DEVELOPING THE CONCEPT PLAN FOR N(S)WRM IN RIVER BASIN

D.T2.3.1

Version 1
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Pilot Catchment Bednja
Croatia/ Croatian Waters

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CONTENT

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1. INTRODUCTION

The present Concept Plan was developed using the GIS Tool FroGIS developed for landscape valorization in the FramWat project and by building upon the first results of the static and dynamic modelling of the pilot catchment. The Concept plan gives information on best locations and suitable types of measures with cumulative effect.

Vision for the pilot area of Bednja catchment:
Improved integrated environmental management capacities for the protection and sustainable use of natural heritage and resources with NSWRM in the Bednja catchment.

The main objectives of the present Concept Plan are:

- to explain transparently the way how the analysis of information, data and context as well as the evaluation of experts knowledge and stakeholders preferences led to the chosen NSWRM design principles;
- to show how the design and location of the selected N(S)WRMs respond to the opportunities & constraints identified during the analyses;
- to explain and justify the way the N(S)WRMs are planned;
- to demonstrate a genuine response to context and not simply justify predetermined design solutions
- to provide a uniform guideline for the NSWRM planning process

2. ELABORATION METHOD OF THE CONCEPT PLAN

Figure 1 demonstrates the main steps of the concept plan elaboration, while details of the needed actions are discussed in the chapters below.

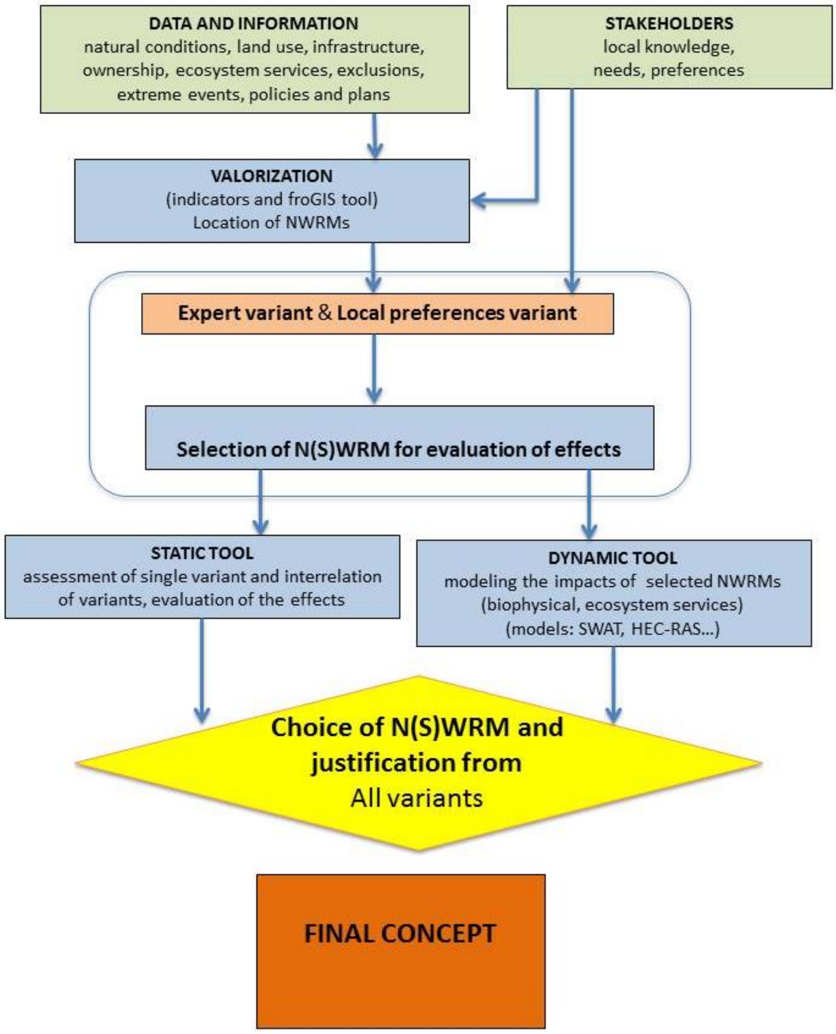


Figure 1: Main steps of the Concept Plan elaboration.

3. CHARACTERISTICS OF THE PILOT AREA

3.1 Natural conditions of the catchment

The Bednja is a river that flows through Croatia along its entire course and is a tributary of the Drava River. It rises near Trakošćan in the Maceljsko gorje hill in Hrvatsko zagorje. It flows through the settlements of Bednja, Lepoglava, Ivanec, Beletinec, Novi Marof, Varaždinske Toplice, and Ludbreg, and flows into the Drava at Mali Bukovec near Ludbreg. It forms a northern natural border separating Mt Kalnik from the Topličko gorje hill in the west and from the Drava plain in the east. The Bednja is the longest river which has a source and a mouth in Croatia and whose entire course flows through Croatia.

The Bednja river basin was chosen because of a serious problem caused by torrents forming after intensive rainfall, causing the movement and transport of significant sediment quantities into the lowland parts of the watercourse. It is common that torrents are accompanied by landslides. According to Natura 2000, in the Bednja basin there are 14 sites important for the conservation of endangered species and a total of 12 sites with different levels of protection. The most important road in the basin is a section of the motorway cutting the basin into two parts slightly further downstream of the natural borderline between the upland and lowland parts of the basin. Its major part was built on an embankment with several culverts causing obstacles for the flow of high waters of Bednja and its tributaries.
Bednja catchment has around 616 km2 catchment size and is composed of about 30% low hills with the rest 70% being lowland. Bednja river has an average flow of 7 m3/s with extreme flow going up to 179 with an annual precipitation averaging 931 mm/year and annual average air temperature of 10.4 ^{0}C.
The basin area is 30% covered with agriculture and around 49% is forest area.
Based on flood modelling scenarios a 100 year return period flood would cover around 37.7 km2.
From the River Basin Management Plan 2016.-2021. we have 6 water bodies with 2 having bad status, 3 moderate and 1 water body has good ecological status with Phytobenthos, Macrophytes, Macrozoobenthos, Total N and Total P being major problems in achieving good ecological status.
The Project activities should comply with the measures proposed by the River Basin Management Plan and the Flood Risk Management Plan (July 2016).
During a field trip to the Bednja basin area a few locations were visited. Terrain review was carried out in October of 2018 by Croatian waters employees accompanied by external consultants.

Table 1. Characteristics of the catchment.

Characteristic	***Unit***	***Value***
Character of catchment		*lowland 30%/low hills 70%*
Catchment size:	*km^2*	*616*
*Average flow low/avg/high**	*m^3/s*	*0,8/7/77*
*Extreme flow low/high**	*m^3/s*	*0,003/179*
*Annual precipitation low/avg/high***	*mm*	*481/931/1312*
*Annual air temperature min/avg/max***	*°C*	*10,4 (avg)*
Agriculture area	*%*	*30*
Urban area	*%*	*2*
Forest area	*%*	*49*
Open Water area	*%*	*0,1*
Flooded area (1/100 years)	*km^2*	*37,7*
Artificial drainage area	*km^2*	

Ecological status no good/bad	*water body*	
Major problems to achieve good ecological status		

* From multiannual statistic 1949-2016
** From multiannual statistic 2007-2016

3.2 Land use, infrastructure, protected areas and ecosystem services

3.2.1 Land use

The basin area is largely un-built, with the vegetation cover made of forests (49 %), orchards and vineyards (app. 21 %), and agricultural land (30 %).

The Corine Land Cover (CLC) 2012 layer was used as the primary data source for the land cover map.

The CLC Croatia represents a digital database with data about the status and changes in land cover and land use in Croatia. The CLC Croatia is consistent and homogenized with with the land cover data of the entire European Union.

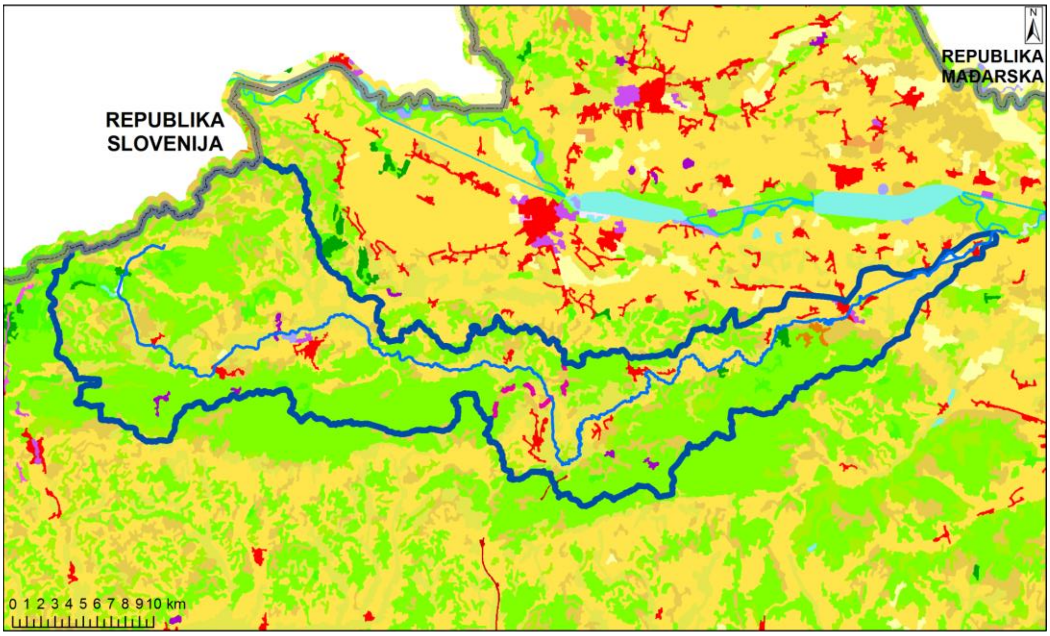


Figure 2. Extract from the CORINE Land Cover Croatia map with delineated Bednja basin.

The characteristics of soil in the upland part of the Bednja basin are defined by the Croatian Soil Map in a scale of 1:300,000. The soil map presents soil units. In the Bednja basin, several soil units with different characteristics are mapped. Based on the characteristics of soil units, hydrological types of soil have been obtained which are used further on in hydrological analyses. One hydrological soil type includes several soil units with similar hydrological characteristics. Hydrological soil types are the result of analysis of soil maps and available data.

There are four basic hydrological types of soil: A, B, C, and D. Type A soils are characterized by a high infiltration rate and a low run-off potential. Soils of hydrological type B are characterized by a medium infiltration rate, while type C soils have a low infiltration rate. Type D soils have a very low infiltration rate and a high run-off potential.

In the Bednja basin, soil units are reduced to the basic hydrological types of soil:

B - Humic ranker silicate on sandstone, conglomerate and shale
- Ranker on eruptive rocks (quartzite)
- Eutric grey soil on deposits
- Acid (distric) brown soil on loess
C - Eutric brown soil on sand
- Gitja
- Alluvial meadow, gley
D - Rendzina on flysch
- Resin on marl
- Loessivized soil typical on clays

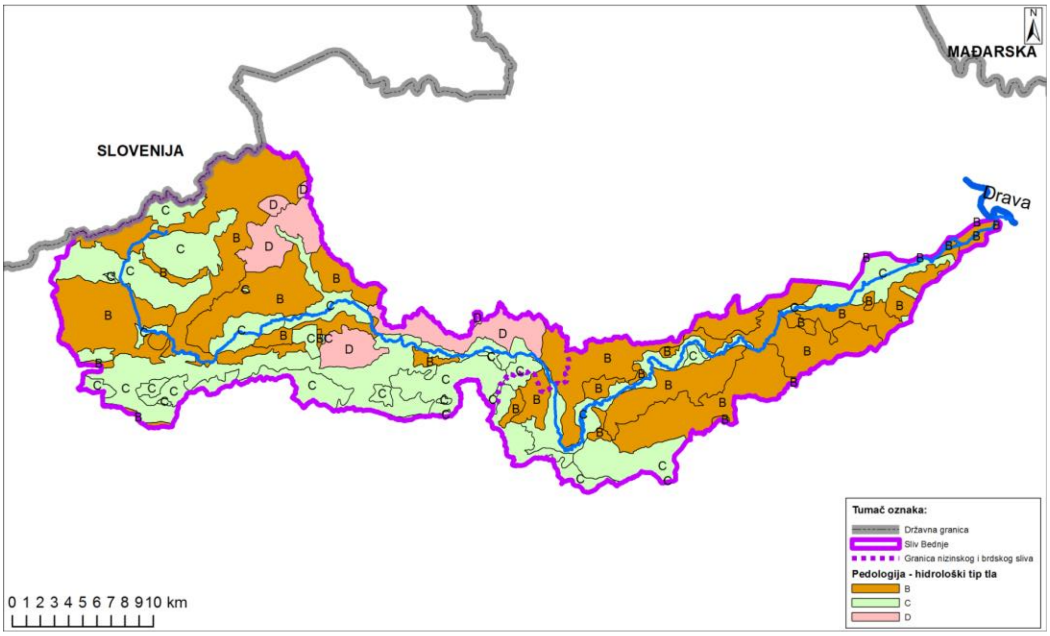


Figure 3. Soil map according to hydrological type in the Bednja basin.

Land use and cover - the main categories and land use information were taken over from the County Plans.

The CLC database was created according to the CORINE Program (Co-ordination of Information on the Environment) approved by the EU and was rated on the EU level as the basic referent set of data for spatial and territorial analyses.

The Bednja basin is divided into 101 spatial planning units (SPU), with the required characteristics defined for each SPU.

The population mostly lives in villages and deals with traditional farming on small, fragmented plots lying on hill slopes, which is highly unfavourable from the aspect of exposure of the surface soil layer to erosion.

3.2.2 Infrastructure

The most important road in the basin is a section of the Zagreb-Goričan motorway which cuts the Bednja basin into two parts at a place slightly further downstream of the natural borderline between the upland and lowland parts of the basin. The major share of the motorway across the basin was built on an embankment with several culverts which represent “obstacles” to the flow of high waters of the Bednja and its tributaries. A similar problem occurs near the Varaždin – Golubovec railway. The most significant hydraulic structures in the basin are multi-purpose reservoirs and barriers (dams). There are flood protection dikes along both Bednja riverbanks, upstream of its discharge into the Drava.
Floods sometimes occur several times a year, as the result of which the flooded area along the Bednja gradually attains swamp-like characteristics and cannot be used for agriculture. In such areas valuable wetlands have developed with endangered species on the county and even national level.

3.2.3 Protected areas

According to Natura 2000, in the Bednja basin there are 14 sites important for the conservation of endangered species and a total of 12 sites with different levels of protection: 1 regional park, 3 nature monuments, 1 significant landscape, 1 park forest and 6 monuments of park architecture.
In accordance with the Decision on the designation of vulnerable zones in Croatia (OG 130/12), areas sensitive to pollution with nitrates from agriculture have been established. Based on that Decision, in the Bednja River basin only its minor part belongs to nitrate-vulnerable zones.

3.2.4 Ecosystem services

Pursuant to the Water Act, flood management is the responsibility of Hrvatske vode. Operational flood risk management and immediate implementation of flood defence measures are regulated by the National Flood Defence Plan and the Master Implementation Plan for Flood Defence. Immediate implementation of preventive, regular and emergency flood defence is, through the implementation of public procurement regulations, assigned by Hrvatske vode to a legal entity (company) possessing a decision confirming that it fulfils special requirements to perform the activity pursuant to the Water Act, with a Framework Agreement concluded for a period of four year for the individual defended areas.

Based on the National Flood Defence Plan, a Flood Defence Centre has been established as the central organizational unit of Hrvatske vode for the management of regular and emergency flood defence. The Flood Defence Centre is the place where central management and main coordination take place and where a flood defence communications and notification system is established. The Flood Defence Centre also provides expert and technical support to the general manager of flood defence. The territorial units for flood defence are: the river basin districts, sectors, defended areas, and sections.

Due to the specific shape and terrain, floods in the Bednja basin come in two types: the upper parts of the course has typical flash floods forming on the streams descending from the slopes of Mts Ivanščica, Ravna gora and Kalnik, whereas the central and lower parts have standard floods caused by heavy rainfall and/or snowmelt. In recent times, the Bednja basin was flooded in 2007 (late October), 2013 (late March) and 2014 (mid August).
The last major flood was in September 2017.

According to an overview flood hazard map (River Basin Management Plan 2016-2021, http://korp.voda.hr/), the Bednja basin is in the upper and middle courses under constant flood hazard already at a high probability of flooding (the most frequent occurrence of flooding). That is due to an exceptionally narrow river valley surrounded by mountains and hills, but with a very mild valley slope, which slows down the flow of water. In the lower course, floods mostly happen during medium and low probability of flooding, when the river floods a large part of arable land.

According to an overview flood risk map, in the Bednja basin there are “areas of potential significant flood risk” based on the Preliminary Flood Risk Assessment (Hrvatske vode, 2013).
A risk analysis for medium flood probability has identified that the largest part of the areas that are flooded belongs to the category “Other agriculture”, which actually includes mosaics of areas with a dominant pattern of exchanging fields, meadows, deserted and other areas. Several settlements are also flooded, primarily Veliki and Mali Bukovec, marginally Ludbreg, Kapela Podravska, Hrastovsko, Kučan Ludbreški, Tuhovec, Varaždinske Toplice, Novi Marof, Ivanec, Lepoglava, Bednja, and several other settlements where a few houses in the low-lying region are flooded. During floods, some roads that run laterally or across the Bednja have to be closed for traffic. The combination of flooding of agricultural areas, settlements, farm buildings and road infrastructure no doubt adversely affects the economic and health stability and existence of the population living along the Bednja.

There is a serious problem of flash floods that form after intensive rainfall in a significant number of the Bednja tributaries. A sudden increase in discharges causes the movement and transport of significant sediment quantities into the lowland parts of the watercourse and the Bednja recipient. It is not rare that flash floods are accompanied by landslides that put houses and commercial buildings at risk.

4. VALORIZATION: A MULTI-CRITERIA ANALYSIS

4.1 The valorization method and tool

The goal of the valorization was to identify areas with the highest need for NSWRM in the catchment.

The GIS based tool FroGIS (Framework for Retention Optimization) was developed for the requested valorization purposes. Users are able to fill the online tool with their catchment data and get catchment maps and statistics as results showing areas with highest need for measures implementation.

The purposes of the test were to:

- apply Frogis to the Bednja pilot catchment in Croatia
- develop valorization maps for flood issues
- test the sensitivity of the analysis to subjective choices, in order to provide suggestions for future application of the valorization tool. The investigated subjective choices were: the choice of spatial plannning units (SPUs) used in the analysis, the choice of indicator classification methods, the choice of weights used for the final aggregation.
- validate the obtained map with expert opinion.

The scope of testing was data preparation, data validation, testing and results validation.

Valorization spatial scale is based on the concept of spatial planning units (SPUs), which are homogeneous patches of the catchment that are assumed to have uniform response. Input data are processed and synthetized as indicators at the SPU scale. The valorization methodology allows incorporating different indicator classes such as land use, geological background, catchment morphology, climate and hydrology into a multi-criteria analysis. The valorization methodology is static, i.e. indicators are spatially explicit but time-independent. Statistics can be used to summarize multiannual time series of flow and climatic indicators into single values.

4.1.1 Spatial planning units (SPU)

Spatital planning units (SPU) were tested based on county data which proved to much coarse, then a SPU based on settlement spatial data was used but that also proved too coarse so a spatial analysis was done which resulted in finer distribution and that SPU was chosen which has 101 spatial planning units ranging from 0,5 km2 to 18,5 km2.

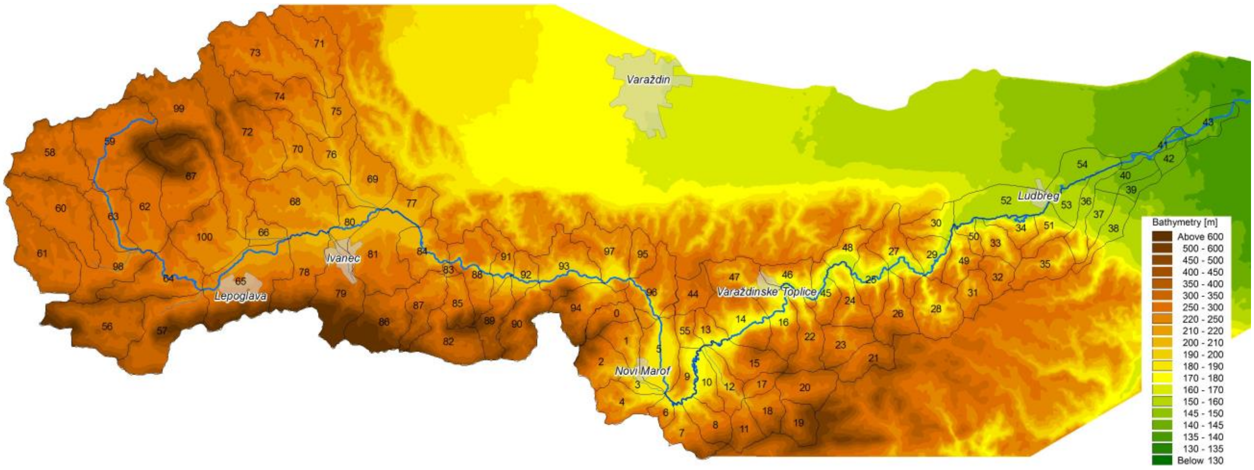


Figure 4. Chosen SPU (Spatial Planning Units) in Bednja catchment.

4.1.2 Input data

Global datasets:

- The Corine Land Cover (CLC) 2012 layer was used as the primary data source for the land cover map.

Local datasets: Input data were collected from local datasets.

Name	Source	Quality/scale	Time interval
Kljuc discharge	Hydrological database	daily	1987-2017
Lepoglava discharge	Hydrological database	daily	1987-2018
Ludbreg discharge	Hydrological database	daily	1987-2019
Tuhovec discharge	Hydrological database	daily	1987-2020
Zeljeznica discharge	Hydrological database	daily	1987-2021
Corine Land Cover	National database	1:25000	2012
Flood extent 100 years	Flood hazard maps	1:25000	2014
Lakes	Study	1:25000	2011
River network	Croatian waters database	1:25000	2015

Weather (meteorological) data was obtained from the Croatian Meteorological and Hydrological Service (DHMZ).

4.1.3 Indicators

Indicators from the list present in the FroGIS tool (levis-framwat.sggw.pl) were selected.

Of all available data BadRHS indicator was rejected due to the fact that only 1 small part of a stream was in bad hydromorphological status and it was decided that it wouldn't have significant impact, next Climatic water balance was discussed and chosen to not be included as the basin is relatively small area with small precipitation and temperature gradient. Orchard and Wetland data from Corine Land Cover had none or one small area which again didn't have a significant impact. Indicators which were used from the available data are ArableRatio and Semi-NaturalRatio from Corine Land Cover, Lakes and River shapefiles and swFlow hydrological characteristics file.

Selected indicators for the analyse in the Bednja catchment:

Nr	Indicator Name	Indicator Short Name	Goals	Unit	Stimulant/ Destimulant
1	Arable area in SPU area ratio	ArableRatio	Flood/Drought/ Quality/General	%	Stimulant
2	Drainage Density	DrainageD	Flood/Drought/ Quality/General	km/km2	Stimulant
3	Semi-natural land cover types area to SPU area ratio	EcoAreaRatio	Quality/General	%	Destimulant
4	Flood hazard zone area ratio	FloodRiskAreaRatio	General/Flood	%	Stimulant
5	Mean low flow to mean high flow ratio	FlowMinMaxRatio	General/Drought/ Flood	%	Destimulant
6	Lakes and reservoirs area to SPU area ratio	LakeRatio	Flood/Drought/ Quality/General	%	Destimulant
7	MeanderRatio	MeanderRatio	N/A	N/A	Stimulant
8	Water yield (specific runoff) for mean flow n the multiannual period	WateYieldAvgFlow	General/Drought	mm	Destimulant

Table 2. Indicators used in Bednja catchment assessment.

4.2 Results of the valorization

Input data were collected from local datasets.

Correlation matrices with chosen indicators were computed based on indicator values obtained for each SPU.
Indicators “FlowMaxAvgRatio”, “FlowMinAvgRatio”,”FlowVarRatio_m”, ForestRatio” were highly correlated (above 0,75) and so were removed.

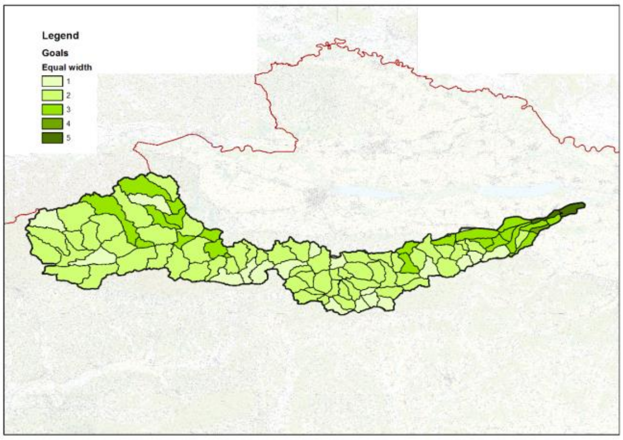
Different classification methods have been used to split the indicators in to 5 classes and to test the sensivity of the tool to classification method.

The folowing statistics was been anaylized:
- Statistics of indicators values Equal Width
- Statistics of indicators values Natural Breaks
- Statistics of indicators values Quantile
- Results of division of indicators values to five classes

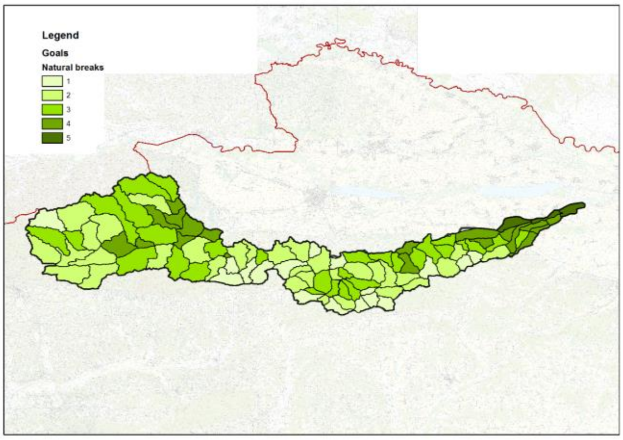
Analysis of variants

a) Valorization for general purpose (5 classes)

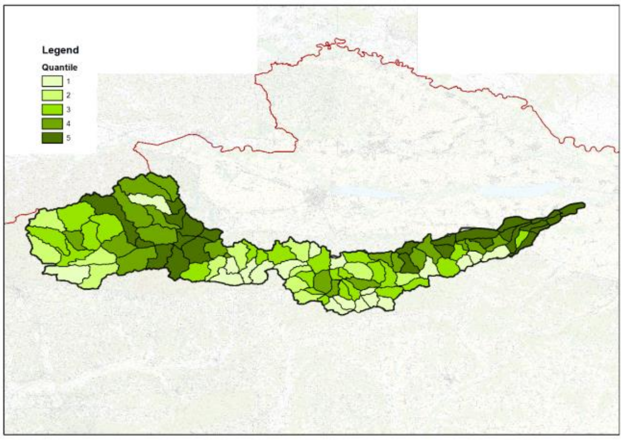
For all map variants in this chapter there is a range of 5 classes ranging from 1 for low potential to 5 for high potential for water retention.



Variant G.NB.Wht1 division into classes by natural breaks for constant weight.

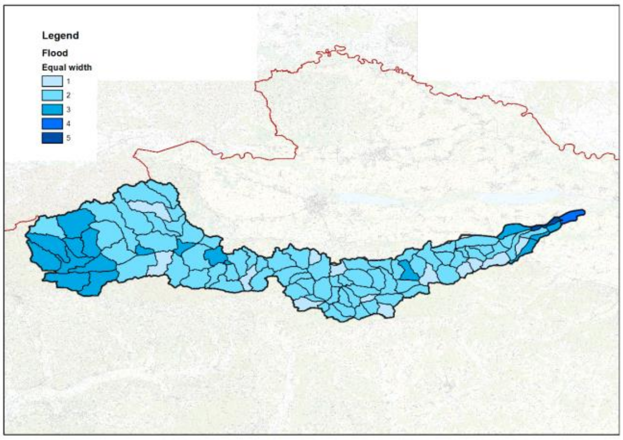


Variant G.Q.Wht1 division into classes by quantiles for constant weight.

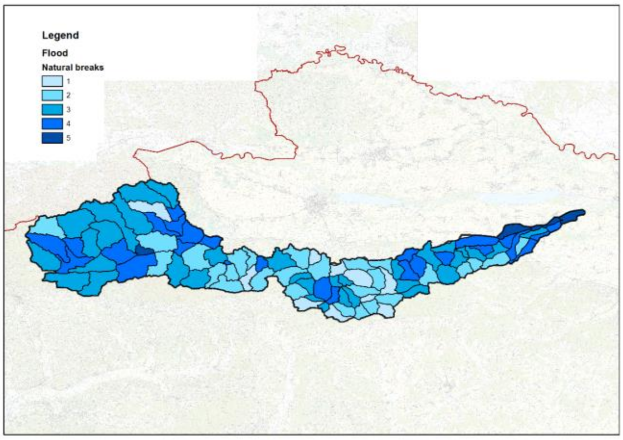


b) Valorization for flood mitigation purpose (5 classes).

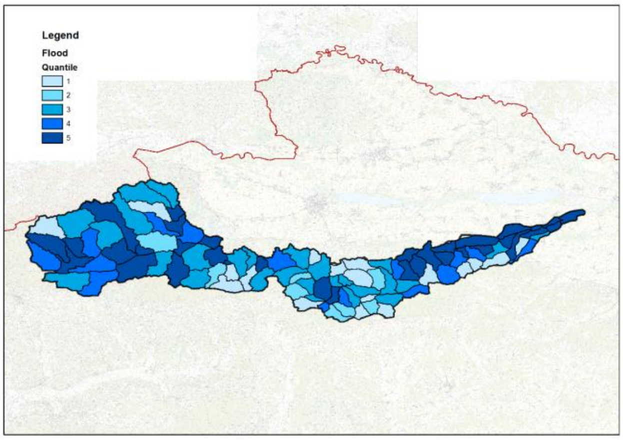
Variant F.EW.Wht1 division into classes by equal width for constant weight.



Variant F.NB.Wht1 division into classes by natural breaks for constant weight.

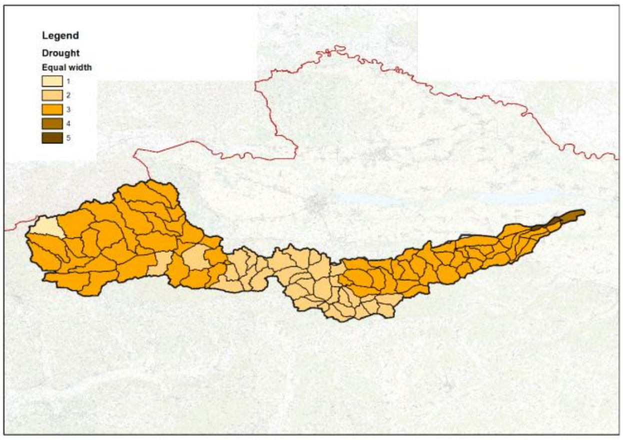


Variant F.Q.Wht1 division into classes by quantiles for constant weight.

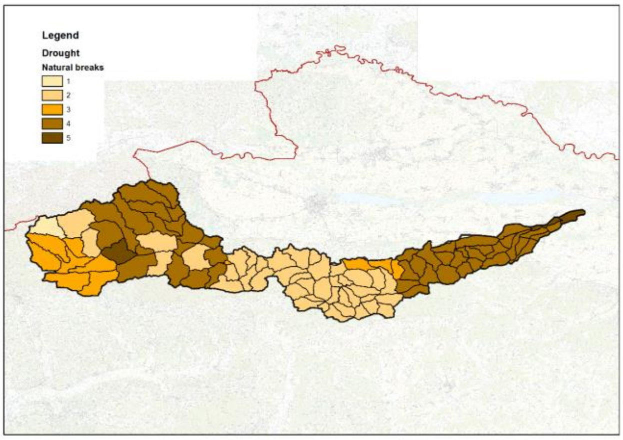


c) Valorization for drought mitigation purpose (5 classes).

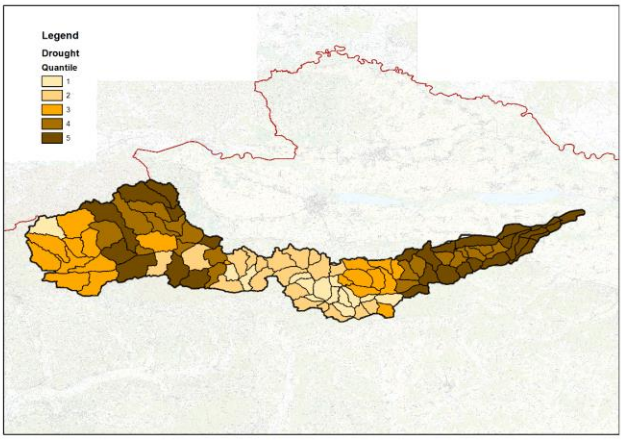
Variant D.EW.Wht1 division into classes by equal width for constant weight.



Variant D.NB.Wht1 division into classes by natural breaks for constant weight.

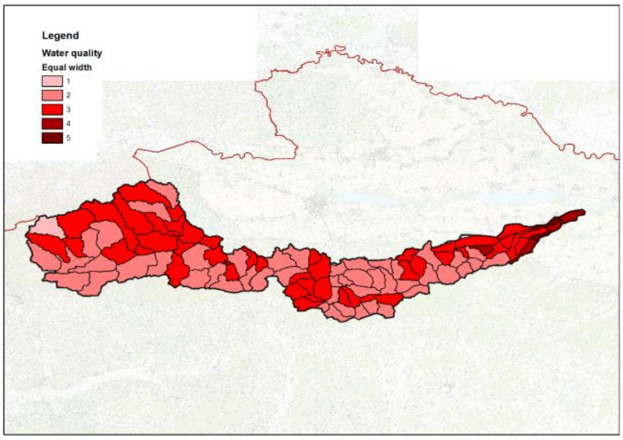


Variant D.Q.Wht1 division into classes by quantiles for constant weight.

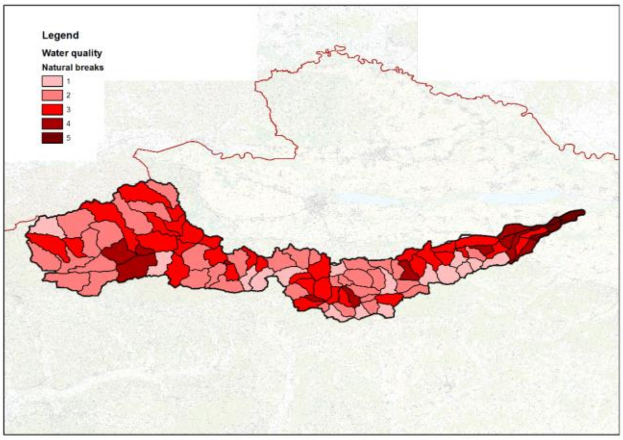


d) Valorization for water quality improvement purpose

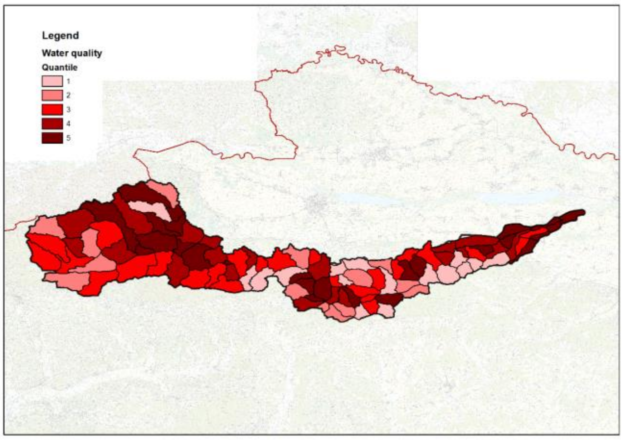
Variant WQ.EW.Wht1 division into classes by equal width for constant weight.



Variant WQ.NB.Wht1 division into classes by natural breaks for constant weight.



e) Variant WQ.Q.Wht1 division into classes by quantiles for constant weight



f) Valorization for reduction of sediment transport purpose.

Not enough data is available for sediment transport analysis, and sediment is not a major problem in Bednja river basin.

Summary:
Results of the FroGIS valorization method for Bednja catchment show that the best method depends on the usage of data. It looks like for general and flood mitigation purposes Natural breaks gives better results and on the other hand for drought and water quality better valorization results are obtained through Equal width method. Weighting has very little influence on the final results.
Only flood data was available for comparison.
Based on these differences the Quantile variant map is the most similar to the map based on previous analysis.
On the whole FroGIS is a good and valuable tool for planning of small water retention measures.

5. DEFINING VARIANTS

There are two types of variants that will be elaborated in the frame of the concept plan:

- expert variant,
- local preferences variant.

In this part of the planning process of the project, we have to select and place the appropriate measures and measures combinations for further examinations.

5.1 Expert variant

The expert variant developed by experts in the field of water management.

Expert measures are foreseen for flood defence in the Bednja basin, with proposed construction of three water retention basins (Koruščak, Kamenica 1 and Čret). In addition to the retention basins, the existing dikes in the lower part of the basin should be moved away from the river. These measures would reduce direct potential flood damage in the Bednja basin. Furthermore, by moving the dikes away from the river, riparian habitats are protected better, floods have a weaker impact, and maintenance requirements are lower.

According to the catalogue of measures and based on the basin analysis, the following basin-wide measures have been selected.

- polders, dry flood protection reservoirs, sediment trapping dams (T1),
- widenning or removing of flood protection dikes (T2).

This measures will be tested by dynamic modelling.

5.2 Local preferences variant

The local preferences variant are chosen for the catchement.

The maintenance of forest areas in the steep upper parts of the Bednja basin has a large significance for erosion reduction, and consequently for reduced sediment transport downstream.

According to the catalogue of measures and based on the basin analysis, the following basin-wide measures have been selected.

- Maintenance of forest cover in headwater areas (FO2)
- Reconnection of oxbow lakes and similar features (NO7)

This measures will be tested by static tool.

6. STATIC TOOL

6.1 Siting of measures to be tested with the static tool

The basis for analysis is a catalogue of measures and the division of the Bednja basin into spatial planning units (SPU), presented in Figure 15.

Static tool will be used to analyze selected measures in several spatial planning units (SPU) assumed as having a favourable impact.

The measures which will be tested in the catchement are presented in Table 3, where the individual selected measures are assigned to the spatial planning units in the Bednja basin (SPU).

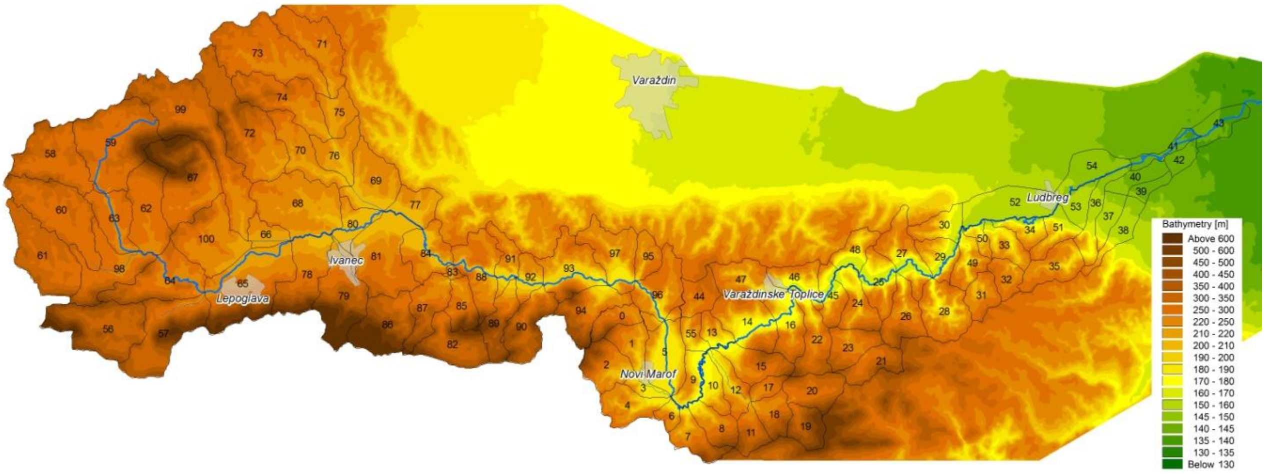


Figure 15. Division of the Bednja basin into spatial planning units (SPU).

Table 3. Measures to be tested in the catchement.

IdNSWRM	Agregated measure	Number of SPU	ENG NameOfNSWRM	Descrption
F02	KF	99, 59, 58, 60, 61, 56, 57, 78, 79, 86, 87, 82, 89, 90, 94, 78, 11, 18, 19, 20, 21, 26, 31, 32, 35	**Maintenance of forest cover in headwater areas**	Waters of the upper course of the river are the sources of rivers and streams. Forests in the upper reaches of the river can therefore have a beneficial effect on the amount of water and its quality. Indeed, forest soils tend to have better infiltration capacity than other types of soil cover, acting like a "sponge", slowly releasing rainwater. In areas with a convex sculpture, afforestation of the upper reaches of the river can contribute to the stabilization of the slope, which may reduce the risk associated with landslides. Forests often have a high rate of evapotranspiration and high water capacity of tree crowns. Therefore, the forest areas of the upper course of the river are able to reduce the absolute amount of water that can ultimately contribute to the runoff. In addition, forest soils are characterized by high porosity, high content of organic matter, good infiltration capacity and high water retention capacity, enabling delays of water runoff and increasing the infiltration rate (replenishment of groundwater resources). Therefore, forest waters in the upper reaches of the river can play an important role in reducing the risk of flooding.
N07	ER	53, 54, 36	**Reconnection of oxbow lakes and similar features**	Oxbow lakes are usually formed in valleys of meandering rivers by cutting meanders (cut off a fragment of a river). They are quickly disappearing by silting and backfilling with sediments from floods and vegetation. Reconnection with the river involves removing barriers between the main channel and the oxbow lake, improving the overall functioning of the river by restoring lateral communication, diversifying flows and cleaning the section of the current oxbow river to improve water retention during floods.
T1	T1	0, 1, 2, 3, 4 - retention Korušćak; 62 - retention Čret; 99, 67 - retention Kamenica1	**Polders, dry flood protection reservoirs, sediment trapping dams**	The measure that relies on construction / planning in the catchment basin: polders (usually the flood plain area, during the river flooding period allows for overflow of the excess water and its natural retention), dry flood protection reservoirs (their entire capacity is designated for flood protection purposes, these are reservoirs that collect water only during floods, except for fences, their bowls are used for agriculture as meadows and pastures - there are no intensive crops) and anti-rubble dams (dams whose main purpose is to retain sediment, mainly rubble on the fraction of wleczyn and wleczyn, and thus, protection of areas located below the structure before floods and rubble).
T2	T2	40, 41, 42, 43	**Widenning or removing of flood protection dikes**	The construction of flood embankments, the purpose of which is flood protection, in fact, limits river flood areas and increases water levels and flow rates. Moving the embankments away from the river bed brings significant benefits. The shafts may then be lower, and thanks to the greater capacity of the embankment, the level of freshets will decrease, and the flow rate will decrease flood waters, the river banks will be less damaged and vegetation. The larger area of the valley floor will improve the conditions of flood water filtration through the ground, the valley retention will increase, reducing the risk of catastrophic flooding in lower lying areas sections of the river. If liquidation of shafts or their removal from the trough it is not possible, then you can make culverts or local depressions in order to allow controlled flooding land falls at higher water levels in the river. Thanks to the action, it is possible to reduce the erosive trend of the channel and to create a nature close to the development of the flood plains. In the acquired floodplains, it is possible to recreate oxbow lakes in

6.2 **Static tool outputs**

Changing of parameter values for measure groups in Algorithm table has an effect on valorisation improvement in the catchment. In our case measures „KF” and „T1” have a larger impact on total improvement in the catchment than measures „ER” or „T2”.

This is to be expected since measures „KF” and „T1” are selected for a larger number of spatial planning units and cover a bigger area.

Measures „ER” and „T2” contribution to total catchment improvement is less than 1.

In the case of addjustment of parameter values to new values based on our expert opinions total catchment improvement can go from 12,28 which is for standard parameter values for measure groups to 15,98 for addjusted parameter values for local conditions.

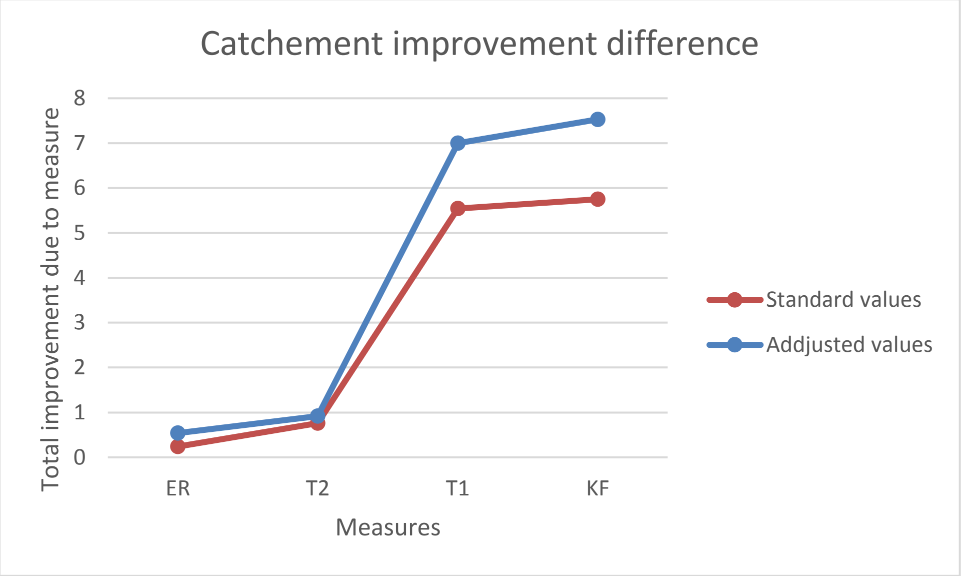


Figure 16. Total catchement improvement difference due to addjustemnt of parameters.