Frisco1

S čezmejnim sodelovanjem do zmanjšanja poplavne ogroženosti

Prekograničnom suradnjom do manjih poplavnih rizika

PROJEKT FRISCO1

ANG

CROSS-BORDER HARMONIZED COMPREHENSIVE FLOOD RISK REDUCTION STUDY FOR THE SOTLA RIVER BASIN

abstract

Interreg
SI-HR
SLOVENIJA – HRVAŠKA
SLOVENIJA – HRVATSKA
Evropska unija | Evropski sklad za regionalni razvoj
Europska unija | Europski fond za regionalni razvoj

INTERREG V-A Slovenia–Croatia 2014–2020 Cooperation Programme

Project:

FRISCO 1 – Cross-border Harmonised Slovenian-Croatian Flood Risk Reduction – Non-structural Measures

Objective:

The FRISCO1 project – Technical assistance in the elaboration of a comprehensive study in the flood risk reduction for the Sotla cross-border basin

Documentation type:

CROSS- BORDER HARMONIZED COMPREHENSIVE FLOOD RISK REDUCTION STUDY FOR THE SOTLA RIVER BASIN

ABSTRACT

June 2019

TABLE OF CONTENTS

1 INTRODUCTORY PRESENTATION OF THE FRISCO 1 PROJECT

The FRISCO1 project is a strategic project aimed at reducing flood risk in the basins of the Dragonja, Kolpa, Sotla and Bregana rivers and parts of the Drava and Mura river basins, which is implemented in the framework of the INTERREG V-A Slovenia–Croatia Cooperation Programme. The INTERREG V-A Slovenia–Croatia Cooperation Programme text is the main document that represents the framework for cross-border cooperation between Slovenia and Croatia in the 2014–2020 financial perspective. The purpose of cross-border cooperation is to overcome the common challenges that both countries have jointly recognised in the border area, while also taking advantage of untapped growth potentials and strengthening the process of cooperation for the overall harmonious development of the European Union.

FRISCO1 substantially examines the non-structural measures for flood risk reduction and the improvement of flood risk management system. The improved, cross-border harmonized flood risk mapping and the elaboration/improvement of cross-border flood forecasting models will provide the necessary expertise and documentation for the proposal and selection of harmonised structural cross-border flood risk reduction measures that will be carried out in the second phase of the FRISCO project, i.e. through the FRISCO2 project implemented in the basins of the Kolpa, Sotla, Drava and Mura.

The FRISCO1 project partners:

- Croatian Waters (CW, Croatian: Hrvatske vode) as the leading partner,
- Ministry of the Environment and Spatial Planning of the Republic of Slovenia (MESP, Slovenian: ministrstvo za okolje in prostor Republike Slovenije),
- Slovenian Environment Agency (SEA, Slovenian: Agencija Republike Slovenije za okolje),
- Slovenian Water Agency (SWA, Slovenian: Direkcija Republike Slovenije za vode),
- National Protection and Rescue Directorate (NPRD, Croatian: Državna uprava za zaštitu i spašavanje),
- Meteorological and Hydrological Service (MHS, Slovenian: Državni hidrometeorološki zavod),
- Institute for Hydraulic Research (IHR, Slovenian: Inštitut za hidravlične raziskave),
- Administration for Civil Protection and Disaster Relief (ACPDR, Slovenian: Uprava Republike Slovenije za zaščito in reševanje).

The FRISCO1 project consists of the following ten work packages:

M Project Management

C Project promotion

T1 Kolpa common tools, models, maps and projects

T2 Sotla common tools, models, maps and projects

T3 Drava common tools, models, maps and projects

T4 Mura common tools, models, maps and projects

T5 Dragonja common tools, models, maps and projects

T6 Bregana common tools, models, maps and projects

T7 Flood warning and alerting systems

T8 Activities for Raising Awareness and Comprehensive Concept and Programme Management – for the Flood Risk Reduction/Flood Relief Project

In the T2 Sutla/Sotla work package, the common tools, models, maps and projects comprise the following activities:

T2.1 Development of common tool 1 (Flood risk database)

T2.2 Development of common tool 2 (Target area study)

T2.3 Development of common model 1 (Improved hydraulic model)

T2.4 Development of common model 2 (Improved predictive model)

T2.5 Development of common map 1 (Improved flood hazard map)

T2.6 Development of common map 2 (Improved flood risk map)

T2.7 Preparation of construction projects

The planned activities and results are interconnected.

In accordance with the project application, the results of the FRISCO1 project are as follows:

- Improved databases for flood risk management
- Cross-border studies of comprehensive flood risk management
- Improved hydrological and hydraulic models
- An improved flood forecasting model
- Improved and cross-border harmonised flood hazard and risk maps
- Joint projects (preparation of project and other documentation)
- Early warning system (upgrade of the prognostic and warning alarm system)
- Raising public awareness in flood risk and institutional strengthening of the flood risk management system

The main objective of the T2.2 Common tool 2 is "A study of cross-border harmonised reduction in flood risk for the Sotla river basin".

2 CROSS-BORDER STUDY OF COMPREHENSIVE FLOOD RISK MANAGEMENT OF THE SOTLA RIVER

2.1 THE PROGRAMME

INTERREG V-A Slovenia–Croatia 2014–2020 Cooperation Programme

2.2 THE PROJECT

FRISCO 1 – Cross-border Harmonised Slovenian-Croatian Flood Risk Reduction – Non-structural Measures

2.3 THE SUBJECT

The FRISCO1 project – Technical assistance in the elaboration of a comprehensive study in the flood risk reduction for the Sotla cross-border basin

2.4 THE SPONSOR

THE REPUBLIC OF SLOVENIA,

Slovenian Water Agency (Slovenian: Direkcija Republike Slovenije za vode)

Hajdrihova ulica 28c, SI-1000 Ljubljana

2.5 THE CONTRACTOR

Lead Partner:

Hidrosvet, d.o.o.
Kidričeva ulica 25, SI-3000 Celje

Responsible task manager:
Branko SKUTNIK, B.Sc., Civil Engineer

Partners:

Water Management Bureau Maribor (Slovenian: Vodnogospodarski biro Maribor d.o.o.)
Glavni trg 19/c, SI-2000 Maribor

Water Science Institute (Slovenian: Inštitut za vodarstvo, d.o.o.)
Hajdrihova ulica 28a, SI-1000 Ljubljana

IZVO-R, projektiranje in inženiring d.o.o.
Pot za Brdom 102, SI-1000 Ljubljana

DHD, d.o.o.
Praprotnikova ulica 37, SI-2000 Maribor

SL-Consult, d.o.o.
Dunajska cesta 122, SI-1000 Ljubljana

2.6 THE TASK MONITORING AND MANAGEMENT

One of the objectives of the FRISCO1 project is a cross-border study in flood risk reduction for the Sotla area, which was carried out by a qualified contractor selected through a public procurement process. The contract was officially carried out by the Slovenian Water Agency, but the study was also monitored in accordance with the project assignment by the leading structure of the FRISCO1 project, which comprises multiple project management groups and working groups:

- The Sotla Working Group (WG)
- The Project Management Team (PMT)
- The Strategic Management Team (SMT)
- The Quality Management Team (QMT)
- The Project Communication Team (PCT)
- The Expert Panel (EXP)

2.7 THE PURPOSE AND OBJECTIVES OF THE STUDY

The cross-border study carried out for flood risk reduction in the Sotla river basin contains an analysis of the existing situation and alternative solutions as well as the identification and justification of flood risk reduction measures in the relevant area, including the identification of key natural water retention areas and an analysis of potential green infrastructure measures, which is based on hydrological, hydraulic and technical economic analyses. The elaborated study serves as a support tool for decision makers and as an informative tool for all stakeholders. The proposed optimal flood risk management programme in the study is divided into measures that are feasible in the short term and could be implemented during the current implementation period of the European flood directive (2016–2021) as well as measures that could be implemented later.

2.8 THE PURPOSE AND OBJECTIVE OF THE SUMMARY OF THE CROSS-BORDER HARMONISED STUDY IN FLOOD RISK REDUCTION OF THE SOTLA

Below is a summary of the Cross-Border Coordinated Study of the Comprehensive Flood Risk Management for the Sotla River, which contains the full key content and results of the study.

The summary is an integral part of the T2.2 Development of Common Tool 2 (Target Area Study).

3 SUMMARY OF CROSS-BORDER HARMONISED STUDY IN FLOOD RISK REDUCTION OF THE SOTLA

3.1 ANALYSIS OF THE CURRENT SITUATION

3.1.1 COLLECTION AND ANALYSIS OF EXISTING DATA

For the purpose of the study, the available data was collected, reviewed and analysed, with quality control of the relevant data carried out at the same time. The data obtained from Slovenia and Croatia was then analysed by individual sets. The available project documentation, which had previously been created for the Sotla river area, was analysed and reviewed.

3.1.2 DESCRIPTION OF THE CURRENT SITUATION

3.1.2.1 General description of the Sotla river basin

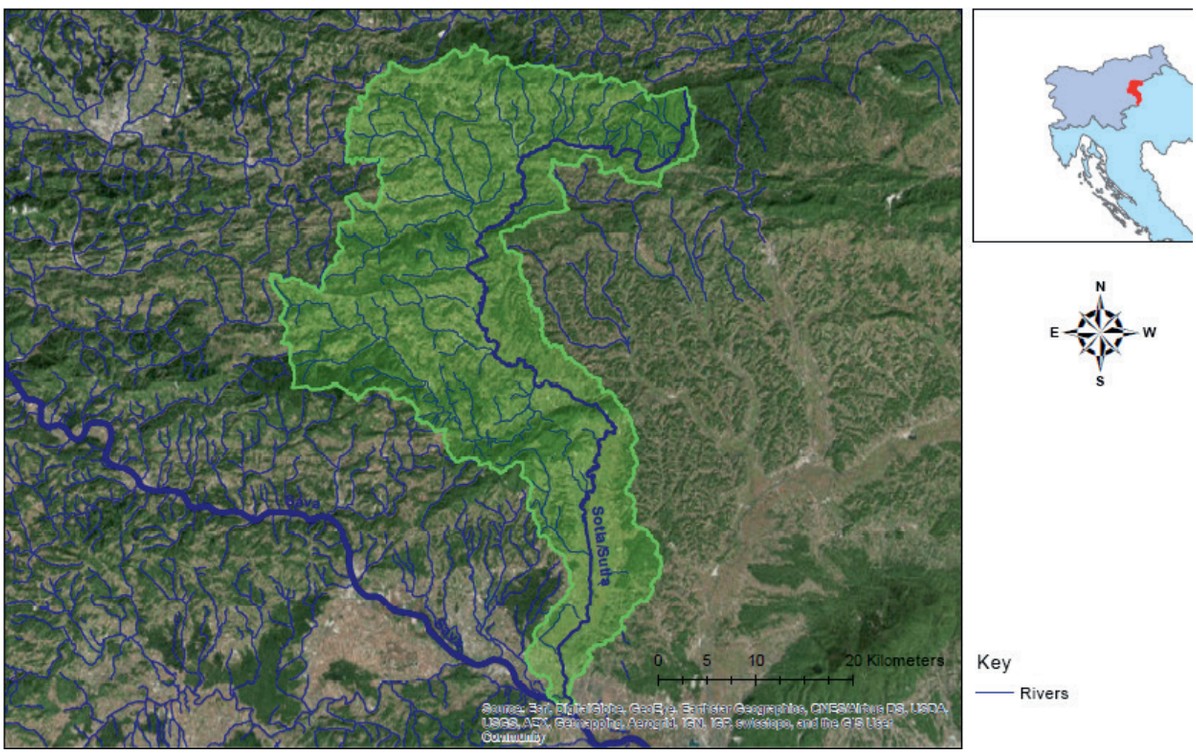
The Sotla is a border river between Slovenia and Croatia . Its source is located on the wooded southern slopes of the MaceljHills under the peak of Veliki Belinovec and after that, the river flows into the Sava near the village of Jesenice. Its basin covers 581 km^2, with the altitude ranging between 134 m and 640 m, and its reach is about 90 km long.

The headwaters of the Sotla are steep and torrential. Further downstream, its gradient decreases and the river transitions into a meandering flatland flow. The Sotla is thus a predominantly lowland river with a generally slow flow within the river channel. In the valley, it alternates between wide and narrow sections. The river has a pluvio-nival regime of the Pannonian type with the first maximum in late autumn, the second maximum in March, and a very pronounced minimum in August.

The most important water management facility on the Sotla is the Vonarje barrier, which is located upstream of the inflow of the Mestinjščica river into the Sotla. Except for a few short sections, almost the entire Sotla river channel flows in the Natura 2000 area.

3.1.2.2 Area of the Sotla river basin relevant for the FRISCO 1 project

The subject of this study is the Sotla river basin, treated from its very source found on the wooded southern slopes of the Macelj hills under the Veliki Belinovec peak to its outflow into the Sava near the village of Jesenice.



An overview map of the area in line with the project assignment

3.1.2.3 Geographical description of the relevant area

The Sotla, which flows on the eastern edge of the region, is also the border river between Slovenia and Croatia. In regard to geographical regions of Slovenia, the Sotla basin is located in the regions of Voglajnsko in Zgornjesotelsko gričevje (the Voglajna and Upper Sotla Hills). The eastern side of the valley is home to the hills of Croatian Zagorje. The entire relevant territory covers an area of 58,449 hectares. A major part of the relevant area (approximately 77%) lies in Slovenia, while the rest is part of Croatia.

3.1.2.4 Climatic features

The treated region has a subpannonian climate. From 1971 to 2000, the average annual temperature was about 10 °C, the average temperature in January was 0 °C, and the average temperature in July stood at 20 °C. In this period, the annual amount of corrected precipitation was between 1,100 mm and 1,300 mm, which on average fell in 115–135 days. The annual precipitation, which is between 1,000 mm and 1,200 mm, slightly decreases towards the east. The autumn months are drier then the rest of the year, while July and September are the rainiest months.

3.1.2.5 Soil

The area under consideration is geologically diverse. It is home to limestone, clay slate and tufa. The valleys of rivers and streams are filled with alluvial sediments.

3.1.2.6 The water environment

Surface water

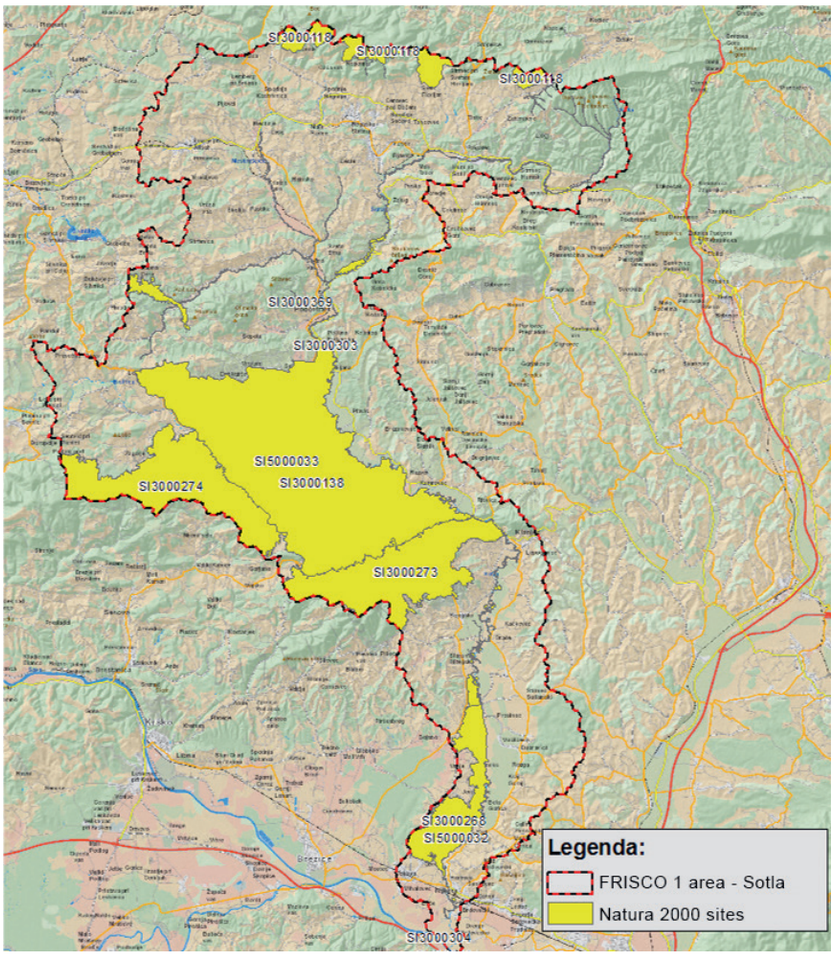
In the upper part of the basin, a few short right tributaries flow into the Sotla, among them the Draganja brook in Rogatec. One of the Sotla's major right tributaries, i.e. the Mestinjščica river, flows into the Sotla in the settlement of Podčetrtek. The following large right tributaries flow into the Sotla further downstream: the Tinski potok brook, Župnijski potok brook, Golobinjek brook, Olimščica brook, Buča brook, and the largest right tributary – the Bistrica river. Downstream of the Bistrica confluence, the Sotla flows along the Kumrovško polje plain and then passes into the narrow Zelenjak valley. Further south, two large right tributaries flow into the Sotla on the alluvial plain, namely the Dramlja brook and the Bizeljsko brook. The left part of the Sotla river basin flows mostly at the foot of the hills, only occasionally crossing a few small valleys. All left tributaries are short and torrential, with pronounced signs of erosion. The large left tributaries comprise the Škrnik, Kladnik and Razvor brooks near Kumrovec, the Čemehovec brook near Kraljevec na Sotli, and the Dubravica brook. The most important water management facility on the Sotla is the Vonarje barrier, which is located upstream of the inflow of the Mestinjščica river into the Sotla.

Groundwater

The area is home to several water protection areas with drinking water sources protected by municipal decrees, both on the Slovenian and the Croatian side.

3.1.2.7 Nature

The area is home to agricultural landscapes, which can roughly be divided into hills and lowlands in terms of topography. The hills are home to deciduous and mixed forests, vineyards as well as dry, extensively cultivated meadows. The lowlands next to the Sotla predominantly comprise wet meadows that are subject to semi-intensive and intensive agricultural use. A well-preserved cultural landscape with a variety of ecological conditions is an important habitat for species that are protected at the European level. The Kozjansko Regional Park, which is one of the largest protected areas in Slovenia, offers perfect conditions for exceptional biotic diversity.



Natura 2000 sites in Slovenia (Source: Slovenian Environment Agency)

Natura 2000 site – Eco-network in Croatia (Source: Croatian Meteorological and Hydrological Service)

3.1.2.8 Cultural Heritage

The units of immovable cultural heritage in the Slovenian part of the region are registered in the Register of Immovable Cultural Heritage (Register nepremične kulturne dediščine, RKD), which is kept by the Ministry of Culture. The cultural heritage in the territory of Croatia is defined and protected through the spatial plans of Krapina–Zagorje County and Zagreb County.

3.1.2.9 The Population

Apart from valleys, the hills used to be inhabited as well. At the turn of the 20th century, the main source of income in the region was agriculture. Between 1961 and 1991, the share of the farming population fell from almost 50% to less than one sixth of the population. This can be attributed to migrations from the countryside to large settlements such as Hum na Sutli, Klanjec, Kumrovec etc.

3.1.2.10 The Economy

Until recently, agriculture played the most important economic role. In the second half of the 20th century, the share of people working in industry, transport, tourism and the service industry increased. The naturally and culturally rich landscape is a great starting point for the development of tourism, which currently revolves around spa tourism.

3.1.2.11 The spatial use

More than 65% of the area is dedicated to agriculture. The agriculture is followed by approximately 30% of forest land and only about 1% of construction land, which is due to the sparsely populated areas. The share of water and waterside land is relatively high, standing at 18%.

3.1.2.12 The current state of the environment

Air quality

The livestock farming with numerous facilities used for intensive animal breeding represent an important source of air pollution, and also the source of emissions.

Water status

Based on measurements performed at the Trlično, Rogaška Slatina and Rigonce measuring stations in 2012 and 2013, the Sotla river showed a GOOD chemical status. Data on general physical-chemical elements is VERY GOOD, while the results of measurements on specific pollutants show GOOD results. For this reason, the total ecological status of the Sotla is assessed as GOOD. Based on the Water Management Plan for the 2013–2015 period, the Sotla river is divided into several bodies of water in the treated area. The chemical status of the Sotla river in all these water bodies is GOOD, while the ecological status of the CSRI0029_001 Sotla and CSRI0029_006 Sotla water bodies is assessed as BAD. For the remaining bodies of water, the ecological status is assessed as GOOD, except for CSRI0029_005 Sotla, which is assessed as MODERATE.

In 2015, the chemical status of groundwater in the water body stretching from Posavsko hribovje (Posavje Hills) to central Sotla was generally assessed as GOOD.

3.1.3 THE HYDROLOGICAL ANALYSIS

3.1.3.1 Description of starting points and used data

An analysis of the existing data showed that due to the lower amount of precipitation (about 1,200 mm per year) and the predominance of low hills, the Sotla river has a relatively low specific outflow (16.8 l/s/km^2) and a drainage coefficient of about 0.45.

The data on topography, soil and hydrography was used for the purposes of a hydrological analysis of the Sotla river basin. The existing hydrographical data covers a channel network, hydrographical areas (only for the Slovenian part of the basin), locations of meteorological and hydrometric stations, and precipitation and flow measurements at these stations.

There are several meteorological stations located in the Sotla river basin and its nearby surroundings, both on the Slovenian and the Croatian side. For the purpose of this study, several stations were selected based on the delimitation of the Sotla river basin and the Thiessen polygons, with a more than 20-year series of daily precipitation measurements collected between 1952 and 2016. The stations are: Bizeljsko,

Ložice, Podčetrtek, Podsreda, Rogaška Slatina, Šentjur, Zbelovska gora, Žetale and Žusem (in Slovenia), and Desinić, Donja Pušća, Klanjec, Kumrovec, Marija Gorica and Veliko Trgovišće (in Croatia). The hourly measurements of flows were also used for the calibration of the hydrological model.

Based on the probability analysis of the maximum daily precipitation measured at the Bizeljsko, Ložica, Podčetrtek, Podsreda, Rogaška Slatina, Šentjur, Zbelovska gora, Žetale and Žusem (in Slovenia) and Desinić, Donja Pušća, Klanjec, Kumrovec, Marija Gorica and Veliko Trgovišće (in Croatia) stations, the Gumbel method was used to determine the maximum 24-hour precipitation values with different return periods. Extreme rainfall with shorter duration was determined by stretching to return periods for the Gornji Lenart, Planina pri Sevnici and Rogaška Slatina stations. The study evaluated precipitation events with return periods of 10, 25, 50, 100, 500 and 1,000 years.

The RiverFlow2D was used to calculate the flows of the Sotla river in selected cross sections during high-water events. The calculation was based on DMR 12.5 m, selected CN values and calculated extreme values of precipitation with different return periods and different durations.

3.1.3.2 Setting up a hydraulic model

In order to make the model more manageable, HEC-HMS (USACE, 2000) was used for hydrological modelling of the Sotla river.

In order to calculate the precipitation losses for individual sub-basins, the SCS method was used, by means of which the surplus of surface drainage was estimated as a function of the drainage potential, the preliminary humidity of the soil and the use of the soil.

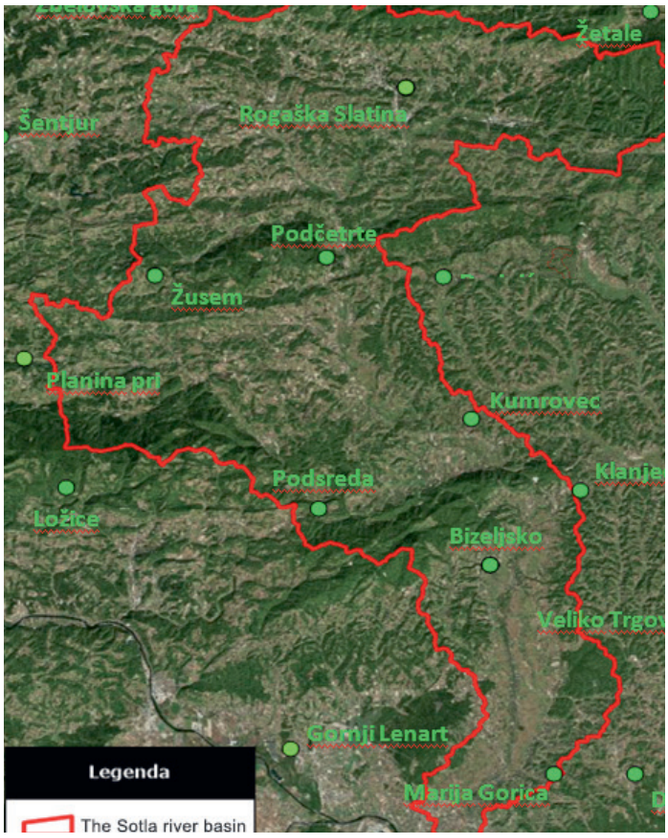
The drainage potential depends on the prevailing soil type, which was determined for the entire Slovenia in a project named *Projection of Water Quantities for Irrigation in Slovenia (CRP Competitiveness of Slovenia 2006–2013, 2012)*. The results of this project were used to determine the drainage potential in the Slovenian part of the Sotla river basin, while the values for the drainage potential in the Croatian part of the river basin were appropriately adapted.

The Muskingum-Cunge method was used for computing propagation. To this end, the data on length (in metres), inclination (m/m) and Manning's coefficient was entered for each propagation. The predominant shape of the riverbed/valley floor was described for each propagation with eight points, based on DMR 1 m (LIDAR).

The Vonarje barrier was also entered in the HEC-HMS model. The data on the barrier size, bottom outlet and side overflow was summarised according to the barrier documentation. The Q-H curve of the overflow was determined as well. The Vonarje barrier was considered as a dry reservoir.

3.1.3.3 Precipitation analysis

There are several meteorological stations located in the Sotla river basin and its nearby surroundings, both on the Slovenian and the Croatian side. From the point of determining the precipitation with different periods of return, the stations with the longest set of measurements are the most important. For the purpose of this study, 17 stations with a more than 20-year series of daily precipitation measurements collected between 1952 and 2016 were selected.



The location of analysed precipitation stations

Since the selected stations (except for the ones in Planina pri Sevnici, Rogaška Slatina and Gornji Lenart) have no values recorded for return periods in extreme precipitation, the archived data was examined and maximum daily precipitation amounts for each year were determined. For each of the stations, a statistical analysis of data on maximum daily precipitation quantities in a particular year was carried out by using the Gumble method by using the FreqPlot programme. The results of the analysis are extreme daily values of precipitation with 10, 25, 50, 100 and 500-year return periods. Extreme precipitation with a 1,000-year return period (for nine of the 17 selected stations) was determined by extrapolation.

Due to the high number of precipitation stations and the comparable values of extreme daily precipitation among certain stations, five representative precipitation stations in the Sotla river basin were selected. These were the Rogaška Slatina station (comparable with the Zbelovska gora and Žetale stations), the Žusem station, the Podčetrtek station (comparable with the Desinić and Kumrovec stations), the Podsreda station and the Bizeljsko station.

Extreme precipitation values of lower intensities could not be statistically evaluated. For this reason, the lower intensity values were stretched to the values that the Slovenian Environment Agency evaluated for the selected stations by using the Gumble method (2015). For this purpose, the ratio between the statistically determined daily precipitation and extreme 24-hour precipitation was used. For the purposes of hydrological calculations, a linear distribution of precipitation was used.

3.1.3.4 Calibration of the hydrological model

The hydrological model was largely attempted to be brought close to the previous studies, which analysed individual shorter sections of the river basin. Depending on the completed comparison, the variation between the flows evaluated in the current study and those from the previous studies do not exceed 10%, which the author of the study deemed as adequate.

3.1.3.5 Results of hydrological modelling

The hydrological model evaluates high water values with a return period of 10, 25, 50, 100, 500 and 1,000 years for 11 profiles along the Sotla river. The hydrological calculations were made by using the HEC-HMS tool for different precipitation times, in order to find the most inconvenient precipitation event at the locations of selected profiles in terms of the flow.

A summary of the modelling results is shown in the table which also includes the least favourable duration times of precipitation for each location in addition to maximum flows with different return periods.

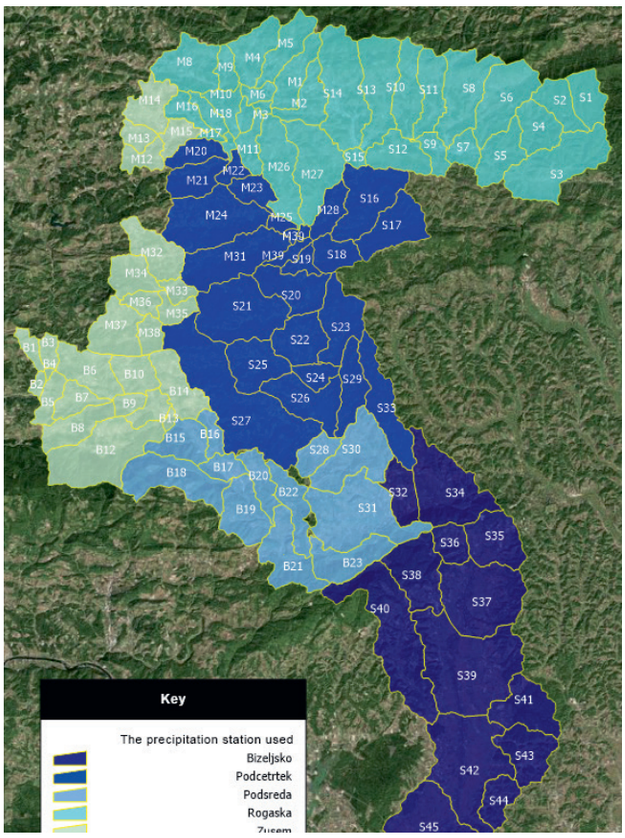
Profile No.	Description	Catchment area (km^2)	Return period					
			Q10	Q25	Q50	Q100	Q500	Q1000
1	HS Rogatec	40	43.6	54.4	65.0	77.0	103.9	116.6
2	Downstream of the Draganja brook	48	54.3	67.5	80.1	95.6	129.2	145.4
3	Up to the Ločnica brook	66	68.1	88.1	103.4	122.9	167.6	189.4
4	Downstream of the Ločnica brook	88	91.3	119.0	141.3	166.7	225.8	254.1
5	The Vonarje barrier	107	89.8	110.7	131.3	156.8	214.7	243.5
6	Downstream of Mestinjščica river	241	97.7	121.8	142.2	158.9	209.6	231.9
7	Up to the Bistrica river	326	101.9	130.3	153.7	175.5	236.2	262.7
8	Downstream of the Bistrica river	434	143.5	190.2	229.9	275.1	378.3	420.2
9	HS Zelenjak	458	150.2	198.3	238.1	285.2	394.0	439.1
10	HS Rakovec	559	162.7	214.3	251.7	290.2	414.6	468.4

11	Outflow into the Sava river	573	163.1	215.1	252.9	290.3	413.0	467.4
	Least favourable duration of precipitation:	**6h**	**12h**	**15h**	**18h**	**24h**	**30h**	**36h**

Calculated maximum flows (in m^3/s) with different return periods and the least favourable duration of precipitation

3.1.3.6 Flood waves

For the purposes of entering the hydrological model results into the hydraulic model, hydrographs for the outflow parts of all tributaries and for individual shorter sections of the Sotla river ("own water") were evaluated in the hydrological model. Flood waves cover the entire basin of the Sotla river. Flood waves were evaluated at 40 locations. The flood waves are divided into two parts: the area upstream of the Vonarje barrier and the area downstream of the Vonarje barrier. Hydrographs belonging to the least favourable precipitation were evaluated. In the section upstream of the Vonarje barrier, the precipitation lasting 6, 12, 15 and 24 hours proved to be the least favourable for the 10 and 25-year return periods, while the precipitation lasting 18, 30, 36 and 42 hours proved to be the least favourable for the 50, 100, 500 and 1000-year return periods, in addition to the above-mentioned durations. In the section downstream of the Vonarje barrier, the least favourable events were synthetic precipitation events lasting 15, 18, 24, 30, 36 and 42 hours.



Division of the Sotla river basin into sub-basins, showing the considered precipitation stations

3.1.4 HYDRAULIC ANALYSIS

3.1.4.1 Section from the source of the Sotla to Kunšperk (Bistrica ob Sotli)

3.1.4.1.1 Characteristics of the valley

The Sotla valley can be considered a flood valley even at the section close to the headwaters (upstream of Trličnо), where the river channel is relatively shallow, the banks are overgrown, and high water flows over the floodplain covered in forest. This section of the river channel is crossed by several bridges, which are mostly abandoned or very rarely used.

The Sotla river channel in its headwaters

The Sotla flooding does not pose significant problems in this section. Although some residential buildings are found in the valley, they are located away from the channel on higher or elevated ground.

Trličnо represents the first major damage potential in the Sotla valley, as high waters there often flow out of the channel. The problem is in the insufficient sized bridges and the overall low conductivity of the channel upstream of the village.

Downstream of Trličnо, a railway embankment crosses the Sotla valley. Serving as a dividing line of the flood area, it detains some of the water (which is positive with regard to flood water detention). At the section between Dobovec and Rogatec, the Sotla river channel winds through the valley between the railway embankment on the Slovenian side and the Hromec–Hum na Sutli road. Except for the area along the bridges, the meandering channel has been kept in its natural state and is home to various trees and bushes. This stretch of land is sparsely populated/built-up. Only a few buildings are found here, located at the very edge of the valley. The land of the floodplain is largely dedicated to agricultural use.

Rogatec, which is the largest settlement in the Sotla valley, lies in immediate vicinity of the river. A significant part of the settlement lies on the river's flood area. According to previous hydraulic analyses,

the high water of the Sotla reaches all the way to the Rogatec–Dobovec road at the edge of Rogatec. From the Zahenberški potok brook to the railway bridge crossing the Draganja brook, the Grobelno–Zaprešić railway gets flooded as well. Above the Draganja brook outflow, the residential and commercial buildings near the river channel and the area between the railway and the main road are at risk. Due to the insufficient size of the bridge, the broader surroundings of the Rogatec border crossing are also flooded.

The inadequately sized bridge on the Celjska cesta road in Rogatec and the Hum na Sutli HS

Up to the perpendicular embankment of the road leading towards the Rajnkovec border crossing, there are no elements in the valley that would affect the water regime. The flood waters freely spill over meadows and grassland. There are also no settlements found in the lower parts of the valley floor, except for the left bank of the Sotla just downstream of the confluence with the Teršnica brook.

The average height of the embankment along the road leading towards the Rajnkovec border crossing is 1 m, interrupting the longitudinal flood flow. Beyond this point, water converges towards the bridge opening and flows south, over the embankment, once the area upstream of the embankment reaches its full capacity. Supposedly, the flooding of 10 October 1980 (rank up to Q_5) did not lead to waters flowing over the embankment, but this was the case during the flooding of 5 August 1987 (rank up to Q_{10}–Q_{20}). Other spatially recorded flood events in the Sotla valley are not available. In the event of floods with longer return periods, it can realistically be expected for the water to flood the perpendicular road.

Under the Rajnkovec border crossing, the Rogaška Slatina municipality treatment plant (9000 PE), which is located on the floodplain at the right Sotla bank, treats waste waters from Rogaška Slatina and Rogatec. The technical sections of the treatment plant are located above the current terrain level, which is supposed to protect them from high water, while the appurtenant commercial facility is within the existing terrain level. The treatment plant is obviously important because of its overall function in the waste water treatment. Furthermore, by reducing the flow of pollutants into the Sotla, it improves the

chances of reaching an acceptable level of pollution of the Sotla, which would allow the re-establishment of the Vonarsko jezero lake.

Downstream of the treatment plant, the Sotla transitions into the (project) area of influence at the Vonarsko jezero lake (Sotelsko jezero lake) reservoir, which is the most important Sotla water management structure, with its 12-m barrier. The barrier is located in a narrow part of the valley under the village of Vonarje, upstream from the outflow of the Mestinjščica river into the Sotla. The reservoir was built as a multi-purpose retention basin.

The Vonarje barrier (source: Hidrosvet, d.o.o.)

Extending across the valley, the reservoir is approx. 6 km long and covers 195 hectares. It has two barriers, i.e. the upper one is found at Prišlin and the lower one at Vonarje. The upper concrete barrier at Prišlin would create a continual lake during the operation of the system and prevent swamps from developing in the upper part of the valley. The lower barrier at Vonarje is, in fact, a 12 m high dirt embankment. Both barriers are currently in the function of dry reservoirs.

the Prišlin barrier

In accordance with the agreement made with Croatia, Slovenia manages the facility at the barrier and carries out regular maintenance works. In recent years, significant damage to both regular concrete and reinforced concrete structures on the barrier has occurred and the hydromechanical and electro-mechanical equipment has deteriorated as well, which is why renovations are needed.

In the area of reservoir's influence, where the valley is uninhabited, the land predominantly comprises meadows and agricultural surfaces.

The Mestinjščica river flows into the Sotla about 500 m downstream of the Vonarje barrier. The Mestinjščica river and the Bistrica river are the largest Sotla tributaries. The flooding that occurred after the Vonarje reservoir had been emptied proved that, even with the detention of its high waters, the Sotla will still flood the downstream section of the valley, as it is enriched with the Mestinjščica water.

Downstream of the confluence of the Sotla and Mestinjščica, the Aqualuna water park, which is part of the Terme Olimia spa resort, is located on the Sotla right bank in Podčetrtek. The outflow of water from the flood area above the water park is directed back into the channel by a transversal embankment found north of the park. Downstream of the water park, the floodplain widens only to narrow down again near Harina Žlaka. Right before it narrows down, the Sotla valley, especially the lower left bank, is intersected by an embankment that connects the two Podčetrtek border crossings.

Downstream of the border crossing, the valley widens up again and the floodplain is mostly encapsulated by the railway embankment on the Slovenian side and the hills of Poljanska Luka on the Croatian side. While practically the entire plain is dedicated to agriculture/cultivation, trees and bushes only grow on the river banks.

The high water of the Sotla flows over the bridge at the Olimski potok brook into the catchment of the railway embankment. In the wider area of the confluence with the Olimski potok brook, the Sotla river channel was regulated during the construction of the Stranje–Savski Marof railway line (1956–1960).


The Bratkovec hydrometric station and the state of the downstream channel

The channel, which is unregulated downstream of the hydrometric station, is full of vegetation and partly filled with deposited debris.

In the Imeno/Sutlanska Poljana area, the Sotla valley widens up to a width of more than 1 km. In both Imensko polje and Sedlarjevo, the river channel has a natural, meandering flow. While practically the entire valley is dedicated to agriculture, trees and bushes only grow on the river banks. The floods in 1980 and 1987 covered the valley floor across the entire width. The bottom of the valley is virtually uninhabited, while the buildings closest to the river are found on a higher ground.

In Golobinjek, the field of Imensko polje ends at the railway embankment, which serves as the NE border of Sedlarjevo polje at the western edge of the valley. The embankment serves as a sort of a dam for the flood flow, but neither buildings nor sensitive infrastructure are located within the flood area, which is why this effect causes a positive increase in water detention. During the construction of the railway line, the Sotla was regulated at the section where the embankment crosses the plain.


Railway bridge at the edge of Imensko polje

Sedlarjevo is a small village situated on a terrace above the Sotla river. The village also features a border crossing found at a bridge over the Sotla. On each bank, the border crossing point is placed approx. 0.6–0.8 m above the level of the surrounding terrain, while the road that runs through the Croatian territory towards the village of Plavić is located only 0.3 m above the surrounding terrain, which is why it can get flooded even during the most common high water events. A small settlement in the middle of the valley, comprising only a few houses, is found on no higher ground, which is why it can be assumed that the buildings are at risk of flooding.

The railway embankment runs on the NE/N edge of the valley, while the culverts in the embankment allow the Sotla flood waters to flow into the catchment area of the embankments. Because of the recorded floods and the terrain configuration, flooding of the entire valley floor is to be expected during major flood events.


The Sotla valley under Zagorsko Selo

Near Pleška hosta, the Sotla changes course from north-east towards south-east and the valley, i.e. flood-prone area, significantly narrows down towards the confluence with the Bistrica. Besides the geomorphological narrowing, the valley features an abandoned railway and a road. The Sotla channel was regulated in this section when the railway was built.

The way the Sotla enters the Bistriško polje plain is quite complex from a hydrotechnical point of view. First, the Bistrica, which is a forceful tributary, flows into the Sotla, and then the railway embankment channels the waters just downstream of the confluence, and an embankment with the road leading towards the Bistrica ob Sotli border crossing and the border crossing itself is found downstream of the railway.

The trail of the railway embankment with its bridge, which has two flood openings on each side, besides the main opening, creates a pocket which retains the spilled waters of both the Sotla and the Bistrica. There is another smaller flood opening in the railway embankment south of the bridge (2 m wide) that does not have a significant impact on the passage of flood waters. There is a weir in the Sotla channel upstream of the bridge.

On the Bistriško polje (Croatian: Kumrovačko polje) plain, the railway embankment again crosses to the Slovenian side. Approx. 1 m above the terrain of the valley floor next to the Sotla lies the settlement of Polje pri Bistrici, while some buildings in Kumrovec also reach the valley floor. The Sotla channel on the Bistriško polje plain was regulated, so the remnants of the meanders are now turned into backwaters. The Bistriško polje Plain transitions into the narrow Zelenjak valley near Kunšperk.

Bistriško polje upstream of Kunšperk

3.1.4.1.2 Hydrological data

Three hydrometric stations (HS), namely those of Rogatec (SLO), Hum na Sutli (CRO) and Bratkovec (CRO), are located on the relevant section of the Sotla. One more hydrometric station, that by the name of Miljana (Imeno), was also active in the past. There is a hydrometric station at the Vonarsko jezero lake as well. That one is equipped with a measuring stick. Measurements are only carried out during high-water events. In Rogatec, a hydrometric station was located on the right bank, just downstream of the border crossing bridge. It was active between 1949 and 1989. In 2016, the station was re-established at the same location as part of the BOBER project.

On the same section of the Sotla, in Rogatec (Hum na Sutli), a Croatian HS is positioned upstream of the bridge at the border crossing. There is no archived data for this station to be found online, only a statistical analysis of the measured flows for the 2008–2015 was carried out. The station is located downstream of the insufficiently sized bridge, which is why the interpretations of the flows in relation to the water level during high water events can be erroneous. In the area around Imeno (Bratkovec), the Bratkovec HS is located on the Sotla. Managed by the Croatian Hydrological and Meteorological Service, it has been in operation since 1993.

3.1.4.2 Section from Kunšperk (Bistrica ob Sotli) to the outflow into the Sava river

3.1.4.2.1 Characteristics of the channel

The Sotla section from the Zelenjak gorge to the outflow into the Sava is considered part of the lower Sotla reach. Downstream of the Zelenjak gorge, an extensive valley with an average width of approx. 1.5 km spreads around the Sotla. In this section, the Sotla has several small right and left tributaries (mainly regular and hydromeliorating ditches of small size), i.e. the Sračjek brook, Bizeljski potok brook, Brezovski potok brook, Sicejev Graben brook, Dramlja brook and Šica brook. In this section, a railway runs through the valley along the Sotla, most of it 0.5 m–1 m above the surrounding terrain. All left tributaries of the river flow under the embankment through culverts. In time, the flow profile of the Sotla channel has transformed due to interventions in some of its sections.

The Sotla shows distinct meanders on the stretch from the Zelenjak gorge to the Gregovce settlement. The channel on this stretch of the river is not regulated. The banks of the river channel in the section of

the river near the settlements of Mehanićev Dol and Lepoglavec are predominantly overgrown with tall trees and sparse, low vegetation. In some parts, such as the left bank near the settlement of Mehanićev Dol, where the channel is exceptionally shallow, the banks are completely free of vegetation. In this area, the bend is characterised by two weirs (smaller spurs) that decrease the flow of water and reduce lateral erosion at the bend and the erosion on the left Sotla bank. The sections further downstream are characterised by even more pronounced meandering of the Sotla and by the banks of the channel being even more overgrown. The low, dense vegetation is not only present on the banks but also in riparian areas. Due to the pronounced meanders, this area is also characterised by the formation of bars on the inner side of the bends.

A bar at a Sotla bend, in a section characterised by pronounced meandering

At the section downstream of the Gregovce settlement, the channel banks are less overgrown and high trees are present everywhere. The channel here conveys evidently larger quantities of water than in sections further upstream, which are shallower and feature more meanders. Nevertheless, some parts of the channel on this straighter stretch of the river are heavily overgrown in low, dense vegetation, which has a pronounced negative impact on the flood safety for settlements in riparian areas.

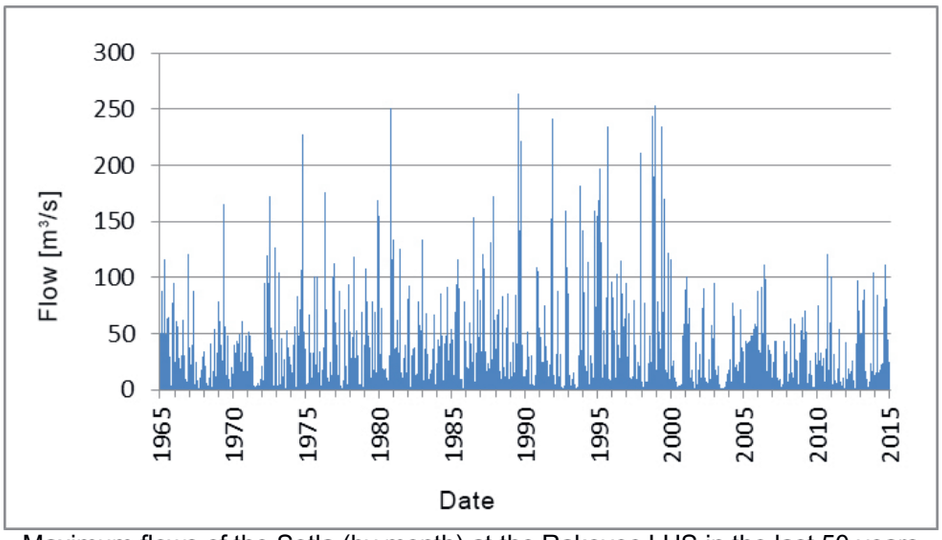
Moderate vegetation on the banks and a formed channel profile downstream of the settlement of Gregovce (on the left) as well as weirs downstream of the bend before the Rakovec border crossing (on the right)

The section near the Rakovec border crossing, features several weirs in the downstream direction. They effectively reduce the flow and lateral erosion on the upstream part. In the downstream sections, weirs on the Sotla are also located near the settlement of Vukovo selo near the Rigonce (Harmica) border crossing and the Rigonce settlement. The Sotla valley runs all the way to the Zagreb–Ljubljana railway line, where the river flows under the railway bridge onto the Sava flood area. During the flooding of the Sava, this section of the Sotla is dammed. Based on the recorded flooding of 2010, the conclusion can be drawn that the Sava affects the Sotla upstream from the Zagreb–Ljubljana railway.

3.1.4.2.2 Hydrological data

There are two hydrometric stations on the relevant stretch of the Sotla, i.e. Zelenjak and Rakovec I. The first one is located at the start of the section on the left bank in the Zelenjak gorge, upstream of the settlements of Lepoglavec and Mihanovičev Dol, and the other is found on the right bank near the settlement of Rakovec.

HS Zelenjak – the left bank (on the left) and HS Rakovec I – the right bank (on the right)



Maximum flows of the Sotla (by month) at the Rakovec I HS in the last 50 years (archives: www.arso.gov.si)

A document titled "Assessment of the risks for the municipality of Brežice" (Municipality of Brežice) was analysed; it states that the Sotla poses a threat for some of the exposed buildings in the villages of Orešje, Bračna vas and Nova vas, the road leading to the Nova vas international border crossing and the settlements of Stara vas, Veliki Obrež and Rigonce due to increased precipitation, saturation of the soil with water, and the thawing of snow in the basin.

In an article "Floods and landslides in the autumn of 1998" (Slavko Šipec, UJMA, 2000), the author presents the following findings regarding the floods of 1998:

Floods on 13 and 14 September 1998: "In Rogatec and Dobovec, high waters of the Sotla flooded basements in some of the residential buildings and in the Emkor commercial building. The Sotla river also flooded the Podčetrtek–Bistrica ob Sotli road and spilled in its lower reach as well. Due to the Sotla flooding, the Bizeljsko–Orešje road and the Orešje border crossing were closed. Two houses were flooded in Nova vas. Water flooded one road in Drožanje in the Sevnica municipality as well as several other roads in the Blanca area. In Podvrh, a landslide destroyed 50 meters of the Klenovček–Podvrh road and a wine cellar."

Floods occurring from 5 to 10 October 1998: "In Trebež in the municipality of Brežice, rainwater flooded several basements and residential buildings.

Floods occurring from 4 to 6 November 1998: "In the municipality of Brežice, the Sava river flooded the nearby areas, as well as the villages of Rigonce and Loče and part of Brežice. Once the Sava and some smaller watercourses had already calmed down, the Sotla started to flood. In Rigonce in the municipality of Brežice, it damaged a reconstructed road embankment and flooded the Dobova–Rigonce–Republic of

Croatia regional road. The Orešje border crossing was also closed as a result of the Sotla flooding, while houses and commercial buildings were also endangered."

As a result, the flood risk for these settlements was assessed according to the existing flood data. The following GIS layers regarding floods were used:

- a Slovenian integral map of flood hazard and flood hazard classifications for the area of influence of the Mokrice Hydroelectric Power Plant (the Sotla river right bank),
- a map of flood hazard classifications for the Sotla section stretching from the inflow of the Šica brook to the outflow into the Sava river ("Regulation of the Sotla for the protection of Rigonce and Dobova against flooding", Preliminary design, 2012, IS projekt d.o.o. Project No.: 13 and 13b-S /12)
- the flooding line recorded during high water events in 1990 and 2010 near the confluence of the Sava and the Sotla (right and left banks of the Sotla),
- Croatian flood hazard and risk maps for the entire left bank of the Sotla – the section stretching from Bistrica ob Sotli to the confluence with the Sava (*Croatian: Karte opasnosti od poplava, Karte rizika od poplava).*

Croatian flood hazard and risk maps cover the low, medium and high flood probability. The medium probability represents flooding with a 100-year return period and low probability represents flooding with a return period greater than 100 years, while also comprising flooding due to collapses of flood control embankments and barriers (artificial flooding).

Croatian flood risk maps are made based on flood hazard, land use and information on the locations of vulnerable facilities such as schools, kindergartens, landfills, retirement homes, roads and railways, which are exposed to low, medium and high probability of flooding. The land is divided into the following categories according to its use:

- Areas of intensive agricultural use
- Areas of other agricultural use
- Wetlands and rare vegetation
- Water surfaces
- Sports and recreational facilities
- Areas of commercial use
- Inhabited areas
- Forests and low vegetation

According to Croatian hazard maps, only a small part of the inhabited area is at risk of flooding. These are the following four locations (the farthest upstream to farthest downstream section):

- the area between the Sotla river and the railway at the settlement of Mihanovićev Dol,
- the area between the Sotla river and the railway at the Rigonce border crossing (Harmica),

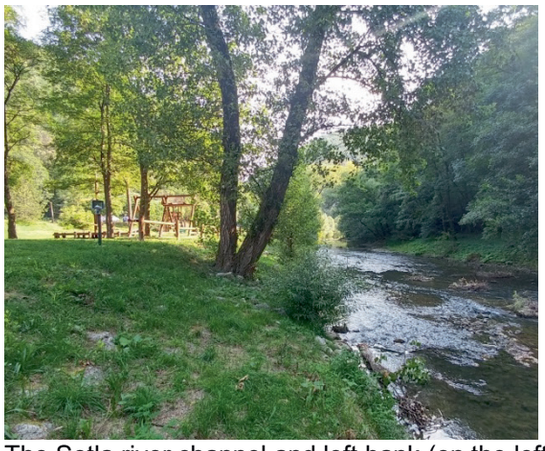
- the area between the Sotla river and the flood control embankment near the village of Ključ Brdovečki,
- and the area on the catchment side of the flood control embankment near the settlements of Ključ Brdovečki, Drenje Brdovečko and Savski Marof.

The first area is located near the settlement of Mihanovićev Dol, a bit further downstream from the Zelenjak gorge. According to the Croatian flood risk map showing the medium and low flooding probability, the inhabited area on the left bank of the Sotla between the river and the railway is at risk of flooding. The second area is located a lot further downstream, at the Rigonce (Harmica) border crossing. The location is well known for being at risk of flooding, since the buildings are located near the river banks.

Mihanovićev Dol (on the left) and the Rigonce border crossing (on the right) according to Croatian flood hazard maps The third and fourth area are located south of the railway and the Rigonce settlement. It should be pointed out that the extensive flooding in this section is probably a result of the flooding of the Sava. In this area (the Sotla section from Rigonce to the outflow into the Sava), the high waters of the Sotla have a minor impact on the flood risk for the settlements of Ključ Brdovečki, Drenje Brdovečko and Savski Marof. The water from the Sava flows around the existing Croatian flood control embankment to its catchment-area side. According to the analyses of hybrid hydraulic models for the Mokrice Hydroelectric Power Plant area (University of Ljubljana, Faculty of Civil and Geodetic Engineering and the Institute for Hydraulic Research, 2012), the Sava river does not yet flow over the embankment at the 100-year flow. The following figure shows the exposure of inhabited areas to low-probability flooding (flows greater than Q_{100}) in the area downstream of Rigonce.

<u>The Zelenjak gorge</u>

Croatian flood hazard maps show that the left bank buildings in the Zelenjak gorge are at risk of flooding. The following photos show the flood area near Zelenjak. The left side shows the location of the channel, where high waters of the Sotla spill over the inhabited area, and the right side shows the entire lowland area, along with buildings that get flooded during high water events.




The Sotla river channel and left bank (on the left) and the flood area in the Zelenjak gorge (on the right)

Bračna vas

The Bračna vas village is located on the right bank of the Sotla. A local road runs right along the river channel, and several residential buildings are located south of the road. According to Croatian flood hazard maps showing medium probability (the extent of flooding: Q_{100}), the Sotla spills over the banks and flows onto the floodplains in this particular section. The created maps cover the left bank of the Sotla. An extensive plain is found both on the left and the right side.

Nova vas pri Sotli and Gregovce

Nova vas pri Sotli is located on the right bank downstream of Bračna vas. The inhabited area is a little farther away from the Sotla river channel than the one in Bračna vas, but a relatively wide valley still extends at the right bank. According to Croatian flood hazard maps, the right bank area on the section between the channel and the railway represents land that is exposed to flooding, while flood area occasionally also extends to the catchment side of the railway embankment. Once again, maps were only created for the left bank of the Sotla, where the flooding reaches an elevation similar to the one of the Nova vas pri Sotli settlement on the right bank.

Gregovce is a settlement located on the left bank of the Sotla approx. 2 km south of Nova vas pri Sotli . Although the settlement is situated next to the Sotla river, it lies just slightly more than a metre higher than the left bank area along the river.

Gornji Čemehovec and Donji Čemehovec

Gornji Čemehovec is located on the left bank of the Sotla, east of the railway line. A perpendicular culvert runs along the railway embankment just north of the settlement. During a high water event, the Sotla water runs through the culvert and spills over the floodplain on the catchment side of the embankment towards the settlement of Gornji Čemehovec.

The settlement of Donji Čemehovec is located south of Gornji Čemehovec, right next to the Sotla river. Fields and a local road can be found between the buildings and the Sotla channel. According to Croatian flood hazard maps, the residential buildings do not get flooded, save for three building that are found right next to the border crossing. The high water of the Sotla gets near a local road.

Gmajna (near Veliki Obrež and Mali Obrež), Harmica and Rigonce

In the area between the Kraj Donji settlement (the left bank) and the Sava river, the Sotla flooding gets crucially affected by the Sava, which in 1990 and 2010 flooded all the way to the railway embankment. According to the recorded flood line of 2010, the area north of the railway near the settlements of Veliki Obrež, Mali Obrež, and Gmajna was also flooded. This area is therefore characterised by major overspill of the Sotla, predominantly on its right bank.

Slovenian flood hazard and flood hazard classification maps are available for the Sava area of influence and they are included in the integrated flood hazard map. The maps were made in the framework of the national spatial plan for the Mokrice Hydroelectric Power Plant. The following figure shows the flooding

and depth at the Q_{100} flow in both the Sava and Sotla, based on the Slovenian and Croatian flood hazard maps.

During high water events, the Rigonce settlement found at the right bank of the Sotla, is at risk of flooding from both the Sava and Sotla. Flood control embankments were planned for this area in the national spatial plan for the Mokrice Hydroelectric Power Plant. Flood control embankments from the national spatial plan for the Mokrice Hydroelectric Power Plant were designed to protect, among other things, the settlements of Mihalovec and Loče.


The Sotla channel downstream of Rigonce

The Harmica settlement is located on the left bank of the Sotla, right next to the river channel. The area between the channel and the railway is at risk of flooding. The Rigonce border crossing (Harmica) and a couple of residential buildings are found in the area.

According to the measured flooding extent, during the 2010 flood event the water came dangerously close to the inhabited area of Gmajna, which on the right bank of the Sotla, lies on slightly higher ground, within the settlement of Veliki Obrež.

Drenje Brdovečko and Ključ Brdovečki

Several settlements on the left bank of the Sotla, south of the Zagreb–Ljubljana railway, are at risk of flooding. It should be emphasised that this area gets flooded by the Sava river, while the Sotla only contributes to the increased flow in the Sava. In this section, a flood control embankment next to the settlement of Ključ Brdovečki has already been built (length: 3,480 m), but it is quite old and some water allegedly penetrates through it when the Sotla and the Sava are flooding. During a high-water event, water from the Sava spills over the flood control embankment and flows north, along the catchment side, as the water level in the channel gets considerably higher than the terrain in Ključ Brdovečki. The nearby settlements of Drenje Brdovečko and Savski Marof are also at risk of flooding from the Sava river.

The Republic of Croatia has a rescue and protection plan in place for this area ("Provedbeni plan obrane od poplava branjenog područja sektor c – gornja Sava, branjeno područje 12: područje maloga sliva

Krapina-Sutla i sjeverni dio područja maloga sliva Zagrebačko prisavlje" (2014, Croatian Waters)), which emphasises the critical points of the current flood-control measures.

The protection and rescue services constantly monitor the seepage of water through the embankment, exchange information and take appropriate measures for the protection of the buildings and the embankment.

In view of the aforementioned document, elevating the flood control embankment along the Sotla river by 100 cm would protect Ključ Brdovečki from floods with a return period of Q_{50}

Flood control embankment near Ključ Brdovečki (upstream view)

3.1.4.3 Measures for mitigating flood hazard

In the first phase of the study, the following flood protection measures were designed based on the available and analysed data, knowledge about the area and data based on monitoring the occurrence of high water events, and the implementation of flood protection measures in the last twenty years as well as an expert assessment:

- the construction of a replacement bridge at the Rogatec/Hum na Sutli border crossing and the regulation of a 600-m stretch of the Sotla river channel,
- repairs of the concrete and hydromechanical parts of the Vonarje barrier (Sotelsko jezero reservoir), installation of seismic observation and remote control equipment, including an overhaul of the water level control and warning system,
- a reconstruction and enhancement of the embankment/replacement embankment in the Gmajna settlement (Kumrovec),
- an analysis of the Risvica–Kunšperk road bridge impact on flood risk,
- structural measures for protecting the settlements of Bračna vas, Gregovce, Nova vas and Rigonce, Harina Žlaka, Luka Poljanska, Bratkovec, Plavić, Čemehovec, Harmica, Ključ Brdovečki and Drenje Brdovečko against flooding.

Water retention in the Sotla basin was analysed in a study titled *Comprehensive Water Management of the Sotla river basin, 1st phase* , no. C-123, VGI Ljubljana, March 1996, which, in addition to a general description of the state and characteristics of the Sotla basin, from the outflow into the Sava river to the Žahenberški potok brook (the right Sotla tributary upstream of Rogatec), also shows the possibilities of retaining high waters of the Sotla and its tributaries. The study found that most of the proposed reservoirs only have a local impact and that they are suitable for a multi-purpose use (tourism, irrigation, conditionally high water).

The flood hazard reduction measures were then defined based on new hydrological starting points and the hydraulic model. Based on the analysis of the existing situation, the areas with existing flood danger were defined in the following parts of the study and (mostly local) measures were proposed for them. To the greatest possible extent, the proposed measures also preserve the existing morphology of the river channel and the associated biotopes (Natura 2000).

3.1.4.4 Basic characteristics of the hydraulic model

A hydraulic analysis of the Sotla river was carried out using the 1D-2D hydraulic model of the Sotla valley from the river's source to its outflow into the Sava. The model was developed in the MIKE Flood tool by the Institute for Hydraulic Research as the project partner.

3.1.4.4.1 The Sotla 1 model

The 1D model

The subject of the *Sotla 1* hydraulic model is the section stretching from the source of the Sotla (calculation chainage: 0 m) to the Vonarje barrier (calculation chainage: 34,251 m). In the hydraulic model, the calculation chainage increases in the downstream direction. At the chainage of 25,216 m, the 1D model is completed and transitions into the 2D model in the area of the Vonarje reservoir. The outflow from the reservoir is modelled with the 1D section simulating a lateral overflow of 8 m in length at the elevation of 207.5 m a.s.l.

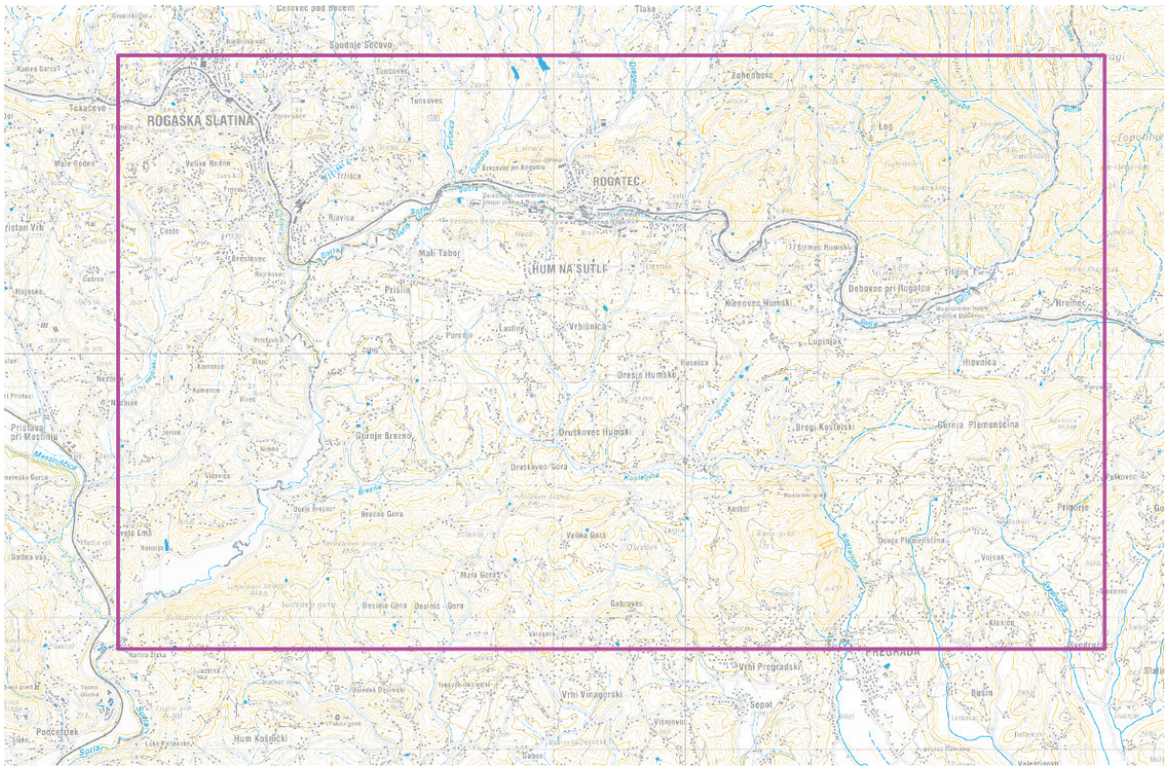
As part of the FRISCO1 project, 280 cross sections were measured on the Sotla river between the Dobovec GS (chainage: 7,519 m) to the outflow into the Sava (chainage: 95,528 m). On average, the profiles are measured every 320 m, but realistically they get measured every >350 m (e.g. 2–3 cross sections together for weirs; measured tributaries).

Due to the low frequency of the measured profiles, the hydraulic model developer used other methods to increase the number of profiles. The LIDAR data was used to generate cross sections (upstream of the Dobovec GS, the profiles obtained from the LIDAR DMR 1 × 1 m points were incorporated into the model) as well as the profile interpolation among the already measured the profiles. Generally speaking, the LIDAR cross sections were generated at generically defined equidistant locations (dX = 50.0 m).

The 2D model

Bathymetry (3D terrain model) for the 2D hydraulic model was made based on the LIDAR data that is publicly available on the eVode website (http://gis.arso.gov.si/evode/profile.aspx?id=atlas_voda_Lidar@Arso).

The calculation area comprises 3001 cells measuring 5 x 5 m in length and 1801 cells in height (15005 m × 9005 m). The model consists of 5.4 million cells. It was created in the D96 coordinate system.



Area of the Sotla 1 hydraulic model

Boundary conditions

Lower boundary condition
The lower boundary condition of the Sotla 1 model represented the 1D outflow from the reservoir through lateral overflow.

Upper and intermediate boundary conditions
The Sotla flood waves for 10, 25, 50, 100, 500 and 1000-year return periods were incorporated into the hydraulic model. They were generated based on 6, 12, 15, 18, 24, 30, 36 and 42 hours of precipitation. The following combinations were calculated by using the model: Q10–Q100 (6 h–24 h), Q500 and Q1000 (6 h–42 h).

Complementary flood waves were added to the main inflowing flood wave in the area of the Sotla 1 model at 13 locations (40 hydrological profiles were processed in a hydrological study from the source to

the Sava). The table below shows the theoretical characteristic flows of the Sotla through selected hydrological cross sections for different return periods.

Profile no.	Description	Catchment area (km^2)	Return period					
			Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}	Q_{1000}
1	HS Rogatec	40	43.6	54.4	65.0	77.0	103.9	116.6
2	Downstream of the Draganja brook	48	54.3	67.5	80.1	95.6	129.2	145.4
3	Up to the Ločnica brook	66	68.1	88.1	103.4	122.9	167.6	189.4
4	Downstream of the Ločnica brook	88	91.3	119.0	141.3	166.7	225.8	254.1
5	The Vonarje barrier	107	89.8	110.7	131.3	156.8	214.7	243.5

Table 1: view of the relevant high-water peaks of the Sotla in the area of the Sotla 1 hydraulic model

Calibration of the model

The calibration of the model was carried out in accordance with the recorded water levels in the channel during the increased flow of the Sotla between 19 and 20 September 2017, when the flow at the Rogatec (Hum na Sutli) HS was determined at a value of 36.9 m^3/s. Depending on the calibration and guidelines from the literature, the author of the model set the river channel roughness coefficients n_G between 0.031 and 0.1.

The following roughness coefficients were used for the inundation areas:

Type of land use	Manning's roughness coefficient
fields, meadows	0.035
shrubs, orchards	0.07
forest	0.10
built-up land	0.15

Table 2: roughness coefficients applied for the inundation areas

3.1.4.4.2 The Sotla 2 model

The 1D model

The subject of the *Sotla 2* hydraulic model is the section from the Vonarje barrier (calculation chainage: 34,251 m) to the Zelenjak gorge (calculation chainage: 64,419 m). In the hydraulic model, the calculation chainage increases in the downstream direction. The relevant section is 30 km long.

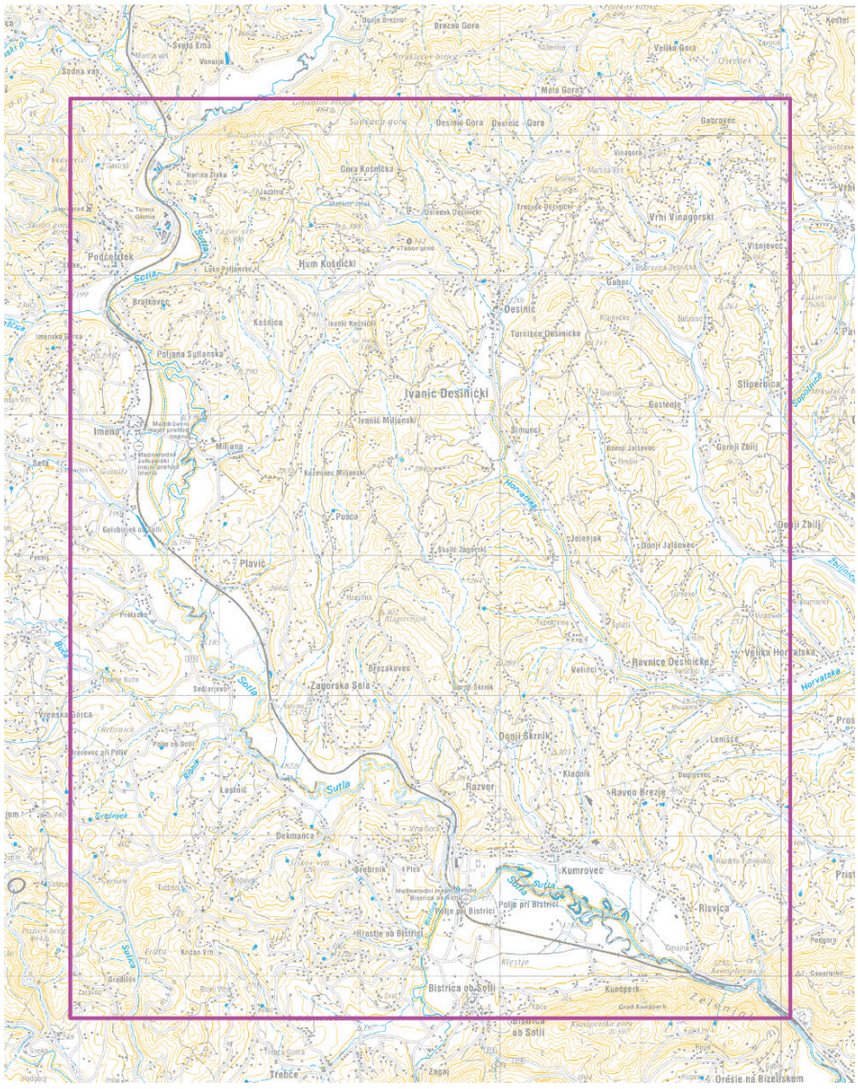
The Sotla cross sections, which were geodetically measured for the FRISCO1 project for the period between the January and March of 2017, are included in the hydraulic model. As part of these

measurements, 280 cross sections were measured on the Sotla river between the Dobovec GS (chainage: 7,519 m) and the outflow into the Sava river (chainage: 95,528 m). On average, the profiles are measured every 320 m, but realistically they get measured every >350 m (e.g. 2–3 cross sections together for weirs; measured tributaries). Due to the low frequency of the measured profiles, the author of the model decided to use cross section interpolation among the already measured sections to increase the number of cross sections.

The 2D model

Bathymetry (3D terrain model) for the 2D hydraulic model was made based on the LIDAR data that is publicly available on the eVode website (http://gis.arso.gov.si/evode/profile.aspx?id=atlas_voda_Lidar@Arso).

The calculation area comprises 2051 cells measuring 5 x 5 m in length and 2625 cells in height (10255 m × 13125 m). The model consists of 5.4 million cells. It was created in the D96 coordinate system.



Area of the Sotla 2 hydraulic model

Boundary conditions

Lower boundary condition

The Sotla 2 model lower boundary condition is the Q/h curve at the Zelenjak HS, which was calibrated to a previously derived aggregate model.

Upper boundary condition

The Sotla flood waves for 10, 25, 50, 100, 500 and 1000-year return periods were incorporated into the hydraulic model. They were generated based on 15, 18, 24, 30, 36 and 42 hours of precipitation.

Complementary flood waves were added to the main inflowing flood wave in the area of the Sotla 2 model at 16 locations (40 hydrological profiles were processed in a hydrological study from the source to the Sava). The table below shows the theoretical characteristic flows of the Sotla through selected hydrological cross sections for different return periods.

Profile no.	Description	Catchment area (km^2)	Return period					
			Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}	Q_{1000}
1	Downstream of Mestinjščica river	241	97.7	121.8	142.2	158.9	209.6	231.9
2	Up to the Bistrica river	326	101.9	130.3	153.7	175.5	236.2	262.7
3	Downstream of the Bistrica river	434	143.5	190.2	229.9	275.1	378.3	420.2
4	HS Zelenjak	458	150.2	198.3	238.1	285.2	394.0	439.1

Table 3: view of the relevant high-water peaks of the Sotla in the area of the Sotla 2 hydraulic model

Calibration of the model

The report enclosed to the hydraulic model does not specifically describe the model calibration. It only states that the model calibration was carried out in line with the recorded water levels in the river channel during the increased Sotla flow between 19 and 20 September 2017, when the flow rate at the Zelenjak HS was determined at a value of 94.7 m^3/s. Depending on the calibration and guidelines from the literature, the author of the model set the river channel roughness coefficients n_G between 0.04 and 0,066. The following roughness coefficients were used for the inundation areas:

Type of land use	Manning's roughness coefficient
fields, meadows	0.035
shrubs, orchards	0.07
forest	0.10
built-up land	0.15

Table 4: roughness coefficients applied for the inundation areas

3.1.4.4.3 The Sotla 3 model

The 1D model

For the 1D model, the cross sections of the Sotla channel, as measured by the Slovenian Environment Agency (measurements from 4 January 2017 to 29 March 2017), were used for the needs of the project. On this stretch, 113 cross sections (cross sections from 167 to 280) were measured with an average of 290 m distance between each of them.

On the Sotla stretch between the confluence with the Sava and the abandoned railway embankment, 140 additional geodetically measured cross sections of the Sotla and 22 cross sections of the Šica brook, as obtained from the existing study/the preliminary project for flood protection measures for Rigonce (IS Projekt, 2012), were included in the model.

The hydraulic model also includes the outflow stretches of two right Sotla tributaries, i.e. the Dramlja brook and Šica brook. The Slovenian Environment Agency measured two cross sections on the Dramlja brook, which cover the outflow stretch of this tributary along with additional interpolated cross sections. More detailed geodetic data about the channel of the Šica brook tributary was available in a study titled "Regulation of the Sotla for the protection of Rigonce and Dobova against flooding", Preliminary design, 2012, iS projekt d.o.o. Project No.: 13 and 13b-S/12 (hereinafter referred to as "the iS Projekt study"). For this reason, 22 transverse profiles are included in the hydraulic model, covering the 665 outflow metres of the Šica brook.

Since the measured cross sections were too far apart for suitable results of the hydraulic analysis, additional interpolated cross sections were included in the model.

The 2D model

The LIDAR data, which is accessible on the eVode website, was used for the 2D model (1 × 1 m DMR). It also covers the Sotla flood area on the left bank (Croatia), on the section between the outflow of the Sotla and the Rakovec HS. There is no more precise LIDAR data for the floodplains at the left bank available for the stretch upstream of the Rakovec HS. An older Slovenian digital elevation model (DEM) was used for creating a hydraulic model for these stretches, with a resolution of 1 elevation point for a 12.5 m × 12.5 m square, which is relatively insignificant. Also, the DEM 12.5 is highly inaccurate in terms of elevation (for an accurate elevation, the distance between the points would need to be 1 m). The 2D model comprises 5,248,881 of 5 × 5 m calculation cells.

Boundary conditions

The hydraulic model incorporates flow data, which was specified in the hydrological study within the FRISCO1 project. The tributaries are included in the hydraulic model as point data source for the Sotla as the main watercourse, while the increase in flow due to own waters along the Sotla main stream is included continuously as a lateral inflow. In the model, the upstream boundary condition is defined as a

hydrograph for an specific high-water wave obtained from the upstream hydraulic model (marked as "Sotla2") results.

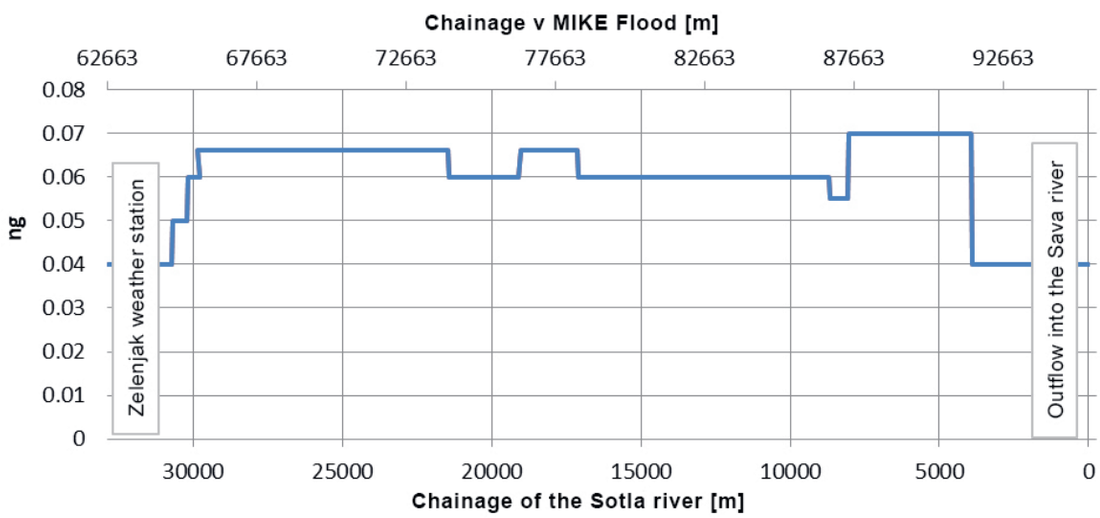
The downstream boundary condition of the Sotla is defined as the Sava water level at the confluence with the Sotla. The data on water levels is taken from a study titled "Hybrid Hydraulic Model of the Mokrice Hydroelectric Power Plant, Institute for Hydraulic Research", UL Faculty of Civil and Geodetic Engineering, IBE, 2012 (hereinafter HHM Mokrice Hydroelectric Power Plant). The Sava river channel is not separately modelled with a 1D model, but rather included in the 2D model from the LIDAR data. The constant water level taken from the same study is the boundary condition for the inflow into and outflow from the 2D model (the upper and lower boundary condition of the Sava).

In the hydraulic model, the following scenarios with coincidences are taken into account:

- **Q10**: Q10 of the Sotla and Q100 of the Sava,
- **Q25**: Q25 of the Sotla and Q100 of the Sava,
- **Q50**: Q50 of the Sotla and Q100 of the Sava,
- **Q100**: Q100 of the Sotla and Q20 of the Sava,
- **Q500**: Q500 of the Sotla and Q20 of the Sava,
- **Q1000**: Q1000 of the Sotla and Q20 of the Sava.

Calibration of the model

The roughness coefficient along the watercourse was determined according to the state of the river channel and the recommended values obtained from professional literature and past studies that involved the Sotla river basin.



The ng coefficients used in the Sotla 3 hydraulic 1D model (Institute for Hydraulic R, 2018)

The following roughness coefficients were used for the inundation areas:

Type of land use	Manning's roughness coefficient
fields, meadows	0.035
shrubs, orchards	0.07
forest	0.10
built-up land	0.15

the roughness coefficients applied for the inundation areas

The roughness coefficients were selected conservatively enough for the results to be on the safe side. The gravest errors in results might arise from the fact that the cross sections were measured too far from one another. Locally, errors could occur where the LIDAR data from the eVode website was unavailable (certain areas on the left bank of the Sotla).

3.1.5 Hydraulic analysis – the hydraulic model results

The flooding of the area is described based on the hydraulic model results that was developed under the FRISCO 1 project by the Institute for Hydraulic Research. In line with the selection of areas for hydraulic models, the descriptions of the Sotla flooding are also divided into three parts for the following three typical Sotla sections:

a) The Sotla river from its source to the Vonarje barrier
b) The Sotla river from the Vonarje barrier to the Zelenjak gorge
c) The Sotla river from the Zelenjak gorge to its outflow into the Sava river

a The Sotla river from its source to the Vonarje barrier

The Sotla spills onto the vast plains in its upper section (upstream of Trličnо) even during a mere **10-year high-water event**. At the edge of the settlement of Trličnо, i.e. the wood mill, the entire strip of the valley floor is flooded. Besides the wood mill, the residential building is also at risk of flooding. Floods in the area have already been recorded in the past. Downstream of the wood mill, the water mainly spills over the right bank. The flood area is intersected by the railway embankment and all water converges in the opening under the bridge. Downstream of Trličnо, i.e. the Dobovec GS, the extent of the 10-year flooding is reduced and the water remains in the narrow area right next to the channel. It is only near Lupinjak that the water again spills over onto the inundation area. The flood area remains sandwiched between the railway embankment on the right and the road on the left bank. Downstream of Vidina, the 10-year waters start to flow over the railway embankment. By the time the river gets to Rogatec, a wider strip of the valley floor is flooded. Only a few small commercial buildings and a natural gas station in the Straža area are at risk. In the upstream part of Rogatec/Hum na Sutli, 10-year water is contained in the channel, but it spills over in the catchment area of the Rogatec GS, where it comes over the right bank and floods five residential buildings. The cause of the flooding is the insufficient size of the bridge opening in the GS area. The Sotla water regime in Rogatec (a 1200 m stretch of the watercourse) is determined based on 11 measured cross sections. An area where large spilling occurs is downstream of Rogatec, where even a 10-year water floods a 200 m wide floodplain. In Rogatec, the industrial/commercial buildings that are located in the direction of the flood area lie mostly outside of the flood zone. The 10-year waters only

flood the northernmost one of the two Omco Croatia buildings. Near the settlements of Prišlin and Rjavica, the flood area of the Sotla widens up to 400 m. While the grass fields and agricultural surfaces get flooded, there are no buildings in this area. The flood area once again narrows down upstream of the confluence with the Ločica brook, where besides the Sotla, a railway line and a local road run across the narrow valley floor. The road gets flooded even at Q_{10}. In Rajnkovec, the flood area again widens up, and the Slovenian border crossing building and one of the buildings at the Rogaška Slatina (Pristavica) municipal treatment plant are at risk. Under Pristavica, the Sotla high waters spill over onto the area of the Vonarje barrier influence (a special water regime area without any elements of risk).

During a 25-year event, the flooding in and around Trlično is very similar to the 10-year event. No additional flood areas are activated. An important change occurs in the section downstream of the Dobovec GS, where the waters spill from the channel onto the right bank plain. In the section between Vidina and Klenovec, the railway embankment is flooded in several places. At the edge of Rogatec, the flood situation is significantly aggravated in terms of a 10-year event. The Gorenje plant on the right bank is flooded. On the other side of the river, in Straža, the water floods the main road. In the very centre of Rogatec, high water spills over the access road leading to the border crossing and flows around the northern side of the border crossing. Downstream of the confluence with the Draganja brook, the extent of flooding next to the channel significantly increases, but the water does not yet flood the nearby buildings. The commercial/industrial zones (except for the building which gets flooded even at the Q10 flow) remain safe from flooding. In the section between Rogatec and the confluence with the Ločica brook, the flooding situation does not change significantly, since the entire valley floor gets flooded even at the Q10 flow. The first point of spilling over the railway embankment is found near Tržišče. No more buildings are at risk of flooding here. There are no significant changes in the extent of flooding under the confluence with the Ločica brook. Considering that practically the entire valley floor of the relevant section gets flooded during a 25-year event and that the increased flow does not significantly affect the flood rate, only those areas where significant changes occur at certain flows will be mentioned hereinafter.

During a **50-year high-water event**, the spilling from the channel in the Sotla section downstream of the Dobovec GS noticeably increases. Downstream of Vidina, the high waters, besides flooding the railway embankment, flow onto the main road, which would probably be inoperable during such an event. Near the border crossing in Rogatec (Hum na Sutli), high waters flow over the railway embankment and flood the area stretching between the road and the railway line, whereby residential buildings are at risk of flooding. The flooding rate of parking areas between the railway and the Sotla downstream of the confluence with Draganja brook also significantly increases. The spill onto the left bank also intensifies, whereby the high waters reach the restaurant below the border crossing. The amount of water that flows over the railway embankment downstream of Tržišče increases, as does the flow of water into the depression behind the embankment (the settlement of Ogrizek), but no further buildings are at risk. In view of minor flooding, no significant changes in the extent of flooding are observed on other sections of the Sotla, where wide floodplains are present.

During a **100-year event**, the spilling of the Sotla significantly increases in Vidina, where high waters flow over a good portion of the main road and into a slight depression located in the catchment area of the

road. The water does not reach the residential buildings. Increased spilling is also noticeable on the edge of Rogatec, where the extent of the flood increases on the right bank (between the Gorenje plant and the buildings that belong to Vetropack). A long stretch of the railway line is flooded and the water reaches some buildings in the area between the railway and the main road. The Vetropack building does not get flooded. Downstream of Rogatec (Hum na Sutli), the reach of the flood does not get increased significantly with a 100-year event.

The greatest change in flooding during a **500-year event** is in Rogatec (Hum na Sutli). The flooding on the right bank of the Sotla increases at the greatest rate in the area of the Gorenje plant, the buildings that belong to Vetropack and their catchment area, and the parking area downstream of the confluence with the Draganja brook. On the left bank, the flood spreads to the kindergarten area (opposite the confluence with the Draganja brook) and a good part of the road in Straža also gets flooded. The water reaches the first row of the buildings south of the road. The 500-year waters flood the wider area of the Rogaška Slatina municipal treatment plant. They flow around the main basin, which remains unflooded, on the NW side over the area where greenhouses are located.

Since a 500-year event floods practically all of the exposed areas on the relevant section of the Sotla, the extent of a **1000-year event** is practically no different from the one of a 500-year one. In accordance with the previously described characteristics of the Sotla water regime in the section from its source to the Vonarje barrier, it can be determined that Rogatec and Hum na Sutli are exposed to the greatest risk of flooding in the upper reach of the Sotla. Some other dispersed buildings, i.e.Trlično, Vidina and Ceste, get either flooded or close the very edge of flooding. The depths of the flow on the selected locations further confirm that due to the wide floodplains, the extent of flooding does not increase significantly with the flow increase. On the plains, the water level increases from Q10 to Q1000 by 20 cm to 50 cm. The increase in narrower areas or in areas where the bridges have an effect is greater (60 cm–75 cm). The Vonarje barrier can detain a 100-year high-water wave without it spilling laterally. The lateral spilling occurs at 500- and 1000-year flows, but the water level remains below the maximum allowed value.

b The Sotla river from the Vonarje barrier to the Zelenjak gorge

Up to a Q100 flow, high waters of the Sotla downstream of the Vonarje barrier are in fact high waters of the Mestinjščica river, since high waters of the Sotla are retained in the reservoir up to Q500 flows. The extent of the Sotla flooding does not increase significantly with increases in its flow. Due to the low conductivity of the channel and due to the wide and flat floodplains, the maximum extent of the flooding occurs even during events with short return periods (marked in light blue). On the field of Kumrovačko polje (Bistrica ob Sotli), local embankments that limit the water from spilling onto a wider area are in place.

As early as the confluence with the Mestinjščica river, **10-year high waters** of the Sotla spill over the entire valley floor between the railway embankment and the foot of the hills on the Croatian side of the valley. They also flow over the embankment above the Aqualuna water park and the nearby cluster of holiday apartment homes. Approximately 100 holiday facilities are at risk. On the left bank, where the valley narrows down between Aqualuna and the foot of a small ridge, 10-year high waters reach the first

row of buildings. The water reaches the first row of buildings in the settlement of Harina Žlaka as well, while also flowing over the road between the border crossings. Near Terme Olimia, the valley floor widens up and the flooding, once again, spreads to almost 400 m in width. Near the Podčetrtek train station, the valley floor narrows to a good 100 m. Further downstream, the primary flood area next to the Sotla gets further narrowed down by the railway embankment that narrows the flow corridor to 70 m. The high waters use the Olimski potok brook channel to spread into the catchment of the railway and the road embankment. In Bratkovec, the 10-year water flows over the road leading to the bridge (HS) and reaches the first row of facilities under the local road. Downstream of Bratkovec, the valley widens up and the flood area gets up to 800 m wide. The average depth of the flood water on the plain is low, measuring 10 cm–30 cm. In Imeno/Miljana, a road connecting the Croatian and the Slovenian side of the border, as well as the two border crossings, crosses the valley. Even a 10-year event floods the road, but the border crossing building remains on dry land. Between Golobinjek and Prelasko (Maroski Breg), the railway embankment again crosses the flood area and all water is channelled into the opening of the railway bridge. East of Prelasko, two farms are located in the valley, with some buildings lying on slightly higher ground. These remain unflooded during a Q10 event, while the others are flooded. Downstream of these farms, two more (uninhabited) buildings of the Županc farm are located in Plavić, which the 10-year high waters of the Sotla only just reach. A larger settlement on the valley floor is located NE of Sedlarjevo (Logariček and Bugec farms). The buildings are flooded during a 10-year high water event. Near the (abandoned) railway station of Zagorska Sela, 10-year high water floods the railway embankment locally, but otherwise remains in a 200 m–400 m wide flood corridor between the railway embankment on the left and the hills on the right bank. The settlement is located on high ground and is not at risk of the Sotla flooding. The water once again spills over the railway embankment at Pleška hosta (Razvor), but flows into the catchment area due to a culvert in the railway embankment. To the north of the Ples settlement, the railway embankment narrows the flood area (including the channel) to a mere 50 m. Although a part of the water would flow into the catchment of the embankment through the railway culvert (a remnant of an old branch of the Sotla), the catchment does not play the role of an active flow corridor. In Razvor (Ples) the Sotla channel takes a sharp turn south and flows into Kumrovačko polje through the slopes of nearby hills. The 10-year high water does not reach residential buildings at the confluence with the Bistrica. With one commercial building getting flooded, the flood spreads upstream along the Bistrica river. The flood area downstream of the confluence with the Bistrica is crossed by two embankments – the abandoned railway embankment and the embankment of the road connecting the border crossings on both sides of the river. During a 10-year event, the bridges carry the water normally. Under the road bridge, the water mostly flows onto the left bank but remains limited to the sports facilities. A small secondary stream emerges on the meadows at the right bank, but most of the water remains in the channel. A more extensive spilling from the channel occurs upstream of the Gmajna village. Its southern part is within reach of the 10-year high water event of the Sotla. Approximately ten residential buildings are at risk. At the end of Bistriško polje (Kumrovačko polje), the flood water flows from a 600 m wide flood area into a 35 m wide bed between the road and the nearby hill.

During a **25-year event**, the most significant changes in the water regime (compared to Q10) emerge in Podčetrtek (the confluence with Olimski potok brook), where the Sotla floods a longer stretch of the road embankment, rendering the road unusable. The extent of flooding on the railway embankment at Pleška hosta (between Zagorsko selo and Razvor) also increases, but the greatest change in the water regime is recorded on Bistriško polje, where 25-year waters flood most of the plain on both banks.

A **50-year** high-water event causes additional flooding at the railway embankment in Zagorsko selo and has a significant impact on Bistriško polje, where high waters overflow the road north of the Razvor border crossing, rendering it impassable. The road connection would also be interrupted at the downstream end of Bistriško polje, since the water would flow over the stretch of the road at the mouth of the Zelenjak gorge.

There are no significant differences in the extent of flooding for a **100-year event** compared to a 50-year event. No additional major areas get activated.

A 500-year event increases the risk of additional areas getting flooded near the Sotla, since the extent of the flooding significantly increases in Aqualuna (flooding of the water park), Imeno (more water flowing over the railway embankments) and south of Sedlarjevo (flooding of a local road creates a new flood area, but the water does not reach the settlement).

During a **1000-year event**, the greatest change to the water regime takes place in Razvor, where the water floods a long stretch of the railway embankment upstream of the confluence with the Bistrica and floods the area featuring buildings on the left bank of the Sotla. On the plains, the water level increases from Q10 to Q1000 by 30 cm to 40 cm. The increase is greater in narrower areas or in areas where the bridges demonstrate an effect (70 cm–210 cm). With regard to flooding, the section of the Sotla between the Vonarje barrier and the Zelenjak gorge is relatively unproblematic. On this 30-km stretch of the river, flooding mostly occurs on uninhabited floodplains. The settlements that are located in the valley are situated at the foot of the nearby hills. Nevertheless, there are some problematic spots in this section. The biggest risk of flooding is present in the holiday village of Aqualuna in Podčetrtek (flooding even during a 10-year event, approx. 100 buildings affected) and in the Gmajna settlement on Bistriško polje (Kumrovačko polje), where the lower part of the village (approx. 10 buildings) is also flooded during a 10-year event, while the flood also being notable in Bratkovec and Harina Žlaka. In case of longer return periods (over Q100), the flood risk gets significantly increased in the wider area of the Bistrica ob Sotli border crossing. Besides buildings, high water events in the Sotla valley flood certain stretches of the road, which makes the transport through (flooding of the road below Podčetrtek) and across (cross-border roads between border crossings) the valley impossible.

c The Sotla river from the Zelenjak gorge to its outflow into the Sava river

Hereinafter, all previously mentioned areas and other settlements which were determined to be at risk of flooding according to the hydraulic model results (at flows no higher than Q1000) are described in detail.

The Zelenjak gorge

Croatian flood hazard maps show that the left bank buildings in the Zelenjak gorge are at risk of flooding. The buildings belong to a restaurant and B&B called Villa Zelenjak-Ventek. The hydraulic model results show a similar situation.

Mihanovičev Dol

According to the hydraulic model results, the Orešje–Mihanovičev Dol road is flooded even at the Q10 flow. The Orešje border crossing is located on an elevated plateau which is not flooded even at the Q1000 flow. According to the results of the model, the settlement of Mihanovičev Dol is not at risk of flooding.

Bračna vas

The hydraulic model results show that at the Q10 flow, the Sotla reaches the road level in Bračna vas, but does not flood it. Starting with the Q25 flow, the water starts flooding the road and reaches the driveways of some residential buildings.

The roughness coefficient in this section is 0.066, which is corresponds with the meandering of the channel and growth in the riverbed. The cross sections on this stretch are measured at approx. 300 m of distance between each of them. The unreliability of the results could be mitigated by a larger frequency of the channel cross sections (included in the model). According to the hydraulic model results, a significant number of buildings in the settlement of Bračna vas get flooded (or surrounded by water) at the Q100 flow, while almost all get flooded (or surrounded by water) at the Q1000 flow. Whether the buildings are actually flooded during these flows could obviously only be determined with the help of more precise geodetic measurements of the thresholds of the houses.

Nova vas pri Sotli

The hydraulic model results show that the water reaches the first building in the settlement of Nova vas pri Sotli at the Q500 flow and floods it at the Q1000 flow. At this left bank section on the Sotla, a building located right next to the water is flooded even at the Q10 flow. According to Google Maps, this building is a fire station.

Gregovce/Gornji Čemehovec

The hydraulic model results show that the water level does not reach the lowest level of the plateau, where the buildings are located, not even at the Q1000 flow. The elevation of the terrain is approx. 20 cm to 50 cm higher than the water level at the Q1000 flow.

Donji Čemehovec

The hydraulic model results show that no buildings are located within the Q100 flow. At the flow of Q1000, the water begins to flow over the left bank on the upstream section (a couple of centimetres in total) and then flows towards the settlement of Donji Čemehovec and floods approx. four buildings in the area (the northern part of the settlement upstream of the border crossing). It then returns to the Sotla channel just before the border crossing. At the Q1000 flow, the water spills over a local road in the southern part of the settlement and floods approx. six buildings.

Vučilčevo

The hydraulic model results show that the water at the Q100 flow reaches the edge of the settlement and floods a residential and an agricultural building (probably a warehouse or a barn. At the Q1000 flow, the extent of the flooding does not increase significantly. It should be noted that the hydraulic model for this section is made based on an older 12.5 m DEM (digital elevation model) and that room for error regarding the calculated depths and volumes is therefore greater than for other areas.

Kraj Donji

The settlement of Kraj Donji is located on the left bank of the Sotla on a section near the Rakovec HS. The hydraulic model shows that a part of the settlement gets flooded at the Q100 flow (approx. 15 buildings). According to a 1:5000 scale Croatian Base Map (Croatian: Hrvatska osnovna karta), which includes terrain contours, it is evident that all buildings are mostly located on the slopes of a hill and above 147 m a.s.l., while the calculated elevation for the Q1000 flow for this area is 146.6 m a.s.l. It can be concluded that all buildings are out of the reach in case of a Q1000 event.

Gmajna

The hydraulic model shows that the buildings on the edge of the Gmajna settlement are flooded at the Q100 flow.

Dobova and Veliki Obrež

The results of the model show that buildings on the south-east edge of the Dobova settlement and the east edge of the Veliki Obrež settlement are at risk of flooding at the Q100 flow. Similar conclusions were made in the iS Projekt study. The water spills over the right bank as early as the section upstream of Veliki Obrež, then flows along the western side of the abandoned railway embankment towards Dobova and through the culvert in the abandoned railway embankment towards Rigonce/Harmica.

Rigonce/Harmica

The hydraulic model shows that less than five buildings in the Rigonce settlement are at risk of flooding at the Q100 flow and that approx. ten are at risk at the Q1000 flow.

Loče

Loče is located outside the area of validity in the flood hazard maps created for the existing state, which were made within the FRISCO1 project by the Institute for Hydraulic Research. However, the results of

the model still cover this area. Since the boundary conditions in this section (the upper and lower boundary condition of the Sava flood area) were obtained from the results of hybrid hydraulic models made for the national spatial plan for the Mokrice Hydroelectric Power Plant, the results of the FRISCO1 model are very similar (almost identical) to the results of the study carried out for the national spatial plan for the Mokrice Hydroelectric Power Plant. It should be emphasised that the area is characterised by flooding of the Sava, not so much of the Sotla, which is why the flow of the Sava with a 100-year return period of the Sava, not of the Sotla (see the used coincidences of the Sava and the Sotla in chapter 2), should be used as the relevant results of a 100-year flooding, i.e. an envelope of the following scenarios should be used: Q100 of the Sava – Q50 of the Sotla and Q20 of the Sava – Q100 of the Sotla.

Ključ Brdovečki

According to the hydraulic model results, the water levels in this section are the highest at the Sotla flow with a 50-year return period, since the coincidence of the Sava with a 100-year return period is taken into account (while an event with a 20-year return period of the Sava is used for the coincidence with an event with a 100-year return period of the Sotla).

3.1.6 ANALYSIS OF FLOOD RISK

3.1.6.1 Analysis of flood risk in the existing situation

The first large flood area is found next to the Mestinjščica outflow, where the Aqualuna water park (Terme Olimia) is located in the middle of a semi-swamp floodplain. The water park was built on an artificial, slightly elevated plateau, which provides no protection from flooding. The second flood area is mostly located on the Slovenian side of the river, between Imeno in Prelasko. The area in question is the uninhabited, wet plain of Ločica. The lowest part of the Bistrica basin is also at risk of flooding from the Sotla and its right tributary, the Bistrica, but the floods here do not cause significant damage, since the settlements are predominantly located on slightly higher ground. In this section, the winding stream of the Sotla was regulated during the construction of the railway.

At the exit from the Zelenjak gorge, a wide floodplain opens up on both sides of the river, but flooding only occurs on the lowest lying parts, which mostly consist of wet meadows. The largest flood area is found in Jovsi, but the flooding here does not come from the Sotla. The wet meadows are inundated by ground water and precipitation, usually in late autumn or early spring.

The entire low-lying area along the Sotla, which extends from Dobovec to the Sava, is at risk of flooding. Regulation in some urbanised areas managed to limit the flooding or reduce its frequency. The Sotla tributaries flow towards the river through relatively narrow valleys. Along the Mestinjščica river, Zibiški potok brook, Tinski potok brook, Buča brook and the Bistrica river, high waters with medium to long return periods (more than Q_5) mostly flood agricultural land and some small settlements or individual buildings. In the past, the main road near Podčetrtek was often flooded, while high water fully floods the plains on both banks of the river every year.

Areas at risk of flooding on the Slovenian side that need to be mentioned are:

- the road leading to the Orešje border crossing,
- buildings in the settlements of Bračna vas, Gregovce, Nova vas, Rigonce, and Loče,
- a part of the settlement and tourism infrastructure in the municipality of Podčetrtek,
- Rogatec – the part right next to the Sotla.

Areas at risk of flooding on the Croatian side that need to be mentioned are:

- the area between the Harmica border crossing (Zaprešić–Dobova road) and the Zagreb–Ljubljana railway without an embankment. In this part, several houses which are located between the railway embankments and the Sotla river are at risk,
- the Gmajna settlement in Kumrovec, where several residential and commercial buildings are at risk of flooding,
- the settlement of Plavić, where the local road L22026 is flooded during high water events,
- the villages of Bratkovec, Luka Poljanska and Harina Žlaka, where several residential and commercial buildings are at risk of flooding,
- the area up and downstream of the Hum na Sutli border crossing, where several residential and commercial buildings and a kindergarten are at risk of flooding.

3.1.6.2 Definition of parameters for the treated flood area

The assessment of flood risk serves as the basis for the optimisation of measures as well as financial and economic analysis. The basis for the definition of flood damages for the FRISCO1 project was the methodology from "The Basis for the Bilateral Methodology of Economic Assessment of Flood Damage on Cross-border Basins, Huizinga Methodology with Parameters for the FRISCO1 Project" (University of Zagreb). This methodology defines a limited set of damage categories, which on average account for 80% of the total damage in all EU countries concerned. The method covers the assessment of damage to (1) residential buildings, (2) commercial buildings, (3) industrial buildings, (4) roads, and (5) agricultural facilities.

For the needs of the Frisco project, only flood damage to buildings was identified for flood damage assessment in the Sotla basin. All measures largely preserve the agricultural land as existing flood areas, which is why no economic effects can be observed in connection with them. Similarly, no significant damage to transport infrastructure is expected, since there no extensive infrastructure can be found in the area.

All together, 600 buildings are located within the reach of a 1000-year return period flooding. All buildings from the Building Cadastre of the Republic of Slovenia (2018), i.e. 462 buildings, as well as 138 buildings on the Croatian side have been identified.

In order to calculate the expected annual flood damage, it is first necessary to calculate the damage of individual events with the Q10, Q25, Q50, Q100, Q500 and Q1000 flows. The tables below show calculations for each damage category.

Phase	Damage category	Type of Damage	Anticipated annual damage (EUR/year)
Existing	BUILDINGS	buildings (buildings and fixtures) – residential /model/	101,009
Existing	BUILDINGS	buildings (buildings and fixtures) – commercial /model/	31,804
Existing	BUILDINGS	buildings (buildings and fixtures) – undefined /model/	178,659
Existing	BUILDINGS	buildings (buildings and fixtures) – agricultural /model/	235,668
Existing	BUILDINGS	buildings (buildings and fixtures) – industrial /model/	10,076
Existing	BUILDINGS	buildings (buildings and equipment) – other buildings /model/	1,320
		Total (buildings)	558,535
		Other damages (20% of the total damage)	139,634
		TOTAL – anticipated annual damage (without a threshold)	**698,169**

Anticipated annual flood damage in the flood area of the SOTLA by category (methodology: H.J. Huizinga 2017) – Flood damage model for buildings without a threshold

	AAD without elevation	
	EUR/year	percentage
Slovenian side	421,881	76%
Croatian side	136,655	24%
Total	558,535	

The anticipated annual flood damage in the SOTLA flood area by affected areas (buildings only) with an analysis of the share in anticipated annual damage by location (in Slovenia and in Croatia).

3.1.6.3 Flood damage and economic efficiency of the Vonarje barrier

The main issue with the Vonarje barrier is poor maintenance, since the required funds exceed the annual budget for the maintenance and operation of water management facilities in the basin. As a result, significant damage to concrete and reinforced concrete structures of the Vonarje barrier has occurred in recent years and the state of the hydromechanical and electro-mechanical equipment has deteriorated.

In the event of a collapsed barrier, the risk of flooding is the highest for Podčetrtek and the holiday homes near Podčetrtek. The collapse of the barrier can cause a flood wave with destructive and catastrophic consequences. The Aqualuna water park in Terme Olimia is exposed to the greatest risk, since it is located less than 1000 m from the barrier, right in the path of the flood wave next to the Sotla channel.

Aqualuna, tourism infrastructure – *the greatest risk of flooding*

In previous documentation, the potential flood damage from a single catastrophic flood event was estimated at EUR 7.3 million.

The proposed measures will improve the safety and efficiency of the Vonarsko jezero reservoir. The measures alter neither the characteristics and dimensions of the barrier, nor the boundary conditions of its operation, as all this will remain unchanged. In fact, they will be carried out as an optimisation and modernisation of a previously implemented solution, i.e. the Vonarje barrier. The dimensions of the barrier and the boundary conditions of operation will remain unchanged after the planned measures have been carried out.

It has been established that the cost of renovation and modernisation of the Vonarje barrier is significantly lower than the potential of damage arising from a possible collapse of the barrier. Within the investment, 80 inhabitants will enjoy the benefits of flood-control measures, the Aqualuna water park will be protected, and the development of tourism in the wider project area will be secured.

3.2 PREPARATION AND ANALYSIS OF ALTERNATIVE SOLUTIONS

3.2.1 PREPARATION OF ALTERNATIVE SOLUTIONS

based on all preliminary analyses, the following local arrangements were proposed for the area in the first phase of the study:

- Elevating the existing flood control embankment on the left bank of the Sotla downstream of the Ljubljana–Zagreb railway to protect the settlement of Ključ
- Combining flood control embankments and high water walls to protect the settlements of Gmajna (near Dobova), Dobova, Harmica and Rigonce

- Carrying out individual flood protection measures for the settlement of Nova vas pri Sotli
- Building flood control embankments/building a wall/elevating the road to protect the Bračna vas settlement
- Demolishing the existing flood control embankment and constructing a new one near Kumrovec
- Elevating the Gmajna–Kunšperk bridge
- Carrying out measures in the Aqualuna area (arranging a secondary channel and elevating the existing road)
- Regulating the channel and replacing the bridge in Rogatec (Hum na Sutli)

For retaining high waters of the Sotla, the following reservoirs are proposed:
- Renovation of the Vonarje reservoir
- Reservoirs on the Mestinjščica river
- Reservoirs in the Sotla headwaters (Trlično)

In the second phase of the search for alternative solutions, the proposed measures were examined in detail and, if necessary, improved with the help of the hydraulic model results. Solutions that proved to be economically infeasible, hydraulically unsound or unnecessary were eliminated from the set of possible alternative solution. For this reason, the hydraulic model was used only to analyse solutions which proved to be suitable for further analysis.

This chapter includes a selection of improved solutions that were presented in the previous chapters of this study.

3.2.1.1 The section from the source of the Sotla to the Zelenjak gorge

The Gmajna settlement – Kumrovec

Along the Sotla, a 980 m long embankment has already been partially constructed. The embankment, which ends in the middle of the floodplain, has not been brought to a higher ground, which is why the water can to run along the catchment area and reach the Gmajna settlement.

Embankment along the Sotla near Gmajna

Besides high waters from the Sotla, the area in question is affected by water from the catchment area. The culverts are in poor condition (damaged, clogged), which is why the system used for the drainage of catchment waters during high-water events does not work and the flood hazard for the Gmajna settlement is greater.

Accumulation of catchment waters behind the embankment

The first phase of the alternative solution design included an embankment in the Gmajna settlement, which was open on the downstream (eastern) side. The hydraulic analysis results showed damming on the SE part of Bistriško polje (Kumrovačko polje) during high-water events, where the elevation contours upstream and downstream of the village are practically identical. Because of these findings, it was necessary to change the flood protection concept for the village of Gmajna. The flood-control embankment will have to surround the Gmajna settlement on three sides.

Apart from the embankment, the protection against flooding in the Gmajna settlement will also need to include measures for catchment waters. It is unnecessary to provide protection for the plains above Gmajna, as there are no buildings in this area. However, a water treatment plant is located in this part, with basins elevated above the surrounding terrain. If necessary, local measures for the protection of mechanical equipment and other sensitive fixtures could be carried out (elevating the equipment above the flood water level; constructing another embankment next to the plant, which includes the design of a pump for own water).

Podčetrtek – Aqualuna (Harina Žlaka)

The water park area with about 100 holiday homes as well as a local road on the left bank get flooded during high water events of the Sotla. Comprehensive measures are proposed for the protection of both the buildings and infrastructure that are at risk in Aqualuna. In order to improve the conductivity of the narrow corridor along Aqualuna, a secondary channel on the left bank of the watercourse is proposed. The outer edge of the widened channel is connected to the local road, which can be elevated at least

0.5 m above the current level as part of the measures (depending on driveways at the local buildings). The secondary channel will be 2 m lower than the existing terrain, which is why the improvement of flow during flooding is expected. The secondary channel/widening of the main Sotla riverbed will be carried out at the length of 200 m. Before the construction, two (abandoned) buildings will have to be demolished. For re-routing waters from and then back into the Sotla, three new bridges will need to be constructed along the new channel (two for the railway line and one for the Aqualuna access road).

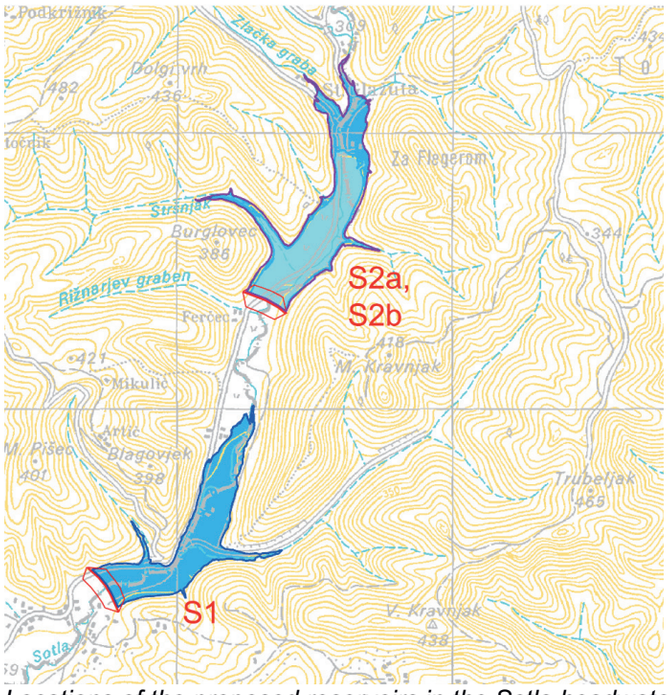
The construction of a secondary overflow corridor is important both from the hydrotechnical as well as environmental point, since a bypass on the railway's west side would decrease the flow passing the Aqualuna water park, and at the same time, the solution would partly restore the identity of the natural habitat, which the Sotla used to have in this area and which was lost due to the construction of Aqualuna and holiday homes on the flood area right next to the river. The overflow corridor is 950 m long, and the length of the natural habitat is 670 m. Due to the construction of the overflow section of the canal, a gravel road that currently leads to the surrounding fields across the embankment would need to be moved.

Rogatec (Hum na Sutli)

In Rogatec (Hum na Sutli), the flooding is the most problematic at a bridge over the Sotla near the border crossing. The current bridge is arched and its opening above the surface of the river is too small for the flood waters to flow through unobstructed. Besides, locally speaking the size of the channel is too small.
For the section of the Sotla in Rogatec (Hum na Sutli), flood safety could be improved by constructing a wall or elevating the top of the left bank on the section downstream of the border crossing. After the implementation of the proposed measures, the flood hazard in the settlement upstream and downstream of the border crossing will decrease significantly.

Reservoirs in the Sotla headwaters (Trlično)

Regardless of the solution planned for the respective Sotla section and reconstruction of the Rogatec bridge, it should be noted that the Sotla spills out of its channel even before entering the town. Furthermore, an adequate retention of high water in the basin needs to secured along with the regulation of channels in the watercourses and the flow increase, since the increase in flow would also increase the intensity of events downstream of the implemented measure. With these facts in mind, potential locations for retaining high water upstream of Rogatec were analysed. Two locations for the reservoir were identified and analysed.



Locations of the proposed reservoirs in the Sotla headwaters

Due to the distance of the proposed measure from the primary subject of the measure (Rogatec), the effect of high water retention would not be as great as an equal volume just upstream of Rogatec, as the reservoirs could only control the upper third of the basin. As an additional measure to reduce the flood peak, floodplains along the Sotla valley between Trličnо and Rogatec should be activated to the greatest possible extent.

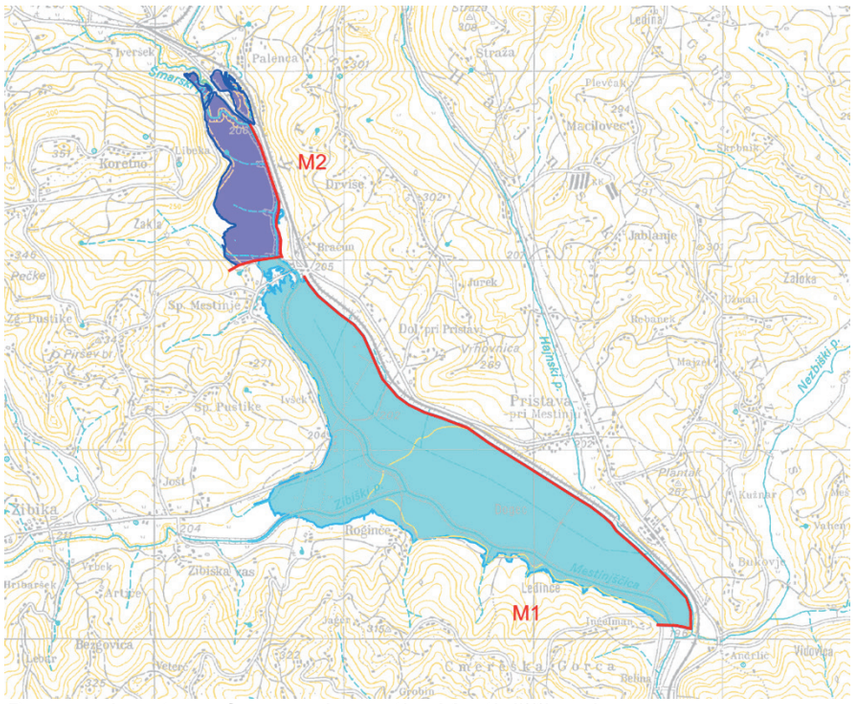
The Vonarje barrier

The Vonarje barrier was built in 1980 with the aim of retaining high waters as well as providing drinking water and irrigation water. Due to the poor quality of water in the reservoir and the negative effects on the fauna in cases of releasing this water, the reservoir was emptied in 1988. Currently, it serves as a retention basin for high waters. Visible damage to the concrete structures has appeared lately, and the hydromechanical and electrical equipment is also worn out.

Reservoirs on the Mestinjščica river

As one of the largest Sotla tributaries, the Mestinjščica river has a significant impact on the water regime in a large section of the valley upstream of the Vonarje barrier. Because of its effect, we examined whether some of the high waters could be retained in the Mestinjščica valley. The M1 reservoir would thus be the primary reservoir on the Mestinjščica river. The barrier would be located in a narrow part under Cmereška gorca, downstream of the Jerčinski potok brook. The barrier would consist of one frontal embankment and one that would need to be constructed along the railway. Along with the embankment, adequate retention and outflow of the catchment water that currently flows towards the Mestinjščica river would need to be secured. The construction of a smaller reservoir (M2) is planned upstream of the

M1 reservoir. Just like in case of the M1 reservoir, the barrier consists of a frontal part which is positioned near Spodnje Mestinje and an embankment that runs along the existing main road.



Proposed system of reservoirs on the Mestinjščica river

3.2.1.2 The section from the Zelenjak gorge to the outflow into the Sava

In the section between the Zelenjak HS and the outflow into the Sava (i.e. the area of the Sotla 3 hydraulic model), the risk of flooding is relatively low. Hereinafter, the proposed solutions are described in detail for various sections (areas/settlements) in cases where they are expected to demonstrate an extensive impact on the flood hazard.

Protection of the Loče settlement (Arrangement No. 1)

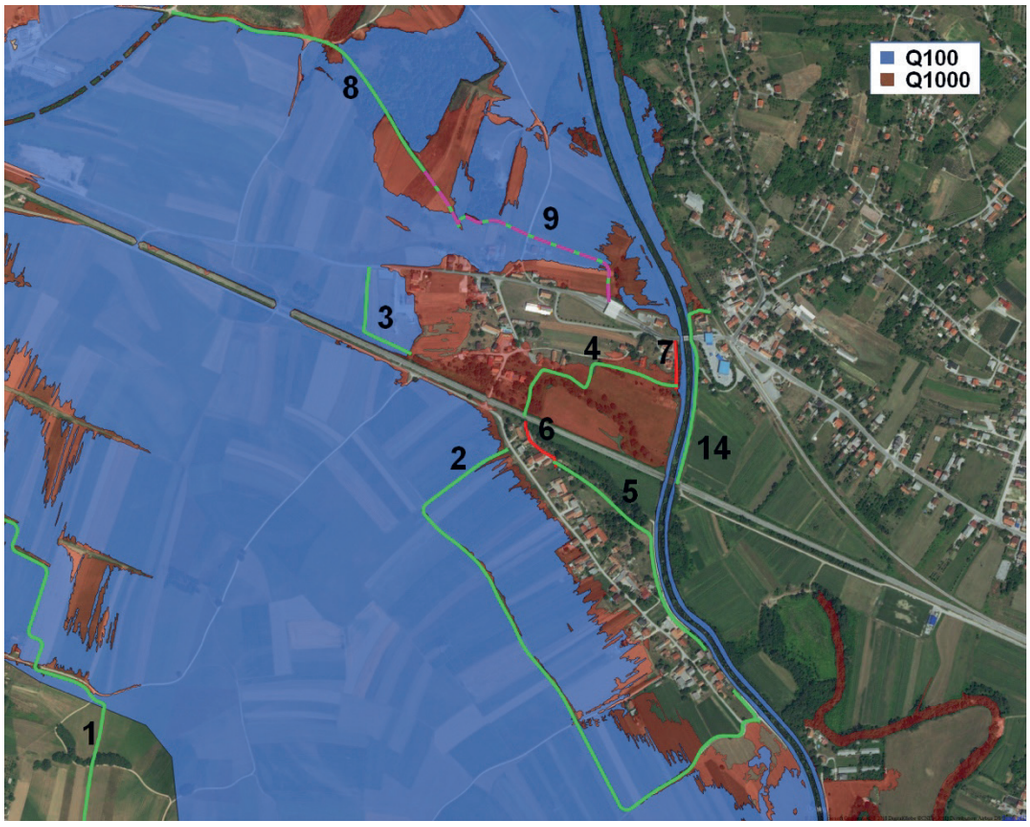
A flood control embankment for the protection of Loče has already been planned in the national spatial plan for the Mokrice Hydroelectric Power Plant. It should be emphasised that this area is characterised by flooding of the Sava, not the Sotla.

Protection of Rigonce/Harmica – the right bank (Arrangements No. 2 to 9)

The following are the arrangements for protecting the Rigonce settlement:

- Arrangement No. 2: A flood control embankment designed to protect the Rigonce settlement against the high waters of the Sava (already included in the national spatial plan for the Mokrice Hydroelectric Power Plant)
- Arrangement No. 3: A flood control embankment designed to protect the Rigonce settlement against the break in of the Sava waters through a culvert in the railway embankment (already included in the national spatial plan for the Mokrice Hydroelectric Power Plant)

- Arrangements Nos. 4, 5, 6, 7: Flood control embankments (or elevating of the Sotla banks at certain sections) and walls designed to protect the Rigonce settlement against the Sotla high waters
- Arrangement No. 8, 9: A flood control embankment designed to protect the Rigonce settlement (preventing the water from flowing onto the inhabited surfaces from the areas further upstream during the Sotla high-water events)

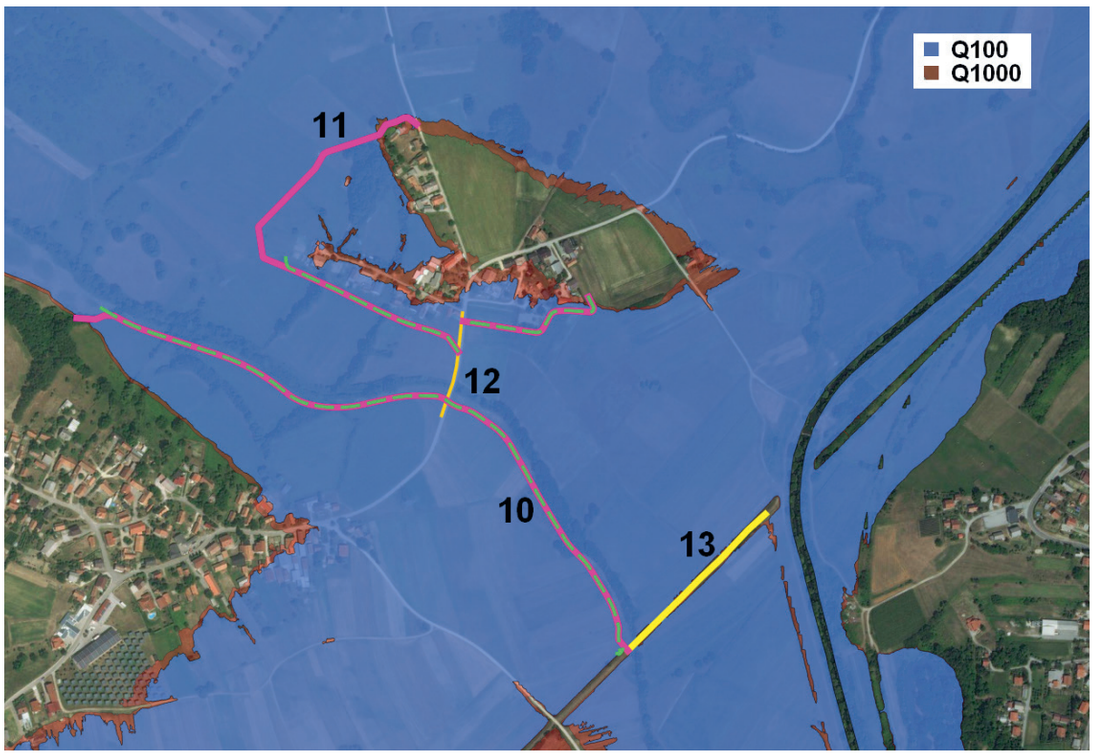


A view of trails in all arrangements planned for the Loče and Rigonce/Harmica area

Protection of Dobova, Veliki Obrež and Gmajna the settlements (Arrangements No. 10 to 13)

The following arrangements are planned to secure protection against flooding:

- Arrangement No. 10: A flood control embankment on the Šica brook's right bank designed to protect the Veliki Obrež and Dobova settlements (preventing water from flowing into the area west of the abandoned railway embankment).
- Arrangement No. 11, 12: Building a flood control embankment designed to protect the Gmajna settlement and elevating the currently existing road to allow access to the settlement during high water events.
- Arrangement No. 13: Removal of the abandoned railway embankment with the aim of reducing the damming and water level upstream, near the Gmajna settlement.



View of the embankment trails from the IS Project, 2012 study (green dotted line) and of the improved embankment trail according to the hydraulic model results for the existing condition (pink) and the relocation of the road and removal of the abandoned embankment (remained unchanged from the IS Project, 2012 study)

Protection in the area of Rigonce/Harmica – the left bank (Arrangement No. 14)

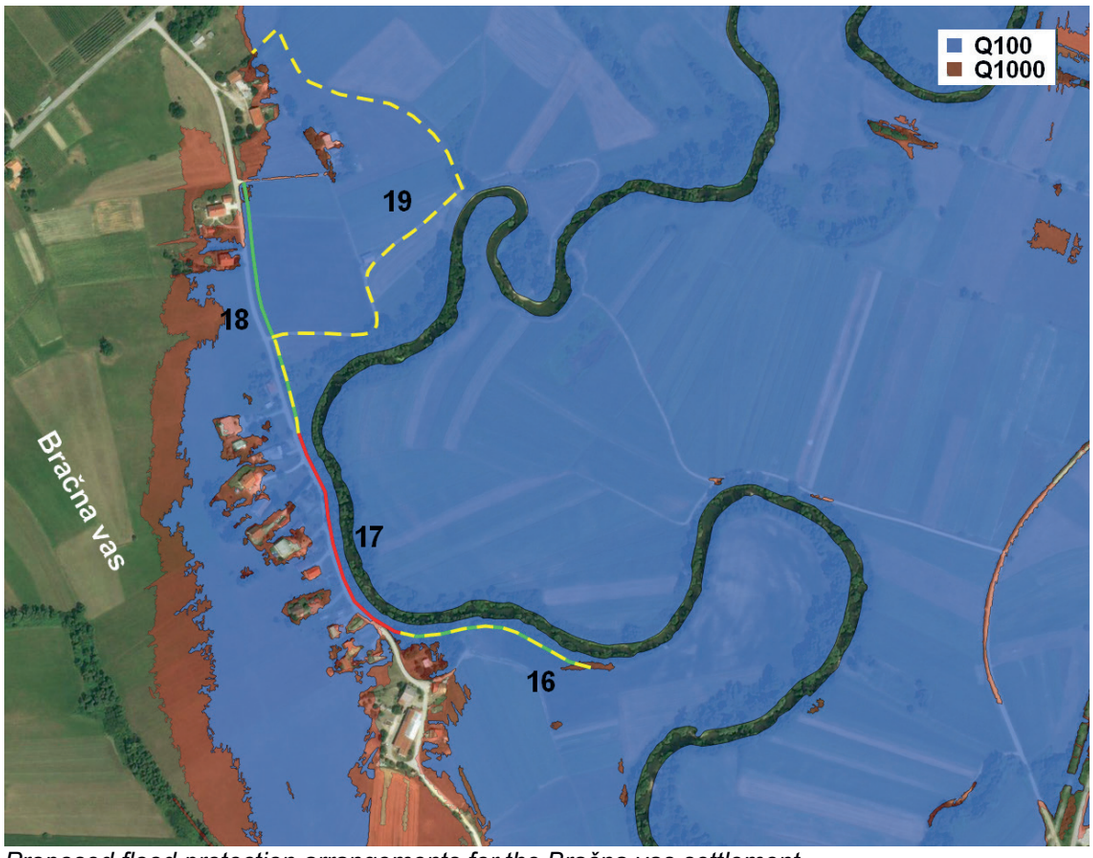
Based on a site survey, current data on flood hazard, interest expressed by Croatia, and findings about the effect that the right bank solutions might bring along, the construction of a flood control embankment on the left bank of the Sotla between the Rigonce/Harmica border crossing and the railway is proposed.

Protecting the Ključ Brdovečki settlement (Arrangement No. 15)

Several settlements on the left bank of the Sotla, south of the Zagreb–Ljubljana railway, are at risk of flooding. It should be emphasised that this area gets flooded by the Sava river, while the Sotla only contributes to the increased flow in the Sava. In this section, a flood control embankment next to the Ključ Brdovečki settlement has already been built (length: 3,480 m; illustrated by a green line in the next figure). As the embankment is quite old, some water allegedly seeps through during the Sotla and Sava flooding. The nearby settlements of Drenje Brdovečko and Savski Marof are also at risk of flooding from the Sava river. The findings of a site survey for this project concluded that the existing embankment has a significantly lower crown in this section compared to the section further downstream. The proposed first phase solution was therefore to elevate the flood control embankment that runs on the left bank, right along the Sotla channel.

Protection of the Bračna vas settlement (Regulations No. 16 to 19)

The hydraulic model results show that the Bračna vas settlement (the right bank of the Sotla) gets flooded during the Sotla events with a 100-year return period. The residents of Bračna vas said that, during the high-water event of 2010, the water reached the edge of the road leading through the settlement. On the right bank of the Sotla, a flood control embankment (Arrangement No. 16) on the south side by the river channel, which would begin approx. 300 m downstream of the settlement and connect with the high water wall next to the existing road (Arrangement No. 17), is planned as the protection of the Bračna vas settlement. The planned flood control wall then runs along the road leading the north (on the location of the existing border fence) and after approx. 500 m joins the existing dirt road that will probably need to be elevated.



Proposed flood protection arrangements for the Bračna vas settlement

Protecting other buildings that are at risk of flooding

One of the alternative solutions for protecting buildings against floods is the protection of buildings with prefabricated elements (securing the doors and windows with flood protection panels, automatic pipeline valves). Such a measure will definitely have to be carried out on other buildings, which are also at risk but cannot be protected against the Sotla flooding by the above-mentioned flood control measures. Given the relatively low flood risk in the section of the Sotla between the Zelenjak HS and the outflow into the Sava, such measures (i.e. individual flood protection measures) could represent an alternative solution to all previously described measures in the economic analysis.

COMBINATIONS OF DIFFERENT ARRANGEMENTS

As some of the arrangements were designed interdependently, the following combinations were analysed in the flood risk analysis:

Description (combination of different arrangements)	Designation (No.)	Arrangement
protection of Rigonce – the S part	5	embankment
	6	wall
protection of the NE part of Rigonce	4	embankment
	7	wall
protection of NW part of Rigonce during >Q100 events – 1st option	9	embankment
protection of NW part of Rigonce during <Q100 events – 2nd option	8	embankment
protection of Gmajna – the embankment	11	embankment
protection of Gmajna – removal of the abandoned embankment	13	removal of the embankment
protection of Obrež and Dobova – protection of Gmajna	11	the Gmajna embankment
	10	the Šica embankment
	12	elevation of the road
protection of Bračna vas – 1st option	16	joint part of the embankment
	18	1st option for the closing section of the embankment
	17	wall
protection of Bračna vas – 2nd option	16	joint part of the embankment
	19	2nd option for the closing section of the embankment
	17	wall
Arrangements contained in the national spatial plan for the Mokrice Hydroelectric Power Plant	3	the Rigonce embankment (short)
	2	the Rigonce embankment (long)
	1	the Loče embankment

Combinations of arrangements in the section from the Zelenjak gorge to the outflow into the Sava

3.2.2 ANALYSIS OF ALTERNATIVE SOLUTIONS

The following local arrangements were proposed:

- Elevating the existing flood control embankment on the left bank of the Sotla downstream of the Ljubljana–Zagreb railway to protect the settlement of Ključ
- Combining flood control embankments and high water walls to protect the settlements of Gmajna (near Dobova), Dobova, Harmica and Rigonce
- Carrying out individual flood protection measures for the settlement of Nova vas pri Sotli

- Building flood control embankments/building a wall/elevating the road to protect the Bračna vas settlement
- Demolishing the existing flood control embankment and constructing a new one near Kumrovec
- Elevating the Gmajna–Kunšperk bridge
- Carrying out measures in the Aqualuna area (arranging a secondary channel and elevating the existing road)
- Regulating the channel and replacing the bridge in Rogatec (Hum na Sutli)

For retaining high waters of the Sotla, the following reservoirs are proposed:

- Renovation of the Vonarje reservoir
- Reservoirs on the Mestinjščica river
- Reservoirs in the Sotla headwaters (Trlično)

The analysis of alternative solutions considers the costs of investment, operation and maintenance as well as other costs, if any (costs of reducing environmental impact etc.), and benefits. The analysis of selected alternative solutions is based on the results of hydraulic modelling carried out for the planned state and on the calculated flood damages.

In the next chapter of the study, the solutions were narrowed down by using a hydraulic model and a detailed economic analysis was made. Given the fact that the damage potential is insignificant for agricultural land, the hydraulic analysis was targeted towards optimising alternative flood risk reduction solutions for the currently inhabited areas. This is also in line with the principle that new construction measures should be carried out primarily to protect the safety and health of the population and the most valuable economic assets and activities, as well as cultural and natural heritage.

3.2.2.1 The section from the source of the Sotla to Zelenjak (Bistrica ob Sotli)

The following measures were proposed in the section of the Sotla above Zelenjak:

- replacing the bridge and regulating the channel in Rogatec (Hum na Sutli),
- expanding the Sotla cross section and constructing a sustainable secondary overflow corridor (green infrastructure) in the area of Aqualuna in Podčetrtek/Harina Žlaka,
- building an embankment with the construction of drainage ditches in the area of the Gmajna settlement (Kumrovec).

Rogatec (Hum na Sutli)

In Rogatec, the flooding reaches the most problematic level at a bridge over the Sotla near the border crossing.

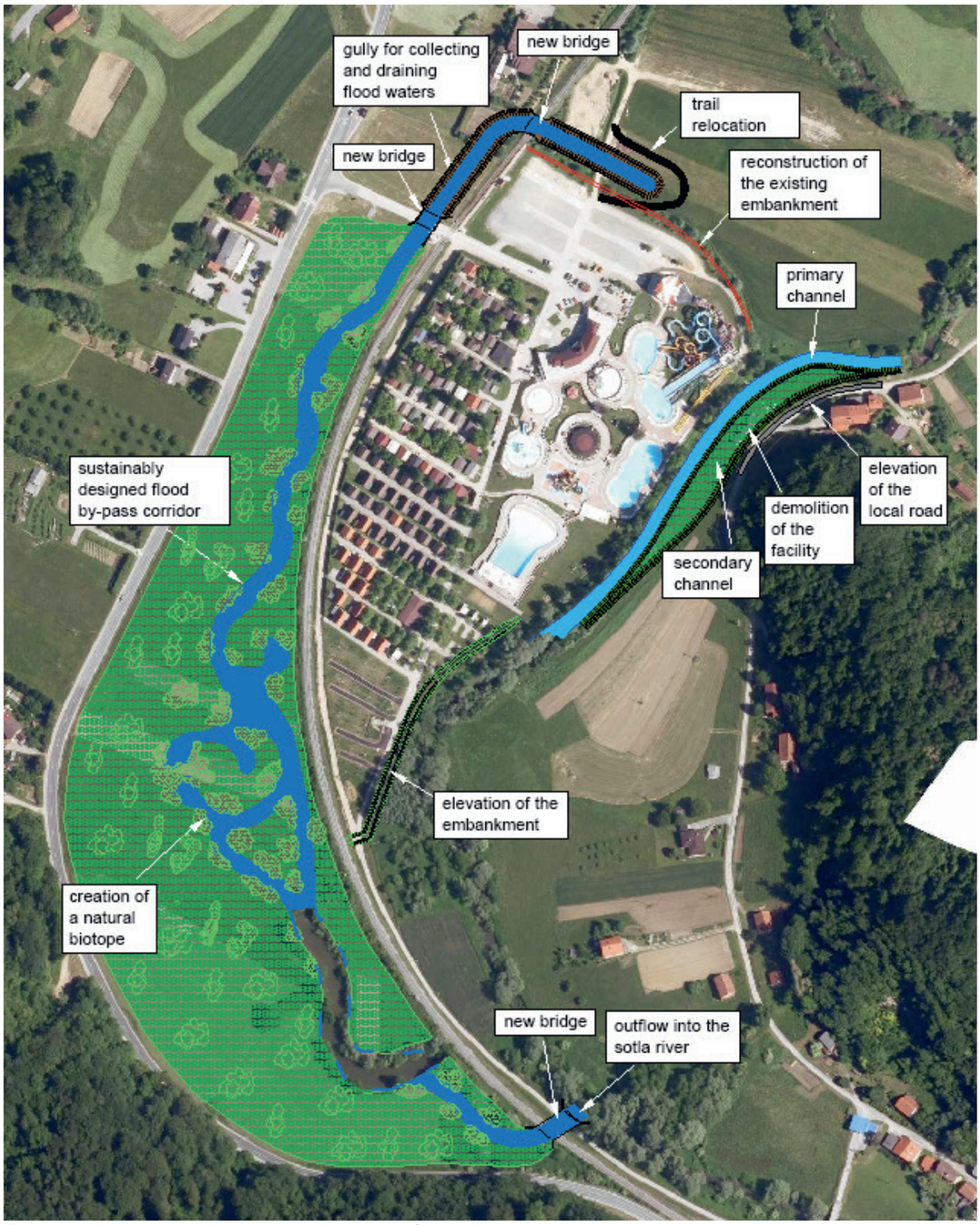
Area of planned measures in Rogatec

A hydraulic analysis showed that buildings on the right bank upstream of the bridge and those on the left bank downstream of the bridge would still be flooded during a 100-year high water event despite the better conductivity of the improved channel and bridge. Given that some areas would still be under threat once the channel has been regulated and the bridge replaced, the construction of an RC flood control wall that would protect the buildings against the 100-year Sotla flooding is proposed for the protection of buildings in two sections of the Sotla river stretch that runs through Rogatec/Hum na Sutli.

The proposed measures would positively affect the flood safety of Rogatec during a Q100 event. The flood control wall also protects the buildings next to the wall and the railway. The hydraulic analysis of the planned state during 1000-year high water events showed that spilling over the planned walls mostly leads to improved flood conditions, but that the situation is worse in case of certain buildings located next to the planned flood control wall on the left bank. For this reason, a 5 m slat-based flood protection (IBS or similar) is constructed on the downstream side of the planned wall on the left bank, which can be removed in the event of water flowing over the wall (e.g. at the Q1000 flow), so that the high water in the catchment can flow back into the Sotla channel. Once the proposed measures are implemented, the danger of the Sotla flooding the settlement during high water events upstream and downstream of the border crossing will significantly decrease. The project includes no analyses or designs of potential solutions for the Draganja brook flood risks.

Podčetrtek – Aqualuna (Harina Žlaka)

Comprehensive measures are proposed for the protection of both the buildings and infrastructure that are at risk in Aqualuna. In order to improve the conductivity of the narrow corridor along Aqualuna, a secondary channel on the left bank of the watercourse is proposed. The channel would be constructed approximately 1 m above the water level, considering normal hydrological conditions. The outer edge of the widened channel would be connected to a local road that would also be elevated by 1 m. The area of the secondary channel will be 2 m lower than the existing terrain, which will improve the flow during flooding. The secondary channel/widening of the main Sotla riverbed is 260 m long. Before the construction, two (abandoned) buildings and a small bridge over the Sotla will have to be demolished.



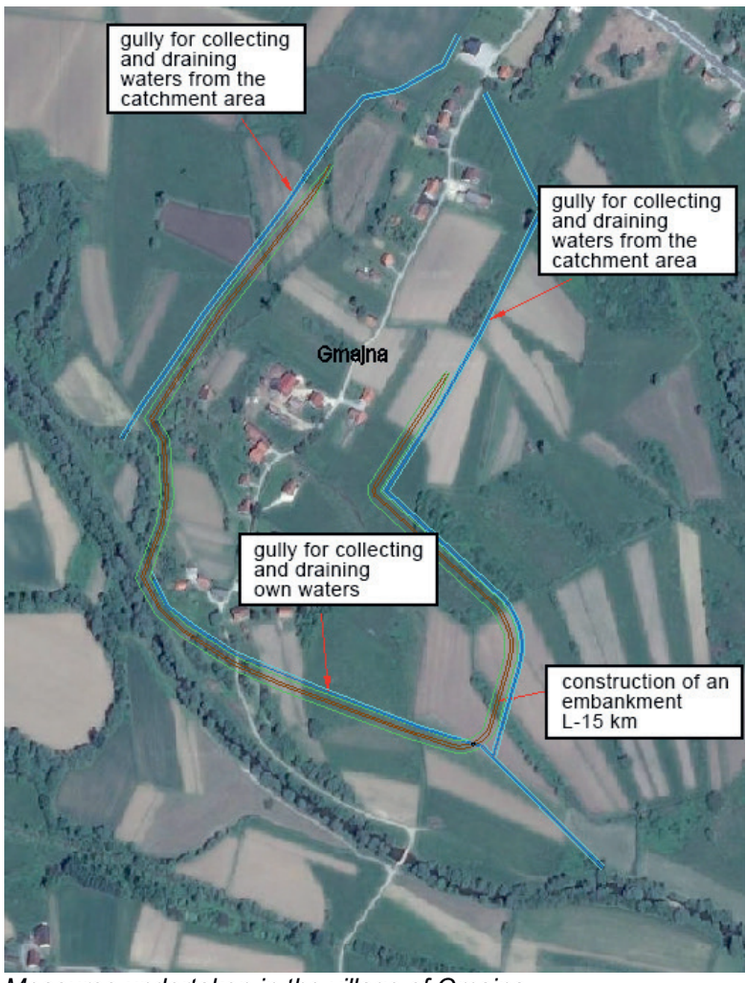
Proposed measures in the broader area of Aqualuna

The proposed measures were verified by using a hydraulic model. In the 1D model, we modified the cross sections for the proposed Sotla secondary channel trails. We generated profiles for the respective section based on the national LIDAR terrain image (taken in 2014) and determined the bottom by using the level from the existing situation model. The arrangements included the removal of the existing bridge on this section, which was not considered in calculations made for the current situation. The hydraulic

analysis of the planned situation showed that the proposed measures have a positive effect both on the flood safety in buildings and the depth of flood waters in the agricultural areas. During a Q100 event, Aqualuna and the elevated section of the local road are safe from flooding, while the depth of high water on the meadows and fields decreases by 25 cm. During a Q500 event, the buildings in Aqualuna are not at risk. Some spillover occurs at the extreme NE part, where the slides are located, but the water is no deeper than 8 cm. During a 1000-year event, flood water starts flowing onto the NE part of Aqualuna, from where it flows onward to the west and then south. The holiday homes are partly flooded. The average water depth is 15 cm and the maximum depth is 45 cm. The railway is safe from flooding in this section, even during a Q1000 flow.

The Gmajna settlement – Kumrovec

A 1360 m long flood-control embankment is planned for the protection of the Gmajna settlement, embracing it from three sides. Besides the embankment, the protection against flooding in the Gmajna settlement also needs to include measures designed for catchment waters. Two ditches, which would be constructed west and east of the planned embankment, would be connected to the existing ditches (corridors where surface waters is expected to flow) and finally to the existing meander/the Sotla channel. Within the protected area, it would be necessary to construct a ditch for the drainage of own water. Gravitational drainage of own water would be possible during low water levels of the Sotla. During increased water levels, it would be necessary to prevent the water from flowing from the flood area to the protected area of Gmajna. To this end, a non-return valve should be installed in the drainage ditch and a pumping station for pumping own water into the Sotla should be designed for the protected area. The planned embankment should be slightly removed from the settlement in the SE part. The area, which serves several purposes, allows the retention of water if the pump breaks down as well as the retention of water as its primary function (i.e. a smaller pump or even a mere drainage ditch), or it can be used as a detention basin for water that would seep onto the protected area from the ground due to the increased groundwater levels.



Measures undertaken in the village of Gmajna

The existing embankment is demolished in its entirety and the surface levelled to match the surrounding terrain. The impact of the planned embankment was examined with a hydraulic model, which showed that the embankment protects the village of Gmajna against the 100-year high water. During a Q500 event, the water flows over the east side of the embankment and spreads towards the west, completely flooding the area behind the embankment. During a Q1000 event, the water spills over the embankment along the entire length.

The hydraulic analysis showed that the proposed embankment has a negative impact on the water level, especially on the meadows and agricultural surfaces. For flows with longer return periods (Q100 or more), the risk of flooding (the water level rises by a few cm) for the existing residential buildings on the right bank (Krunšperk 19) increases as well. For this reason, a panel-based flood protection for openings in buildings up to the 1000-year flood level (173.0 m a.s.l.) is planned as an additional measure for offsetting the negative impact caused by the construction of an embankment near Gmajna.

It is unnecessary to provide protection for the plains above Gmajna, as there are no buildings in this area. However, a water treatment plant is located in this part, with basins elevated above the surrounding terrain. If necessary, local measures for the protection of mechanical equipment and other sensitive

fixtures could be carried out (elevating the equipment above the flood water level; constructing another embankment next to the plant, which includes the design of a pump for own water).

3.2.2.2 The section from Zelenjak (Bistrica ob Sotli) to the outflow into the Sava river

Four sets of construction measures are considered for the section between the outflow into the Sava and Zelenjak (Bistrica ob Sotli):

- protection of the NW part of Rigonce up to the Q100 flow (an embankment which is 536 m long and on average 1.4 m high),
- protection of Obrež and Dobova, protection of Gmajna (constructing an embankment which is 809 m long and on average 1.7 m high, constructing an embankment along the Šica brook, which is 944 m long and on average 2.1 m high, elevating a 128 m long stretch of the road 1.9 m on average, replacing a bridge and constructing a return valve in the culvert in the abandoned railway embankment near Dobova),
- measures related to the national spatial plan for the Mokrice Hydroelectric Power Plant (the Rigonce embankment which is 228 m long and on average 2.1 m high, the Rigonce embankment which is 1285 m long and on average 1.3 m high, the Loče embankment which is 3137 m long and on average 1.6 m high),
- individual measures for the protection of residential buildings (pre-fabricated flood-control barriers).

The economical aspects of the flood control embankments and other measures relating to the national spatial plan for the Mokrice Hydroelectric Power Plant which is currently in force are not included in the study, since the financing of such measures is covered in the national spatial plan. However, such measures are taken into account in the hydraulic analysis of the planned situation because they could affect the areas included in the FRISCO1 project. The elevations of flood control embankments from the national spatial plan for the Mokrice Hydroelectric Power Plant were summarised from the construction plans in the preliminary design for the Mokrice Hydroelectric Power Plant, project number IBMK-A200/037, IBE, April 2013, which we received from the Institute for Hydraulic Research.

3.2.2.3 Impact on flood hazard

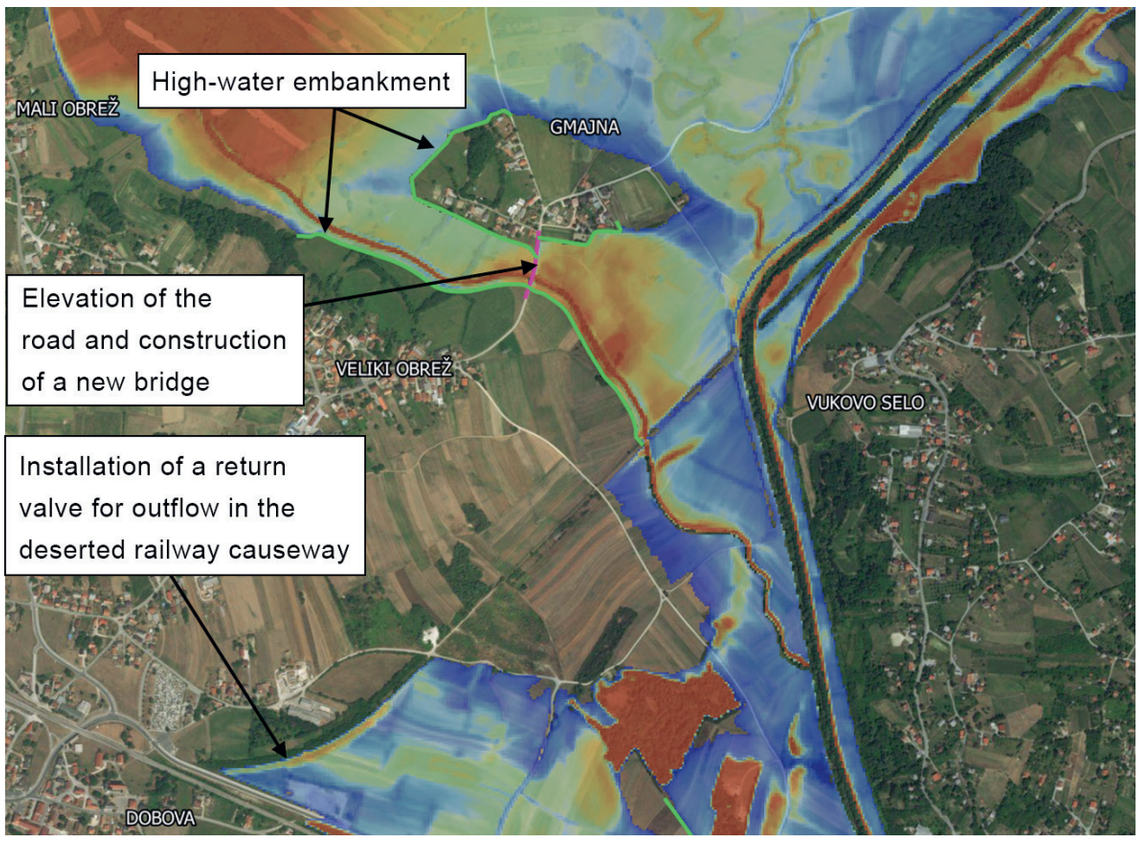
Hydraulic model

For the hydraulic analysis of the planned situation, a hydraulic model, developed by the Institute for Hydraulic Research for the FRISCO1 project, was used. The solutions from the national spatial plan for the Mokrice Hydroelectric Power Plant were included in the hydraulic model, but not in the economic analysis. The lower boundary condition for the planned state was determined in the same way as for the existing situation. The upstream boundary condition (upstream from the Mokrice Hydroelectric Power Plant) was also changed in the 2D model, i.e. for the part where the Sava high water flows into the relevant area of the Sotla and the Sava confluence. The outline of the water level for this boundary condition was summarised according to the results of the HHM Mokrice Hydroelectric Power Plant. All

selected arrangements are to be carried out on a relatively short stretch of the Sotla. It was found that this section is characterised by the durations of precipitation that cause the most prominent peaks.

Impact of the selected solutions on the flood hazard in the area around Gmajna, Veliki Obrež and Dobova

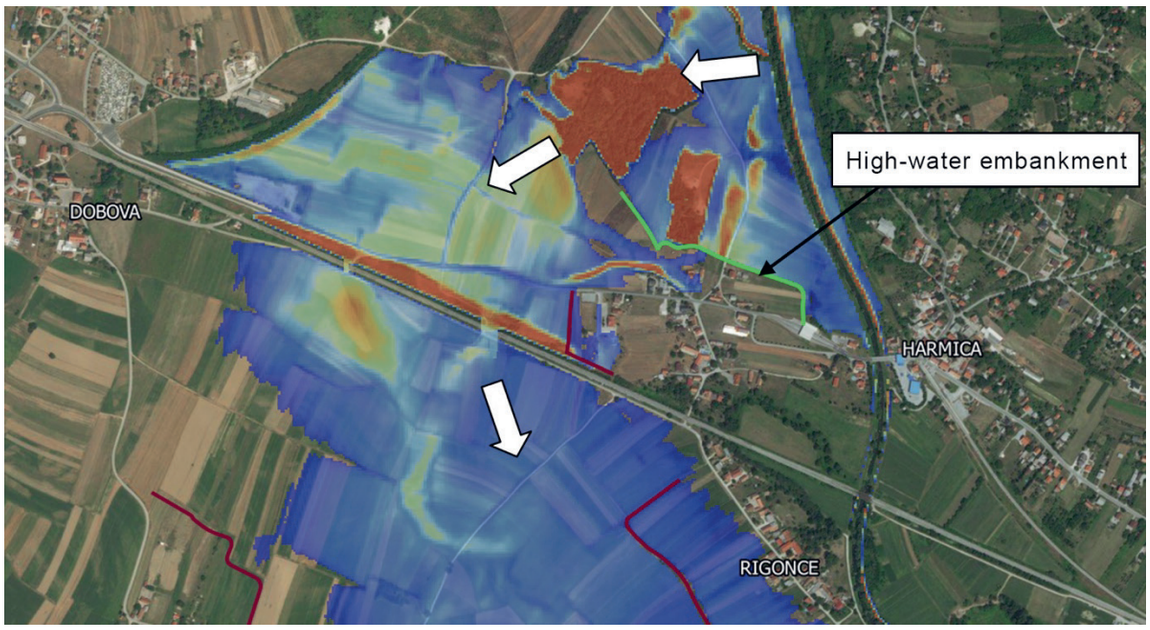
Arrangements in the area of Gmajna, Dobova and Veliki Obrež (preventive elevation) sufficiently protect all settlements against high waters as intense as the 1000-year ones. By elevating the road and constructing a new bridge, access to the Gmajna settlement would be possible even during high water events.



Depths at the Q100 flow in Gmajna, Veliki Obrež and Dobova with all selected solutions

Impact of the selected solutions on the flood hazard in the area around Rigonce/Harmica

The embankment planned for the protection of the NW part of Rigonce adequately protects that part of Rigonce which currently gets flooded at a flow up to Q100.



Depth at Q100 in the area around Rigonce/Harmice

Due to all measures, more water would flow in the channel than in the current situation, which is why the Sotla level near the Rigonce/Harmica border crossing would increase by approx. 17 cm at the Q100 flow. There is no significant impact at Q10. Due to a minor rise in the water level in the Sotla channel at Q100 in Rigonce/Harmica, the elevation of the left bank of the Sotla channel at the section between the Rigonce/Harmica border crossing and the railway line, at those parts where the bank elevation is lower than the Q100 + 0.5 m, is proposed as a mitigation measure. Because the difference between the water levels at Q100 and Q1000 in this section is quite small, such a mitigation measure will prevent the water from spilling over the left bank even during a Q1000 event.

3.3 SELECTION OF THE MOST SUITABLE SOLUTION

3.3.1 DEFINITION OF THE SET OF MEASURES

The following measures were defined within the measure identification framework:

a) The section from the outflow into the Sava to Zelenjak (Bistrica ob Sotli)

- Protection of the NW part of Rigonce during <Q100 events
- Protection of Obrež and Dobova, protection of Gmajna

b) The section from Zelenjak (Bistrica ob Sotli) to the source of the Sotla

- Solutions for Gmajna
- Solutions for Aqualuna
- Solutions for Rogatec

c) A no regret measure

- Renovation of the Vonarje barrier

3.3.2 Investment costs of the arrangements & financial and economic viability

The table below shows the estimated value of the investment for the proposed measures.

Investment value of the project

		Value (EUR)	VAT (EUR)	Value with tax (EUR)	Costs eligible for co-financing (EUR)
A	The section from the outflow into the Sava to Zelenjak (Bistrica ob Sotli)	899,316.00	197,849.52	1,097,165.52	1,097,165.52
1	Protection of the NW part of Rigonce during <Q100 events	*113,418.00*	*24,951.96*	*138,369.96*	*138,369.96*
2	Protection of Obrež and Dobova, protection of Gmajna	*704,142.00*	*154,911.24*	*859,053.24*	*859,053.24*
	Unforeseen works at the section (10%)	81,756.00	*17,986.32*	*99,742.32*	99,742.32
B	The section from Zelenjak (Bistrica ob Sotli) to the source of the Sotla	3,356,677.50	780,996.15	4,137,673.65	4,137,673.65
1	Solutions for Gmajna	*699,600.00*	*174,636.00*	*874,236.00*	*874,236.00*
2	Solutions for Aqualuna	*1,579,847.50*	*351,612.25*	*1,931,459.75*	*1,931,459.75*
3	Solutions for Rogatec	*1,077,230.00*	*254,747.90*	*1,331,977.90*	*1,331,977.90*
C	The Vonarje barrier	1,103,993.57	259,438.49	1,363,432.06	1,363,432.06
D	Construction supervision (2%)	127,119.87	27,966.37	155,086.24	155,086.24
E	Informing the public	70,825.00	15,581.50	86,406.50	86,406.50
	TOTAL	5,557,931.94	1,281,832.03	6,839,763.97	6,839,763.97
	SLOVENIAN VAT (22%) / CROATIAN VAT (25%)	1,281,832.03			
	TOTAL, inclusive of VAT (Slovenian and Croatian rate)	6,839,763.97			
	TOTAL, without unforeseen works	6,238,115.11			

The total value of the investment exclusive of VAT is estimated at EUR 5,557,931.94. The total value, taking into account the 22% Slovenian VAT rate and the 25% Croatian VAT rate, amounts to EUR 6,839,763.97 and represents in its entirety the eligible costs of the project, since the value added tax is non-refundable.

The financial net present value of the investment is negative and totals EUR 7,432,332. The financial rate of return is also negative and totals 17.58%.

The economic net present value of the project is positive, amounting to EUR 1,978,399, which means that the benefit of the project is greater than its cost. This is also confirmed by the internal rate of return of 7.57% for the project. Similarly, the project has a favourable benefit-cost ratio of 1.38.

3.3.3 Multiple-criteria analysis

The common bilateral harmonized methodology for the economic assessment of flood damages in the cross-border river basins (September 2018) is intended for the assessment of flood damages in the cross-border river basins of the rivers of Kolpa, Sotla, Drava, Mura, Dragonja and Bregana for the purpose of implementing the FRISCO1 project activities.

The methodology was developed based on a bilaterally harmonized and accepted document called Basis for the Bilateral Methodology for the Economic Assessment of Flood Damages in the Cross-border River Basins (hereafter: "Methodology Basis"), which was elaborated by the Faculty of Civil Engineering at the University of Zagreb (Građevinska fakulteta Sveučilišta u Zagrebu) in August 2018.

The adopted Methodology Basis suggests that, with the aim of a comprehensive flood risks assessment, pursuant to the presented methodological approach to demonstrating the economic viability and feasibility of the proposed flood risk reduction measures, the analysed proposals of the measure variants additionally take into account the damage consequences related to the human health and the environment.

In the preparation of the Cross-border coordinated studies of integrated flood risk management in the cross-border basins of the Kolpa, Sotla, Drava, Mura, Dragonja and Bregana rivers within the project, the following the calculation of economic viability and feasibility of the proposed variants of flood risk reduction measures, as an additional aspect of choosing the most appropriate solution, i.e. the effect of all "acceptable solutions" on reducing the impact of floods on human health and the environment, will be taken into account. An additional procedure of selecting the most suitable solution is performed for all variants of the acceptable solutions in the following steps:

A. Assessment of positive effects of acceptable solutions on human health
B. Assessment of positive effects of acceptable solutions on the environment
C. A joint assessment of consequences of flood events on human health and the environment
D. Selection of the best solution

A. <u>Assessment of positive effects of acceptable solutions on human health</u>

For the area that was the subject of the FRISCO project for the Sotla river, the number of affected residents was analysed based on the Central Population Register of the Republic of Slovenia (data from 2015). On the Croatian side of the border, an assessment of effects demonstrated on the flood area was made for the settlement of Risvica, which has 277 inhabitants according to the 2011 census by the Croatian Bureau of Statistics (Statistička izvješća 1583/2016 (Statistical Reports)). The values for individual houses, which could not be accurately determined due to the aggregate nature of the data, were estimated at approx. 20% of residential buildings being located within the reach of high waters with a 100-year return period, which means that 55 inhabitants are exposed to flooding.

B. Assessment of positive effects of acceptable solutions on the environment

Based on the available data for the state of the sewerage system in the analysed flood area of the Sotla river (ZKGJI 2018, CRP-EHIŠ 2015), a spatial inquiry with a defined "buffer" area of 50 meters was performed on each side of the public sewerage system, which identified both the buildings and inhabitants who are not yet connected to the sewerage system and thus represent a criterion under the proposed multiple-criteria analysis.

C. A joint assessment of consequences in flood events on human health and the environment for the FRISCO Sotla area

Considering that, under the prescribed multiple-criteria analysis, all treated variants have a common definition recognized as the most appropriate, we find that the choice of one or the other solution variant is perfectly appropriate. However, the very selection of either one solution should be based on other criteria.

3.4 CONCLUSION

The entire low-lying area along the Sotla, which extends from Dobovec to the Sava, is at risk of flooding. Regulation in some urbanised areas managed to limit the flooding or reduce its frequency. Along the Mestinjščica river, Zibiški potok brook, Tinski potok brook, Buča brook and the Bistrica river, high waters with medium to long return periods (more than Q_5) mostly flood agricultural land and some small settlements or individual buildings. In the past, the main road near Podčetrtek was often flooded, while high water fully floods the plains on both banks of the river every year.

The area of the study covers the entire Sotla river basin. Based on the collected data and documentation, the analysis of the existing situation as well as the hydrological and hydraulic analysis, the flooding rate for the area which is sparsely populated and not urbanised was specified. For the purpose of analysis and based on hydrological characteristics, the Sotla river basin was divided in two sections, i.e. the one stretching from the source of the Sotla to the Zelenjak gorge and the one extending from the Zelenjak gorge to the outflow into the Sava river.

At the first phase, alternative solutions were developed based on an expert assessment in view of the available information, knowledge about the area, as well as data obtained from monitoring the situation during high-water events and the data on the implementation of flood-protection measures in the last twenty years. The Sotla mostly lies within the Natura 2000 area, with its entire riverbed being designated as a natural asset. It was estimated that any major interventions in the channel for the purpose of increasing its conductivity or changing the morphology would have a devastating impact on the natural asset, which is why such interventions have not been addressed.

Based on analysis of the existing situation and the available data, the current flood hazard areas were defined and (mostly local) measures proposed. At the first phase of the study, a set of solutions was proposed, which was then analysed in detail.

During the second phase of analysing the alternative solutions, the proposed local solutions and reservoirs were studied based on the hydraulic model and a flood risk assessment, so that the economic effectiveness of alternative solutions could be better evaluated and the solutions better categorised according to the parameters of economic effectiveness and other key factors.

The hydraulic analysis confirmed the findings of previous expert assessments, namely that the Sotla valley is at considerable risk of flooding, but that there are relatively few elements with a significant level of vulnerability present, especially considering the length of the watercourse. The areas that show the greatest risk of flooding are Rogatec, Aqualuna in Podčetrtek, Gmajna, Bračna vas, Gmajna (near Obrež), Veliki Obrež, Dobova, Rigonce/Harmica and Loče. In the second phase, only those solutions that proved to be feasible in this phase were analysed with the hydraulic model.

Solutions that proved to be economically infeasible, hydraulically unsound or unnecessary were eliminated from the set of possible alternative solution. based on multi-stage analyses, the following measures were proposed at the conclusion of the study:

The section from the source of the Sotla to Zelenjak (Bistrica ob Sotli)

- Solutions for Gmajna
- Solutions for Aqualuna
- Solutions for Rogatec

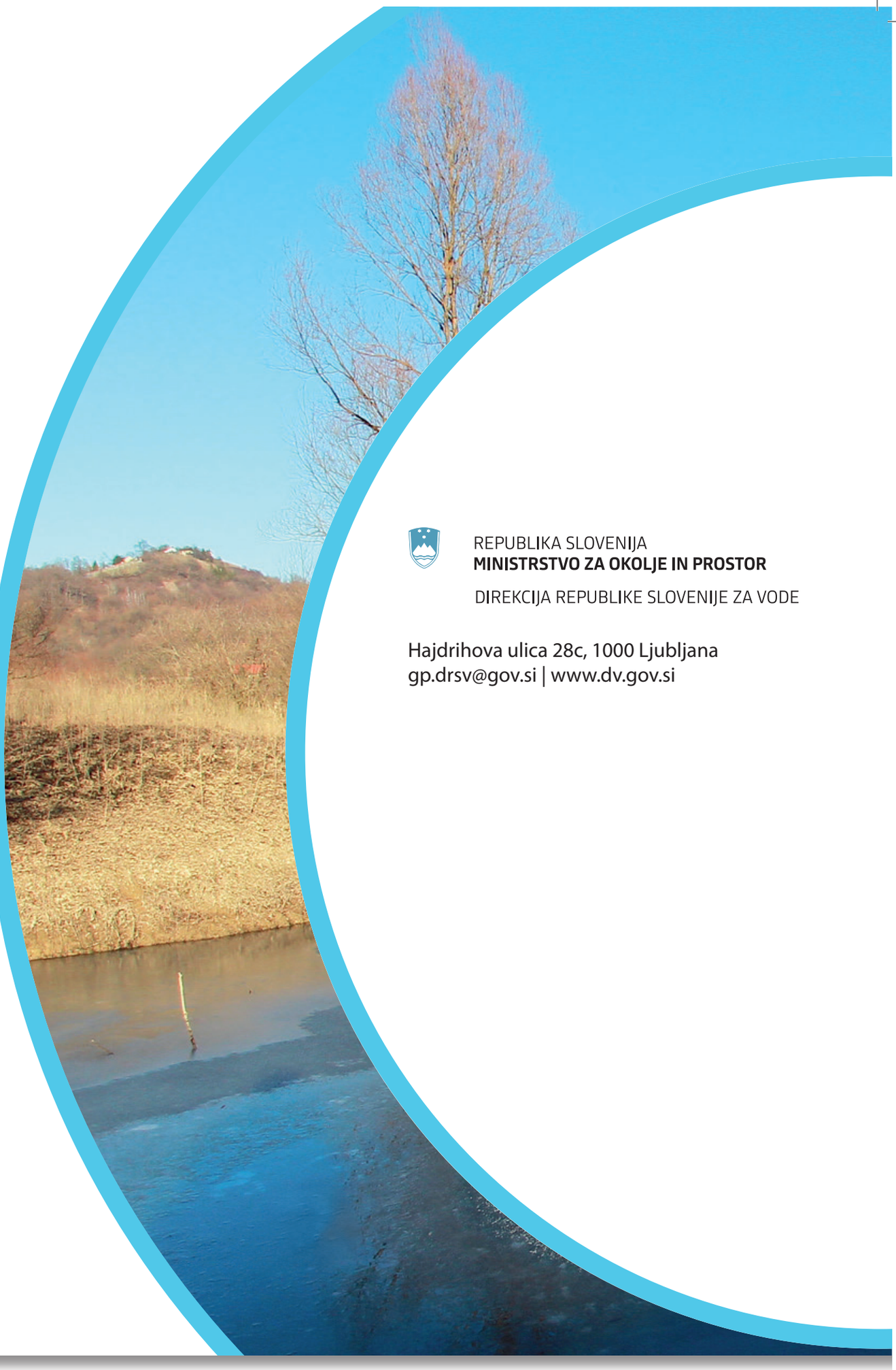
The section from Zelenjak (Bistrica ob Sotli) to the outflow into the Sava river

- Protection of the NW part of Rigonce
- Protection of Obrež and Dobova, protection of Gmajna

No regret measure – the renovation of the Vonarje barrier

The proposed measures were further treated in a cost-benefit analysis, which showed they also have favourable economic benefits.

The proposed optimal flood risk management programme in the study is divided into measures that could be implemented during the current implementation period of the European flood directive (2016–2021) as well as measures that could be implemented later. One of the measures to be implemented during the current Flood Directive implementation period is the reconstruction of the Vonarje barrier, while the study prepared in accordance with the FRISCO1 application form represents a support tool for decision makers regarding the further preparation and implementation of other proposed measures.



REPUBLIKA SLOVENIJA
MINISTRSTVO ZA OKOLJE IN PROSTOR
DIREKCIJA REPUBLIKE SLOVENIJE ZA VODE

Hajdrihova ulica 28c, 1000 Ljubljana
gp.drsv@gov.si | www.dv.gov.si

www.frisco-project.eu