESRI raster (GRID), Band Interleaved by Line (BIL) and ASCII (text) format. The raster data has 0.00833 degrees (30 arc seconds) resolution and contains population density (persons per square kilometre in year 2000, adjusted to match UN country totals). For further analysis gridding with cell size 100 x 100 m and SRB extent is done.

The population density is classified into three vulnerability classes/levels as shown in Table 4.8. The two classifications are applied. Classification 1 has classes accordingly to the proposed methodology in 4.1. Classification 2 with the class limit of 300 inhabitants per km^2 is introduced for the testing of Classification 1.

Table 4.8: Population density: vulnerability classification

Vulnerability classes/level	Classification 1 Population density (number of inhabitants per km2)	Classification 2 Population density (number of inhabitants per km2)
1	1-100	1-100
2	101-500	101-300
3	>500	>300

The resulting reclassified grid for the population density has resulted in the flood vulnerability figures shown in Table 4.9 and areas shown in the Annex, Figures A1 and A2.

Table 4.9: Population density: vulnerability classification of the affected areas by Q_{100} flood scenario

POPULATION DENSITY (C1)	no vulnerability	1 – low vulnerability	2 – moderate vulnerability	3 – high vulnerability	Σ (Q_{100} area)
Classification 1 (500) Affected area by Q_{100} flood scenario (ha)	0	804.907	104.638	30.074	939.619
Classification 2 (300) Affected area by Q_{100} flood scenario (ha)	0	804.907	91.432	43.280	939.619

See Annex Figure A1: Population density: vulnerability classification 1
See Annex Figure A2: Population density: vulnerability classification 2

4.3.2 Economic activities (criterion C2)

Format of source data is ESRI raster (GRID), cell size 100mx100m. Accordingly to the proposed methodology in 4.1, the economic activities are classified into three vulnerability classes/levels as shown in Table 4.10. For demonstration purpose, land use criterion has been chosen as a replacement for economic activities.

Table 4.10: Economic activities: vulnerability classification

Vulnerability classes/level	**CORINE 2000 GRID description – Label 3**
0 – no vulnerability	Road and rail networks and associated land
0 – no vulnerability	Airports
0 – no vulnerability	Dump sites
0 – no vulnerability	Construction sites
0 – no vulnerability	Green urban areas
0 – no vulnerability	Sport and leisure facilities
0 – no vulnerability	Pastures
0 – no vulnerability	Broad-leaved forest
0 – no vulnerability	Coniferous forest
0 – no vulnerability	Mixed forest
0 – no vulnerability	Natural grasslands
0 – no vulnerability	Moors and heathland
0 – no vulnerability	Sclerophyllous vegetation
0 – no vulnerability	Transitional woodland-shrub
0 – no vulnerability	Beaches, dunes, sands
0 – no vulnerability	Bare rocks
0 – no vulnerability	Sparsely vegetated areas
0 – no vulnerability	Burnt areas
0 – no vulnerability	Glaciers and perpetual snow
0 – no vulnerability	Inland marshes
0 – no vulnerability	Water courses
0 – no vulnerability	Water bodies
1 - low	Land principally occupied by agriculture, with significant areas of natural veg.
2 - moderate	Vineyards
2 - moderate	Fruit trees and berry plantations
2 - moderate	Complex cultivation patterns
3 - high	Continuous urban fabric
3 - high	Discontinuous urban fabric
3 - high	Industrial or commercial units

3 - high	Mineral extraction sites
3 - high	Non-irrigated arable land
3 - high	Permanently irrigated land

The figures from resulting reclassified grid for the economic activities are shown in Table 4.11 and consequent areas are shown in the Annex, Figure A3.

Table 4.11: Economic activities: vulnerability classification of the affected areas by Q_{100} flood scenario

ECONOMIC ACTIVITIES (C2)	**no vulnerability**	**1 – low vulnerability**	**2 – moderate vulnerability**	**3 – high vulnerability**	**Σ (Q_{100} area)**
Affected area by Q_{100} flood scenario (ha)	381.907	76.091	228.475	253.146	939.619

See Annex, Figure A3: Economic activities: vulnerability classification

4.3.3 Special structures and objects (criterion C3)

Format of source data is ESRI raster (GRID), cell size 100mx100m. Accordingly to the proposed methodology in 4.1, the special structures and objects have to be classified into three vulnerability classes/levels as shown in Table 4.12. For demonstration purpose, land use criterion has been chosen as a replacement for special structures and objects. No CORINE category could represent low vulnerability for the special structures and objects, and thus the reclassified grid has only categories of 0-no vulnerability, 2-moderate and 3 – high vulnerability.

Table 4.12: Special structures and objects vulnerability classification

Vulnerability classes/level	CORINE 2000 GRID description – Label 3
0 – no vulnerability	Continuous urban fabric
0 – no vulnerability	Discontinuous urban fabric
0 – no vulnerability	Industrial or commercial units
0 – no vulnerability	Mineral extraction sites
0 – no vulnerability	Green urban areas
0 – no vulnerability	Sport and leisure facilities
0 – no vulnerability	Non-irrigated arable land
0 – no vulnerability	Permanently irrigated land
0 – no vulnerability	Vineyards
0 – no vulnerability	Fruit trees and berry plantations
0 – no vulnerability	Pastures
0 – no vulnerability	Complex cultivation patterns
0 – no vulnerability	Land principally occupied by agriculture, with significant areas of natural vegetation
0 – no vulnerability	Broad-leaved forest
0 – no vulnerability	Coniferous forest
0 – no vulnerability	Mixed forest
0 – no vulnerability	Natural grasslands
0 – no vulnerability	Moors and heathland
0 – no vulnerability	Sclerophyllous vegetation
0 – no vulnerability	Transitional woodland-shrub
0 – no vulnerability	Beaches, dunes, sands
0 – no vulnerability	Bare rocks
0 – no vulnerability	Sparsely vegetated areas
0 – no vulnerability	Burnt areas
0 – no vulnerability	Glaciers and perpetual snow
0 – no vulnerability	Inland marshes
0 – no vulnerability	Water courses
0 – no vulnerability	Water bodies
2 - moderate	Construction sites
3 - high	Road and rail networks and associated land
3 - high	Airports
3 - high	Dump sites

The resulting reclassified grid for the special structures and objects has resulted in the flood vulnerability figures shown in Table 4.13. and areas shown in the Annex, Figure A4.

Table 4.13: Special structures and objects: vulnerability classification of the affected areas by Q_{100} flood scenario

SPECIAL STRUCTURES AND OBJECTS (C3)	no vulnerability	1 – low vulnerability	2 – moderate vulnerability	3 – high vulnerability	Σ (Q_{100} area)
Affected area by Q_{100} flood scenario (ha)	937.963	0	212	1.444	939.619

See Annex, Figure A4: Special structures and objects: vulnerability classification

4.3.4 Protected areas – nature (criterion C4)

Format of source data is ESRI shp data (polygons and point shapes), therefore data is converted to grid format with cell size 100 x 100 m and SRB extent. Accordingly to the proposed methodology in 4.1, the protected area types are classified into three vulnerability classes/levels as shown in Table 4.14.

Table 4.14: Protected areas – nature: vulnerability classification

Vulnerability classes/level	Protected areas type
1 - low	Other (PAs protected by national or subnational legislative)
2 - moderate	Natura Site – Important Bird Areas,
2 - moderate	Natura Site – Habitat Directive,
2 - moderate	Natura Site – Important Bird Areas and Habitat Directive
3 - high	Ramsar Area
3 - high	Ramsar Area and Natura Site – Important Bird Areas
3 - high	Ramsar Area and Natura Site – Habitat Directive
3 - high	Ramsar Area, Natura Site – Important Bird Areas and Habitat Directive
3 - high	Ramsar Area and Other (PAs protected by national or subnational legislative)
3 - high	Park of Nature and Natura Site – Habitat Directive
3 - high	National Park
3 - high	National Park and Natura Site – Important Bird Areas and Habitat Directive
3 - high	National Park, UNESCO Site and Natura Site – Habitat Directive UNESCO Site and Natura Site – Habitat Directive

The resulting reclassified grid for the protected areas – nature has resulted in the flood vulnerability figures shown in Table 4.15. and areas shown in the Annex, Figure A5.

Table 4.15: Protected areas – nature: vulnerability classification of the affected areas by Q_{100} flood scenario

PROTECTED AREAS – NATURE (C4)	no vulnerability	1 – low vulnerability	2 – moderate vulnerability	3 – high vulnerability	Σ (Q_{100} area)
Affected area by Q_{100} flood scenario (ha)	663.430	1.211	262.321	12.658	939.619

See Annex, Figure A5: Protected nature areas: vulnerability classification

4.3.5 Cultural heritage (criterion C5)

Cultural heritage criterion has been omitted from the demonstration analysis because of lack of adequate data. Actually, only Slovenia developed a detailed methodology for identification of potential damage of cultural heritage and classification regarding flood vulnerability "Ocena poplavnega škodnega potenciala nepremične kulturne dediščine" (2011). Potential damage is being assessed according to the following criteria:

- exposure,
- dimension,
- vulnerability and
- value,

achieving the same weight.

Cultural heritage vulnerability has been assessed according to uniform criteria and classified into categories of vulnerability. The vulnerability was defined for each immobile cultural heritage according to the following criteria:

- material quality,
- age,
- concentration of cultural values and,
- height distribution of cultural values in 1m of flood water.

Experts have classified whole significant cultural heritage in Slovenia.

4.3.6 Final vulnerability level

The previous steps have resulted in four criteria, each categorized into three vulnerability classes (1-low, 2-moderate, 3-high, and 0 for areas of no vulnerability). Each criterion is presented as grid with same cell size and extent, and cell values correspond to vulnerability class.

The final vulnerability level is maximum value of the criteria levels (C1, C2, C3, C4, C5). For the demonstration purpose, the final vulnerability level was calculated for each cell taking the maximum value of the criteria, but without criterion C5 (cultural heritage) because of lack of adequate data.

The population density (criterion 1) has two vulnerability classifications, and therefore the final vulnerability has two results. The final vulnerability classification 1 is derived from population density classification 1 (class limit 500), and the final vulnerability classification 2 is derived from population density classification 2 (class limit 300), as follows:

Final vulnerability level 1 = Max (C1-classification 1, C2, C3, C4)

Final vulnerability level 2 = Max (C1-classification 2, C2, C3, C4)

The resulting reclassified grid for the final vulnerability 1 and 2 has resulted in the flood vulnerability figures shown in Table 4.16 and areas shown in the Annex, Figures A6 and A7.

Table 4.16: Final vulnerability classification 1 and 2 (population density classification 1 and 2) of the affected areas by Q_{100} flood scenario

FINAL VULNERABILITY CLASSIFICATION **Affected area by Q_{100} flood scenario (ha)**	**no vulnerability**	**1 – low vulnerability**	**2 – moderate vulnerability**	**3 – high vulnerability**	**Σ (Q_{100} area)**
Final vulnerability classification 1 (population density 1, 500)	**0**	**214.356**	**447.264**	**277.999**	**939.619**
Final vulnerability classification 2 (population density 2, 300)	**0**	**214.356**	**439.852**	**285.411**	**939.619**

See Annex, Figure A6: Final vulnerability classification 1 (population density classification 1)
See Annex, Figure A7: Final vulnerability classification 2 (population density classification 2)

The maps are available in GIS format (shape files).

4.4 Vulnerability and Climate Change effect

4.4.1 Vulnerability concept related to Climate Change as proposed by EU

Climate change effects are usually analysed through impact, vulnerability and risk concepts. On 16th April 2013 European Union launched An EU Strategy on adaptation to climate change. The strategy addresses current and projected impact, adaptation, objectives, governance and financing issues. EU Directorate-general for Climate Action issued accompanied document non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient. This document practically explains how to implement vulnerability concept regarding climate change. Thus, for each project site the vulnerability (V) is calculated as follows:

$$V = S \times E \qquad (1)$$

where, S is the degree of sensitivity the asset has and E is exposure to baseline climate conditions/secondary effects. The adaptive capacity of each project is assumed constant and equal across geographical regions. Formulation (1) suggests that future climate vulnerability is a function of sensitivity (e.g., assumed constant in the future) and exposure, which incorporates the element of future climate change (Figure 4.33). Uncertainty in climate model projections should be acknowledged and recorded by incorporating it in the exposure assessment. Uncertainty due to emissions scenario (e.g., IPCC) should also be accounted for in a similar manner.

	Exposure			
Sensitivity		No	Medium	High
	No			
	Medium	Humidity		
	High			Flood

Vulnerability level	
	No
	Medium
	High

Figure 4.33: "Vulnerability classification matrix for each climate variable/ hazard which could impact the project. 'Humidity' and 'flood' have been placed on the matrix as examples." (from Guidelines for Project Managers: Making vulnerable investments climate resilient)

The sensitivity and exposure assessment for the project can now be used to estimate vulnerability according to the simple vulnerability matrix as example. The projections of future exposure will be used to adjust the vulnerability matrix for each climate variable, which could impact the project. The uncertainty inherent in the assessment should also be acknowledged in the final vulnerability classification.

4.4.2 Uncertainty in the vulnerability assessment

The uncertainty is unavoidable issue related to the vulnerability assessment and consequently the assessment of risk. The uncertainty sources are various and ranging form hydrology forecast to criteria quantification for the future land use and land cover. Although some source uncertainty, like hydraulic ones, could be evaluated the other ones related to the land use and future developments are very complex task.

However, the final vulnerability analysis and consequently the risk mapping should be evaluated strongly considering different scenarios for the future land development. The possible source of information should be the physical planning program and regional strategic documents indicating possible future changes that might reflect the selected criteria for the vulnerability assessment.

The presented vulnerability analysis in this report during the implementation procedure may need to be adjusted for the quantification of uncertainty in terms of introducing the concept of confidence intervals evaluated through the propagation of uncertainty assessments for hydraulic (e.g., Q_{100} flooding extent) variables as well as for the criteria classes selection. This exercise, although very demanding in parctical implementation, may result in a much proper selection of proposed adaptivity measures.

4.4.3 Vulnerability concept used in this study

The vulnerability concept used in this study corresponds to its application within the risk assessment. The risk is defined as a combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity and infrastructure associated with a flood event. Considering EU Water Framework Directive (WFD), the basic risk elements are defined as follows:

- Potential adverse consequences – related to a specific hazard,
- Probability of a flood event – hazard, i.e. water velocity and depth/level for a likely return period

Such that the risk assessment is evaluated as:

$$\text{Risk} = f\,(\text{hazard, vulnerability}). \tag{2}$$

Comparing approach described in EU non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient and an approach used in this study it can be readily seen that vulnerability assessment in our study is a special case (subset) of (1). Following EU non-paper Guidelines methodology, we have evaluated vulnerability according to Q_{100} (see Annexes).

$$V = S \times E|Q_{100} \tag{3}$$

The following risk assessment is a three-step procedure.

1. The first step is vulnerability assessment defined as a value of the sensitivity and/or ability to recover from a flood event. Such concept of the vulnerability is based on selected five categories or criteria representing sensitivity within the SRB covered with 100-year flood event.

   The other aspect that could influence flood vulnerability could be duration of an exposure to the flood. Generally, the longer exposure could cause more damages. However, this study proposes to include the duration of exposure (if it will become available in the future) into the impact of the flood.

2. The second step is estimation of a hazard, defined as an impact caused by the flooding water expressed by water level and velocity, which should be calculated using adequate hydraulic models. The hazard descriptors, water level and velocity, should be calculated for different probabilities of a flood event (usually for low, medium and high). An example of hazard classification is shown on the Figure 4.34.

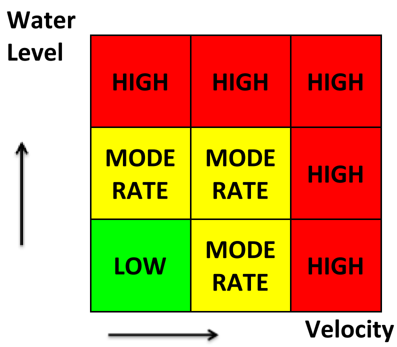


Figure 4.34: Flood hazard classification chart

In addition to WFD recommendations, using hydraulic models, duration of flooding water could be calculated if considered important for particular sensitive areas, and incorporated in the hazard assessment by raising hazard level.

3. The third step is a calculation of a risk using vulnerability and hazard assessment results. The Figure 4.35 shows a common way of combining vulnerability and hazard into the risk appraisal matrix.

RISK		VULNERABILITY		
		HIGH	MODE RATE	LOW
HAZARD	HIGH	HIGH	HIGH	MODE RATE
	MODE RATE	HIGH	MODE RATE	LOW
	LOW	MODE RATE	LOW	LOW

Figure 4.35: Flood risk classification chart

4.4.4 Analysis of the results of the Report on Climate Change

According to the Report on Climate Change impact on flood discharge of the Sava River, the climate change effects are encountered as changes in hydrological variables, i.e. increase peak discharges and consequently water levels. This in turn will cause a greater spatial impact in the future. The results show that the impact of the flood events will be increased, particularly in the head part of the SRB. In all water stations, the gradual increase of water levels of the 100-year return period floods over time could be expected. In case of abovementioned changes the spatial scope and distribution of the flood event will be changed, i.e. the territories influenced by the event will be enlarged.

However, the Report on Climate Change, as indicated in the Conclusions (p. 41), is based on analysis of average values of hydrologic variables. Then, the classic probability functions are fitted to the analysed water stations to forecast high flows up to the 100/year return period. This methodology may provide some insight in expected future trends in high flows but is lacking the analysis of fluctuations and uncertainties present in such extrapolation of high flows. The fluctuations in the hydraulic variables that we all witness today are the reason why the risk assessment for all natural hazards is considered very high in the agenda of IPCC. Natural fluctuations and associated uncertainty in modelling hydraulic variables will create a hazard and consequently the flood risk. The analysis of natural fluctuations and uncertainties in modelling is a "must" for addressing any type of risk estimates. The average values extrapolated in the future may only provide some information about general trends in hydrologic variables on the catchment scale.

However, regardless of insufficient data from the Climate Change Report, the potential flood impact from climate changes is perceived through hazard and cannot be integrated into vulnerability assessment unless the Parties provide different spatial mapping e.g., based upon new agreed flood events with the 100-year return period and the fluctuations around their estimates. If all Parties eventually agree on future increase of flood discharges with associated uncertainty (e.g., $<Q_{100}>$ and standard deviation of Q_{100}) a new vulnerability maps, expressing climate change impact could be evaluated.

4.4.5 Recommendations for vulnerability assessment in the context of Climate Change effect

Following suggestions proposed in the EU "non-paper" the future assessment of the vulnerability could include assessing exposure in terms of different return periods, both actual and predicted, according to the climate change projections. Therefore, in addition to the methodology proposed in this study, the vulnerability could be classified using additional assessment, for example:

- high exposure - areas affected by a more frequent flood event (Q_{10},Q_{20} ...),
- medium exposure - areas affected by a less frequent flood event (Q_{100} ...),
- low exposure - areas affected by a rare flood event (Q_{500},Q_{1000} ...),
- no exposure - areas not affected by a flood event, where applicable (mountain peaks, etc.).

Extending the concept of the vulnerability with above exposures the more detailed vulnerability assessment could be obtained as given in the Figure 4.36.

VULNERABILITY		**SENSITIVITY**			
		HIGH	**MODERATE**	**LOW**	**NO**
EXPOSURE	**HIGH**	**HIGH**	**HIGH**	**MODERATE**	**MODERATE**
	MODERATE	**HIGH**	**MODERATE**	**MODERATE**	**LOW**
	LOW	**MODERATE**	**MODERATE**	**LOW**	**LOW**
	NO	**MODERATE**	**LOW**	**LOW**	**NO**

Figure 4.36: Vulnerability assessment matrix using sensitivity-exposure concept

5. Concluding remarks

The report defines vulnerability assessment methodology, which is applied on the flood prone areas (Q_{100}) for the whole SRB. The methodology proposes three vulnerability classes (low, moderate, high). An overall result is evaluated using five equally weighted criteria: protected areas – population density, economic activities, special structures and objects nature and cultural heritage. The analysis is based on available data and does not include data about cultural heritage. The analysis showed that the most vulnerable areas coincide with the most populated and industrialised zones. During the analysis two different upper thresholds for population density criterion have been used to test the model: 500 and 300 inhabitants per square kilometre. Since there was no significant difference in results, it has been shown that proposed threshold of 500 is an appropriate one. Prior to the analysis on the whole river basin five most populated and developed areas were analysed.

As expected, the most vulnerable zones are those flood prone areas that coincide with big settlements with high population density and economic activities. Some parts between Zagreb and Slavonski Brod as well as some eastern parts of the Basin are vulnerable due to protected natural habitats. Almost 50% of flood area is classified as moderate vulnerability, neglected part hasn't got any grade of vulnerability and other 50% is almost equally distributed between high and low vulnerability. Areas with high vulnerability are mainly those around Zagreb, Belgrade and areas on the mouth of Drina River into Sava River. The objective of the vulnerability analysis performed for this pilot project is only an indication to the SRB riparian countries. The countries shall perform detailed analysis, with particular respect in the transboundary areas. The countries may introduce weights to the criteria, but this process should be undertaken very carefully, not jeopardising either population rights or safety. It is recommended that the weights should be common to the entire Sava River Basin and evaluated by consensus.

The results of the Report on Climate Change impact on flood discharge of the Sava River show that the impact of the flood events will be increased, particularly in the head part of the Sava River Basin. Peak discharges and consequently water levels are expected to increase. This implies that these changes will affect the exposure to the flood event and consequently the evaluation of vulnerability maps. Particularly, a special attention should be paid when assessing vulnerability of the marshes and wetlands since their sensitivity on flooding impacts depends on the water level.

The proposed methodology is also a part of the Program for development of Flood Risk Management Plan in the Sava River Basin. For the purpose of the development flood risk management plan a more comprehensive interpretation of CORINE classification should be used.

6. References

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14. Support to BiH Water Policy, http://www.voda.ba/loc/?p=72

Annex: Vulnerability assessment maps

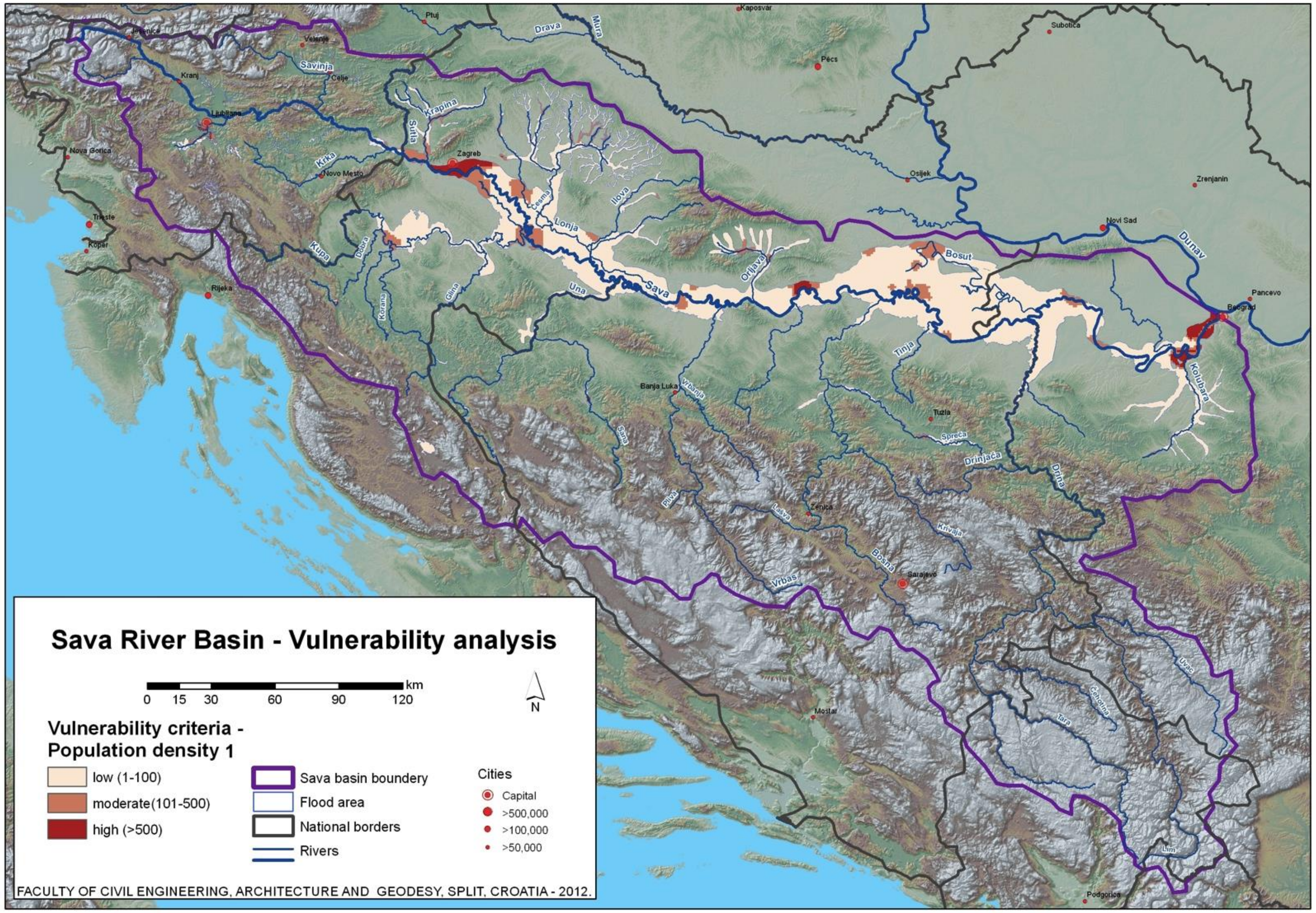

Figure A1: Population density: vulnerability classification 1

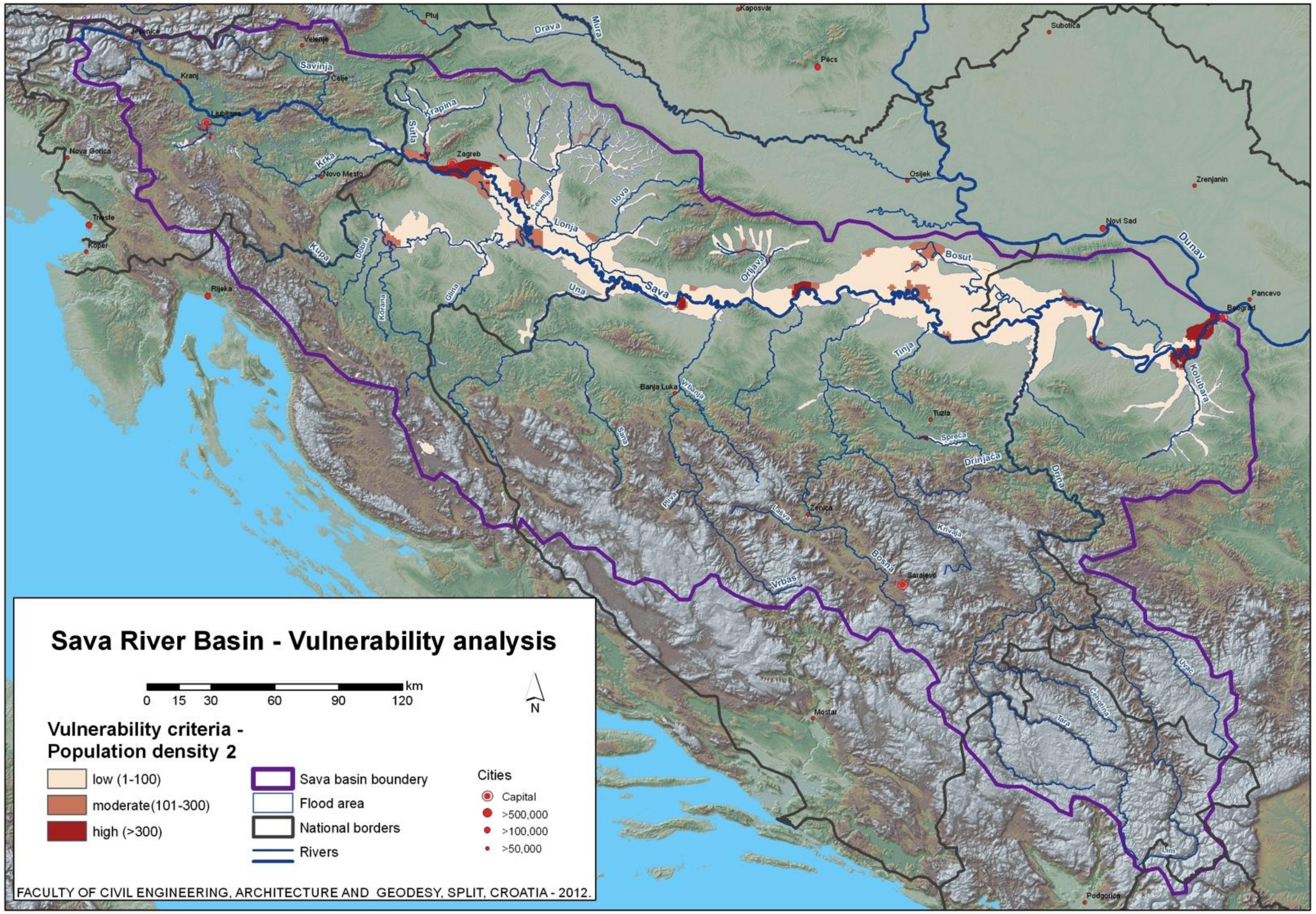

Figure A2: Population density: vulnerability classification 2

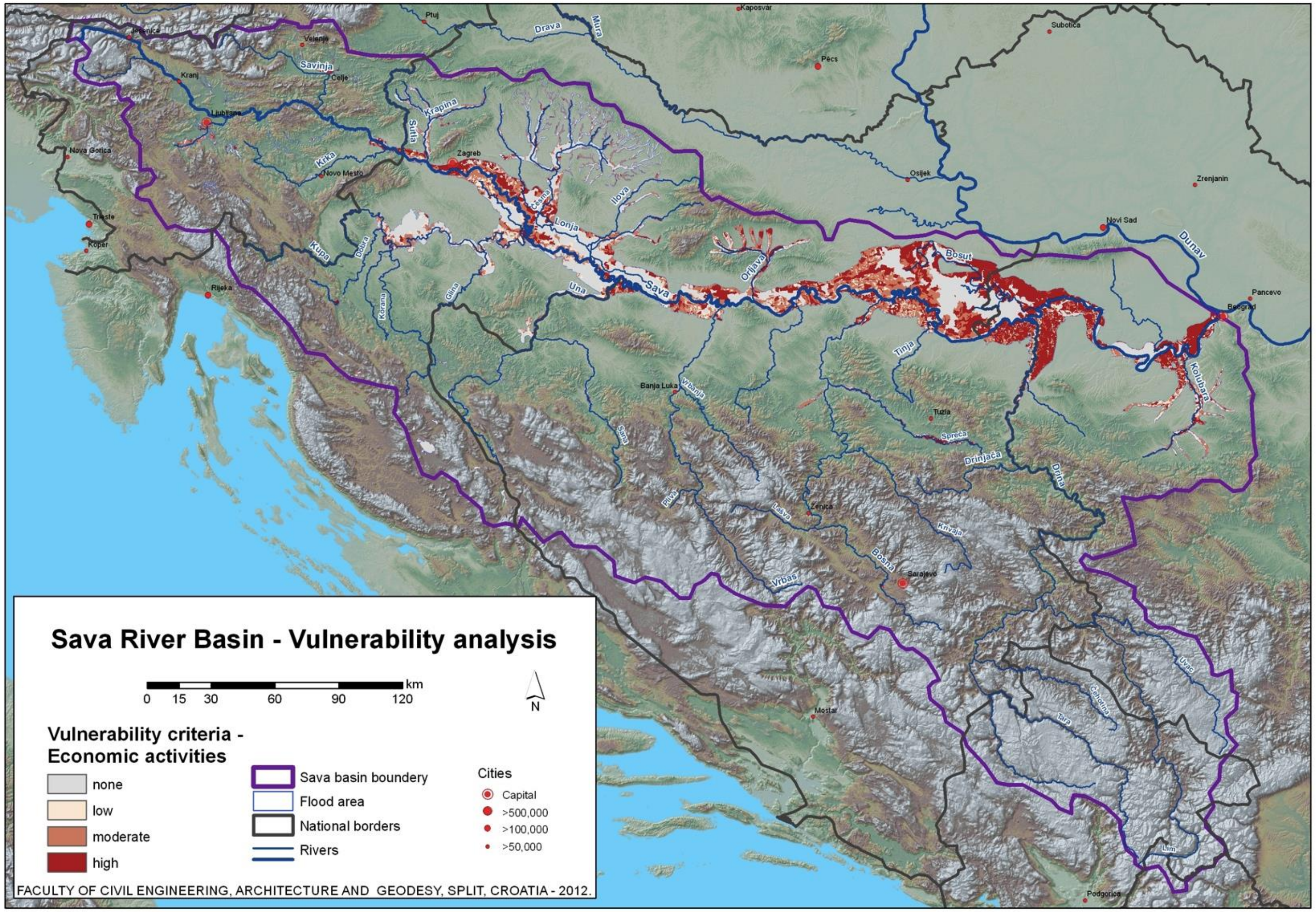

Figure A3: Economic activities: vulnerability classification

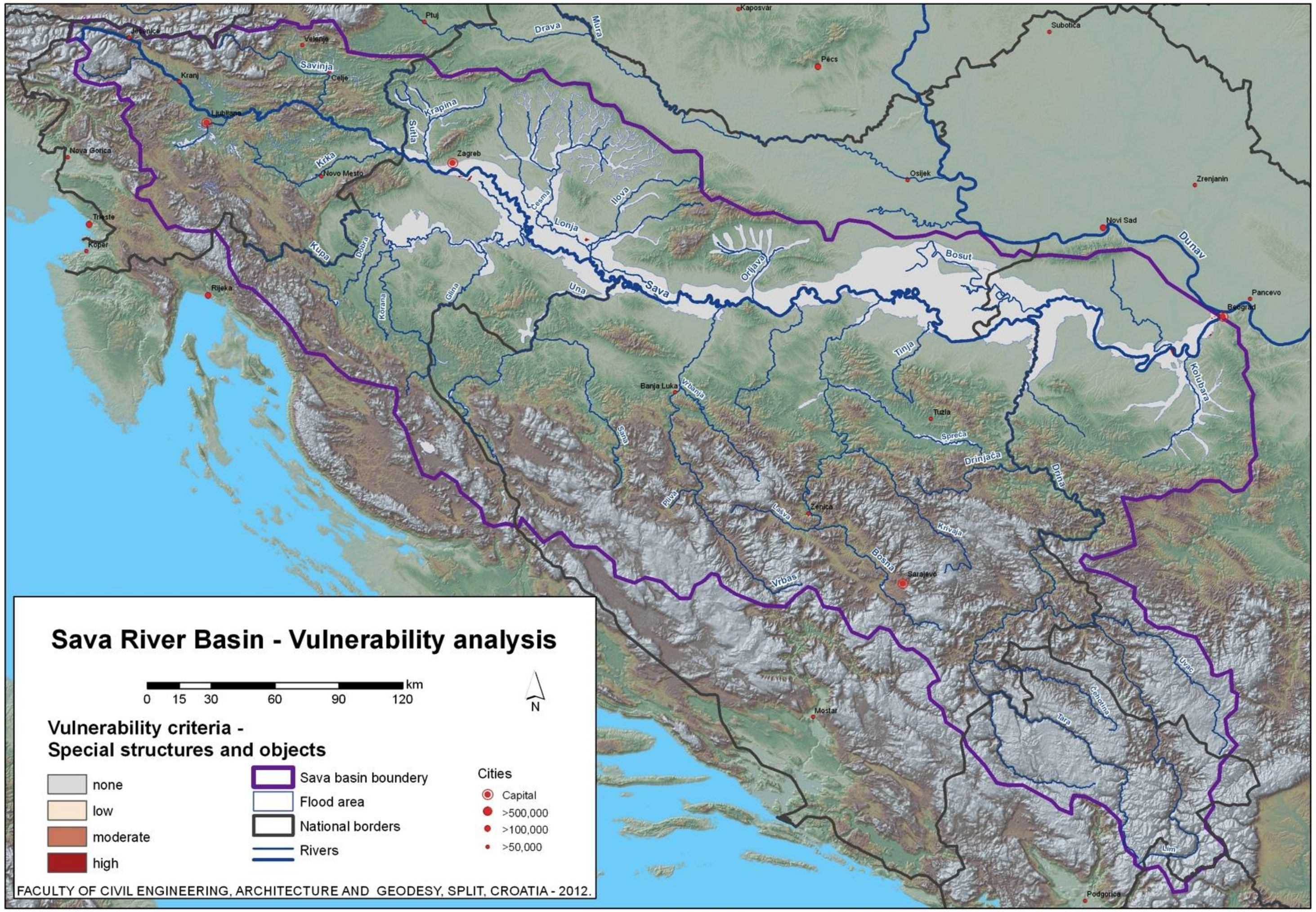

Figure A4: Special structures and objects: vulnerability classification

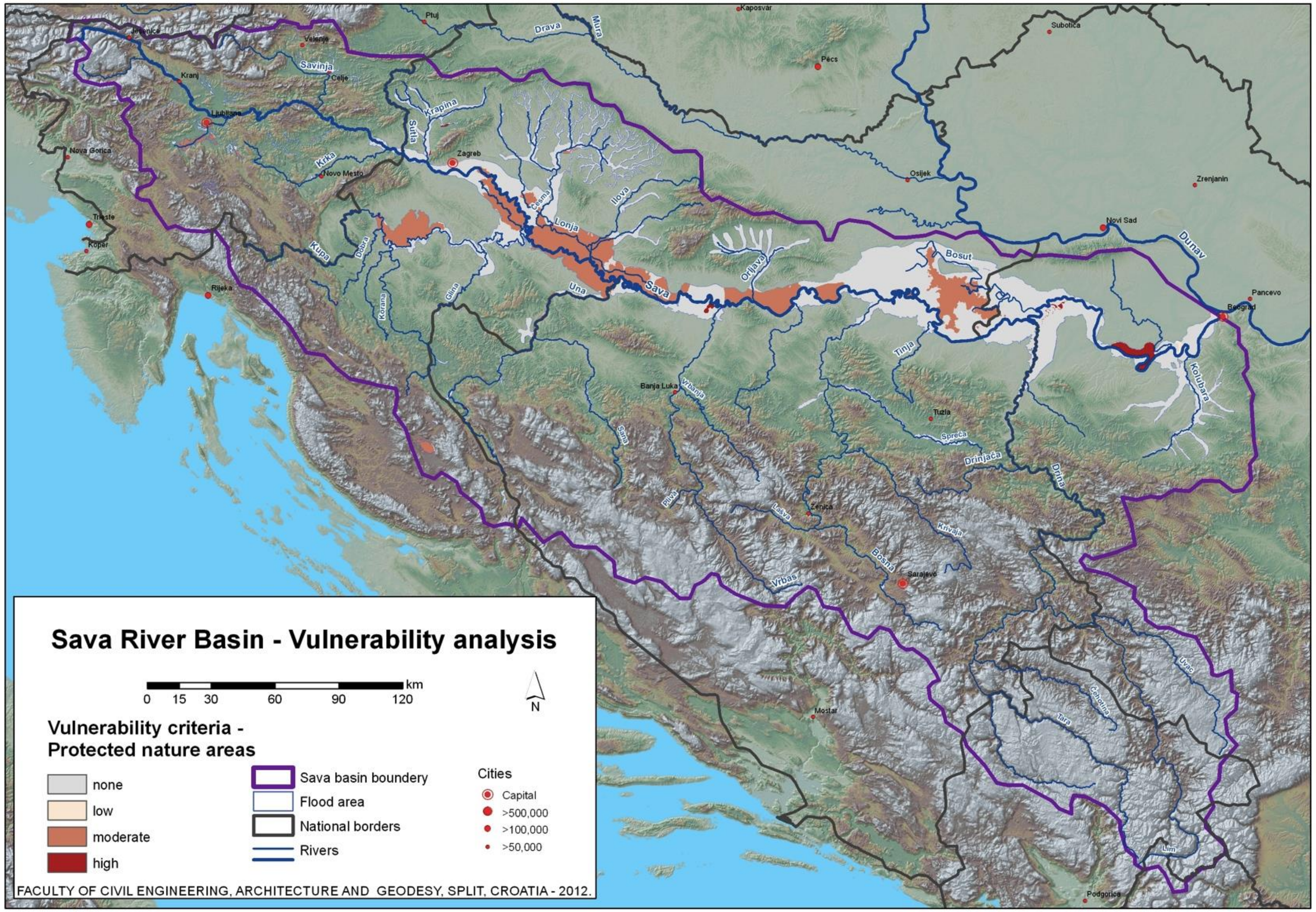

Figure A5: Protected areas – nature: vulnerability classification

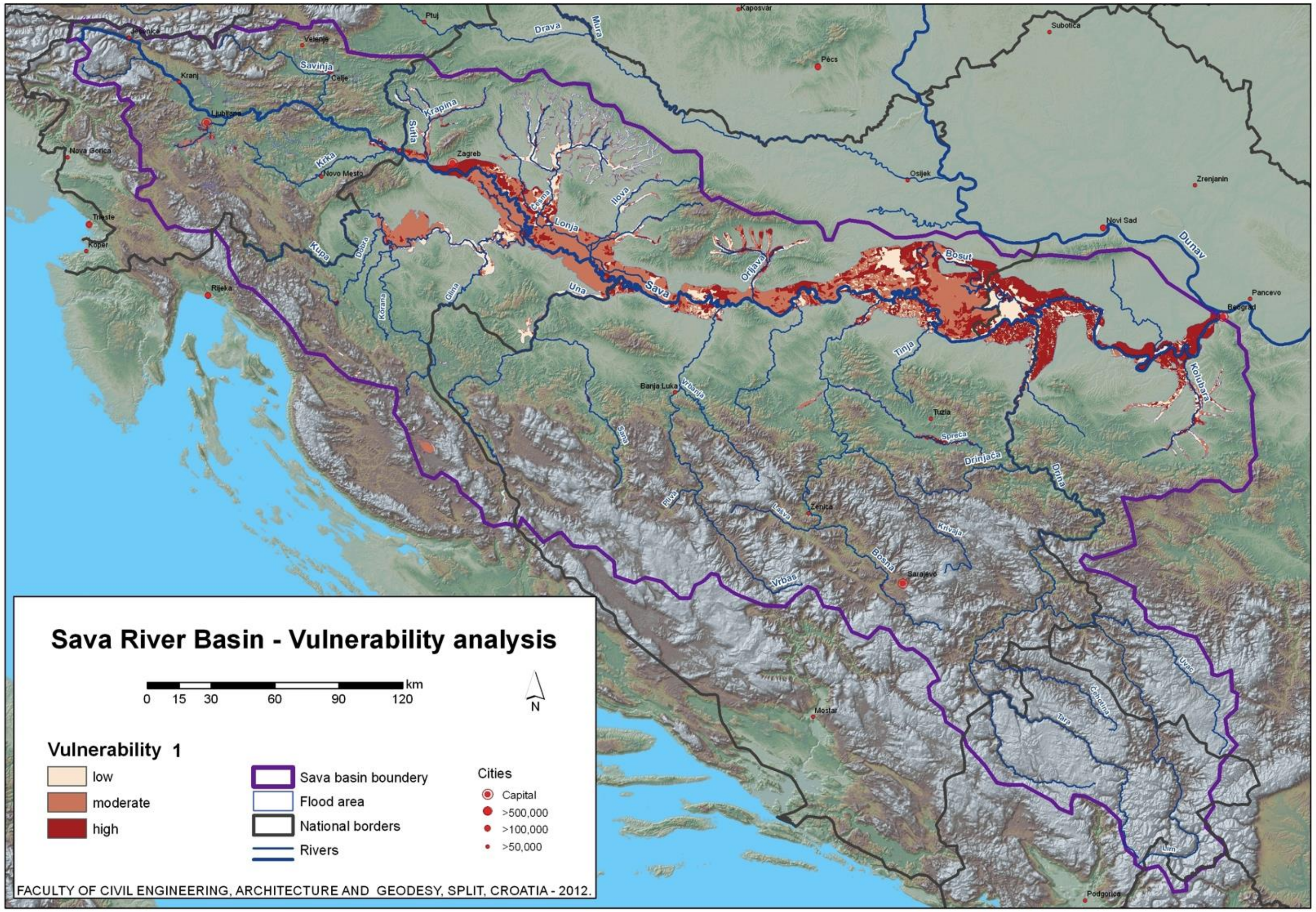

Figure A6: Vulnerability assessment variant 1

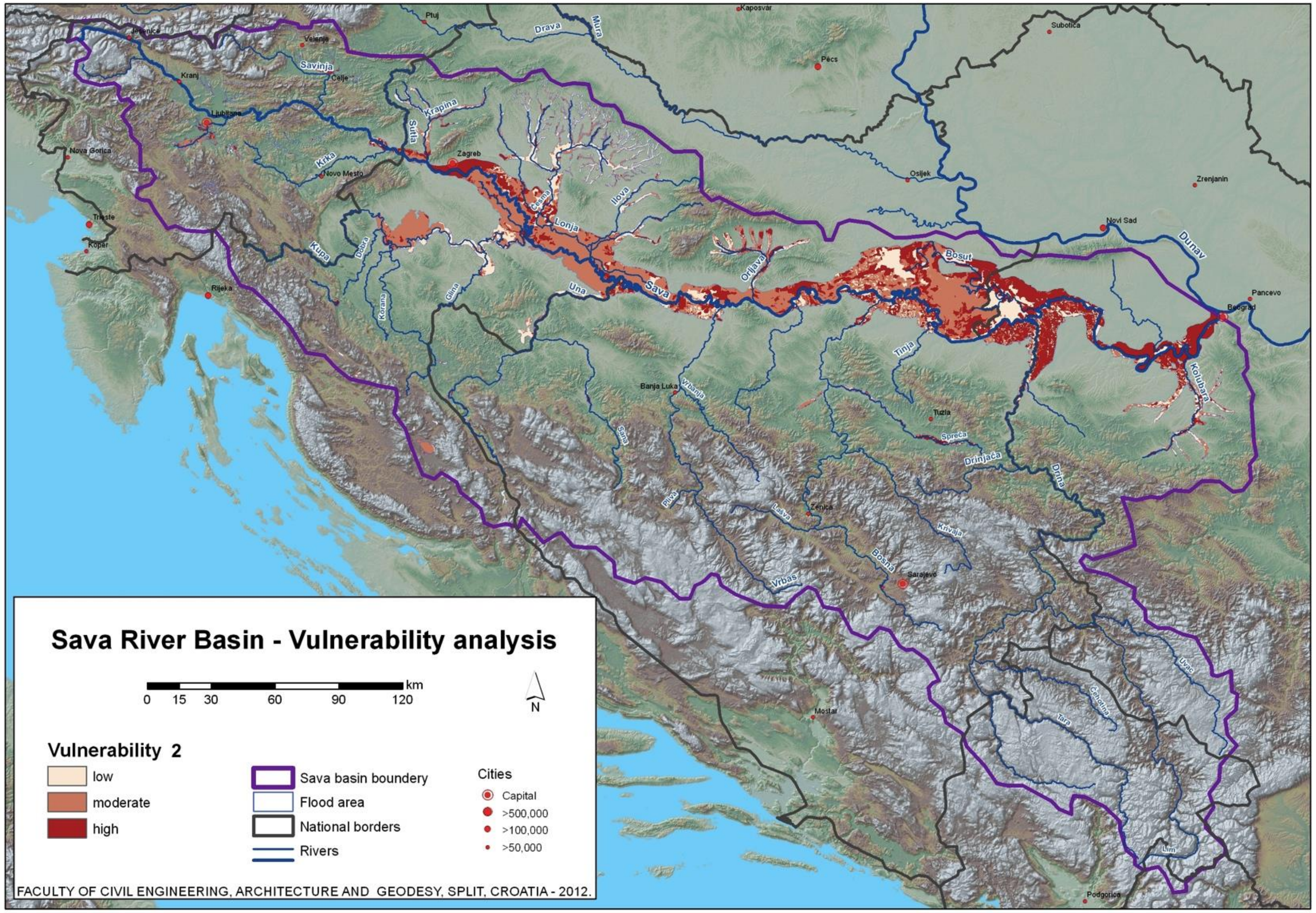

Figure A7: Vulnerability assessment variant 2