7. The Čurug-Žabalj Drainage System

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Description of the location

The Čurug-Žabalj catchment (Fig 7.1 and 7.2) is situated in the South East of Bačka. On the East it is bordered by the river Tisza, on the South and the West there is the Jegrička canal and the village Nadalj, while on the North it is bordered by the village Bačko Gradište and a Tisza oxbow. It covers an area of five cadastral villages and from a hydrographical perspective it forms a single unit.

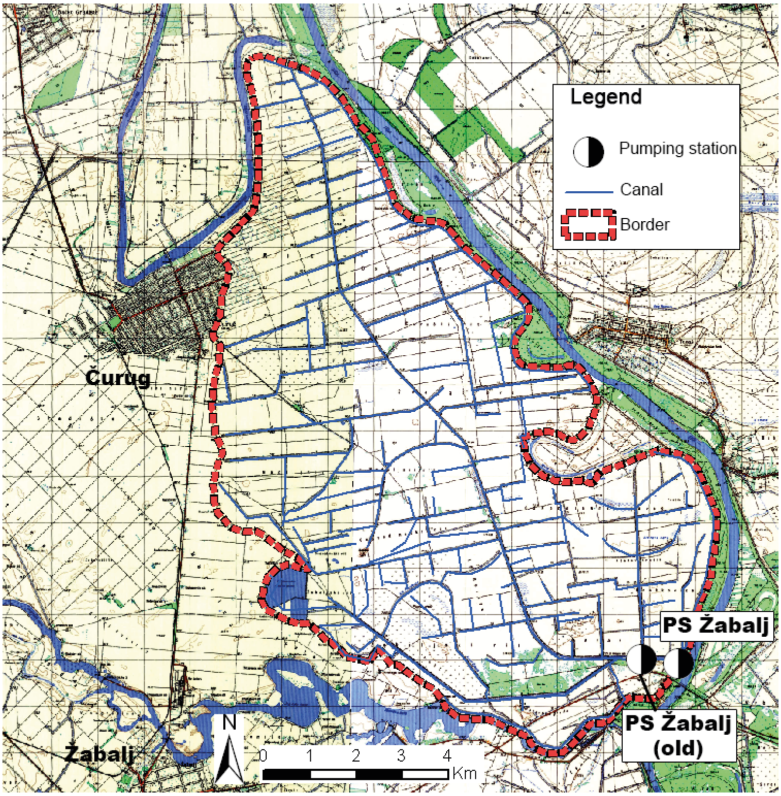

Figure 7.1 *Map of the Čurug-Žabalj catchment*

From a topographical, geological and hydrological perspective, the area can be divided into two characteristic parts:

- The western part of the area, which is a 11,236 ha loess terrace, its average height above sea level is 81.00, its groundwater level amplitude is 76.00 – 77.00.
- The eastern part of the area, which is 9,500 ha and the Čurug-Žabalj meadow can be found here. Its average height above sea level is 74.00 and it is protected from the water of the river Tisza with a dike.

Chernozem is the soil of the loess terrace, while the meadow – which used to be floodplains of the river Tisza – has a soil from river sediment, mostly it is clay and clay earth, while the parts located deeper are sandy, with the soil being lenticular at places and mixed with material characterised by low permeability.

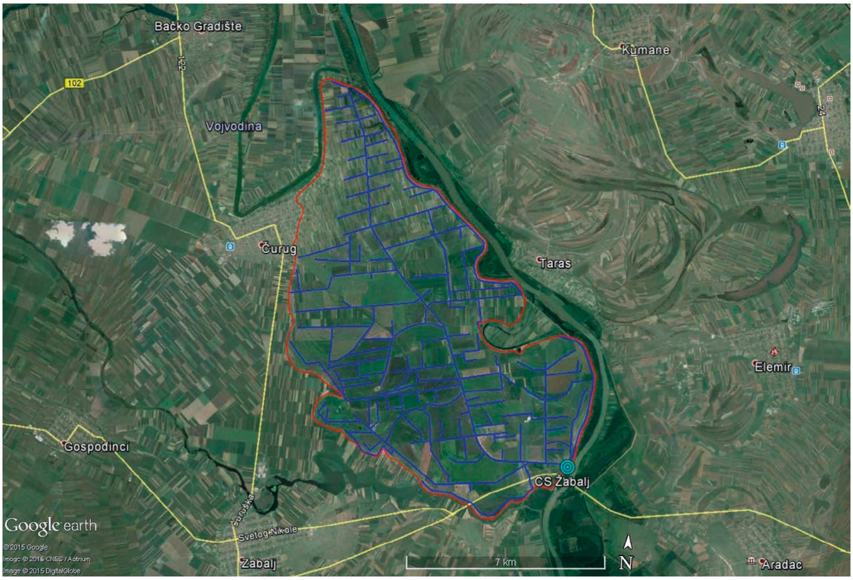

Figure 7.2 *Satellite image of the Čurug-Žabalj catchment (Google Earth)*

As regards height, there are two characteristic terraces in the area. The first one is 'low' with its height points at 73.00 – 75.00 m and the eastern part of the Čurug-Žabalj area belongs to it, the part along the river Tisza. The second one it the 'high' terrace, the western part of the area, where the height points are located between the absolute heights of 79.00 m and 83.00 m.

In a large part of the meadow the groundwater level is high, and in the spring large surfaces of the land are covered with water for a long time. The bad chemical composition of the groundwater degrades the soil and it is losing its productivity. Due to the unfavourable topographic location of the catchment, the permeable soil is saturated with groundwater of foreign origin: this is true for the high loess terrace and the water comes from the Jegrička permanently, while the water from the river Tisza and the Tisza oxbow flows here from time to time, keeping the active soil layer too wet. Drainage of surface waters is also an issue when discussing the Čurug-Žabalj catchment – these accumulate in the depressions in the spring and after heavy rainfalls, and they cause problems in agricultural production.

Geomorphologic and geologic characteristics of the area

From a geomorphologic perspective this area, just like the whole of Bačka, belongs to the Carpathian Basin, which is surrounded by the Carpathian Mountains, the Alps and the Dinaric Alps. The present forms of the Carpathian Basin were created by external and internal forces, and this is also reflected in the height. River Tisza's inundant plain is situated in the lower part of the catchment, and the higher part is the loess terrace that is covered with loess and loess type material.

The catchment area can be divided into two parts, which aren't only different because of their heights, but also due to their morphologic forms, compositions and the way they were formed. Based on their characteristics, we can differentiate between two morphologic units: the loess terrace and the indundant sediment part.

Pedologic characteristics of the area

When mapping the area, 12 types, subtypes and variants of soil were identified here – you can see these in Fig 7.3 (Pantelić, 1966).

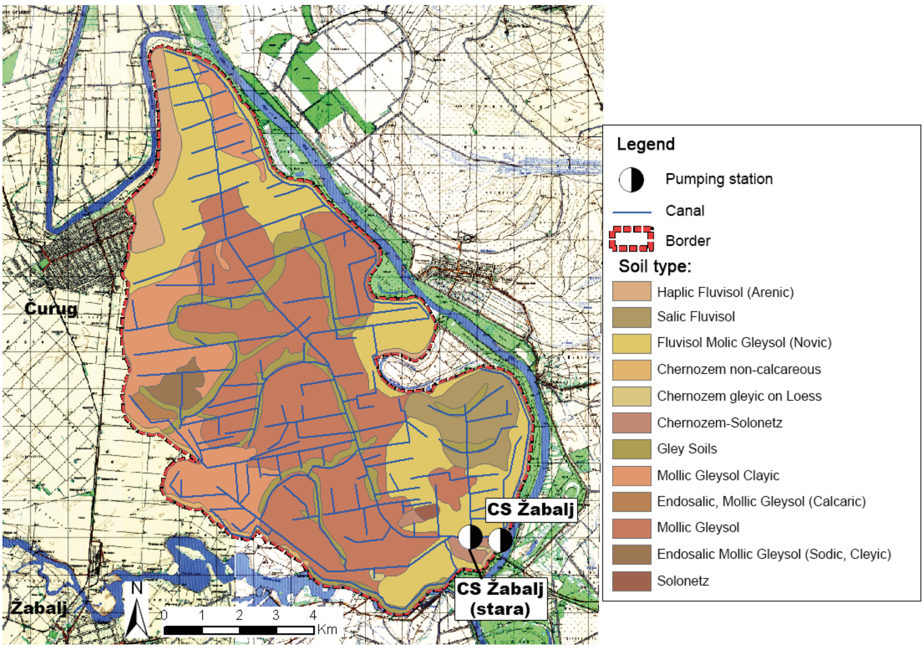

Figure 7.3 *Pedologic map of the Čurug-Žabalj catchment*

Pedologic data indicate that the first problem to be solved in the area is drainage, and the measures that need to be taken for improving the productivity of the soil should follow only after this.

Fundamental characteristics of the drainage system according to the 1966 plans

The main plan from 1966 divides the Čurug-Žabalj area into three subsystems. Drainage of the meadow is taken care of by a 9.50 m^3/s capacity pumping station, while in the other two subsystems gravity sewers are utilised to lead the water into the Tisza oxbow and the regulated Jegrička canal (Pantelić, 1966).

In certain parts of the canal network, when the necessary drainage was determined, and when the canals and structures were designed, those modules were utilised which had been specified in the draft plan for the Čurug-Žabalj water drainage system; it was documented that the drainage model for the meadow was changed from 0.90 l/s/ha to 1.00 l/s/ha.

In accordance with this, draining water originating from winter precipitation and long rainy periods, when the whole catchment area is used, was performed based on the following drainage modules:

For the meadow: $q_r = 1.0$ *l/s/ha*
For the terrace: $q_t = 0.5$ *l/s/ha*

The water drainage modules mentioned are suitable of removing winter waters within 15 days if calculating with 10-year precipitation maximums.

The drainage canal system is made up of open, trapezoid cross-section earth canals, which have the following size characteristics:

- the minimum width of the bottom is 0.50 m,
- the minimum work depth of the water in the depressions is 0.50 m below the surface,
- the minimum depth of the canal is 1.00 m,
- the gradient of the canal wall from 1 to 2 metres is 1:1.25, from 2 to 3 metre depth is 1:1:1.50.

Run-off coefficient and the hydro-module of the drainage

According to the main drainage plan of the Čurug-Žabalj catchment from 1966, the Német and Turazzi formula was used for determining the run-off coefficient and the drainage module. This method isn't featured in contemporary professional literature, but back then it was used for analysing catchments in Vojvodina and Hungary, and for designing drainage systems. In the following you can see several relative numbers, which were used in analysing the Čurug-Žabalj catchment area (Pantelić, 1966).

The starting equation for the medial hydro-module of the drainage system:

$$q_s = 0,1157 \cdot \frac{\alpha \cdot h}{t + \tau}$$

Where: q_s – is the medial hydro-module of drainage ($l\ s^{-1}\ ha^{-1}$), α – run-off coefficient, *h* – relevant precipitation level (mm), *t* – relevant precipitation time length (days), τ – reach time, the path of a drop of water from the remotest part of the catchment to the reservoir (days).

If we multiply the equation above by the coefficient that indicates the ratio of maximum and medium run-off, which is 1.7 in the conditions that apply to Hungary (it can be used for Vojvodina too), we get the per unit hydro-module for maximum drainage - q_{max} ($l\ s^{-1}\ ha^{-1}$):

$$q_{max} = 0,1157 \cdot \frac{\alpha \cdot h}{t + \tau} \cdot 1,7$$

The run-off coefficient plays an important role in determining the hydro-module for the run-off. Several factors need to be known for determining this, such as: permeability, gradient, land cultivation method, type of soil surface. In the main plan for the Čurug-Žabalj drainage system (Pantelić, 1966), we can read that the functional changes in the run-off coefficient on a monthly basis are caused by the following:

(1) land gradient (α_1);

(2) soil's permeability (α_2);

(3) land cover (α_3).

For determining the partial coefficients of run-off, the values are provided in Table 7.1, 7.2 and 7.3, where the relevant values of the water flow specified in relation to the gradient, the permeability and the vegetation that covers the land can be found. The run-off coefficient equals the sum of the three coefficients given.

$$\alpha = \alpha_1 + \alpha_2 + \alpha_3$$

Table 7.1 *Partial run-off coefficient in relation to the land gradient (α_1)*

Terrain slope	**Coefficient α_1**
>35 %	0,22 – 0,25 – 0,30
11 – 35 %	0,12 – 0,18 – 0,20
3,5 – 11 %	0,06 – 0,08 – 0,10
<3,5 %	0,01 – 0,03 – 0,05

Table 7.2 *Partial run-off coefficient in relation to the soil's permeability (α_2)*

Soil permeability	**Coefficient α_2**
Very low permeability	0,22 – 0,26 – 0,30
Moderate permeability	0,12 – 0,16 – 0,20
Permeable	0,06 – 0,08 – 0,10
Very permeable	0,03 – 0,04 – 0,05

Table 7.3 *Partial run-off coefficient in relation to the vegetation that covers the land (α_3)*

Vegetation cover	**Coefficient α_3**
Bare soil	0,22 – 0,26 – 0,30
Marsh, pastures	0,17 – 0,21 – 0,25
Cultivated land	0,07 – 0,11 – 0,15
Forest and seminatural areas on sands	0,03 – 0,04 – 0,05

They used the pedologic map of Vojvodina for determining the α_2 partial coefficient (Živković et al., 1972). Defining the α_2 partial coefficient was done based on the proportions of various soil types and their permeability levels in the given area. In his study Miljković (2005) classifies soil into drainage categories, based on its chemical characteristics. He created the following five drainage classes and described them as follows:

(1) 1st drainage class – soil with naturally weak drainage characteristics, so its surface is very much threatened by excess water;

(2) 2nd drainage class – soil with naturally weak drainage characteristics, so its surface is under medium level threat from excess water;

(3) 3rd drainage class – soil with naturally insufficient drainage characteristics, so its surface is moderately threatened by excess water;

(4) 4th drainage class – soil with a lighter texture, which has a moderate natural drainage capacity, so its surface is under a low level of threat from excess water;

(5) 5th drainage class – soil with a light texture, which has good natural drainage characteristics, so its surface isn't threatened by excess water – it doesn't require drainage.

The value of the α_3 coefficient was determined by analysing the land cover map with the help of CORINE Land Cover 2012 (EEA, 2012). This map contains data on how the land is used and on the size of the plots. Land cover data can be extracted by using the database codes and the CORINE nomenclature (Nestorov and Protić, 2006). Analysing data on the area and creating the map was done using GIS methods.

In the case of both individual plots and large areas, determining the effective precipitation level – which is used in forecasting floods – must be based on high intensity (storm) precipitation time periods or on the time period of the water flow's concentration (Gericke and Plessis, 2011). The time period of the water flow's concentration (τ) is a key time factor in the catchment system's reaction, which is necessary for forecasting the maximum run-off volume (Perdikaris et al., 2018). The time period of the water flow's concentration (τ) indicates the time a drop of rain needs to get from the remotest part of the catchment to the reservoir – in the project (Pantelić, 1966) this was determined by Venturi's equation, in relation to the surface of the catchment area:

$$\tau = 0{,}315 \cdot \sqrt{F}$$

Where *F* – is the territory of the catchment area in km².

The relevant precipitation level was calculated by using Montanari's climate function, and it is calculated separately for each area analysed:

$$h = a \cdot t^{n}$$

Where: ***h*** – is the relevant precipitation level (mm), ***a*** and ***n*** – constants, which depend on the hydrologic characteristics of the area analysed, while ***t*** indicates the time length of precipitation (in days).

According to Rajić and Josimov-Dunđerski (2009), the following coefficients are valid for the territory of Vojvodina, ***a***=64 (this indicates the average maximum daily rainfall in Vojvodina) and ***n***=0,415 – this means that Montanari's function looks like this:

$$h = 64 \cdot t^{0{,}415}$$

Based on Montanari's function and the concentration time of the catchment (τ), the formula for the relevant precipitation time period is:

$$t = \frac{n}{1-n} \cdot \tau$$

In the project (Pantelić, 1966) the time period of the relevant precipitation was determined by the time analysis of the precipitation diagram ***t*** and the analysis of the raindrop's reach time. Three scenarios are characteristic of a given catchment:

(1) The time period of the rain equals the reach time ($t=\tau$);

(2) The time period of the rain is longer than the reach time ($t>\tau$);

(3) The time period of the rain is shorter than the reach time ($t<\tau$);

Maximum per unit water flow occurs when the duration of the relevant rain is longer or equals the reach time, namely that $t \geq \tau$. Analysing consecutive rainy periods occurring for several days, the project calculates that the relevant period of rain is *t* = 3 days. The engineers used this relevant rain value for further calculations for the hydro-module of drainage.

Determining the run-off coefficient and the water drainage module – utilising the empiric formulas of Német and Turazzo – was based on analysing the current conditions dominant in the catchment area. The most demanding part of the method was providing the most accurate definitions of the partial run-off coefficients, which were given as a function of land gradient (α_1), soil permeability (α_2) and land cover rate (α_3).

Having analysed the plan documentation, based on the longitudinal cross-section of the Main Canal – it is in this canal that all the water from the analysed catchment flows to the pumping station in Zsablya – the mean value of the canal's gradient was determined, which was 0.011%. Taking the calculated mean value and the fact that we are talking about a flat area as the starting point, from Table 1 the minimum value of α_1=0.01 was accepted as the land gradient coefficient.

The soil permeability partial coefficient (α_2) was determined based on the soil types characteristic of the area and on the drainage features of the different soil types. Table 7.4 contains how the complex value of the α_2 coefficient was determined. The soil permeability coefficient for the whole catchment was calculated using the proportions of various soil types and the values from Table 2 assigned to them – the coefficient's value is α_2=0.22.

Table 7.4 *Partial coefficient in relation to the soil's permeability (α_2)*

Soil type	**%**	**Drainage class**	**α_2**	**Complex value of the coefficient α_2**
Fluvisol Molic Gleysol (Novic)	25,45	II	0,16	0,04072
Haplic Fluvisol (Arenic)	3,74	III	0,08	0,00299
Salic Fluvisol	4,98	II	0,16	0,00797
Endosalic, Mollic Gleysol (Calcaric)	0,46	I	0,26	0,00119
Mollic Gleysol	38,92	I	0,26	0,10119
Endosalic Mollic Gleysol (Sodic, Cleyic)	1,30	I	0,26	0,00339
Mollic Gleysol Calcaric on Loess terrace	0,01	IV	0,04	0,00000
Mollic Gleysol Clayic	13,73	I	0,26	0,03569
Chernozem-Solonetz	0,85	III	0,08	0,00068
Solonetz	0,22	I	0,26	0,00058
Chernozem non-calcareous	0,72	IV	0,04	0,00029
Chernozem gleyic on Loess	0,22	IV	0,04	0,00009
Gley Soils	9,38	I	0,26	0,02439
Solonchak	0,01	I	0,26	0,00003
Chernozem calcareous on Loess terrace	0,02	V	0,05	0,00001
Σ=	**100**			**0,21921**

The CORINE Land Cover 2012 database was used to determine the partial coefficient (α_3) that depends on the level of vegetation in the given area; this includes information on how the land is used and what its characteristics are. Fig 7.4 presents lands used for different purposes and having different characteristics.

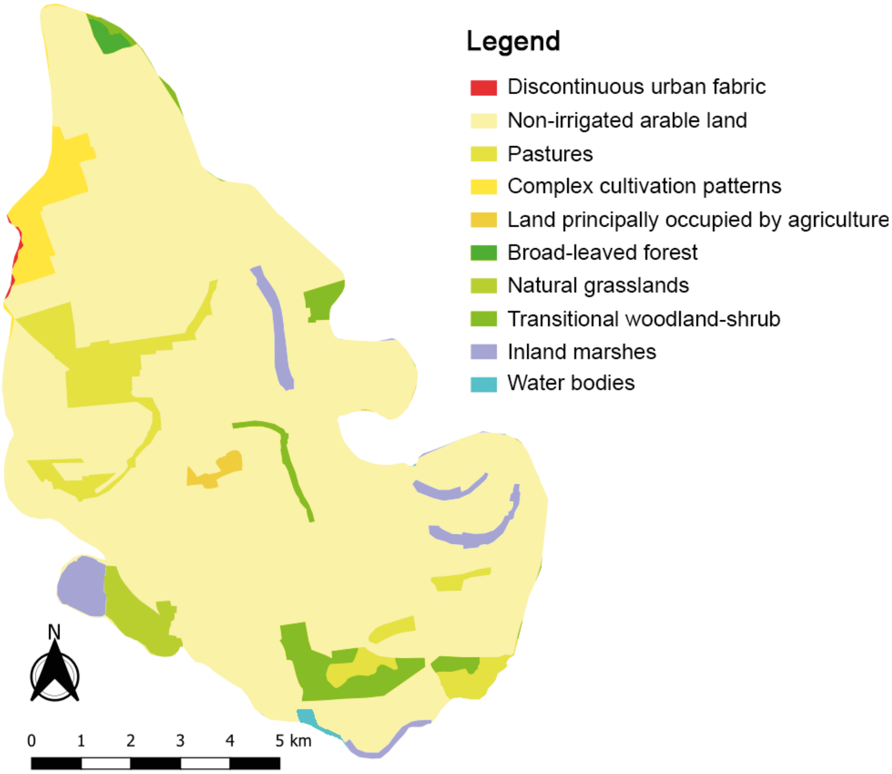

Figure 7.4 *CORINE Land Cover 2012 map: land cover of the Čurug-Žabalj catchment area – land use and characteristics*

Analysis of the land use and characteristics revealed that in the territory of the Žabalj subsystem the largest proportion of land, 85% is arable land that isn't irrigated. Table 7.5 contains the proportions for other land types and the how the complex value of the α_3 coefficient was determined. The accepted value for the land cover rate, which is valid for the whole catchment, is α_3=0.11. Complete run-off coefficient for the area examined: α=0.34. This run-off coefficient value is smaller than the value used in the 1966 project, which – in accordance with the conditions back then – was α=0.43.

Table 7.5 *Calculating the partial coefficient in relation to land cover rate (α_3)*

Cover type	**%**	**α_3**	**Complex value of the coefficient α_3**
Discontinuous urban area	0,09	0,30	0,00026
Non-irrigated arable land	85,26	0,11	0,09379
Pasture	5,50	0,21	0,01154
Complex cultivation patterns	0.11	0,11	0,00013
Land principally occupied by agriculture, with significant areas of natural vegetation	0,41	0,11	0,00046
Broad-leaved forest	0,66	0,04	0,00026
Natural grassland	1,54	0,21	0,00323
Transitional woodland/shrub	3,36	0,04	0,00134
Inland wetlands	2,78	0	0
Water bodies	0,28	0	0
Σ=	**100**		**0,11102**

The calculated concentration time of the catchment is (τ) 3.06 days.

Supposing that maximum per unit run-off occurs when the relevant rain's time period is longer than or equals the time of the catchment's concentration, namely that t≥τ, the relation accepted for further calculation is t=τ, which means that t=3.06 days.

Based on Montanari's function and on the coefficients valid for the territory of Vojvodina, the relevant precipitation level was calculated, which is *h*= 101 mm. After this the hydro-module for the water drainage was calculated, which reflects the current situation of the catchment:

$$q_{max} = 0{,}1157 \cdot \frac{0{,}34 \cdot 101}{3{,}06 + 3{,}06} \cdot 1{,}7 = 1{,}1 \ \ \mathrm{l\,s^{-1} ha^{-1}}$$

Table 7.6 contains the comparison of the newly calculated values and the data from the Čurug-Žabalj catchment area's water drainage project (Pantelić, 1966). The results show that the hydro-module for the drainage is q_{max}=1.1 l s^{-1} ha^{-1}, which describes the current situation of the catchment – this is very close to the q_{max}=1.0 l s^{-1} ha^{-1} value accepted in the project.

Table 7.6 *Comparison of the project's values and the newly calculated values*

Parameter	Designed values (Pantelić, 1966)	New values	Unit
α_1	0,01	0,01	-
α_2	0,25	0,22	-
α_3	0,17	0,11	-
α	0,43	0,34	-
t	3	3,06	day
τ	3,06	3,06	day
h	71,6	101	mm
q_{max}	1,0	1,1	l/s/ha

The results indicate that the current drainage solution of the catchment is very close to the system presented in the project. What the results indicate in this situation is that the system's capacity is sufficient if compared with the conditions currently prevailing on the territory of the catchment. As for the problem of excess water – which stays in the catchment area even after the evacuation period expired – regular maintenance of the melioration-purpose canals and taking additional melioration measures are of key importance. Since water run-off is more difficult in the case of soils with a 'heavier' mechanical structure, in situations like this using a horizontal drainage pipe system or an organic drainage solution must be considered (Vranešević et al., 2017). Taking into account the complexity of the drainage system of the Čurug-Žabalj catchment area, by using the current infrastructure and by taking steps to improve the situation of the catchment using melioration techniques, utilising the maximum agricultural potential of the area seems to be an achievable goal.

Hydrometric measurements and hydraulic modelling

With the objective of studying the operating conditions of the drainage system, in May 2019 we performed a hydrometric examination of the canal's three sections, at 1+550, 3+700 and 6+100 km (Fig 7.5).

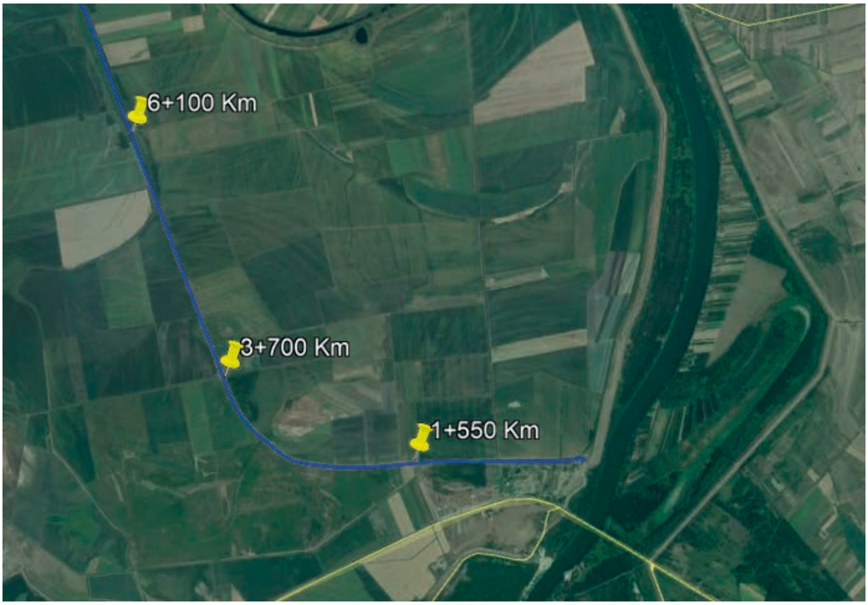

Figure 7.5 *Locations of the sections where hydrometric measurements took place*

Measurement of the section speeds was done using standard hydrometric methods, utilising an OTT Nautilus C2000 device. This modern hydrometric current meter that works with electromagnetic technology has been made suitable for measuring 'very slow' water flow (0.00-2.50 m/s), and the smallest water depth is 3 cm. We determined the hydraulic characteristics of the Čurug-Žabalj main canal with the help of the surface speed method. Fig 7.6-8 and Tables 7.7 and 7.8 contain the results.

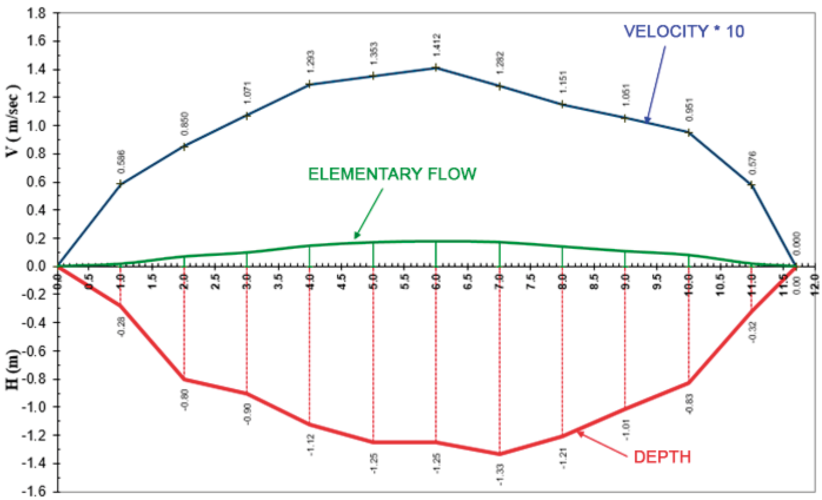

Figure 7.6 *Chart of the hydrometric measurement results, section point 1+550 Km*

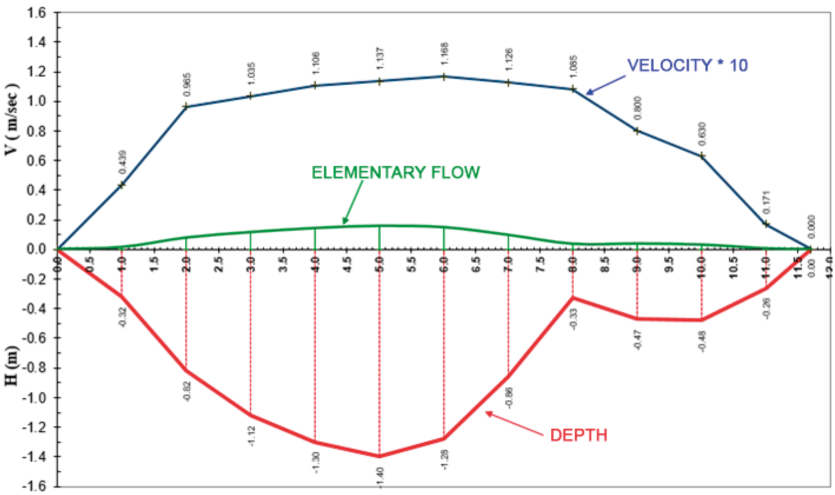

Figure 7.7 *Chart of the hydrometric measurement results, section point 3+700 Km*

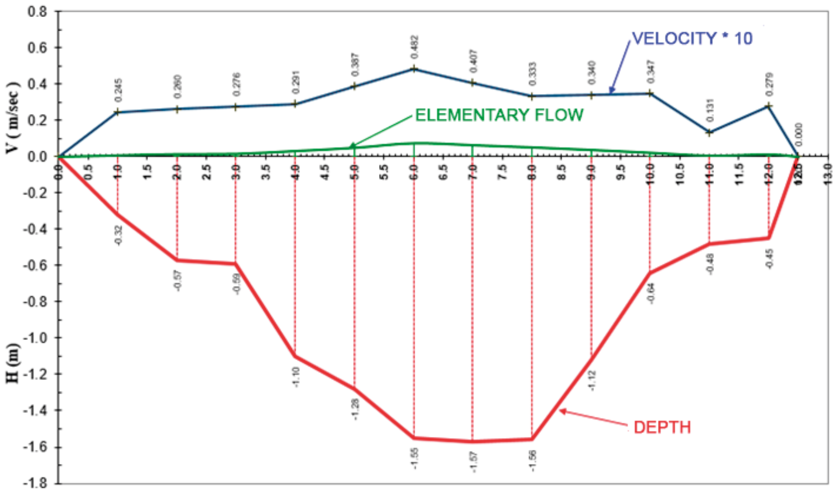

Figure 7.8 *Chart of hydrometric measurement results, section point 6+100 Km*

Table 7.7 *Hydrometric measurement results and comparison with the planned values*

Station (km)	Flow (m³/s)		Velocity (m/s)	
	designed	measured	designed	measured
1+550	7,3	1,18	0,35	0,12
3+700	7,05	0,87	0,35	0,10
6+100	6,17	0,39	0,34	0,04

Table 7.8 *Hydraulic elements of the canal at the sections examined*

Station (km)	Flow area (m^2)		Wetted perimeter (m)		Hydraulic radius (m)	
	designed	measured	designed	measured	designed	measured
1+550	21,03	14,23	16,51	12,89	1,27	1,10
3+700	20,33	12,93	16,11	13,05	1,26	0,99
6+100	18,08	15,87	14,88	13,98	1,22	1,14

The results of hydrometric measurements performed at three sections of the main canal indicate that the registered section speeds and the flow are way below the value planned. It is clear from the results that the counter-flow parts of the main canal that are close to the pump are used with lower intensity. At the examined sections, the canal's geometric characteristics that are expressed through its hydraulic elements indicate that in comparison with the plans, there have been changes in the canal's geometric shape.

Based on the hydrometric measurements, we used the HEC-RAS software to prepare the hydraulic model. Hydraulic calculations revealed that the values of hydraulic resistance against the counter-flow, which are expressed by using Manning's roughness coefficient, are higher than the planned values. The measured average value was n = 0.05 and the planned value was 0.026. Fig 7.9 and 7.10 contain the results and the canal's water surface line.

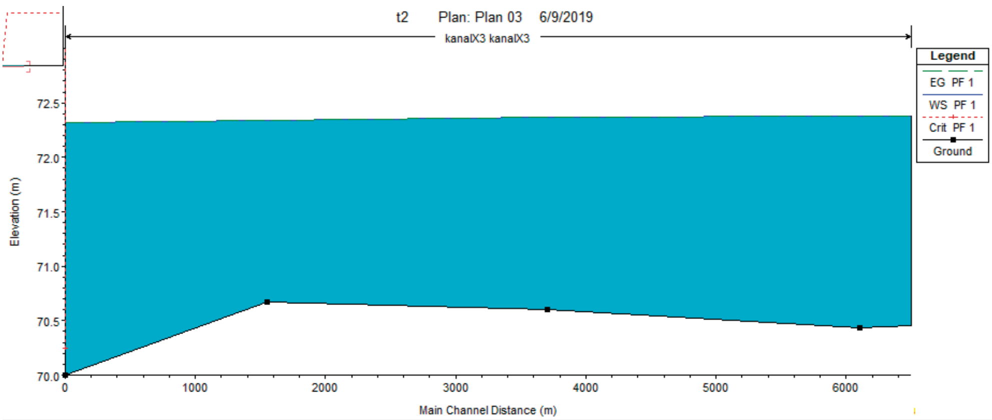

Figure 7.9 *Longitudinal cross-section of the main canal between section points 0+000 and 6+100 Km*

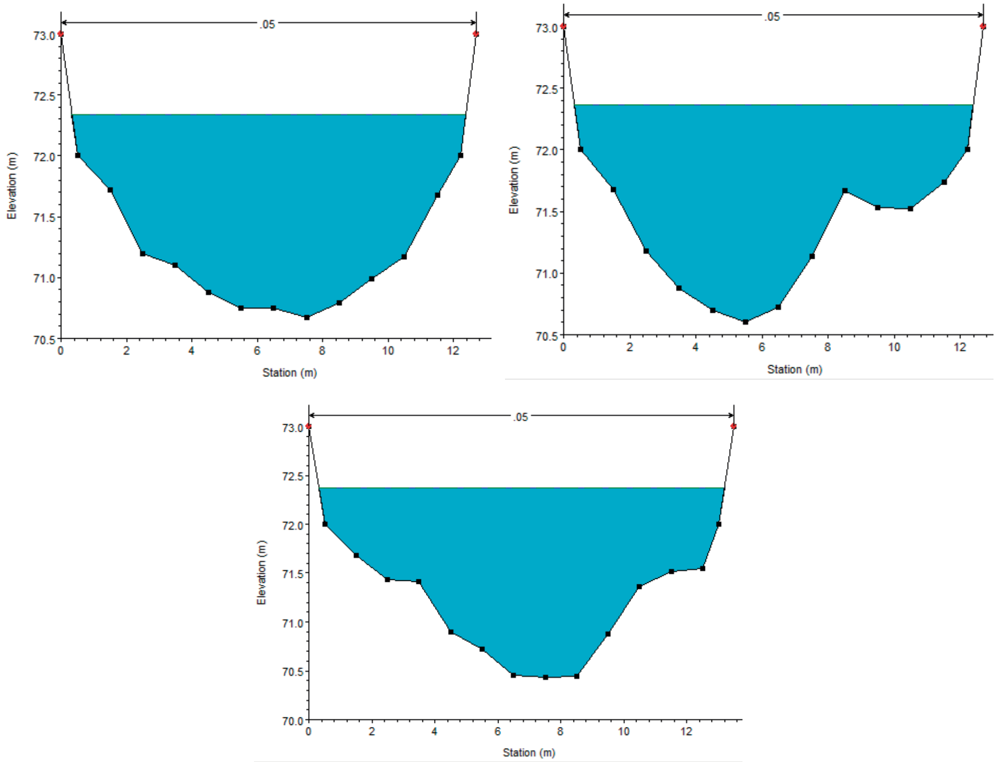

Figure 7.10 *Cross section of the three main canal sections at points 1+550, 3+700 and 6+100 Km*

The results indicate that the water flow conditions worsened in the main canal of the drainage system. These results are logical, as during the use of the system there are erosion processes and the water vegetation keeps growing, so sludge is deposited. Drainage practices used up until the present day show that canal systems must be revitalised every five years, in order to ensure the optimal water flow conditions, and to guarantee the efficiency of water drainage (Kolaković, 2003). Research conducted within the framework of the IPA WATER@RISK project proved that it is necessary to implement an action plan for the monitoring of the system's canal network, the condition of the pumping station and the system's operation, plus for the analysis of the catchment's hydrologic conditions (hydrologic parameters, hydrologic order, hydrologic module of water drainage); what is more, hydraulic modelling must also be done, with the help of which the system's operability can be determined accurately and in detail, and in line with this the necessary steps can be taken for the revitalisation of the water drainage system.