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Crasna river overflow study, including flood extension map

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DANUBE REGION strategy

Acknowledgements

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Contents

Abbreviations

APSFR	Area with Potential Significant Flood Risk
AR	Actual regime of flow influenced by the hydraulic structures
EC	European Commission
1D / 2D	One / Two Dimensional
CA / CI / CP	Attention levels / Flood levels / Danger levels
CV	Coefficient of Variation
CS	Coefficient of Symmetry
DE / DN / DJ	types of roads: European Road / National Road / County Road
DTM	Digital Terrain Model
DTP	Danube Transnational Programme
e.g.	from Latin exempli gratia and means “for example”
γ	River basin shape coefficient
H	Water level
H_{med}	Average altitude
i.e.	from Latin *id est* ‘that is’ (used to add explanatory information or to state something in different words)
L	Length
LP	Lead Partner
P%	probability of exceedance
PP	Project Partner
maMB	meters above Baltic Sea
maMN	meters above Black Sea
NIHWM	National Institute of Hydrology and Water Management
NR	Natural regime of flow
Q	Flow
RO - HU	Romanian - Hungarian
S	Surface
T_p	Peak time
T_b	Base time
WP	Work Package

Introduction

In order to achieve the main objective of the JOINTISZA project – “the strengthening approaches and cooperation among the relevant actors of the river basin management planning process especially actors of flood risk prevention/ flood protection sector to enhace the status of waters of the basin” which is in line with Water Framework Directive and Floods Directive requirements, within the WP5 – ”Flood management”, a case study regarding the transboundary effect of a dike failure on Crasna river was developed.

The partners involved in this activity were from Romania (Ministry of Waters and Forests – PP3, National Administration ”Romanian Waters” – PP2 and National Institute of Hydrology and Water Management – PP4) and from Hungary (General Directorate of Water Management – LP).

Technical meetings were held with the purpose of establishing the mathematical model for the simulation of flood, the scenarios and the necessary data, the exchange of data; of fixing the problems encountered in the process of data harmonization; of hydraulic model validation etc. All these activities were necessary steps to create a common 2D hydraulic model of the Crasna River on the RO - HU border sector.

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The mathematical modeling of the water flow is an indispensable tool for determining:

- the transport capacity of the watercourses;
- water speed;
- the water depth in the floodplains;
- the extension of flood limit for floods with maximum flows with different probabilities of exceeding etc.

In order to achieve the mathematical modeling of the water flow, hydrological and topographical studies are required. The results from these studies, data regarding the river scheme for flood defence (i.e. the location of the hydrotechnical works, their type and description, exploitation rules, etc.) and data on land use (the type of land, the degree of vegetation coverage, the riverbed and the floodplain resistance coefficient, etc.) become input data in the hydraulic models.

The cupled 1D and2D hydraulic model of the Crasna River on the RO - HU border sector was created using HEC-RAS, taking into account different scenarios (dyke breaches on the Romanian border sector, different probabilities of excedance for the maximum flow, different stages of vegetation development), and it reveals the flooded areas, the water level in the floodplain, the velocity values etc. All this information will serve to decide what measures are suitable for flood protection of the study area.

Chapter 1 Physic-geographical presentation of the study area

Crasna River (L=134 km, S=1931 km2) springs from the south of the Silvania Depression, at the contact between the Mezeș Mountains and the Plopiș Mountains. Crasna River basin is bordered by Someș river basin and Crișuri river basin, first order basins.

The study area is situated in the Crasna river basin, on the territory of Satu Mare County, in the Someș-Tisa River Basin Administration area. It begins from downstream confluence of Crasna and Maria rivers and ends at the Romanian-Hungarian border.

In the study area, Crasna river has a length of about 33 km and a river basin with an area of 80 km2.

Relief

The river sector crosses the Western Plain, respectively Low Plain of Someș, from East to West. The Western Plain is part of the depression unit (Pannonian Depression) in the middle basin of the Danube River (eastern part). This plain is also known in the literature under the name of Banato - Crișana Plain, an integral part of the Tisa Plain or the Middle Danube Plain.

The slopes of Crasna river fall from 10 ÷ 30 m/km from the spring area up to 10 ÷ 50 cm/km in the plain sector, where downstream of Moftinu Mic it contributes essentially to the formation of Eceda's eutrophic marshes, the slopes approaching zero. The deep valley of the Crasna River in the plain area creates favorable conditions for the deep drainage of the groundwater.

Geology

Geology includes a crystalline (Proterozoic-Paleozoic-Mesozoic) foundation, fragmented into a perpendicularly near-vertical fault system over which a Mesozoic sediment is found. A thick Neozoic sedimentary cover was deposited over this sediment, over which there are newer Pleistocene and Halocene deposits.

Climate

The climate is continental temperate type with oceanic influences, with mediterranean and north-western wet influences, sometimes with northern polar masses. The average annual temperature is 9^0 C. During winter, the average temperature in January is -9^0 C and in summer the average temperature in July is 20^0 C.

Rainfall is recorded in about 130 days with annual average quantities rainfall ranges between 550 ÷ 700 mm.

The number of winter days (with temperatures below 0° C) is 20 and the number of snow days is 15 ÷ 20. The dominant winds are the Western ones which bring rainfall and blow all year.

Water resources

On the study area, the Crasna River has the following tributaries: on the right side - Tăul Terebești River (L=9 km, S=57 km2) and on the left side - two tributaries: Mergeş river (L=6 km, S=33 km2) and Valea Neagră river (L=14 km, S=125 km2), with its tributary Valea Mare River (L=10 km, S=54 km2).

Valea Neagră River (L=14 km, S=125 km2) flows into the Crasna River on the Hungaryan teritory.

The water resource on the study area is monitored by 3 hydrometric stations: Craidorolț Hydrometric Station, Domănești Hydrometric Station and Berveni Hydrometric Station.

The maximum flows with different probabilities of excedance on Crasna river basin for the Craidorolț locality - Hungarian border sector are shown in table 1.

Table 1 The maximum flows with different probabilities of exceedance on Crasna river basin for the Craidorolț locality - Hungarian border sect

River	Section / Location	Designed flows (m^3/s)
Crasna	Supuru de Jos Hydrometric Station	$Q_{1\%}$ = 480 m^3/s; $Q_{5\%}$ = 294 m^3/s
Crasna	Upstream confluence with Maria river	$Q_{1\%}$ = 519 m^3/s; $Q_{5\%}$ = 318 m^3/s
Crasna	Upstream Moftin polder	$Q_{1\%}$ = 565 m^3/s; $Q_{5\%}$ = 346 m^3/s
Crasna	Downstream Moftin polder	$Q_{1\%}$ = 470 m^3/s (the peak of the flood is retained in the polder); $Q_{5\%}$ = 346 m^3/s
Crasna	Domăneşti Hydrometric Station	$Q_{1\%}$ = 595 m^3/s (natural flow regime) / 495 m^3/s (flow regime affected by the water retention of the polder) ; $Q_{5\%}$ = 408 m^3/s

Source: Regulations for function – exploitation and maintenance of the water management works of the Crasna River basin (2012)

In the figure 1 the hydrografic network and the positions of hydrometric stations are presented.

Through “The improvement of Crasna River scheme in Craidorolț – Vârșolț area“ project with the constraction of the Moftin polder, it was obtained the cutting of flood peak from Q1% = 500 m3/s, in the natural flow regime, to Q1% = 420 m3/s, in the actual flow regime, flow that was considered either to the size of river bed and the downstream dykes or heightening of embankments through capital repairs.

To the border section, according to the Romanian-Hungarian convention the safety flow is 0.1 m3/s.

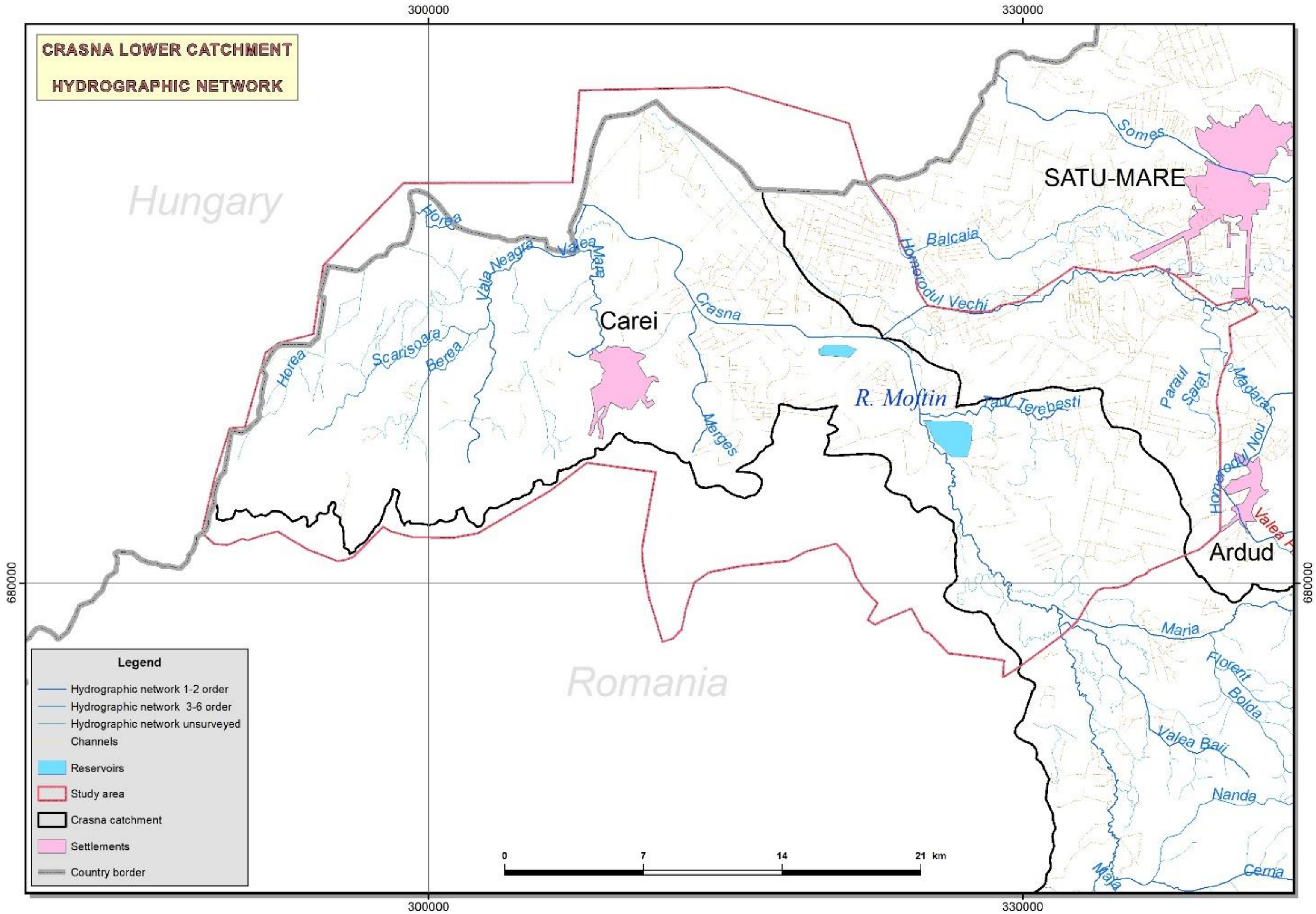


Figure 1 Hydrographic network of the study area

Soil

The hydro-physical properties of the soil are an essential factor in the water circuit, influencing the infiltration, surface leakage and loss of water through evaporation. The texture and the structure influence strongly the infiltration. The classification of soil taking into account their texture and structure is presented in table 2.

Table 2 Classification of soils by hydrological group

Group	Texture	Dominant constituents	Potential for infiltration
A	Coarse	Sand, fine sand and argillaceous sand	Very high
B	Coarse to medium	Light lute and slightly milled lute	High
C	Medium	Slightly milled lute, lute, argillaceous sand and argillaceous dust	Medium
D	Medium to fine	Heavy lute and argillaceous dust	Low
E	Fine	Sandy clay, dusty clay and clay	Very low

source: *Mustățea A. (by C. Diaconu), 2005, p.60*

The following types of soils are found in the study area:

- eutricambosoils;
- luvisols;
- faeozems
- psamosols and sands
- gley soils;
- solonetzs;
- alluvial soils.

The alluvial soils accompany like strips the riverbeds, and are formed from sands and clays.

The tendency to restore the meanders, the high speeds and the poor geological structure of the riverbed have favored the phenomenon of river bank erosion. Also, the riverbed erosion phenomenon has been accentuated, being favored by the blue marl easily erodible which forms the riverbed and by the sand deposits.

In the figure 2 the soil types found in the study area are presented.

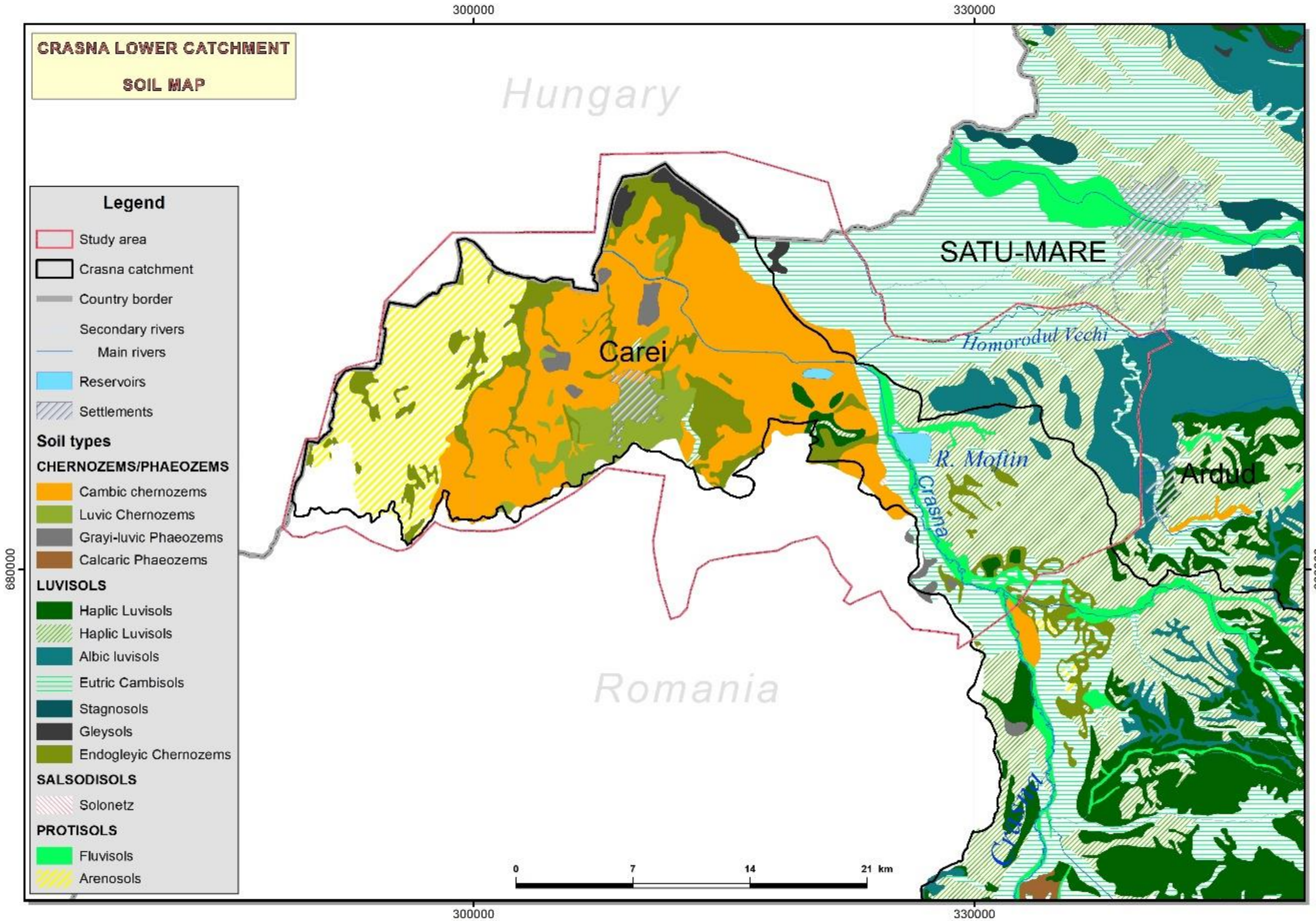


Figure 2 Distribution of soils types in the study area

Biodiversity

The vegetation is specific to the steppe, silvostepa and forest holes being represented by: the maple (Acer campestre), the common oak (Quercus robur), the elm (Ulmus foliacea), the ash (Fraxinus angustifolia), the hornbeams (Carpinus Betulus) to which is added the meadow vegetation, represented by: the aspen (Populus tremula), the white willow (Salix alba), alder (Alnus glutinosa). There are many shrub species as well: the hazelnut (Corylus avellana), the cornet tree (Cornus mas), the species of fescue (Festuca sulcata), the crested wheatgrass (Agropyron cristatum).

The fauna is diversified and is represented by the: wild boar (Sus scrofa), foxes (Vulpes vulpes), rabbits (Lepus europaeus) rodents; birds – gray partridge (Perdix perdix), quail (Coturnix coturnix), blackbird (Turdus merula), pheasant (Phasianus colchicus), to which is addes the aquatic fauna represented by: barbell (Barbus barbus), chub (Leuciscus cephalus), carp (Cyprynus carpio).

Population and human settlements

The analyzed river sector crosses the Craidorolț locality, then on right bank the Pișcari, Ghilvaci, Domănești, Berveni localities, and on the left bank the Crișeni, Moftinu Mare, Moftinu Mic, Căpleni, Cămin, Lucăceni localities, situated in Satu Mare county. The population related to these localities is about 14,000 inhabitants.

The population for the Crasna river basin delimited for the study area is about 27,000 inhabitants.

Land use

Land use is influenced both by physical and geographic conditions and by the anthropic factors, thus, an uneven distribution of arable land, pastures, vineyards, orchards and forests can be distinguished.

On agricultural land, we mainly find cereal crops (wheat, corn, barley, oats), technical plants (sugar beet, sunflower) and potato and legume crops.

In the figure 3 the land use of the study is presented.

Economic activity

The main economic activity is the agriculture.

Transport infrastructure

The main transport infrastructure is comprised of DE 671, DN 19, DN 1F, DJ 195B, DJ 108L, DJ 194 roads.

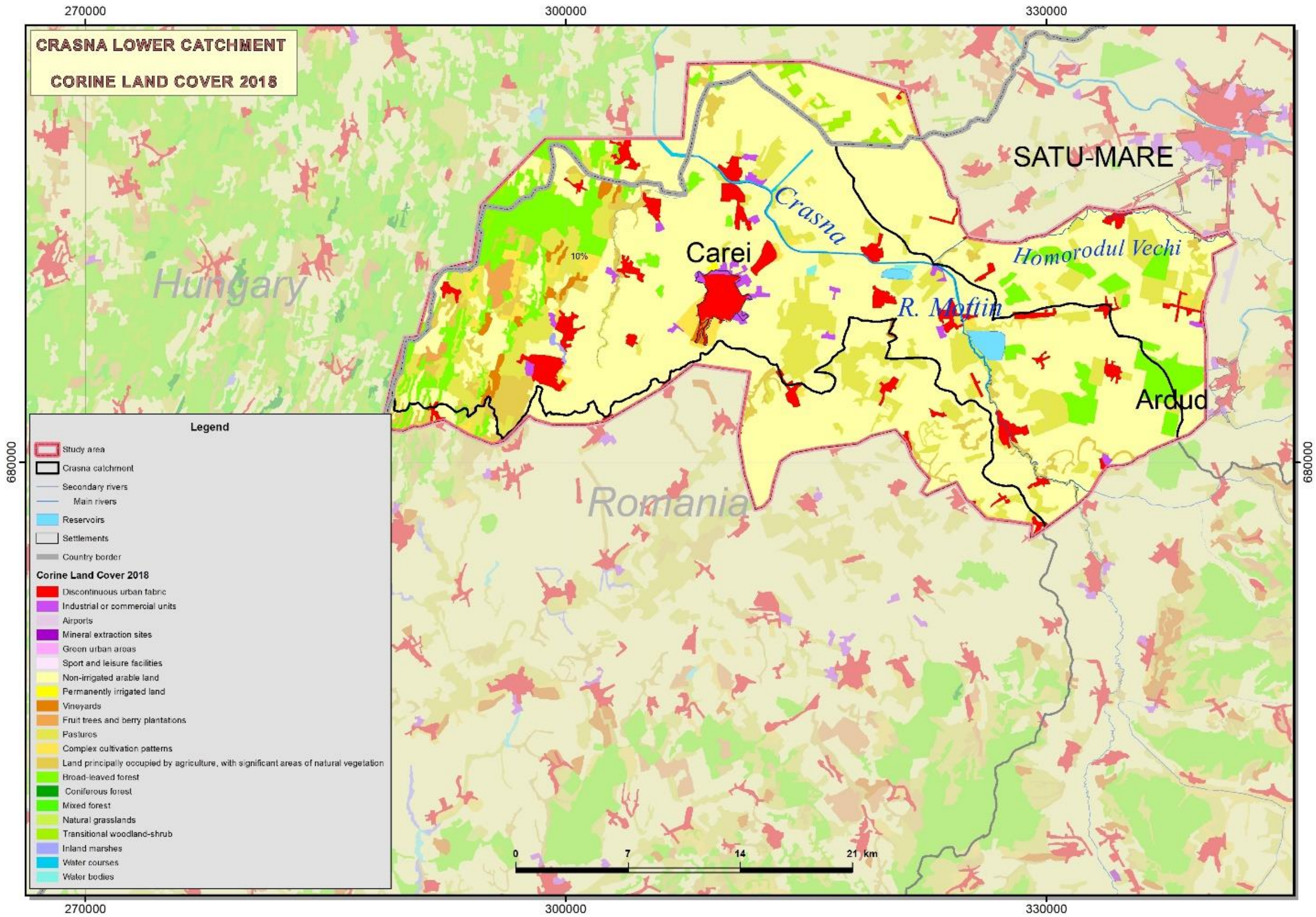


Figure 3 Land use in the study area

Chapter 2 Description of the flood defence infrastructure in the study area

The water management scheme existing in the Crasna river basin is presented in figure 4.

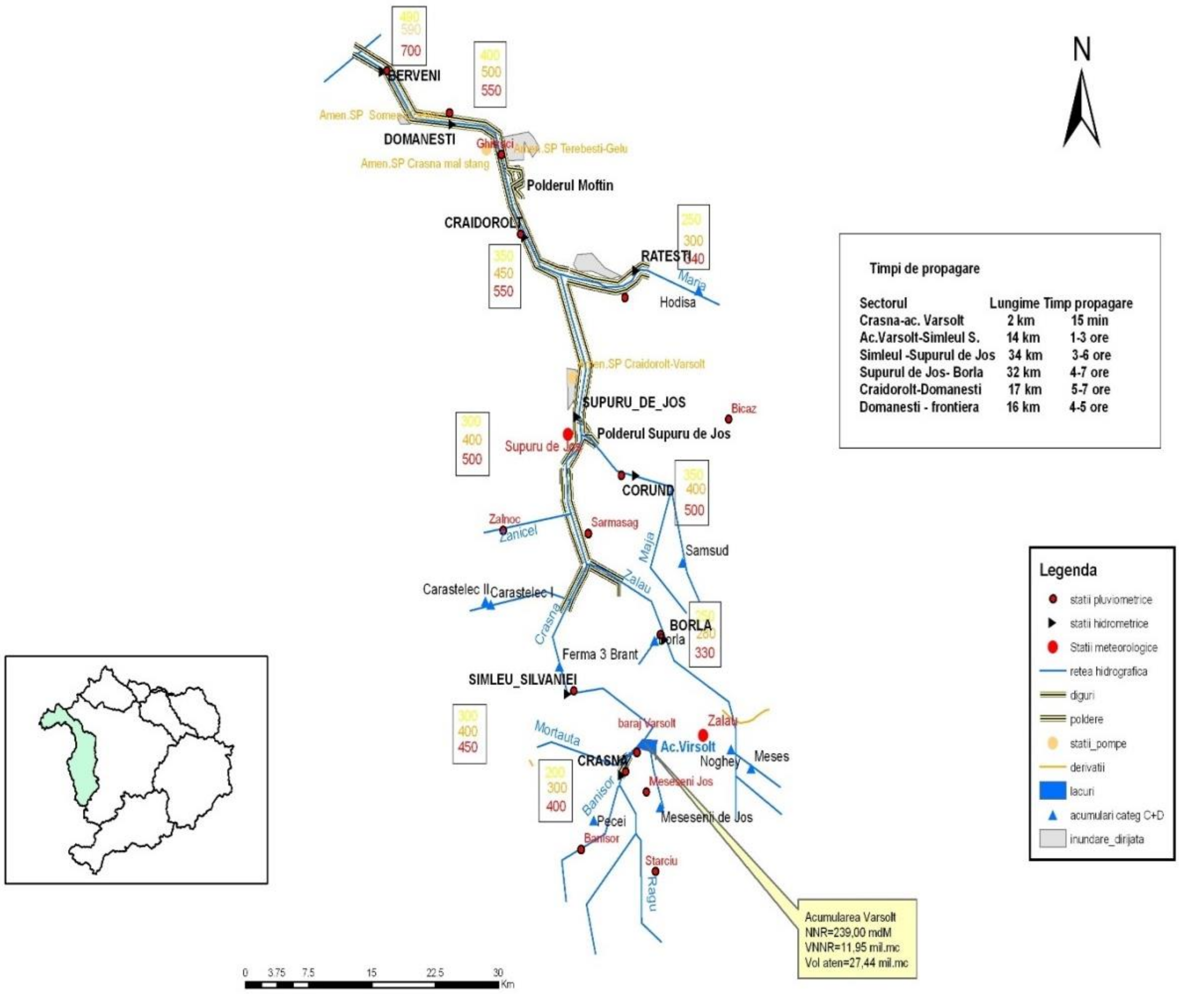


Figure 4 The water management scheme of the Crasna River Basin

In the study area, there is a complex system of hydraulic structures used for a quantitative management of water resources. The main flood defence constructions related to this area are embankments, polders, pumping stations.

Dikes

The repartition of embankments on Crasna river study area is presented below (table 3).

Table 3. The repartition of embankments works on Crasna river study ares

Embankments	Protected localities	The year of commissioning (CY)	Length (m)	Medium height (m)
Right bank embankment on Crasna river, confluence with Maria tributary – Moftin/ Ghilvaci locality	Ghirișa, Craidorolț	1980 – 1988	15580	2.5
The right bank annular embankment on Crasna river, Moftin / Ghilvaci locality sector	-	1980 – 1988	1260	2
Right bank embankment on Crasna river, Moftin /Ghilvaci locality – Hungarian border sector	Ghilvaci, Domănești, Berveni,	1901	23200	3.5
Left bank embankment on Crasna river, Supur / Supuru de Sus locality –confluence with Cerna tributary sector	Giorocuta, Supuru de Jos	1980 – 1988	7000	2
Left bank embankment on Crasna river, between the confluences with Cerna and Maria tributaries sector	Supuru de Jos, Acâș, Mihăieni	1980 – 1988	14600	2.5
Left bank embankment on Crasna river, confluence with Maria tributary – Moftin / Ghilvaci locality sector	Țeghea, Craidorolț, Crișeni	1980 – 1988	15400	2.5
Left bank road – embankment on Crasna river, Moftin / Moftinu Mare locality sector	Moftinu Mare	1980 – 1988	4310	2
Left bank embankment on Crasna river, Moftin / Ghilvaci – Căpleni localities sector	-	1980 – 1988	15100	3
Left bank embankment on Crasna river, Căpleni locality sector	Căpleni	1996	1300	3
The left bank annular embankment on Crasna river, Căpleni locality sector	Căpleni	1901	3450	3
Left bank embankment on Crasna river, Căpleni locality – Hungarian border sector	Lucăceni	1980 – 1988	9400	3
Left bank Agerdo embankment on Crasna river,Berveni/ Lucăceni localities sector	Lucăceni	1942	600	2.5
The left bank annular embankment on Crasna river, Berveni/Lucăceni localities sector	-	1942	1300	1.5

source: *Flood Risk Management Plan of Someș – Tisa River Administration (2016)*

Polders

The Supur polder is located in the area of Supuru de Jos locality, on the right bank of the Crasna river, downstream of the confluence with the Maja river. The volume of polder is about 5.88 mil. m³ and a total area of 134.24 ha. The surface of the controlled river basin is 1189 km², downstream of the Maja river, and the multiannual average flow rate is 3.25 m³/s and transits through the two openings (2.00 x 1.00 m) under the crest of the front spill.

The Supur polder works as a temporary reservoir of peak retention at floods having maximum flow with the probability of raintained of 5% on Crasna river. The embankments' tops correspond to a flood with maximum flow having the probability of 15aintained of 1% and an additional 0.5 m guard height. Supur Polder has the role of floods defence of the population from the riverine localities, the socio-economic objectives that are located in the floodplain area of the Crasna river downstream to the border.

The Moftin polder is located on the right bank of the Crasna river, in the area of Ghilvaci locality, Moftin village. Moftin Polder has a surface of 294 ha and the volumes of the two compartments is 5.618 mil. m³. the surface of the controlled river basin is 1647 km².

It works as a temporary reservoir for peak retention, being flooded at floods of maximum flow with the probability of exceedance of at least 5% on Crasna river. The embankments correspond to a flood with maximum flow with the probability of exceedance of 1% and an additional 0,5 m guard height. The Moftin Polder retains the peak of the great floods, so that the maximum flow rate is lower at Domănești (downstream the polder) than at Craidorolț (upstream the polder).

The hydraulic dimensioning of the polder was based on the need to cut the peak of the flow hydrograph with the probability of exceedance of 1% from a flow rate of 507 m³/s to 415 m³/s, in order to comply with the border condition with Hungary: not to exceed the maximum level of 116.94 maMB corresponding to the flow with the probability of exceedance of 1% on Crasna river and to the channel transport capacity of 415 m³/s.

Pumping Stations

In the Crasna river basin there are land improvement works consisting of drainage networks, pumping stations with gravity discharge and pumping, which are managed by SNIF – Satu Mare branch. The characteristics of the pumping stations for drainage are shown in table 4.

Table 4 The characteristics of the pumping stations for drainage

Pump station	Number of aggregates	Designed flow ate (m³/s)
Căpleni	3	2.1
Domănești	3	2.1
Berveni V	4	1.0
Berveni	3	1.83
Berveni	5	18
Moftin	5	22.5
Terebesti	3	3.6
Ghilvaci	5	4.0
Moftin	4	1.64
Craidorolt	4	2.25

Chapter 3 Flood risk assessment of the study area for the 1st cycle of Floods Directive 2007/60/EC implementation

Historical floods

Except the Crasna upper river basin (upstream of the Crasna hydrometer station) at all the other hydrometric stations on the Crasna river, the highest flows were recorded before 1989 between 1970 and 1980.

The general trend of evolution of the maximum flows is their decrease in the period 1990 ÷ 2006 compared to the period 1965 ÷ 1989.

The most representative floods on the Crasna river are:

- The flood of 12.05.1970, the flood that had a duration of 4 days;
- The flood of 12.06.1998 the flood that had a duration of 37 days;
- The flood of 23.07.2008 the flood that had a duration of 3 days.

The floods have been caused by factors like: the abundant and torrential drainage regime, the uncontaminated riverbed with many meanders and strangulation produced by woody vegetation raised in the riverbed.

Areas with potential significant flood risk

In the first implementation cycle of the Floods Directive 2007/60/EC has been designated and reported to the European Commission 2 areas with potential significant flood risk (APSFR) which overlap over the study area, respectively:

- Crasna river – downstream Acâş locality, upstream Moftinu Mare locality (L = 21.4 km);
- Crasna river – downstream Moftinu Mare locality (L = 23.1 km).

Potential damages in case of 1 in 100 years flood

In case of a flood with a probability of excedance of 1%, based on the flood risk hazards map reported to the European Commission, the following damages can occure on the 2 areas with potential significant flood risk which overlap over the study area:

- 14 localities with a population potential affected of about 4566 inhabitants;
- 5 social objectives (schools, city halls etc.);
- 3 water catchments;
- 1 IPPC and 2 EPRTR (from S.C. ABOMIX S.A. – Moftin Farm);
- 43.33 km of roads;

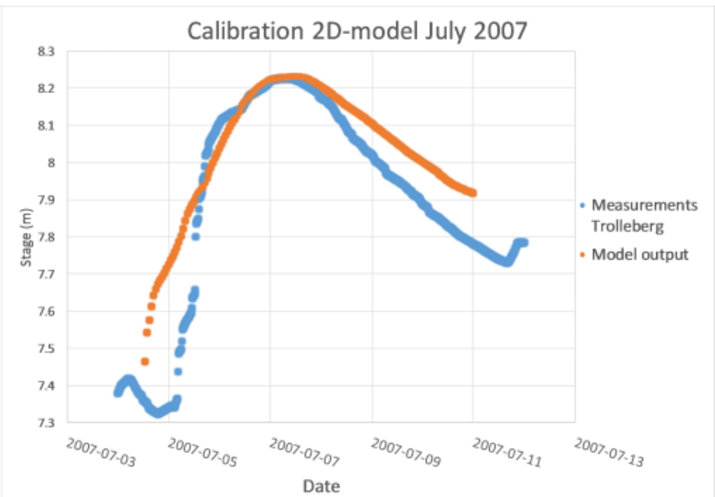
- 9434 ha agricultural terrain;
- 8 cultural heritage objectives (7 churches and 1 monument).

Chapter 4 Description of the software used for flow modelling on the Crasna River

HEC-RAS 5.0 2D software is one of the hydraulic models that meet National Flood Insurance Program (NFIP) requirements for flood hazard mapping activities in USA.

HEC-RAS (River Analysis System) 5.0 2D software has been developed by the Hydrologic Engineering Center (HEC), a department of the Institute of Water Resources (IWR) in the U.S. Corps of Engineer's.

HEC-RAS software, successfully tested for other rivers such as: Höje river situated in western Scania (Sweden) – Figure 5, Mekong River – Figure 6, modeled by JBA, Des Plaines River in The City of Joliet in Illinois, Middle Kansas Watershed (within Wabaunsee County and The City of Wamego in Pottawatomie County) etc.



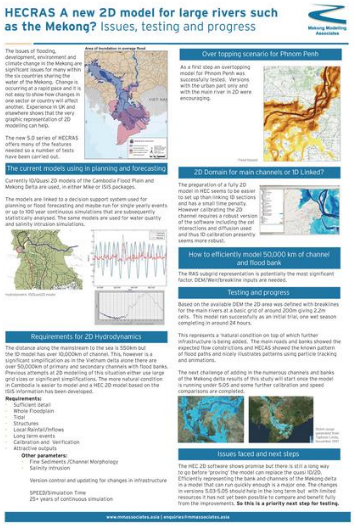


Figure 5. Modeled stage vs. Trolleberg measurement River

Figure 6 Use of HEC-RAS 2D for Mekong

The U.S. Army Corps of Engineers' River Analysis System (HEC-RAS) is software that allows you to perform one-dimensional steady flow hydraulics; one and two-dimensional unsteady flow river hydraulics calculations; quasi Unsteady and full unsteady flow sediment transport-mobile bed modeling; water temperature analysis; and generalized water quality modeling (nutrient fate and transport).

In HEC-RAS, for the 2D hydraulic model, the flow is described either by the 2D Saint – Venant equations (with optional momentum additions for turbulence and Coriolis effects) or by the 2D Diffusion Wave equations, which are solved using an Implicit Finite Volume algorithm.

Using Diffusion Wave equations the model runs faster, but less accurate in some cases, while using the Full Momentum equations the model runs slower, but more accurate.

The Full Momentum equations are recommended for:

- dynamic flood waves (e.g. dam breaches);
- sudden expansions and contractions;
- wave propagation analysis;
- super elevation around bends;
- multiple hydraulic structures (bridges, bridge piers etc.).

The main steps in developing a 2D model using HEC-RAS 5.0 are:

- developing a terrain model compatible with this program;
- improvement of the terrain model using cross sections;
- development of the 2D computational mesh;
- creating a spatially varied Manning's Roughness Layer;
- creating the Hydraulic property tables for the 2D Cells and Cells Faces;
- running the 2D Geometric Preprocessor;
- establishing the 2D flow area Boundary Conditions;
- setting the 2D Flow Area Initial Conditions;
- performing the computations;
- calibration and validation.

Chapter 5 Description of the hydraulic model

Data used for hydraulic modelling

In order to develop a hydraulic model different types of data are needed.

Input data needs to be as accurate and up-to-date as possible in order to achieve successful results.

Inputs for software are considered:

- topographic data – the channel cross sections, the engineering structures descriptions (bridges, weirs, dams, water intakes, etc.), situation plans, aerial photos, digital terrain models etc.;
- hydrological data – flow values in all interest sections, input hydrographs, measured hydrographs, rating curves, gate performance curves, historical flooded areas for calibration of significant events models etc.;
- data regarding the hydrotechnical works scheme;

- land use information, vegetation coverage, riverbed and flooded area nature and in order to establish the roughness coefficients.

Topographical data

Topographical data used to develop the Crasna river 2D hydraulic model in the study area consisted of:

- the digital terrain model of the for the Crasna river, Craidorolţ locality – the Hungarian border sector, from PPPDEI Project 2009;
- the digital terrain model of the for the Crasna river, Craidorolţ locality – the Hungarian border sector, from dike measures project 2018;
- the digital terrain model EUDEM of the for the Crasna river basin, Craidorolţ locality – the confluence with Somes river;105 cross-sections with batimetry on the Crasna river, Craidorolţ locality – the Hungarian border sector;
- 12 descriptions of the bridges on the Crasna River, Craidorolţ locality – the Hungarian border sector;
- the longitudinal profile of the Crasna River;
- the location plan of the cross-sections on the Crasna River (scale 1:25000, 1:100000);
- profiles of the Crasna river embankments in the border area (5 for the left bank and 7 for the right bank for the Romanian sector and 5 for the left and right banks for the Hungarian sector);
- defence lines on Craidorolţ locality – the Hungarian border sector;
- 11 digital orthophotos of the study area.

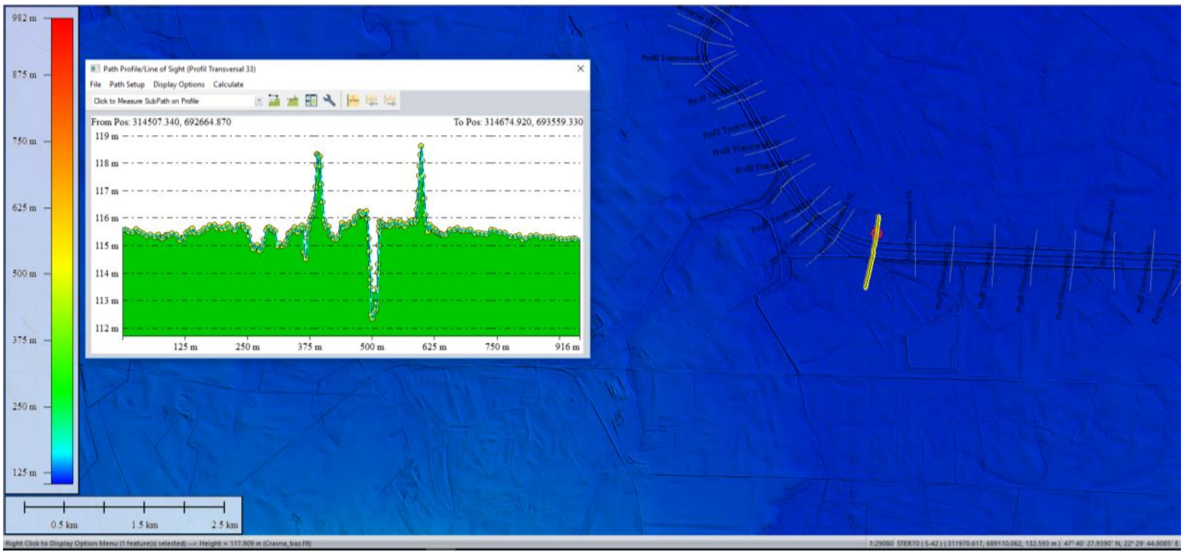


Figure 7 Global Mapper capture of cross-sections distribution on Crasna River

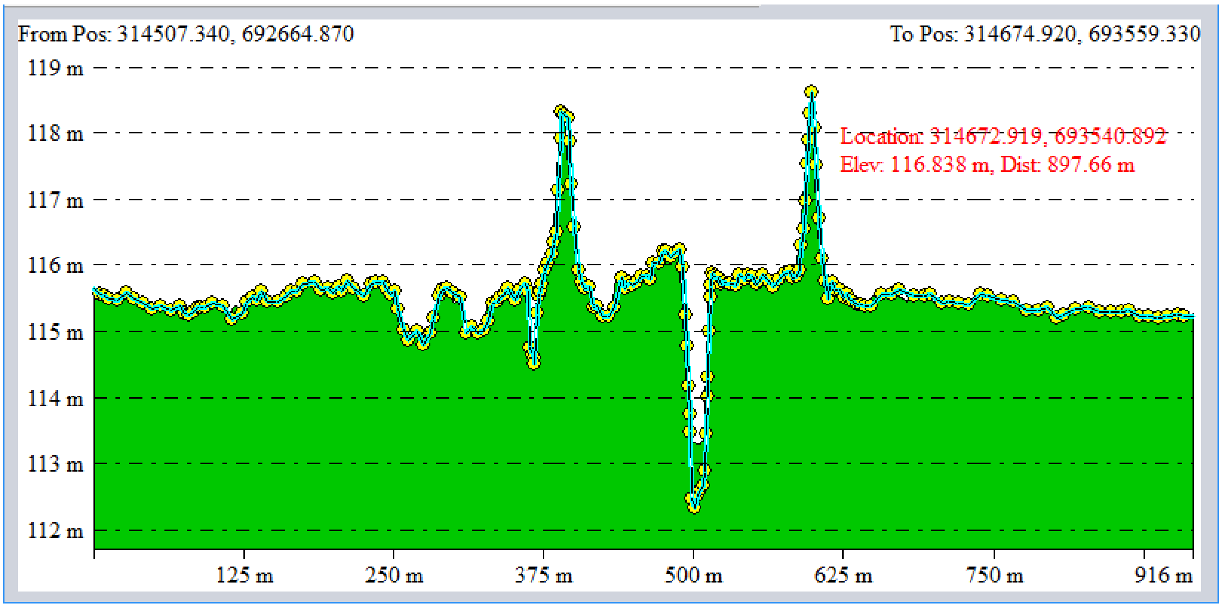


Figure 8 Global Mapper capture of a cross-section on Crasna River

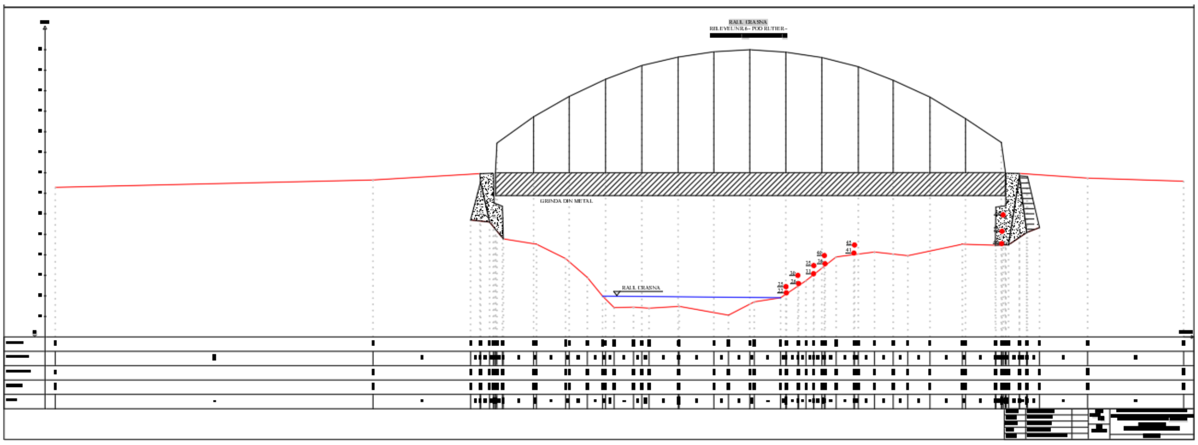


Figure 9 Bridge description

Following the comparison of the data obtained from the joint Romanian - Hungarian measurements in the border area, with the numerical model of the land obtained within PPPDEI project (2009) there were significant differences of about 4 m between the two sets of data. This difference decreases progressively as they arrive on the territory of Romania. This difference and the tendency of decrease was also highlighted by the measurements made by Romanian part to the defence dikes on the Crasna river. The differences between dikes measurements and DTM obtained in the Someș-Tisa PPPDEI project are minimized, reaching acceptable values of about ± 10 cm at about 3 km upstream of the border.

Following the Satu Mare bilateral meeting of 12 February 2019, it was agreed that for the water drain simulations in the Crasna River's major bed behind the defence dikes, the digital model of the EUDEM land should be used. The following figure shows an image captured from HECRAS on the digital terrain model on the Crasna River analysis area.

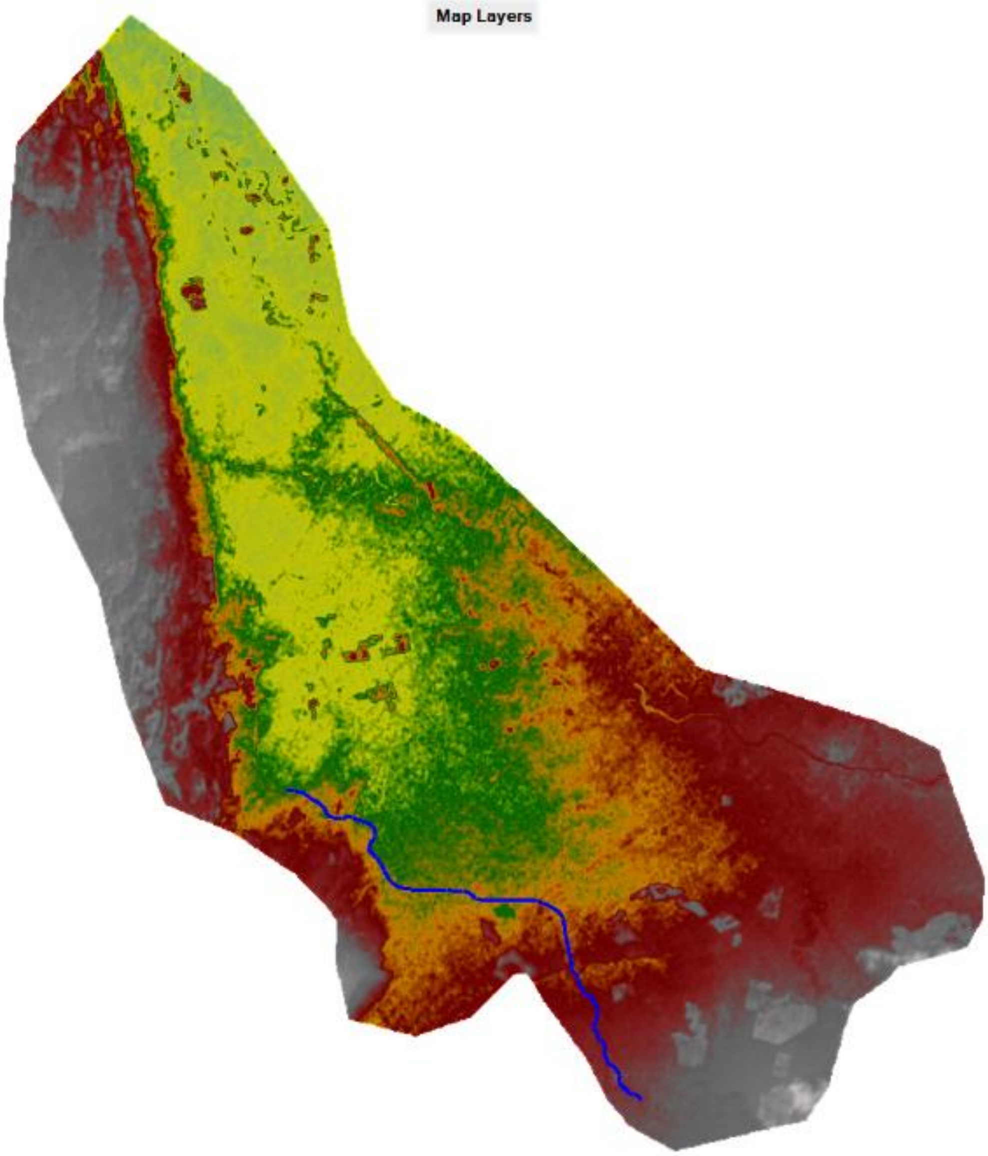


Figure 10 Hec-Ras capture of EUDEM digital terrain model on Crasna River Basin

Hydrological data

Hydrological data used to develop the Crasna river 2D hydraulic model in the study area consisted of:

- 7 hourly hydrographs for the current flow regime for maximum flows with the probability of exceedance of 0.1%, 1% and 10% in different cross-sections on the Crasna river, Craidorolţ locality – the Hungarian border sector (table 5);
- 3 hourly hydrographs for the current flow regime for maximum flows with the probability of exceedance of 0.1%, 1% and 10% on the main tributaries

(Terebești, Megeș and Valea Mare) of the the Crasna river, Craidorolţ locality – the Hungarian border sector (table 5);

- Hydrological data from the hydrometric stations's studies (Craidorolț, Domănești and Berveni);
- Hydrographs of historical floods:
  - ✓ March – April 2000 (figure 10) July – August 2008, March – April 2013 and May – June 2015 at Craidorolţ Hydrometric Station;
  - ✓ March – April 2000, July – August 2008 (figure 11), March – April 2013 and May – June 2015 at Domăneşti Hydrometric Station;
  - ✓ March – April 2013 and May – June 2015 (figure 12) at Berveni Hydrometric Station.

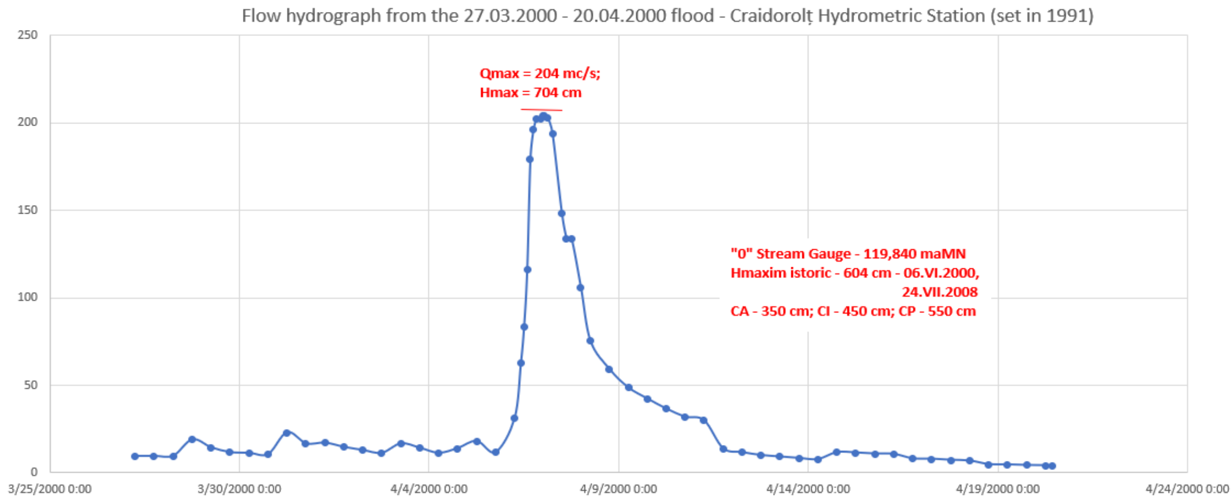


Figure 11 Historical flood hydrograph from Craidorolț Hydrometric Station in March – April 2000

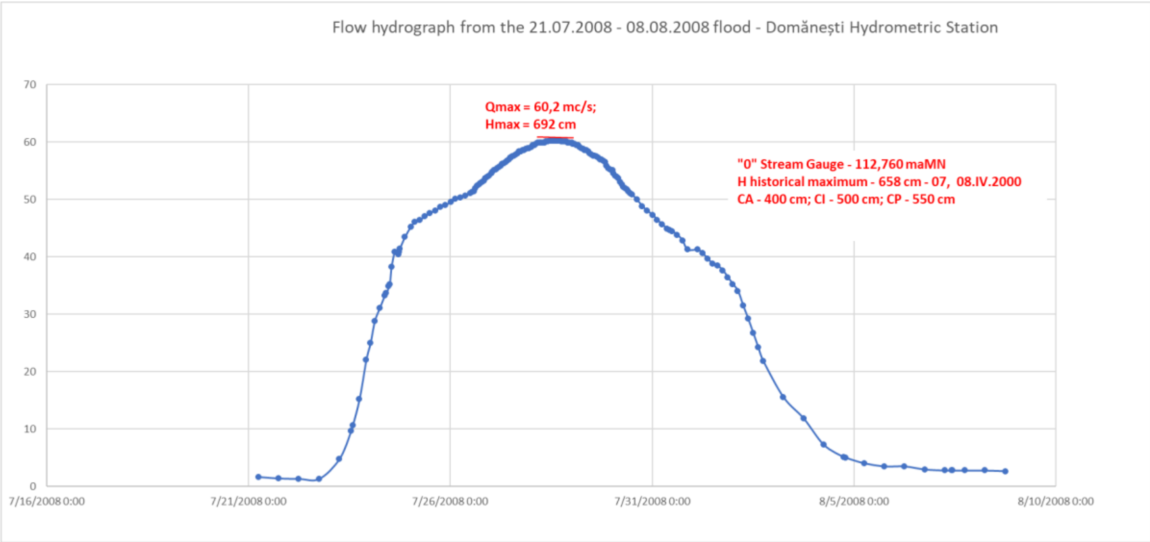


Figure 12 Historical flood hydrograph from Domănești Hydrometric Station in July – August 2008

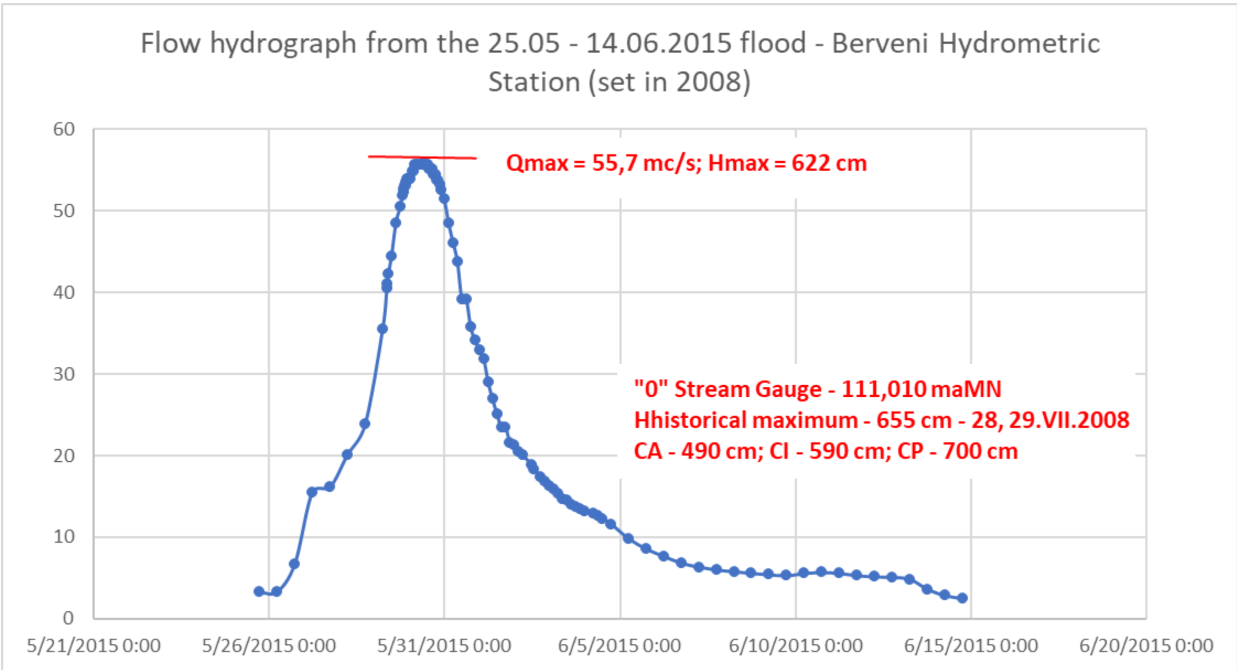


Figure 13 Historical flood hydrograph from Berveni Hydrometric Station in May – June 2015

The methodology for calculating the maximum flows for the current flow regime for the three tributaries Terebești, Megeș and Valea Mare on the confluence with Crasna River was adopted taking into account the size of the river basin section and the possibility of using the existing hydrometric data.

Since in the calculation sections of the maximum flows on the above-mentioned rivers no observations and measurements were made, so there are no direct data on the maximum leakage in the calculation of the required flows, indirect methods were used, i.e. the use of the zonal validation relation valid for the tributaries of Crasna Rriver near the border.

In this synthesis relationship, the maximum flow rates with 1% probability of exceedance (Qmax1%) obtained by statistical calculation at the hydrometric stations from this area, as well as other materials and information on the maximum leakage characteristics were used.

Using the above method, the maximum flow rate with the probability of exceedance of 1% (Qmax1%) for the analyzed sections was determined.

The Pearson III distribution curve with CS and CV adopted according to NIHWM standards was used to obtain the values for the flows with the exceedance probabilities of 0.1% and 10%.

The mean characteristics Tp, Tb and ɣ were determined on the basis of the synthetic relations resulting from the statistical processing of the major floods recorded at the hydrometric stations in the analyzed area.

The resulting values are shown in the table 5 indicating that they refer to the natural flow regime and do not contain the safety margin.

The maximum flow rates for Crasna River were determined in the following sections taking into account the influence of the flood defence scheme:

- downstream the confluence with Maria River (figure 13);
- at Craidorolţ Hydrometric Station (figure 14);
- downstream the confluence with Tăul Terebeşti River;
- at Domăneşti Hydrometric Station;
- downstream the confluence with Mergeş River;
- at Berveni Hydrometric Station;
- downstream the confluence with Valea Neagră River.

In order to obtain the necessary values, an analysis of the maximum run-off conditions on the Crasna River in the Crasna river basin was performed.

Upstream the confluence of Crasna River with Maria River the flow is influenced by Vârșolț permanent reservoir and Supur Polder. Downstream the Moftin Polder, the flow is influenced by the all three reservoirs.

The RAZVAN mathematical model, which determines the shape of the synthetic flood waves produced on the tributaries (components), their composition and propagation, was used to determine the maximum flows on Crasna River, obtaining a flood wave with the maximum probability of exceedance p%, and the change of the flood wave as a result of the influence of the hydro-technical arrangements in the analyzed river basin.

For the application of the model, several computation sectors were established on the Crasna River, depending on the hydrometric stations in the river basin and the location of the reservoirs mentioned above, which influence the maximum flow.

It should be noted that when calculating the influence of the reservoir on the maximum flow, their main characteristics and of the spillways, data from the operating regulations were taken into account.

All these characteristics become input data for the mathematical model with which the calculation of the attenuation of the synthetic flood waves through the abovementioned reservoirs was performed.

Changing these input data can lead to variations in the maximum flow rate which are even higher as the hydrographic basin studied is lower.

It is mentioned that for the Supur and Moftin reservoirs, which have the IV class of importance, in the case of flows with the exceedance probability of 0.1%, the water level exceeds the dam's top.

The modeling results consisted in obtaining of flood waves corresponding to the actual flow regime, modified as a result of their transit through the Vârşolţ, Supur and Moftin reservoirs, whose maximum flows with the probability of exceedances of 0,1%, 1% and 10% are presented in the table 5, with the indication that they do not contain the safety margin.

Table 3 Maximum flow with the probability of exceedance of 0.1%, 1% and 10% on Crasna River and its tributaries in the study area

River	Location	H_{med} (m)	S (km^2)	Flow regime	$Q_{max\ p\%}$ (m^3/s)		
					0,1%	1%	10%
Tăul Terebești	upstream confluence with Crasna River	125	57	NR	103	60	22
Mergeș	upstream confluence with Crasna River	126	33	NR	45	26	10
Valea Neagră	upstream confluence with Crasna River	131	180	NR	155	90	33
Crasna	downstream the confluence with Maria River	268	1518	AR	764	424	164
Crasna	at Craidorolţ Hydrometric Station	265	1552	AR	782	432	165
Crasna	downstream the confluence with Tăul Tereboşti River	257	1669	AR	-	341	146
Crasna	at Domăneşti Hydrometric Station	254	1705	AR	-	350	151
Crasna	downstream the confluence with Mergeş River	248	1773	AR	-	354	157
Crasna	at Berveni Hydrometric Station	245	1824	AR	-	360	160

River	Location	H_{med} (m)	S (km^2)	Flow regime	$Q_{max\ p\%}$ (m^3/s)		
					0,1%	1%	10%
Crasna	downstream the confluence with Valea Neagră River		2056	AR	-	375	172

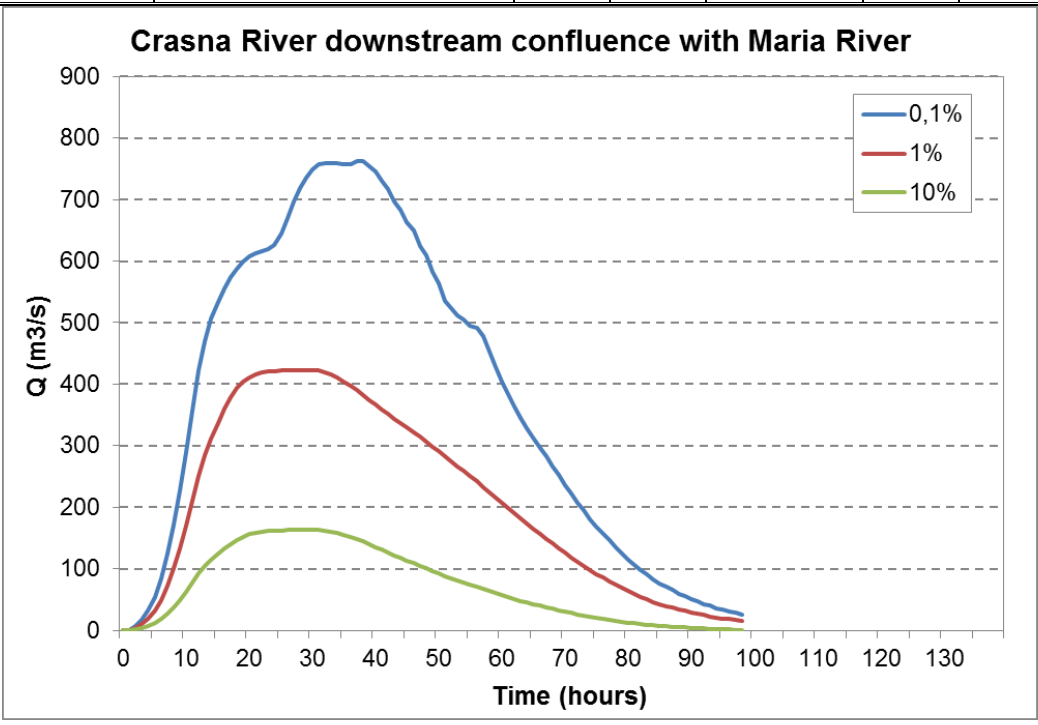


Figure 14 Synthetic flood hydrographs for Crasna River downstream confluence with Maria River for flows with different probabilities of exceedance (0.1%, 1% and 10%)

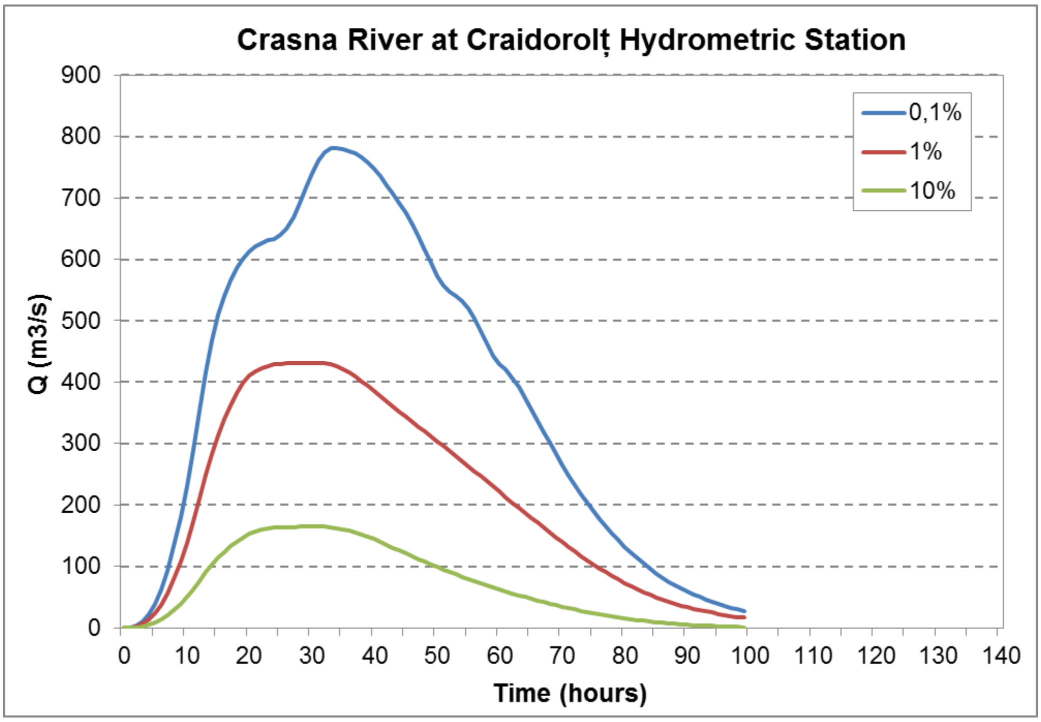


Figure 15 Synthetic flood hydrographs for Crasna River at Craidorolț Hydrometric Station for flows with different probabilities of exceedance (0.1%, 1% and 10%)

Other data and information

Data regarding the Crasna river scheme consisted of:

- Hedging rules for Supur and Moftin reservoirs' operation;
- internal water hedging rules for operation.

In areas where, on the Romanian territory, there are systems for collecting and evacuating the internal waters and the discharges will be transported through them, as well as through the existing border crossing channels, in accordance with the Regulation defence against floods produced by internal waters, which was concluded on the basis of Article 14 of the Convention between Romania and the Republic of Hungary on the regulatory hydrotechnical issues concerning the border – rivers and cross-border rivers, signed in Bucharest on 25 June 1986 and in force at November 20, 1986.

The discharge of the internal waters from areas where internal waters cannot be collected by existing collection and evacuation systems as well as exceptional internal waters exceeding the maximum discharge capacity of these systems will be crossed across the border both within the channels, at the values of flows and levels established by this Regulation, as well as in valleys and depressions. The limitation of the internal water flows will be done by operating the weirs, retention in the channels or other nodes.

Other data necessary in order to establish the Manning's coefficient values consisted of:

- .shp file with land use in the study area;
- pictures of the study area (July 2018).

Roughness data include estimates of the roughness coefficients of the channel and of the two over bank areas for each cross section, and they are considered to be data with a greater degree of uncertainty.

Among the factors influencing the value of channel roughness can be listed:

- the nature of the riverbed and the average particle size;
- irregularities of the channel;
- riverbed shapes (such as ripple marks, dunes, transition forms and flat shapes);
- river sector characteristics of erosion or deposition of alluvial material;
- tendencies of meandering;
- obstructions of the channel (tree trunks, dams built by the beaver, scraps of material that block the section, etc.);
- changes in geometry of the cross sections;
- the presence of vegetation on the riverbed and on the river banks.

The roughness coefficient varies considerably with the period of the year, so it is recommended to estimate roughness values for the year season in which floods occur.

In the estimation of the roughness coefficient, Chow's (1959) tables can be used, including the maximum, minimum and normal values of this coefficient for a variety of types of channel (natural / artificial, variable widths of cross section, different types of over bank areas).

The best method of estimating the value of the roughness coefficient is to indirectly determine it based on the records from the gauges stations.

The following pictures (Pictures 1, 2, 3, 4, 5, 6) show aspects regarding Crasna River channel and floodplain in different sections in the study area

Picture 1. Crasna River at Craidorolț


Picture 2. Pumping station from Ghilvaci locality


Picture 3. Crasna River downstream confluence with Homorodu Vechi channel


Picture 4. Crasna River at Domănești


Picture 5. Crasna River at Căpleni


Picture 6. Crasna River at Berveni

Description of flow scenarios

The following potential assumptions agreed for the development of the Crasna River 1D-2D hydraulic model on the study area are:

- Simulation under current morphological status of riverbed and also taking into account the changes of Manning's roughness coefficient;
- Simulation in case of dike breach (L = 100 m) on the following locations:
  - on the right bank of Crasna River, near Berveni locality;
  - on the right bank of Crasna River, near Domănești locality;
  - on the left bank of Crasna River, near Căpleni locality.

The precise location of the dike breaches were determined after analysing the simulation of the past floods on an 1D hydraulic model (figure 15).

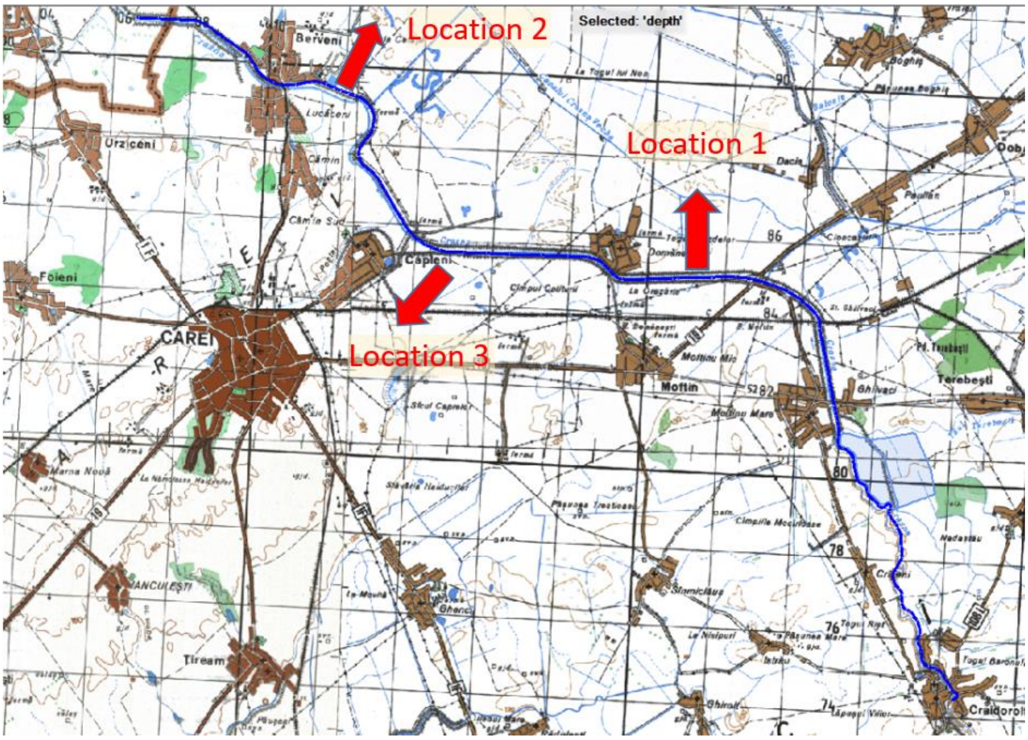


Figure 16. Location of the dike breaches

Model calibration

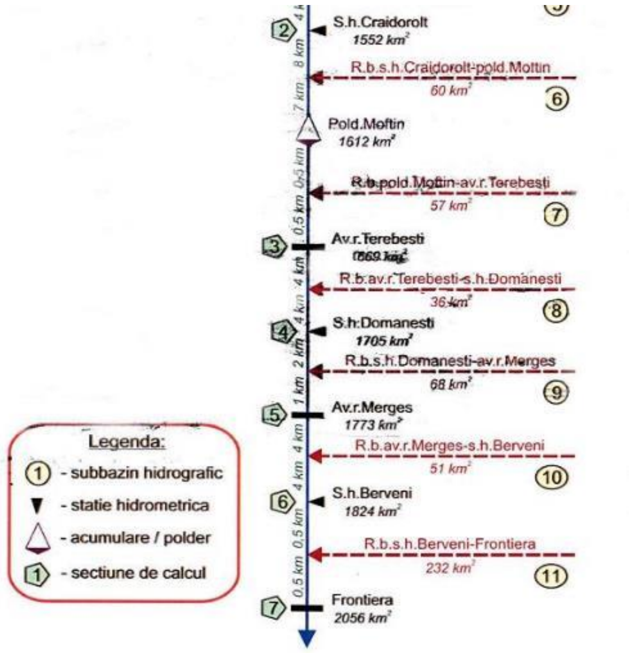
Calibration of the hydraulic model is a very important stage in the process of hydraulic modeling. Without a calibrated hydraulic model, the results obtained from the hydraulic modeling may have a large deviation from the actual situation.

Hydraulic model calibration consists of obtaining coincidences of model results with hydrological observations (flow or maximum level, growth and total time, volume on the growth and decrease branch, total volume, shape coefficient) of the recorded flood waves.

The main parameters that can be used in the tuning process of the mathematical model reproducing the propagation of flood waves are:

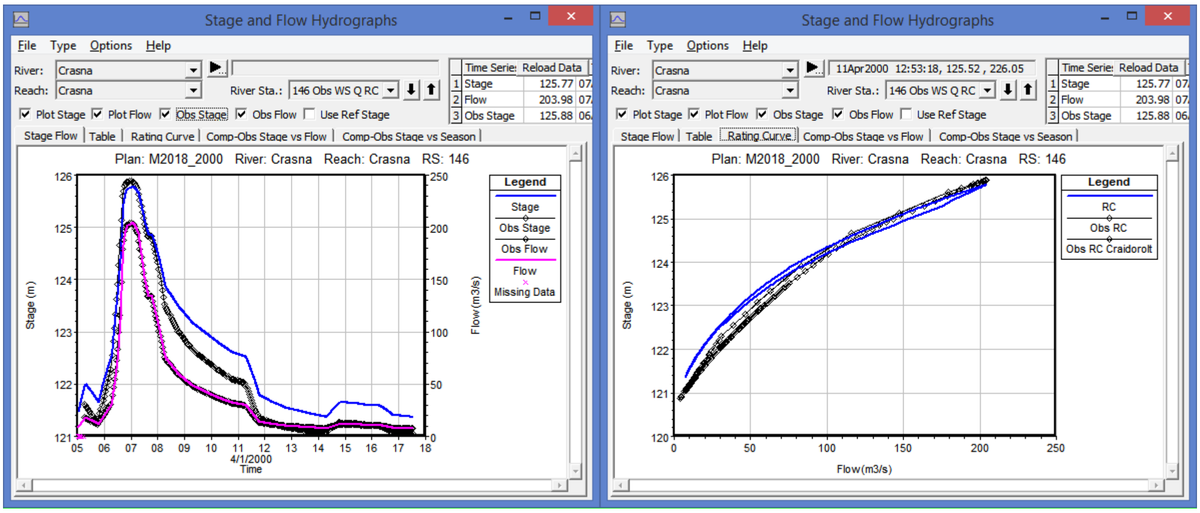
- ✓ roughness coefficients (ni), which model the hydraulic resistance of the river beds;
- ✓ introducing the accumulation mileage of the major riverbeds in the direction of the overall flood sprocket;
- ✓ Determination of the grinding areas and their quotations from where the major bed floods begin, the detection and the modelling of the local depression areas (located below the minor river bed) from the major river bed with polder effect, which not participate in the leakage, but influence the propagation and volume of the recorded floods ;
- ✓ the identification and modelling of the backwater areas;
- ✓ optimal adjustment of the model calculation coefficients by adjusting the magnitude of the time and distance calculation steps along the river (DT, DX), the number of cycles to integrate the equations, etc.

Crasna river, on the Craidorolt-Hungary border sector is monitorized hydrologically by 3 hydrometer stations: Craidorolt, Domănești and Berveni

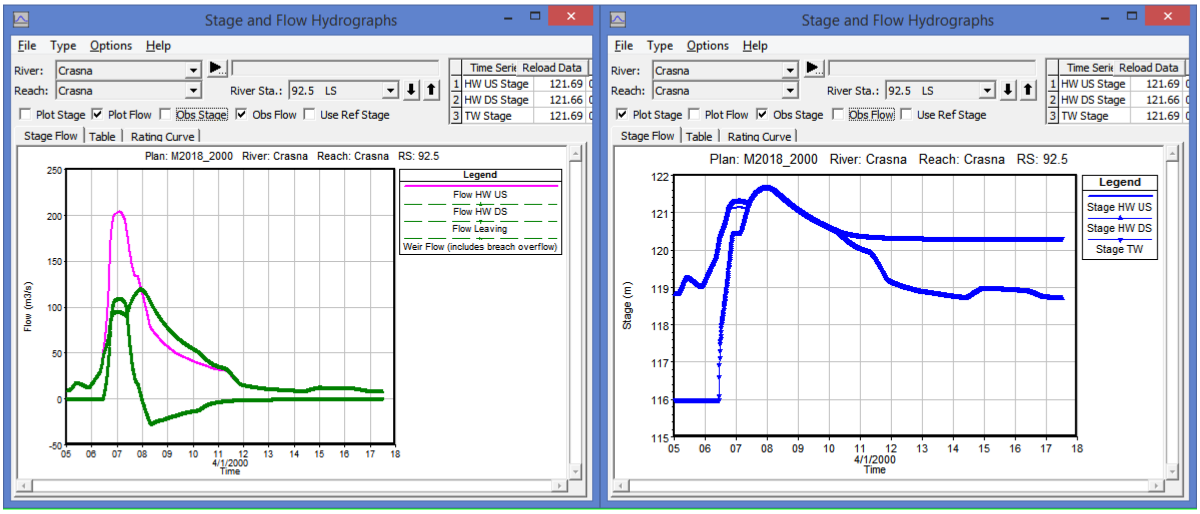


Hydrological data used in the calibration process of the hydraulic model were those recorded during the floods in the years 2000, 2009, 2013, 2018.

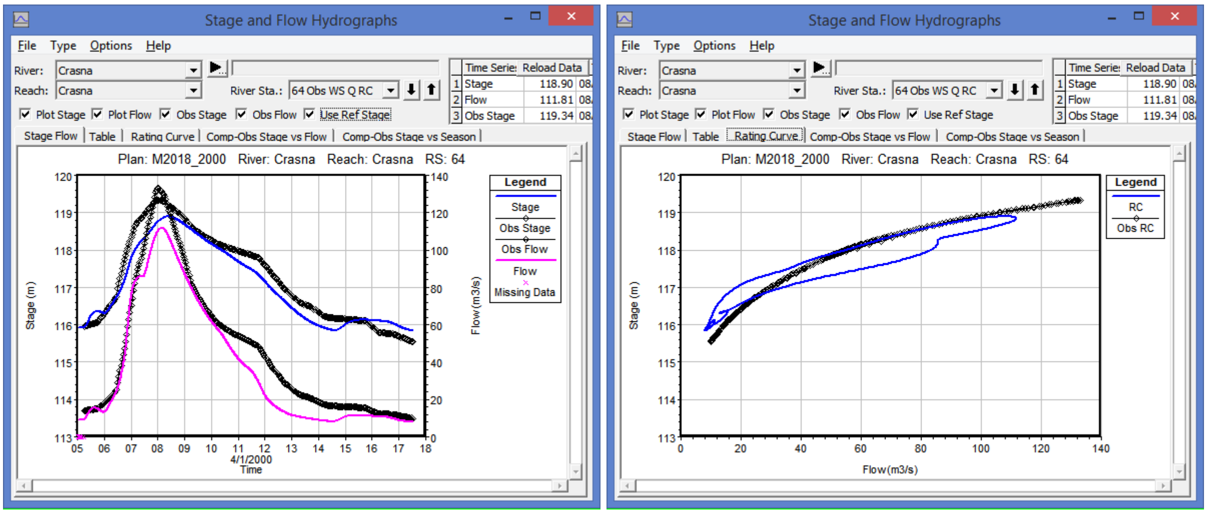
The results of the calibration process in the sections of the Craidorolt, Domanesti, Berveni hydrometric stations corresponding to the floods of the years 2000, 2009, and 2018 are presented below.



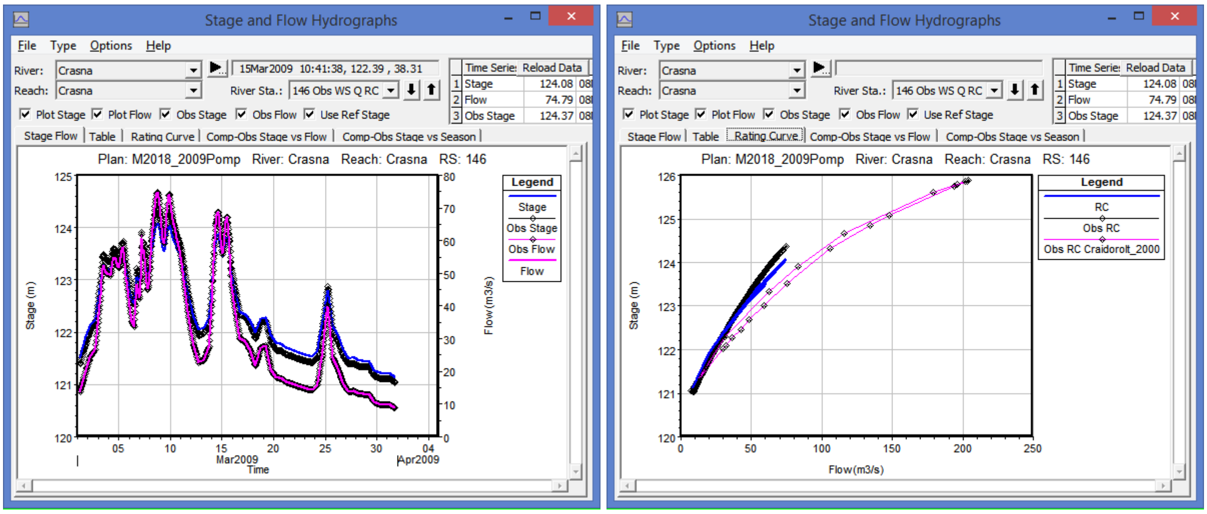
h.s. Craidorolt – highflow from 2000



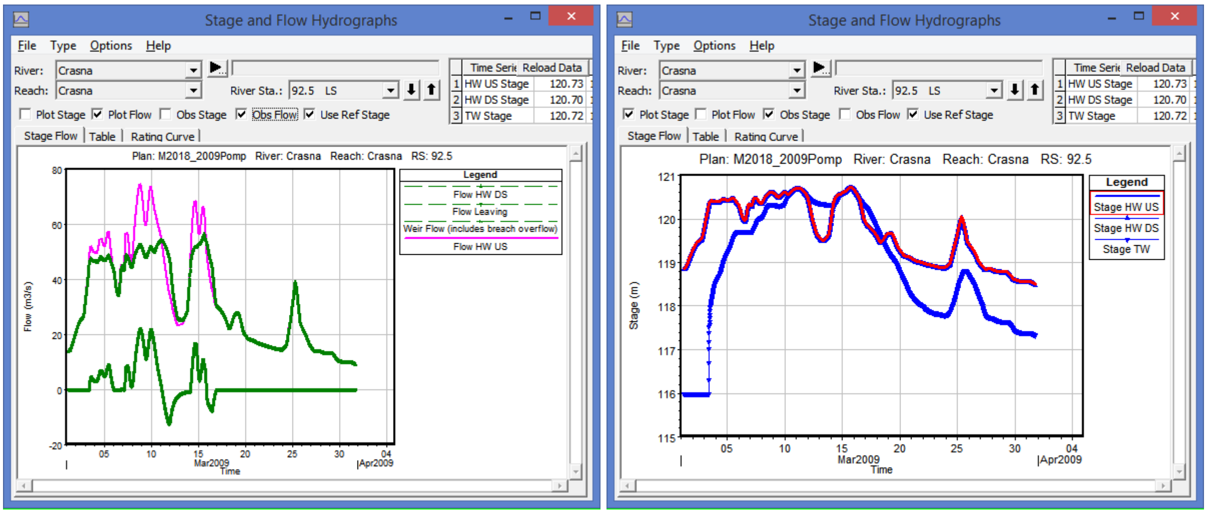
Moftin Polder – highflow from 2000



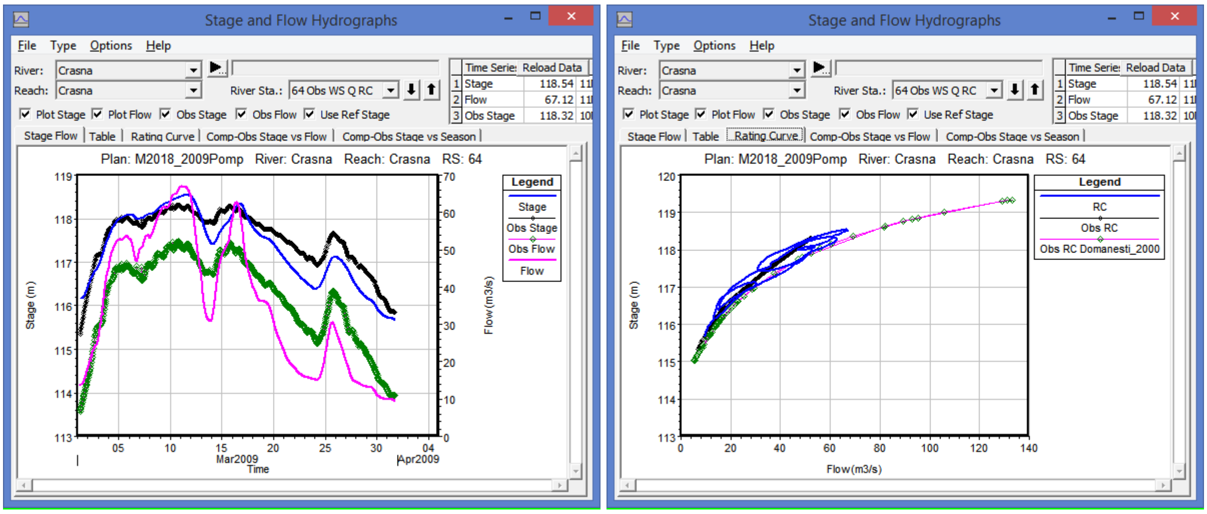
h.s. Domanesti – highflow from 2000



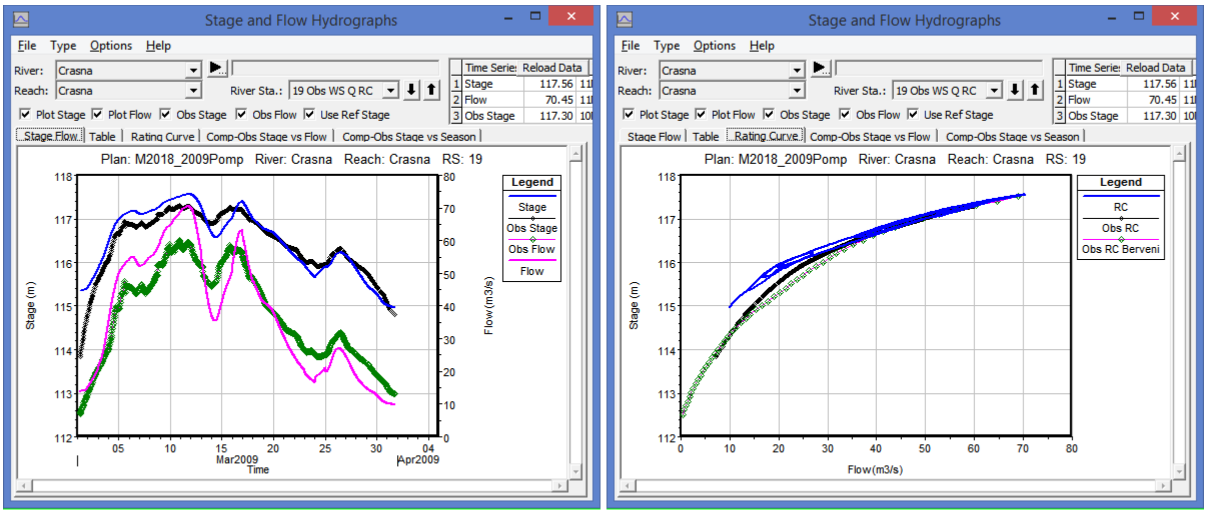
h.s Craidorolt – highflow from 2009



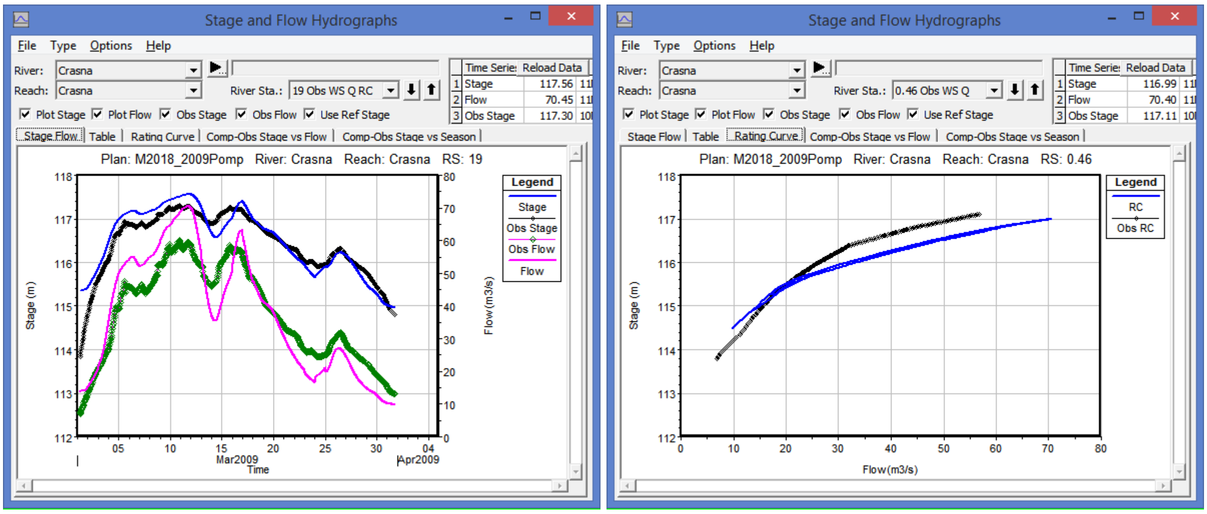
h.s. Moftin – highflow from 2009



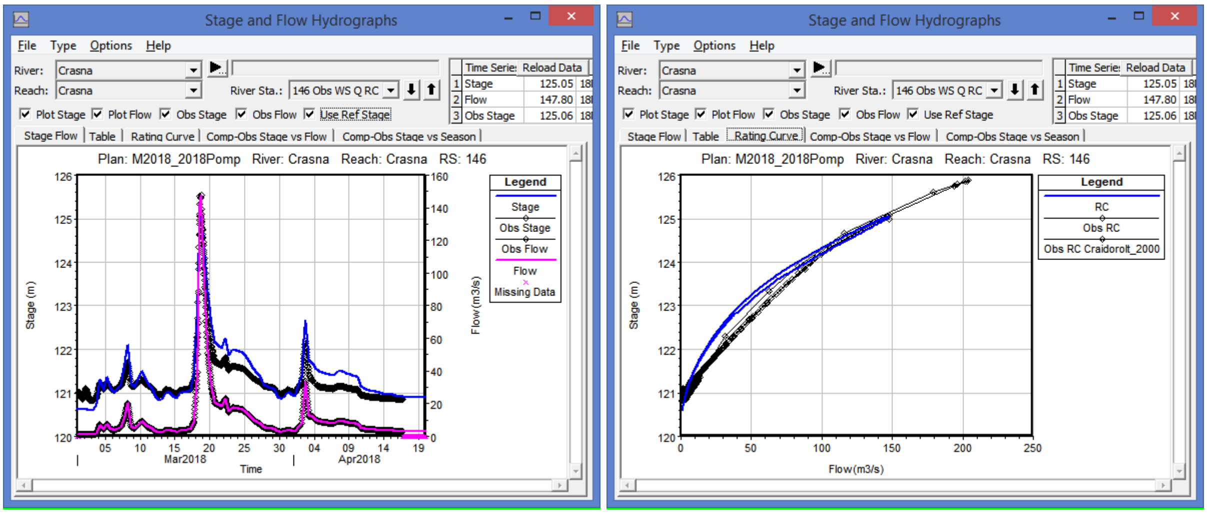
h.s. Domanesti – highflow from 2009



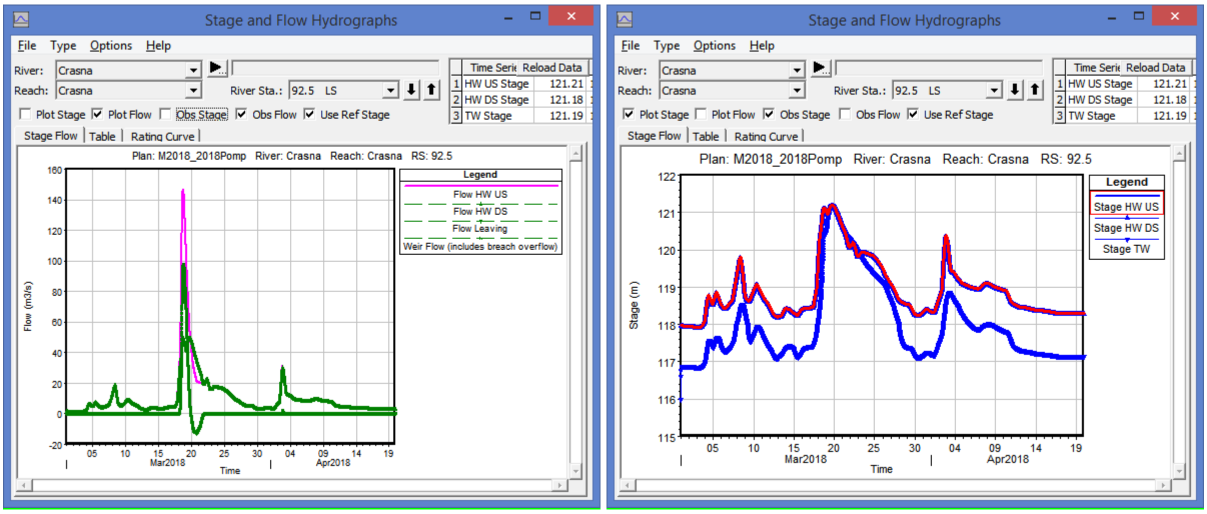
h.s. Berveni – highflow from 2009



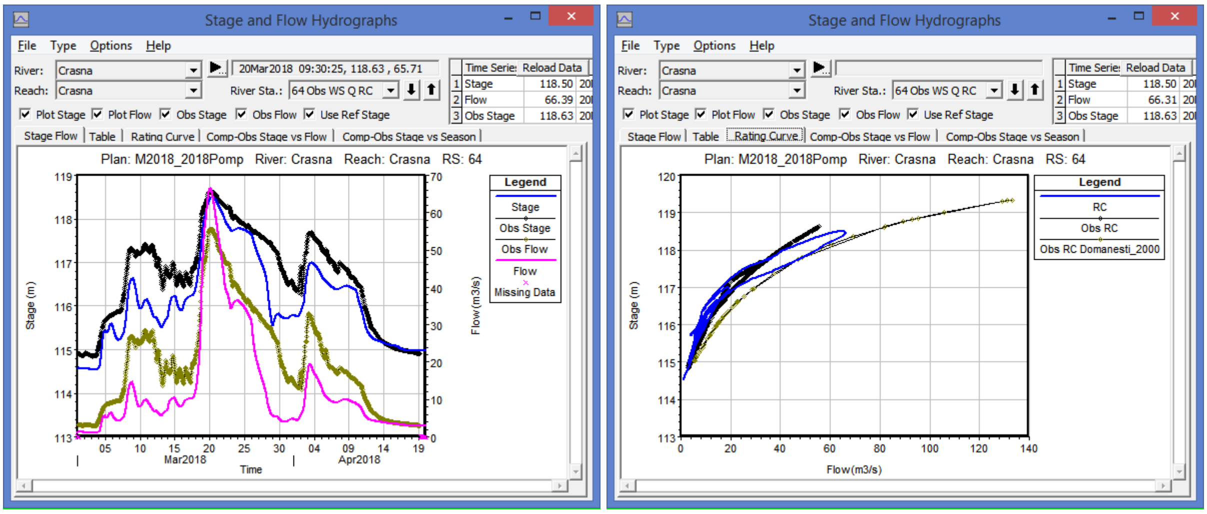
h.s. downstream Hungarian border – highflow from 2009



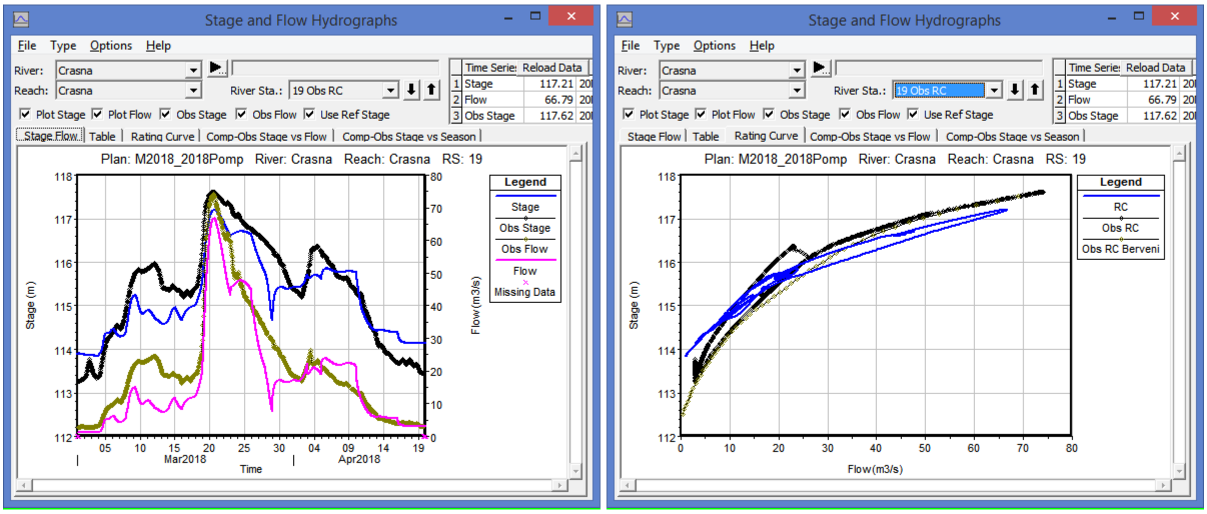
h.s. Craidorolt – highflow from 2018



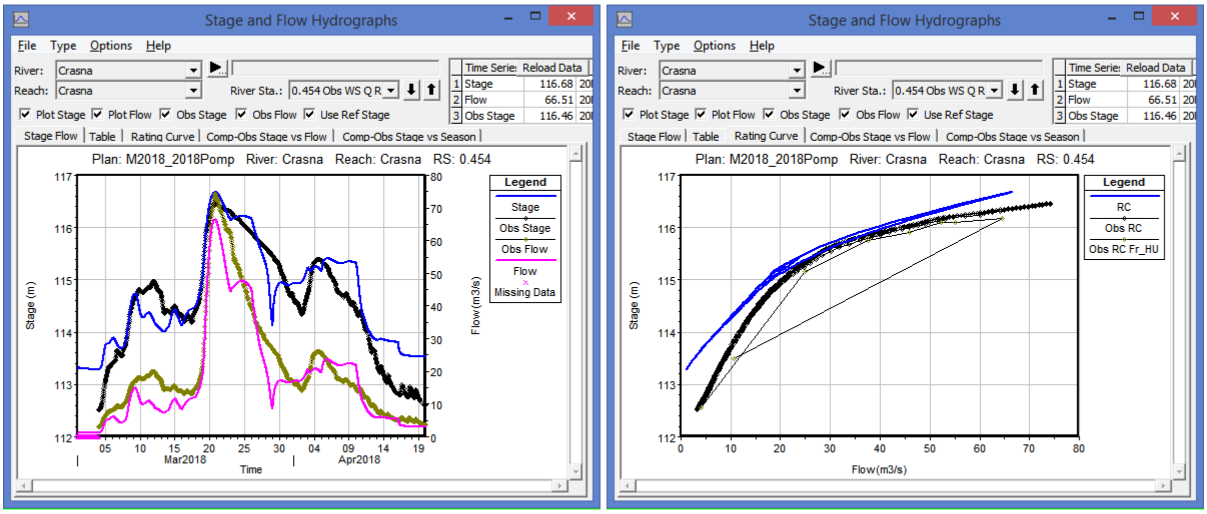
h.s. Moftin – highflow from 2018



h.s. Domanesti – highflow from 2018

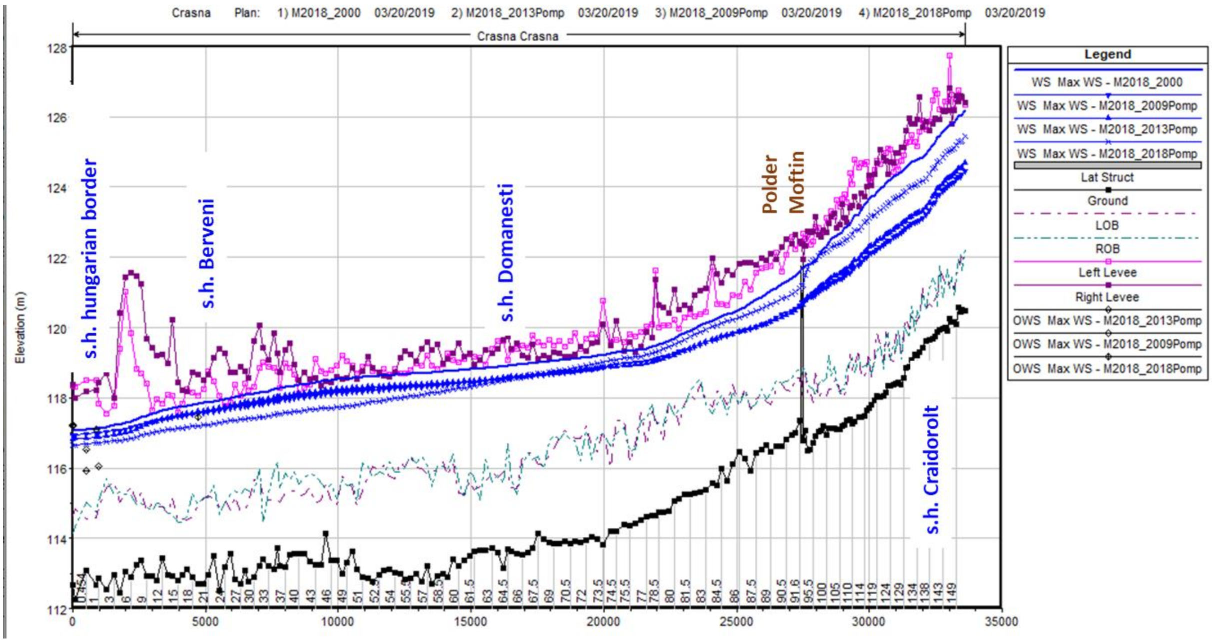


h.s. Berveni – highflow from 2018



h.s. downstream Hungarian border – highflow from 2018

The following figure shows a longitudinal profile on the Crasna River on the Craidorolt-downstream Hungarian border sector, with the markings of thalweg, shores, dikes and maximum levels corresponding to floods in the years 2000, 2009, 2013 and 2018.



In the study area the values adopted for the Manning coefficient n varied from 0.035 to 0.05 for the riverbed and from 0.08 to 0.2 for the floodplain .

Boundary conditions

The limit conditions currently imposed by the model are the limnimetric key in the downstream boundary section and the inbound hydrograph in the upstream limit section

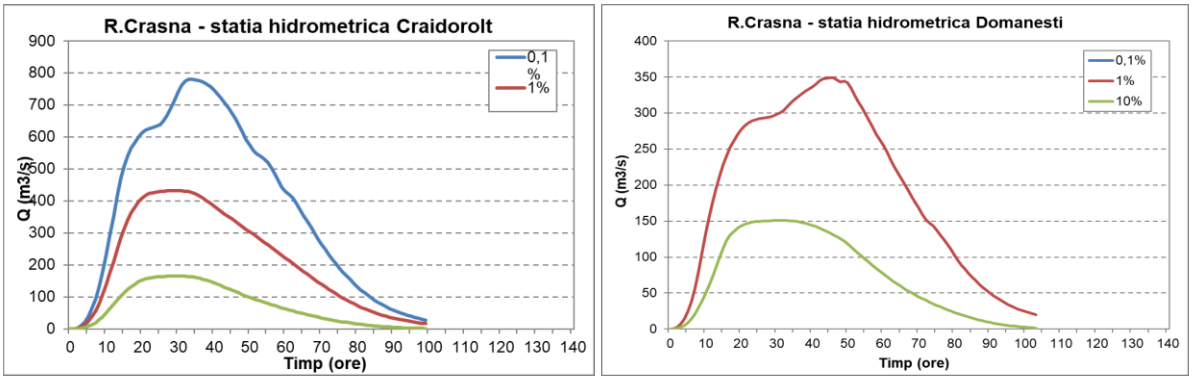
The main hydrological data recorded during the last years' floods in the sections of hydrometric monitoring stations are presented in the following table:

Date	h.s. Craidorolt		h.s. Domanesti		h.s. Berveni	
	Hmax [m]	Qmax [mc/s]	Hmax [m]	Qmax [mc/s]	Hmax [m]	Qmax [mc/s]
27.03 - 20.04.2000	704	204	758	133	-	-
21.07 - 08.08.2008	604	135	692	60.2	-	-
26.03 - 17. 04.2013	532	101	584	54.8	648	68.1
04.03- 15.04.2018	522	147	587	55.6	661	74.1

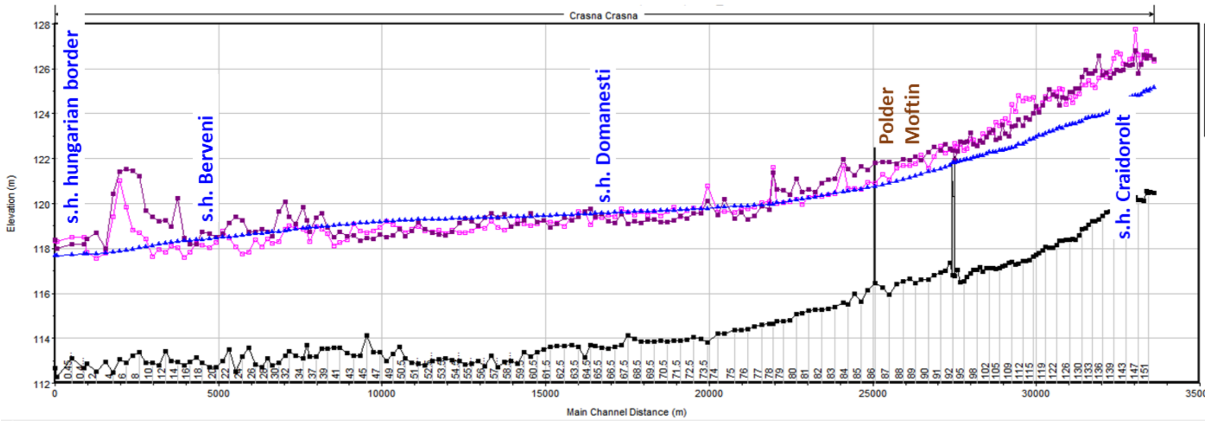
According to the statistical processing, the maximum flow rates with the 1% and 10% overflow probabilities in the improved regime in the sections of the hydrometric stations are as follows:

Section	Maximum flow [mc/s] with exceeding probability	
	10 %	1 %
h.s. Craidorolț	165	431
h.s. Domănești	150	350
h.s. Berveni	159	358

Hydrographs of singular flood waves corresponding to improved flow regime in the sections of Craidorolț and Domănești hydrometric stations are shown in the following figure:

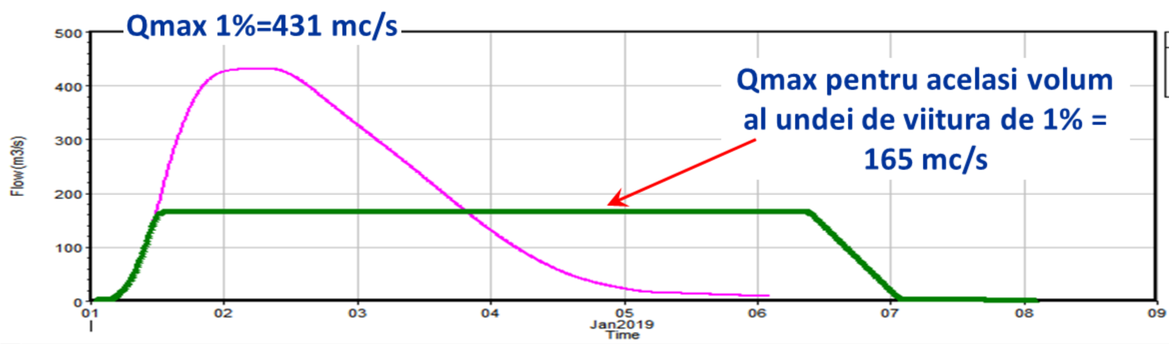


The following figure shows a long profile on the Crasna River on the Craidorolț-downstream of the Hungarian border sector highlighting the maximum transportation capacity of the embanked Crasna riverbed.



As a result of the hydraulic modelling, it can be seen that the embanked riverbed of the river Crasna can pass through a maximum flow of approx. 165 mc/s.

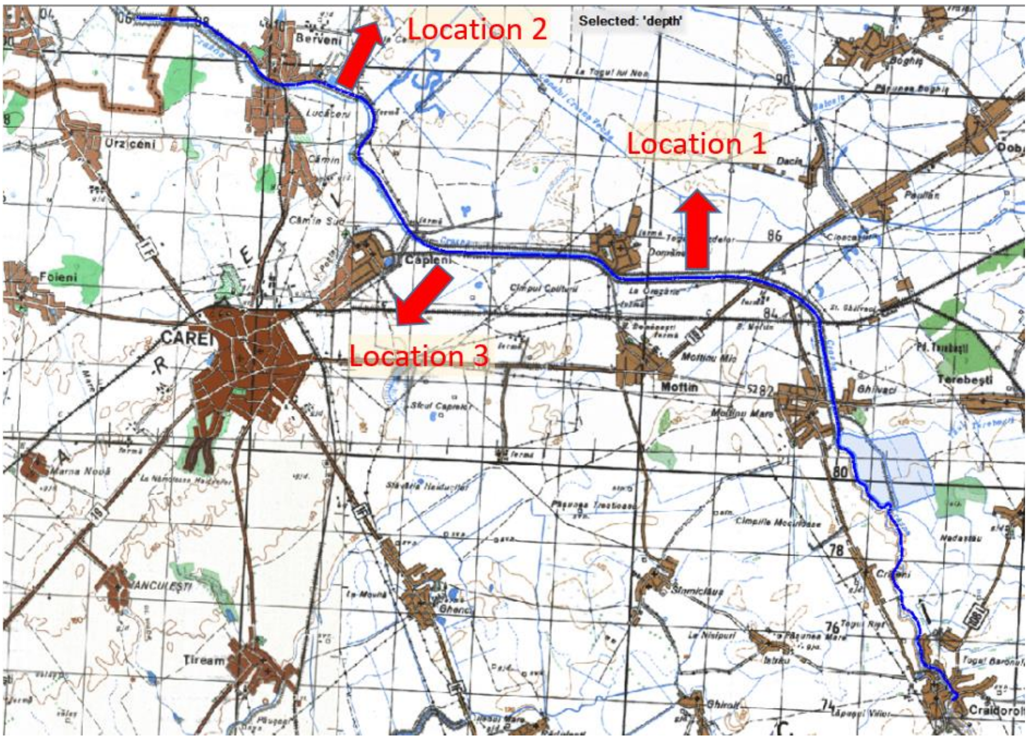
Given the fact that the maximum flow rate with the probability of 1% annual overflow downstream Moftin polder - 431 mc/s is much higher than the transportation capacity of the Crasna riverbed downstream of the polder, for the hydraulic simulations on the breakage of the defence dykes was built a flow hydrograph with a maximum flow rate of 165 mc/s and a volume equal to that corresponding to the maximum flow with 1% exceeding probability.



Chapter 6 Presentation of simulation results

The locations where it is proposed to carry out simulations of the defence dykes failure of the Crasna River are:

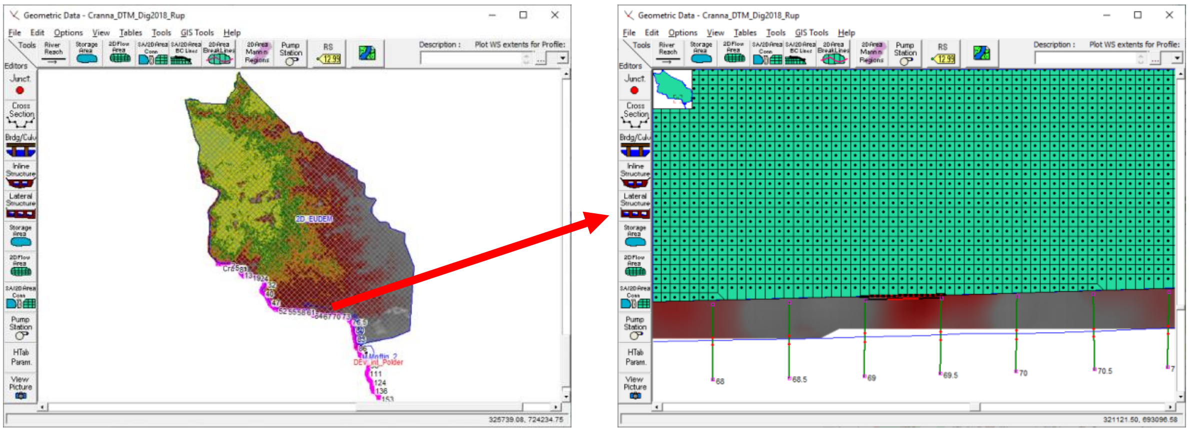
- on the right bank of Crasna River, near Berveni locality;
- on the right bank of Crasna River, near Domănești locality;
- on the left bank of Crasna River, near Căpleni locality.

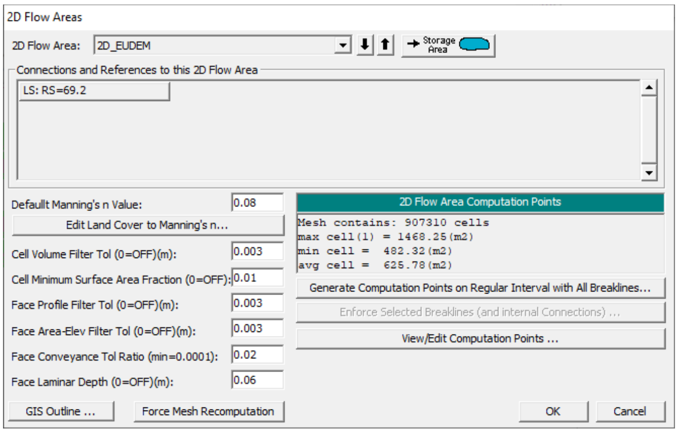


(figure 15).

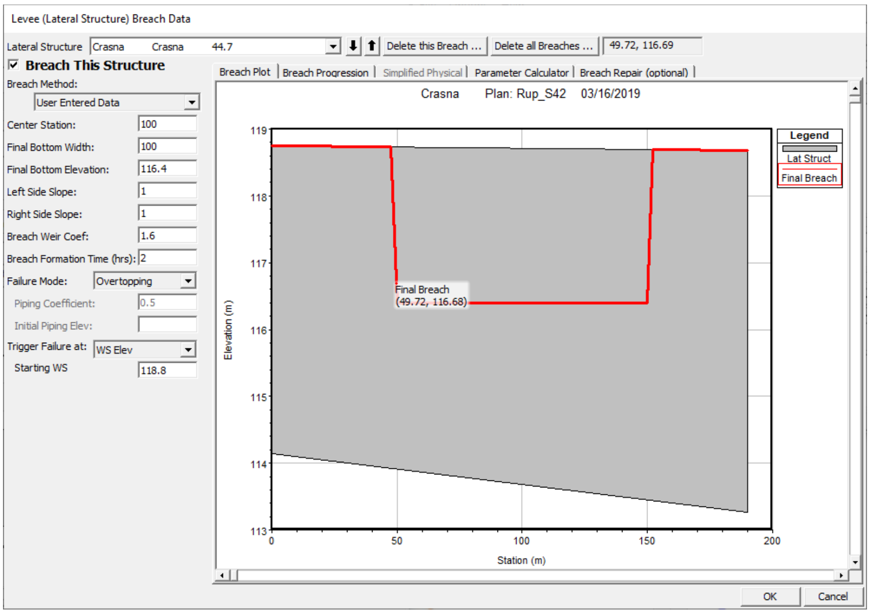
Determination of the effects of the failure of the defence dykes on the Crasna River was made with a 1D coupled hydraulic model - for the minor riverbed area and 2D - for the major riverbed behind the defence dikes.

The construction of the 2D simulation models consisted in delimiting the potentially floodable area and creating a grid with the 15 m side and associated elevation in the terrain numeric model.



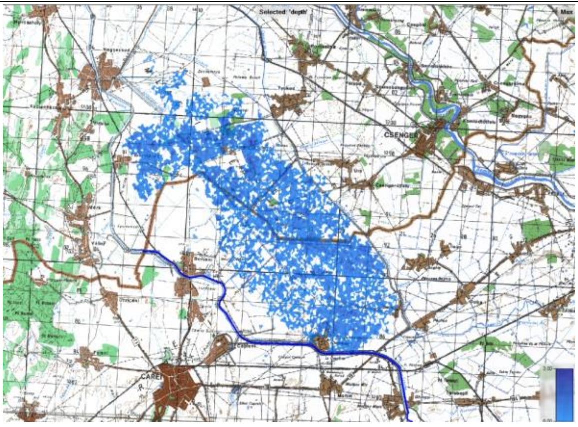
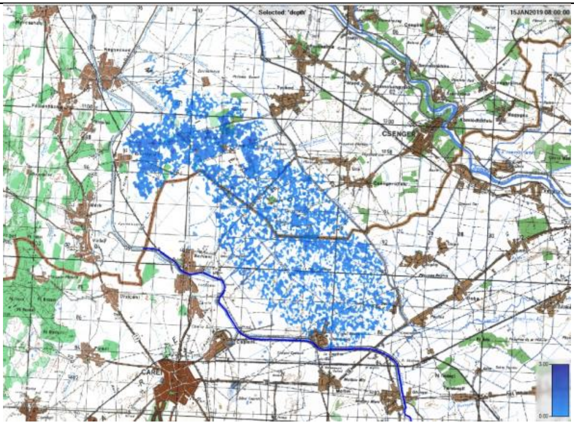


The coupling between the two simulation areas 1D and 2D was accomplished by an overflow connection.



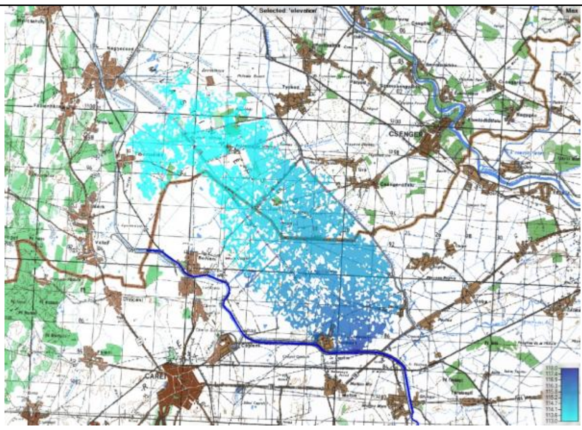
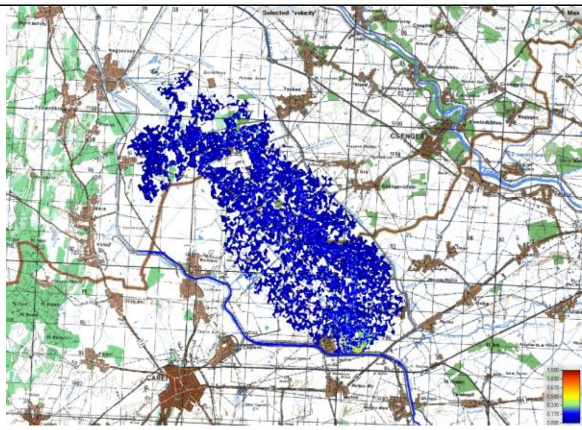
The simulated breaches in the defence dikes were supposed to finally have a trapezoidal shape with a width at the base of 100 m and slope of 1:1. The final quota at the base of the breaches will be appropriate to the terrain level. The forming time of the breaches was assumed to be 2 hours and the failures of the defence embankments on the Crasna River to occur after their discharge.

The results of the calculations for Crasna River failure dikes simulation in these three locations are shown in the following figures.

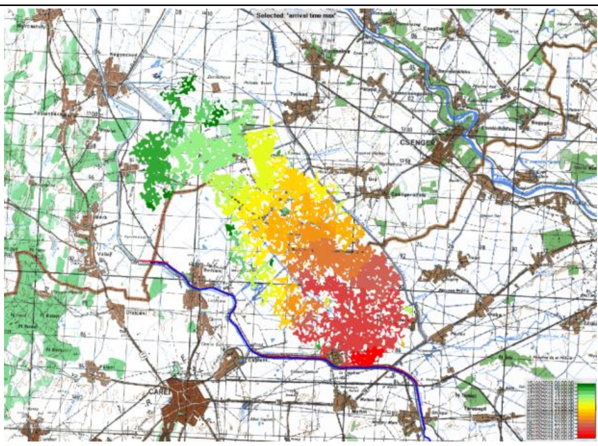
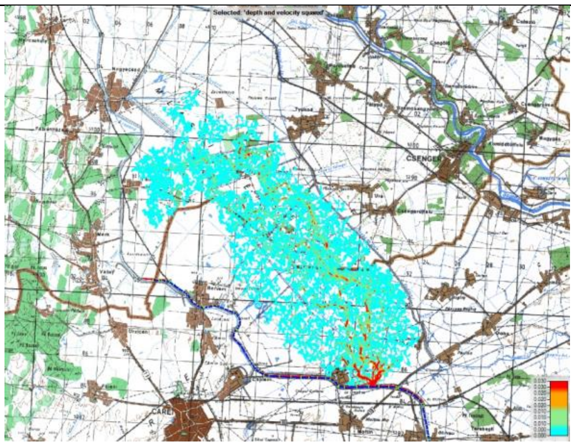
Dike failure on right bank upstream Domanesti

Maximum Depth	*Depth after 15 days from the failure dike*

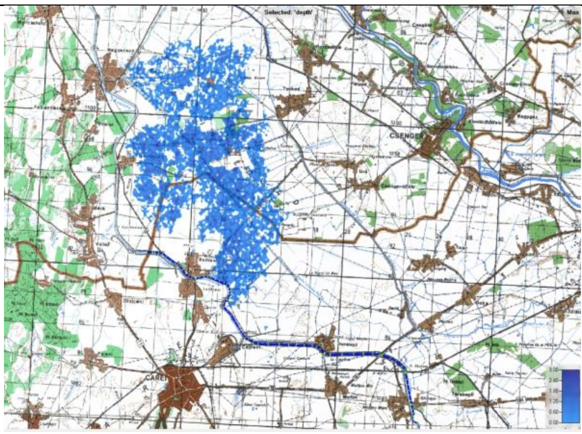
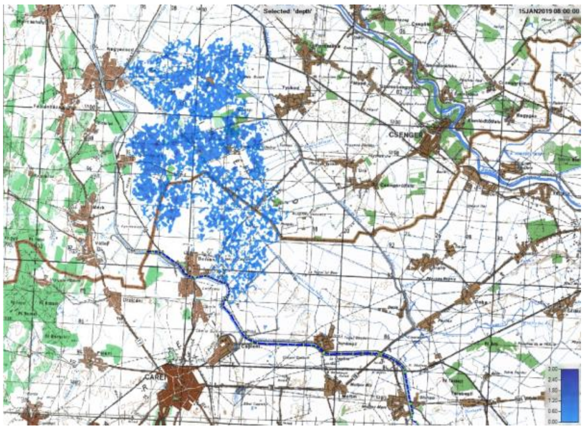
Dike failure on right bank upstream Domanesti

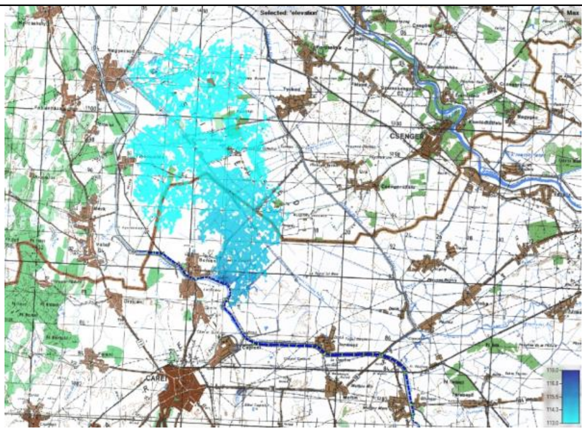
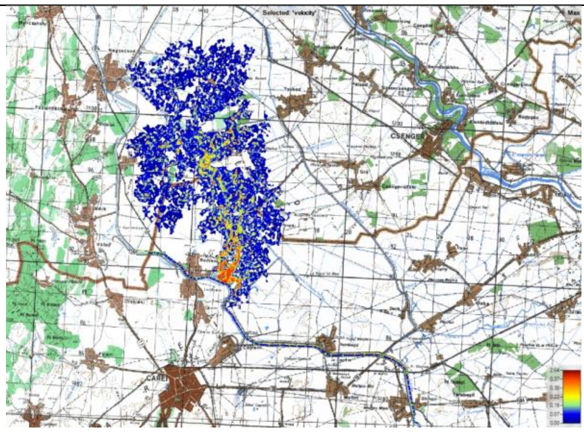
Wather surface elevation	*Velocity*

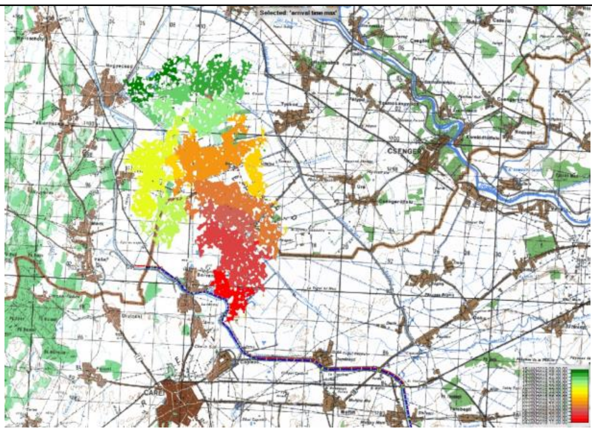
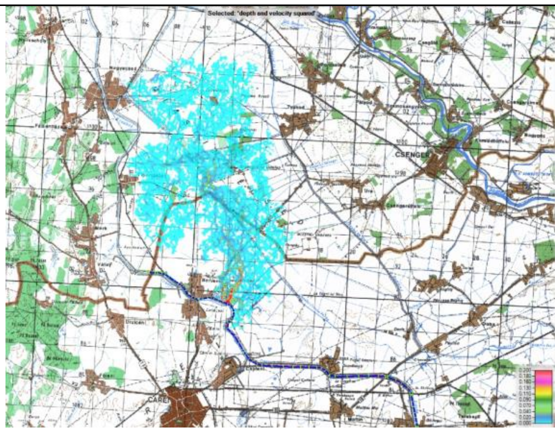



Dike failure on right bank upstream Domanesti

Arrival time	*Hazard Map Depth x Velocity^2*

	
Dike failure on right bank upstream Berveni	
Maximum Depth	*Depth after 15 days from the failure dike*

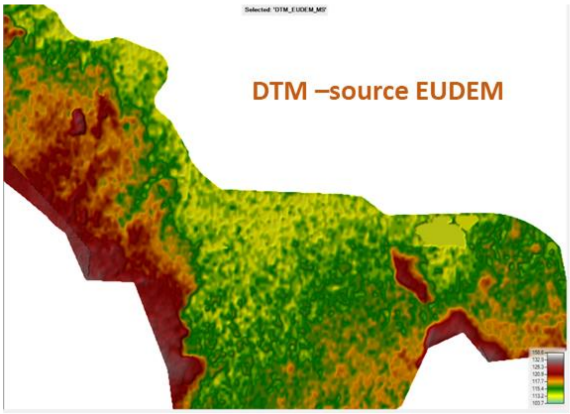
	
Dike failure on right bank upstream Berveni	
Wather surface elevation	*Velocity*

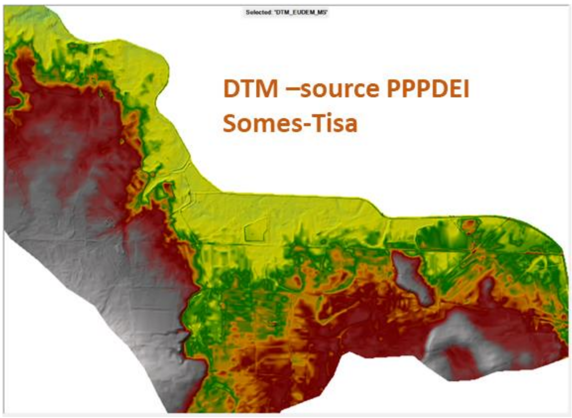
	
Dike failure on right bank upstream Berveni	
Arrival time	*Hazard Map Depth x Velocity^2*

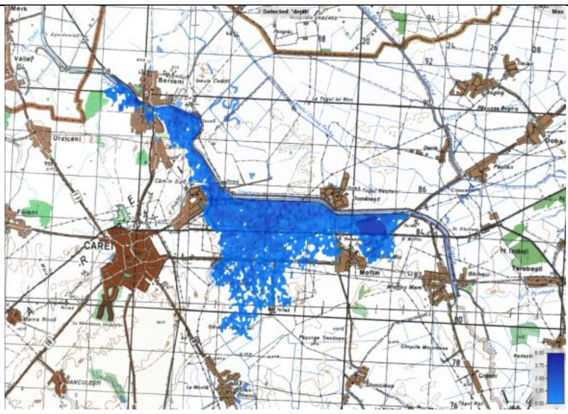
After analyzing the obtained results - depth maps, speed maps etc. - it is found that the use of the terrain model from the EUDEM source with a resolution of 25 m provides only informative information. There is a need to use in a hydraulic simulation a numerical model of the land with a better resolution to highlight all the infrastructure works that can influence the water flow.

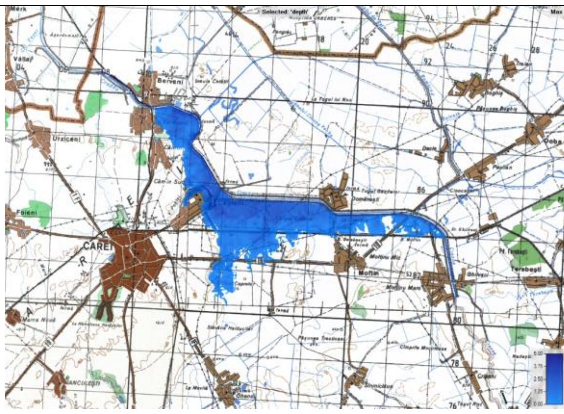
For the breach area of the Crasna river defence dike on the left bank downstream of Căpleni in the hydraulic simulations, both the numerical model of the land from the EUDEM source and the one obtained under the Somes-Tisa PPPDEI project were used.

Comparisons between the obtained results with the two sets of basic data are shown in the following figures:

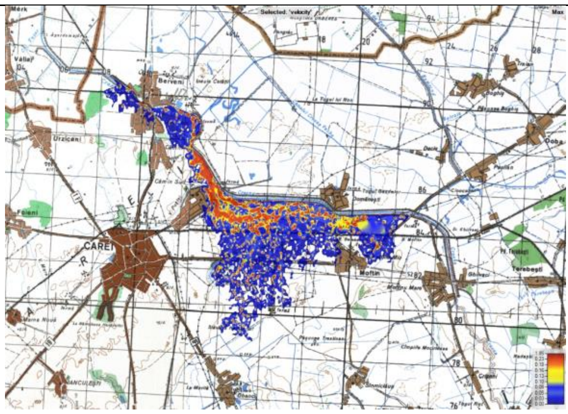


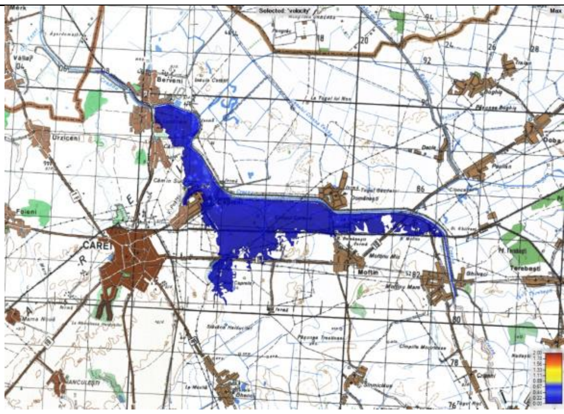




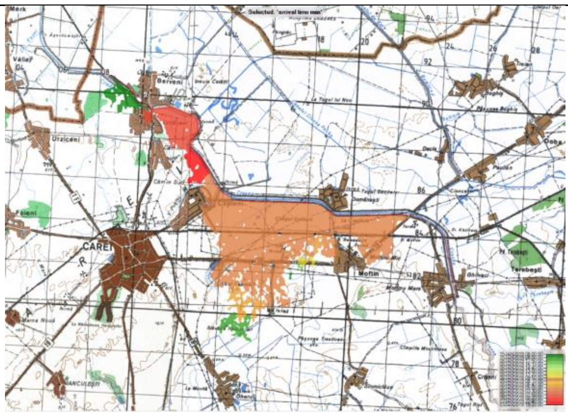


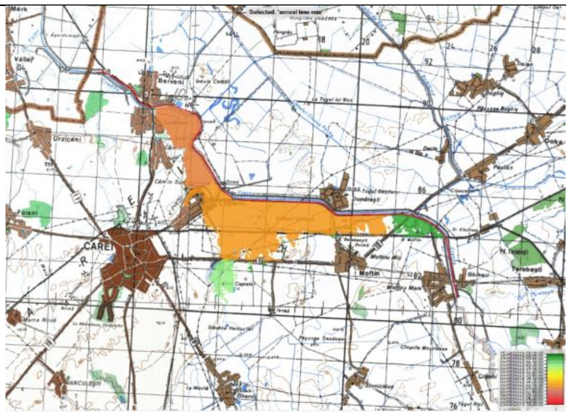
Dike failure on left bank of Crasna river – Căpleni	
Depth after 15 day failure dike (DTM-source EUDEM)	*Depthafte 15 day failure dike (DTM-source PPPDEI Somes-Tisa)*





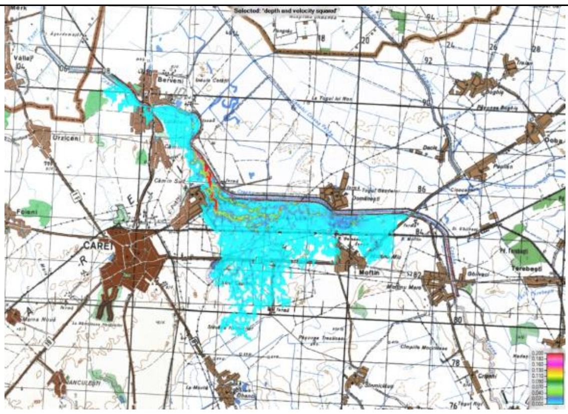
Dike failure on left bank of Crasna river – Căpleni	
Velocity (DTM-source EUDEM)	*Velocity (DTM-source PPPDEI Somes-Tisa)*

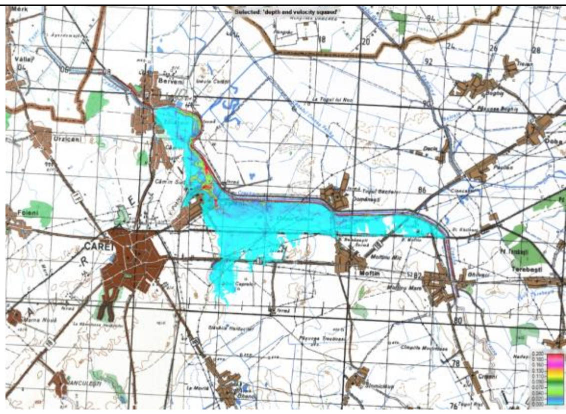




Dike failure on left bank of Crasna river – Căpleni

Arrival time (DTM-source EUDEM)	*Arrival time (DTM-source PPPDEI Somes-Tisa)*





Dike failure on left bank of Crasna river – Căpleni

Hazard map (DTM-source EUDEM)	*Hazard map (DTM-source PPPDEI Somes-Tisa)*

Figure 17 Simulation dike failure on left bank of Crasna river – Căpleni locality
Comparison between flood extent with different sources of DTM (EUDEM and PPPDEI Someș – Tisa

Conclusions

- The transportation capacity of the Crasna riverbed on downstream Craidorolț sector is up to 130 m^3/s;
- Moftin Polder works very well by achieving a reduction of maximum flow rates of up to 50%;
- In the second phase of reporting the implementation stage of the Floods Directive 2007/60/EC, it will be envisaged to identify the residual flood risk on the sectors equipped with flood defence structures;
- In order to obtain the most objective results it is necessary to use high accuracy topographical and hydrological input data.

Chapter 7 Future actions on prevention and protection in order to reduce the risk of floods

For the two areas with potential significant flood risk (that covers the study area), designated in the first cycle of Floods Directive 2007/60/EC - *Crasna river – downstream Acâş locality, upstream Moftinu Mare locality* and *Crasna river – downstream Moftinu Mare locality,* in the *Flood Risk Management Plan of Someș – Tisa River Basin Administration,* measures were established to be taken during 2016 ÷ 2021 period (Table VIII.1) in order to reduce the damages caused by floods:

APSFR	Measures
Crasna river – downstream Acâș locality, upstream Moftinu Mare locality	*Renaturation of river banks (vegetative protection)* Vegetative protection: L = 0.5 km (Hm 980 ÷ 985)
	Improving the forests management in floodplains Improving the forests management in the floodplains covering the Crasna river A.P.S.F.R.'s S = 13.71 ha
	Maintaining the forests area in catchments of A.P.S.F.R. Maintaining the forests area in the catchments covering the Crasna river A.P.S.F.R.'s S = 1932.07 ha
	Increase the transit capacity of the river channel through local dredging and channel reprofiling *”Improvement of Crasna river and tributaries scheme downstream Vârşolţ reservoir”*: dredging of riverbed L = 21 km
	Increasing the safety of existing hydraulic structures (rehabilitation: upgrading, retrofitting measures to limit infiltrations, etc.) *“Rehabilitation and modernisation of Moftin polder”*: Moftin Polder
	Maintenance of existing flood protection infrastructure Maintenance of right bank dike (km 44+000 ÷ km 24+000) and left bank dike (km 36+000 ÷ km 16+000), Moftin polder (Hm 1072 ÷ 1100), Ghilvaci intervention centre (Hm 1108)
	Water courses riverbeds maintenance and bottlenecks, obstacles removal from water courses Removing obstacles: L = 0.4 km (Hm 1100 ÷ 1104)
	Heightening of embankments / existing defence *”Improvement of Crasna river and tributaries scheme downstream Vârşolţ reservoir”*, Sălaj county: heightening of dikes L = 42.8 km
	Improvement of monitoring/forecasting and warning/alarm systems *“Rehabilitation and modernization Moftin polder”*: Berveni, Domănești, Craidorolț, Rătești, Corund Hydrometric Stations, warning / alarm system of Moftin polder
Crasna river – downstream Moftinu Mare locality	*Renaturation of river banks (vegetative protection)* Vegetative protection: L = 0.3 km (Hm 1189 ÷ 1192)
	Maintaining the forests area in catchments of A.P.S.F.R. Maintaining the forests area in the catchments covering Crasna river A.P.S.F.R.'s S = 3547.1 ha

APSFR	Measures
	Increase the transit capacity of the river channel through local dredging and channel reprofiling "*Improvement of Crasna river and tributaries scheme downstream Vârșolț reservoir*": dredging of riverbed: L = 23 km
	Maintenance of existing flood protection infrastructure Maintenance of right side dike (km 0+000 ÷ km 24+000) and left side dike (km 0+000 ÷ km 16+000), Moftin intervention centre Hm 1112, Domănești intervention centre Hm 1186, Căpleni Hm 1239, Căpleni Hm 1241, Berveni intervention centre Hm 1301
	Water courses riverbeds maintenance and bottlenecks, obstacles removal from water courses Removing obstacles: L = 2 km (Hm 1150 ÷ 1170)
	Heightening of embankments / existing defence Rehabilitation and modernisation of Moftin polder – hightening of existing dikes on Moftin polder - border sector L = 46 km

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