„Dunarea de Jos” University of Galați

Doctoral School of Mechanical and Industrial Egineering

Ph.D. THESIS

- ABSTRACT –

The anthropic impact on aquatic ecosystems components specific to the Danube

Scientific Coordinator:
Prof. Ph.D. Eng. GEORGESCU Puiu Lucian

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Series I4 Industrial Engineering No. 54

GALAŢI

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Keywords

Danube, bifurcation Bala branch – Old Danube, aquatic ecosystem, Natura 2000, sturgeon, navigation, anthropic interventions, bottom sill, water quality, sediment, hydrodynamics, morphology, minor alley, numerical modeling, Delft3D, prediction, numerical simulation, quasi-three-dimensional, morphohydrodynamics, erosion, deposition, impact.

INTRODUCTION

The Ph.D. thesis entitled *"The anthropic impact on aquatic ecosystems components specific to the Danube"* addresses an important research topic regarding the influence of the *anthropic* interventions on the riverbed evolution and on the biotics elements of the aquatic ecosystem, on short and medium term.

One of the main objectives of the Water Framework Directive (WFD) is to prevent damage of the aquatic ecosystems. According to the International Commission for the Protection of the Danube River (ICPDR), morphohydrodynamics changes are one of the major problems which affect the aquatic ecosystems. Thus, it is of real scientific interest to know the trends of riverbed evolution in the context of the hydrotechnical works implementation. This is necessary because any change in underwater relief can have many effects on the environment and society.

In this regard, it has been carried out the present research, which has as main objective the elaboration of a numerical model by which to analyze on a small and medium scale the morphohydrodynamics processes of a Danube sector and the correlation of these data with the biotic elements of the aquatic ecosystem.

The subject of the riverbed morphological evolution is receiving great attention, being treated since the 16th century. However, the insufficient data regarding the underwater relief of the Lower Danube sector have not allowed detailed studies.

The originality of this paper consists in the detailed approach of the morphohydrodynamic evolution trend of a Lower Danube sector, through numerical modeling, and the correlation of the results with the biotic elements of the aquatic ecosystem. The novelty and complexity derive from the huge volume of data obtained from the field campaigns, which formed the basis of the configuration of a morphohydrodynamic model and, at the same time, the basis for the investigation of the biotic components characteristics.

The specific objectives of the PhD thesis *"The anthropic impact on aquatic ecosystems components specific to the Danube"* are as follows:

- *Evaluation of the area of interest*. The studied area, located at the Bala branch – Old Danube bifurcation, is important from the point of view of the complex hydro - morphological processes of the riverbed. Given the fact that this sector is part of the Pan-European Corridor no. VII, in this area were implemented hydro-technical works to ensure the navigation conditions throughout the year. At the same time, this sector is part of the Natura 2000 sites - the ROSCI0022 and the ROSPA0039, and, also, represents an important sector in the sturgeon migration route;
- *Processing and interpretation of data obtained from field campaigns* (morphology, hydrodynamics, water and sediment quality, terrestrial and aquatic flora and fauna, anthropic interventions). In this research, data obtained from field campaigns correlated with the construction phases of hydrotechnical structures were used. Along with historical data, this information was the input data required for numerical modeling.
- *Configuration of a morphohydrodynamic model*. Based on the data field, through the *Delft3D* numerical modeling program, a morphohydrodynamic model has been configured to provide information with a high degree of confidence.
- *Evaluation of short and medium-term morphohydrodynamic processes through the Delft3D numerical simulation program*. Using the morphohydrodynamic model, numerical scenarios were developed, which allowed the analysis of the morphological and hydrodynamic trend evolution of the studied sector at intervals of 3 years and 5 years.
- *Biotic-abiotic interaction*. In order to evaluate the anthropic interventions, influence on the components of the aquatic ecosystems that characterize the studied Danube sector, it was necessary to analyze the interaction between the abiotic elements and the components of the aquatic ecosystems based on the results obtained from the numerical simulations and the results of field campaigns.

The methodology used in the elaboration of this paper was based on rigorous documentation conducted over the years of study. In order to characterize and obtain the reference data necessary for the numerical model configuration and the connection with the aquatic ecosystem, documentation sources were used: research projects, monographs, doctoral thesis, articles, scientific communications. Numerous courses have been developed and specialized forums, websites, blogs, tutorials and discussion lists have been consulted. The database necessary for the development of the numerical model was ensured by the collaboration with the monitoring team of the interest sector and by the National Institute for Research and Development for Environmental Protection (INCDPM) information and infrastructure.

In order to achieve the PhD thesis goal, the following steps were taken:

- Delimitation and characterization of the area of interest;
- Processing and interpretation of data obtained from field campaigns (morphology, hydrodynamics, water and sediment quality, terrestrial and aquatic flora and fauna, anthropic interventions);
- Performing comparative analyzes of data, considering the phases of execution of the hydrotechnical works;
- Elaboration of the numerical model;
- Making scenarios based on numerical simulations on short and medium term;
- Evaluating the results obtained from the numerical simulations;
- Correlation of hydrodynamic and morphological parameters resulting from numerical simulations with biotic elements of the aquatic ecosystem.

These stages have been described in the 9 chapters in which the thesis is structured.

In *Chapter 1,* with preliminary purpose, there were presented a series of general theoretical notions regarding the environmental impact assessment, the hydrological regime, the hydraulic water flow, the riverbed dynamics and the aquatic ecosystems.

The current state of the research has been addressed in *Chapter 2*. In this chapter, a series of studies have been presented regarding the alluvial transport investigations, aquatic ecosystem analysis and morphological water courses through the use of numerical modeling programs.

Chapter 3 describes the fundamental elements that characterize some of the techniques, equipment and programs used to develop the research.

In order to assess the anthropic impact on the components of aquatic ecosystems, it was necessary to characterize the reference conditions. In this regard, *Chapter 4* presents the characteristics to the Danube sector studied in this paper.

The stages taken to develop the numerical model used to analyze the morphohydrodynamic processes, have been described in *Chapter 5*. In the present study, the *Delft3D* program was used, as it allows the analysis and prediction of the dynamic water flow, both bidirectional and quasi-three-dimensional.

For short and medium-term analysis of the morphological changes of the riverbed and water velocity variations, *Chapter 6* describes the results obtained from numerical simulations of morphohydrodynamic processes for 3 years and 5 years, these being related to the situation of reference, that is, the calibrated morphohydrodynamic model.

In *Chapter 7* were evaluated the riverbed changes resulting from numerical simulations performed on short and medium term.

The results obtained from the assessment of morphological riverbed changes are the basis for analyzing the influence that morphohydrodynamic processes can have on the aquatic ecosystem components, over time. Thus, in *Chapter 8* these results were correlated with elements of the aquatic ecosystem.

In the conclusions were presented the elements of necessity for the elaboration of the doctoral thesis, trends of morphological riverbed evolution by using numerical modeling, the results of the impact of the morphohydrodynamic modifications on the aquatic ecosystem and the original elements and contributions of the author. At the same time, the conclusions described the arguments regarding the use of the results in the investment strategies and the perspectives of the subject development.

Chapter 1. THE PRELIMINARY THEORETICAL CONCEPTS

The need to review the theoretical notions was due to the complexity of the subject approached in this paper. In this regard, the main ideas on environmental impact assessment at national level were outlined.

In order to characterize the processes which take place in a water body, there were presented both the general elements regarding the hydrological and hydraulic regime of the water flow, as well as the dynamic notions of the riverbed, such as the river system, the regime of the hydraulic resistance of the deformable channels, the flow regime of solid phase, the evolutionary state of the channels, the morphological stability and instability of the channels.

The concepts of aquatic ecosystems have been approached in terms of importance in the national and international legislation. At the same time, regarding the correlation of the morphohydrodynamic processes with the biotic elements of the aquatic ecosystems, it was mentioned that the biotic activity impressed specific features of the sedimentation environment. Also, the biotic components represent a constant and varied source of material for the sedimentation process. Biotic activity contributed, directly or indirectly, at the formation of sedimentary deposits through construction processes, generating sedimentary products, but also through destructive processes, generating organogenic debris, by destroying the skeletons and modifying some pre-existing sedimentary structures.

Chapter 2. CURRENT STAGE OF THE RESEARCH

In the present research is studied a sector of the Călăraşi - Brăila section of the Danube River. The activities of the over 80 million inhabitants of the 19 countries on which the Danube River basin is taking place, have an impact on the environment, leading to water quality and quantity problems and a significant reduction in biodiversity (ICPDR, 2015). Currently, according to the International Commission for the Protection of the Danube River - ICPDR, the major problems which affect aquatic ecosystems in the Danube River basin are related to excessive nutrient loads (especially nitrogen and phosphorus), large quantities of organic substances from untreated or inadequately treated waste waters, **hydromorphological changes and their effect on sediment transport**, contamination by dangerous substances; accidental pollution from shipping, contaminated areas or waste disposal and degradation and loss of wetlands (ICPDR, 2015).

The subject regarding the morphological evolution of the watercourses is receiving great attention, being treated since the 16^{th} century. Leonardo da Vinci was the first who emitted a principle that the valleys are the creation of the watercourses that flow through them, being a particular report between the watercourse flow and the channel size.

Nowadays, due to the fact that the hydromorphological changes and their effect on sediment transport represent one of the major problems affecting the aquatic ecosystems in the Danube River basin, it is of real interest to know the trends of the morphological riverbed evolution. Based on these considerations, river basin management plans may be developed.

In the present paper were presented research studies which focused mainly on alluvial transport investigations, aquatic ecosystems and morphological analysis of water courses using numerical modeling programs. The presentation of these studies aimed on the one hand to highlight the importance of the subject of the Ph.D. thesis, and on the other hand the exposition of the working methodologies approached for the purpose of investigations.

The documentation made for the analysis of the present stage of the research was an important point in the accomplishment of the specific objectives of the Ph.D. thesis *"The anthropic impact on aquatic ecosystems components specific to the Danube".*

Chapter 3. MATERIALS and METHODS

An important role in conducting the investigations regarding the morphological riverbed changes is represented by the research infrastructure. Using the appropriate techniques and equipment provided by the National Institute for Research and Development for Environmental Protection (INCDPM), in collaboration with the monitoring team of researchers, the necessary information was obtained for the delimitation and characterization of the study area. Also, the volume of information used in the analysis of the trend of morphological evolution of the Danube riverbed was resulted after the processing of the primary data, through the specialized programs.

3.1. Topometric measurements

In order to obtain terrestrial surface information from the studied sector, the *GPS Leica Viva GS08 Plus* and the *Leica Sprinter 250M* electronics were used.

The *GPS Leica Viva GS08 Plus* offers the possibility to carry out measurements and verifications even if there is no GSM signal in the area, and the devices communicate with each other, via radio waves and data transmission. Thus, the operator has the flexibility to be independent of the GSM signal and the Internet data transfer speed in the work area (Leica Geosystems, 2012). The *Leica Sprinter 250M* makes accurate measurements possible without reading errors. Error Removal Functions do not allow measurements to be performed if the user is outside the offset range. (Leica Geosystems, 2008). The data resulting from topometric measurements have been used, in particular, to determine the quotients of land needed for numerical modeling.

3.2. Measurements of bathymetry, discharge and water current velocities

In order to determine the riverbed morphology, the systems used included single beam and multibeam ecosystems.

Single beam bathymetric measurement is based on the principle that the water depth is determined by measuring the time from the signal emission to its reception after the riverbed reflection (Egis, 2015) (Manea R., 2003). By using this system, we can perform bathymetric measurements on a watercourse cross section.

In order to obtain the riverbed bathymetry of the analyzed sector, by collaborating with the monitoring team, measurements were made using equipment based on the Acoustic Doppler Current Profiler (ADCP) technique. Through them, both single beam bathymetry and water velocity measurements were performed on different sections. Based on these measurements, the discharges on those sections can be estimated.

In this research, two types of ADCP systems were used. The first is a robust and extremely precise system, specially designed to measure the water depths, velocities and directions of water flow using Doppler technology (SonTek/YSI, 2010). The measurements were made using a low speed boat, perpendicular to the shore, so as to obtain a cross-section. *Figure 1* shows the riverbed geometry, the water flow direction and velocity distribution on a cross-section of the studied sector. In order to verify the accuracy of the records, each profile is made from 2 to 4 crossings.

The second system (*Figure 2*) is designed to measure real-time water discharges, bathymetric profiles and water velocities in rivers with different hydrological regimes. The system is installed on the float and the connection to the field computer is done via WinRiver II (Teledyne RD Instruments, 2015).

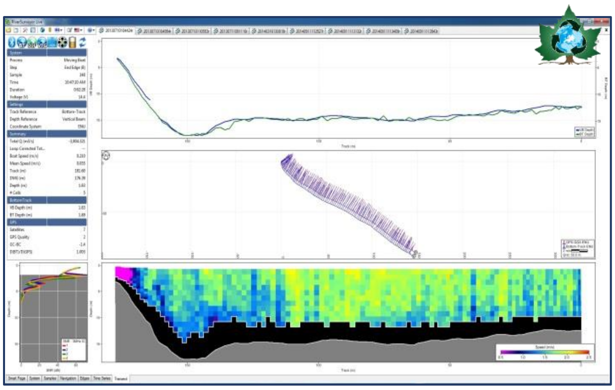


Figure 1 Transects visualization (Nicolae A.-F., Georgescu P.L., et al. 2015)

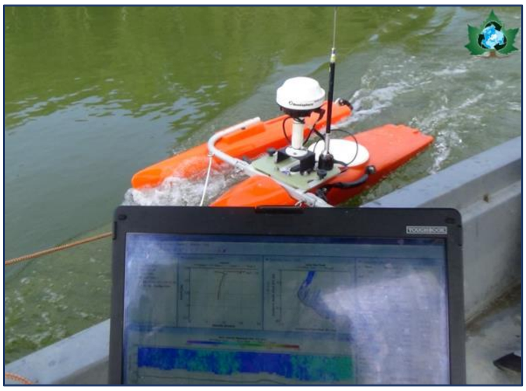


Figure 2 ADCP System (INCDPM, 2011-2018)

Through multibeam measurements, an image of the watercourse riverbed can be obtained. This image presents details which are often not taken over by conventional measurements with single beam sonar (Egis, 2015).

Data obtained from measurements using a multibeam system (*Figure 3*) were also used in the research. The resulted bathymetry is highly accurate, as an outcome of the data processing, resulting a 3D numerical model of the riverbed. By this bathymetric system data is acquired, with profile coverage up to 12 times the water depth (Kongsberg, 2013).

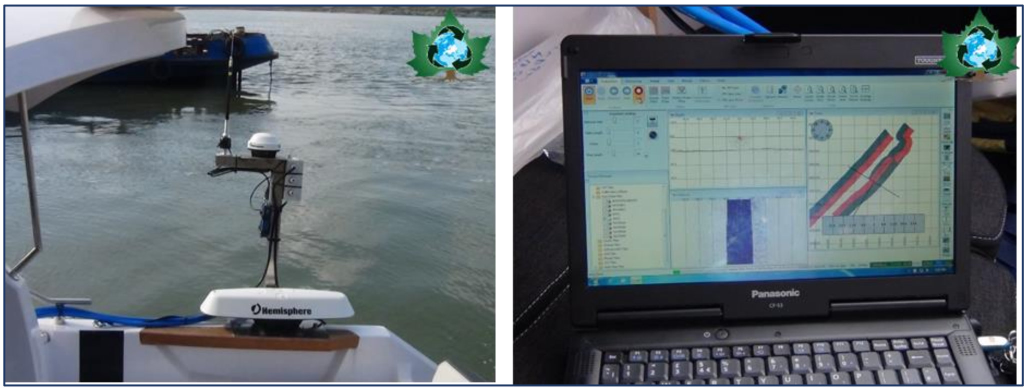


Figure 3 Multibeam System (Nicolae A.-F., Georgescu L.-P., et al. 2017)

3.3. Delft3D numerical modeling program

With the technology evolution, a number of programs have been developed for the hydraulic modeling of water flow in rivers (Sârbu D., 2015). For the numerical modeling of a watercourse, it is generally described the riverbed's geometry, the anthropological interventions in the watercourse and the water flow is simulated by solving the characteristic equations (INCDPM, 2014-2015), the general balance equations representing the basic tools of mechanics fluids for describing the movement (Ministry of Waters, Forests and Environmental Protection - ICIM 1998).

Delft3D is an advanced program used in the field of quasi-three-dimensional modeling for hydrodynamics, sediment transport, morphology and water quality for water courses. This program has been used in over 140 countries for a wide variety of commercial projects and research studies (Delft3D, 2011).

The use of the Delft3D program (*Figure 4*) allows analysis and prediction of water flow dynamics, both bidirectional and quasi-three-dimensional, depending on the input conditions established on the basis of riverbed and water flow parameters (INCDPM, 2015).

The Delft3D suite of programs is made up of modules that cover a number of aspects of a research or engineering problem. In this research, the RGFGRID, QUICKIN, FLOW and QUICKPLOT modules were applied.

After taking field measurements, sampling and processing information in order to obtain the program input data, the following steps were required to complete the numerical model:

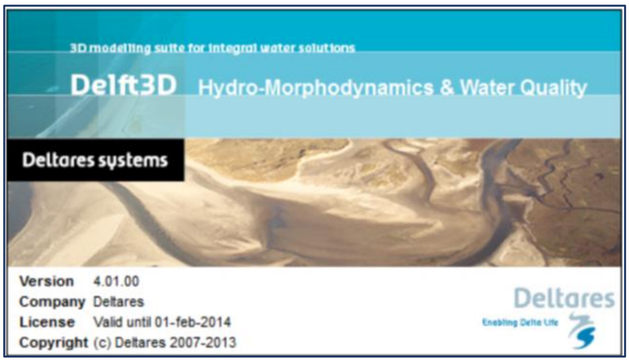


Figure 4 Delft3D window

- Construction of the grid related to the area of interest (Delft3D-RGFGRID);
- Creating the geometric model of the riverbed, based on field measurements (Delft3D-QUICKIN);
- Establish the parameters required for the model to run, depending on the scenario objectives and the data obtained from field measurements/samplings;
- Calibration and validation of the numerical model;
- Configuration of the morphohydrodynamic model by adding the constituent - transport of sediments;
- Creation of proposed scenarios.

Equations of non-permanent, two-dimensional or quasi-three-dimensional water flow are solved in the FLOW module. The flow domain of a three-dimensional model consists of a number of constant layers in the horizontal computing area (L.C. van Rijn and D.J.R. Walstra, 2003). At the same time, the FLOW module allows modeling of the sediment transport based on advection-diffusion equations.

3.3.1. Delft3D – Hydrodynamic model

The numerical modeling of the flow and sediment transport process is done with the Finite Difference Method, which is based on the discretization of the partial derivative equations found in the mathematical model (Holban G.R., 2014). To achieve the hydrodynamic model within the Delft3D FLOW module, the Navier Stokes equations for incompressible fluid (Deltares 2011) have been solved. Navier-Stokes equations are actually the general equations of motion of real, compressible fluids in non-permanent laminar motion (Florescu I., 2007).

$$\begin{cases} \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = X - \frac{1}{\rho}\frac{\partial p}{\partial x} + v\Delta u + \frac{v}{3}\frac{\partial \theta}{\partial x} \\ \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = Y - \frac{1}{\rho}\frac{\partial p}{\partial y} + v\Delta u + \frac{v}{3}\frac{\partial \theta}{\partial y} \\ \frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = Z - \frac{1}{\rho}\frac{\partial p}{\partial z} + v\Delta u + \frac{v}{3}\frac{\partial \theta}{\partial z} \end{cases} \quad (1)$$

Where,

$$\Delta u = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}$$

$$v = \frac{\eta}{\rho}$$

η - dynamic viscosity [m^2/s]; ρ - density [kg/m^3].

In order to obtain a numerical model to provide highly reliable results, it is necessary to calibrate and validate the hydrodynamic model according to a series of hydraulic parameters.

3.3.2. Delft3D – Morphohydrodynamic model

If sedimentology data are used, through numerical modeling may result qualitative data on erosion/accumulation processes, the force by which water acts on the riverbed, etc. Hydromorphological modeling considers all parameters that can influence the flow dynamics and the morphological dynamics of the riverbed (flow, level, sediment types, bedrock etc.) (Deltares, 2011).

The Dleft3D program allows the performing of sediment transport analyzes for both suspense and dragged sediment, for cohesive and non-cohesive sediments.

The three-dimensional transport of suspended sediments is calculated by solving the three-dimensional advection-diffusion equation (Deltares 2011):

$$\frac{\partial c^{(l)}}{\partial t}+\frac{\partial uc^{(l)}}{\partial x}+\frac{\partial vc^{(l)}}{\partial y}+\frac{\partial (w-w_s^{(l)})c^{(l)}}{\partial z} - \frac{\partial}{\partial x}\left(\varepsilon_{s,x}^{(l)}\frac{\partial c^{(l)}}{\partial x}\right)-\frac{\partial}{\partial y}\left(\varepsilon_{s,y}^{(l)}\frac{\partial c^{(l)}}{\partial y}\right)-\frac{\partial}{\partial z}\left(\varepsilon_{s,z}^{(l)}\frac{\partial c^{(l)}}{\partial z}\right)=0 \qquad (2)$$

Where: $c^{(l)}$- mass concentration of the sediment fraction (l) [kg/m³]; u, v, w - the components of the water flow velocity [m/s]; $\varepsilon_{s,x}^{(l)}$, $\varepsilon_{s,y}^{(l)}, \varepsilon_{s,z}^{(l)}$ - diffusivity of the sediment fraction (l) [m²/s]; $w_s^{(l)}$ - deposition rate of the sediment fraction l [m/s].

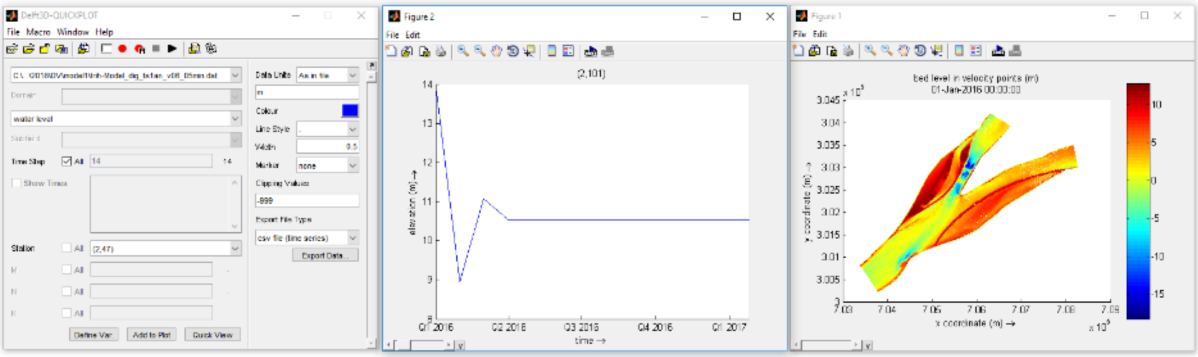


Figure 5 Results visualization - Delft3D-QUICKPLOT

The results obtained from the runs can be viewed using the Delft3D-QUICKPLOT module (*Figure 5*).

3.4. Analysis of ecological status of water bodies

The assessment of the surface water quality was carried out by monitoring the indicators mentioned in the Annex to Order 161/2006 for the approval of the "*Normative regarding the classification of surface water quality in order to establish the ecological state of the water bodies"*.

The water and sediment samples were taken according to the standards in force and each one was divided into several samples from which the specific physicochemical indicators were analyzed. Sediment samples were collected from the left bank and the right bank of the cross-section analysis using a special sampler. To ensure a high level of confidence in the monitoring, water samples were taken from 3 points located on the cross sections of analysis - left bank, right bank and water line.

Figure 6 describes the steps taken to carry out the research regarding the riverbed changes trends, in a Lower Danube sector.

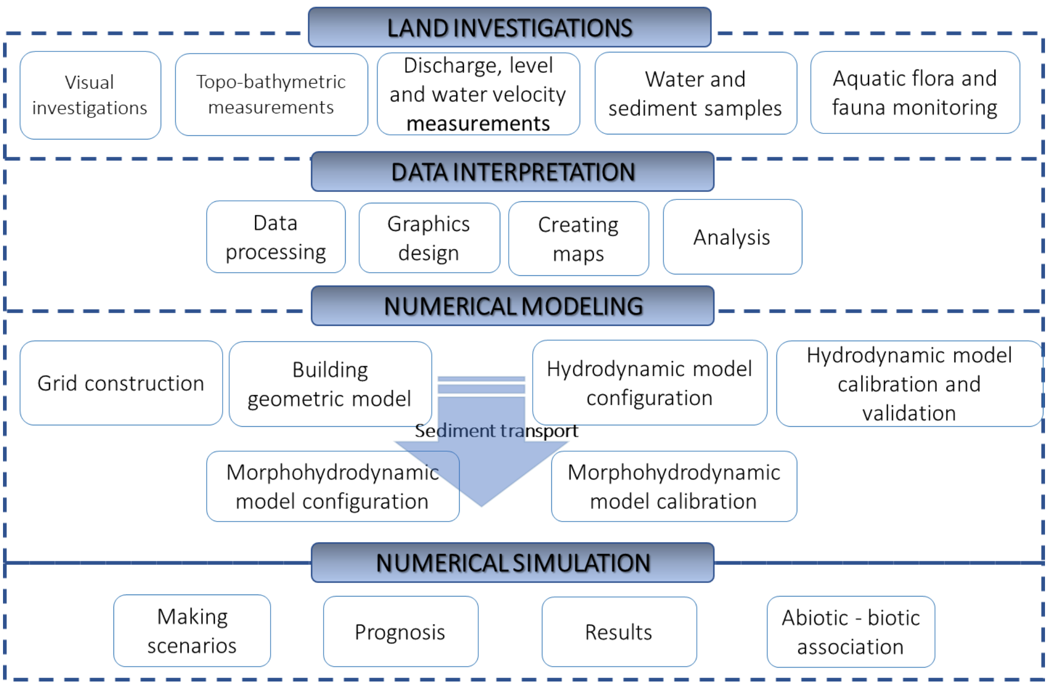


Figure 6 The stages made in order to develop the research

Chapter 4. THE STUDY AREA CHARACTERIZATION

In order to assess the anthropic impact on the aquatic ecosystems components, it is necessary to characterize the reference conditions. In this regard, the characteristics of the water sector studied in the present paper are presented below. The Danube River is the second largest in Europe, after the Volga. The Danube is particularly important for Romania, the country being almost entirely in the Danube basin, covering about one third of the surface of the basin and the total length of the watercourse (ICPDR).

The Danube sector, between Călăraşi and Braila (km 375 - km 175) (*Figure 7*) is part of the Pan-European Corridor no. VII, ensuring the connection between the Danube River and the Danube - Black Sea navigable channel. Taking into account the strategic position of the Danube as a transport corridor from the river ports to the port of Constanta, it is necessary to ensure the navigation conditions (INCDPM, 2011-2018).

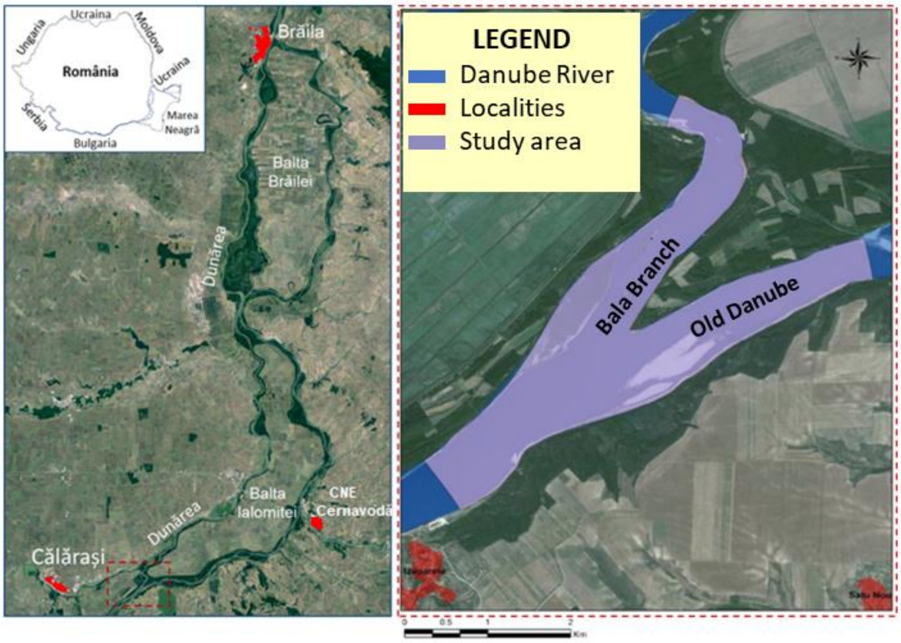


Figure 7 The Danube sector, between Călăraşi and Braila. Localization of the study area - Bala branch – Old Danube bifurcation

Considering that during the summer-autumn period water flows are considerably reduced on this river sector, on the main Danube branch – Old Danube, between km 346 and km 300, the minimum depth is no longer ensured for a period of 160 days each year, the fairway depth being reduced in some areas to 1.5 - 2.0 m.

This leads to the deviation of the navigation on the secondary route Bala-Borcea, which takes a higher water flow and it has a bigger depth than the Old Danube, but which presents inconveniences related to the width of the channel and its curvature (INCDPM-ICIM 2005). At the same time, the flows on the main branch of the Danube influence the water volume required for the cooling of the 2 units of the Cernavodă Nuclearoelectric Power Plant (EnergoNuclear 2011). Thus, a number of hydrotechnical works have been proposed to ensure optimal navigation conditions on the Old Danube (*Figure 8*) (Nicolae, A.F., et al., 2016).

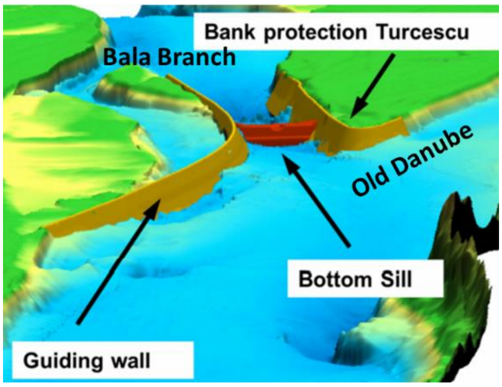


Figure 8 Details on the anthropic interventions in the Bala – Old Danube bifurcation zone - processing after BOKU IWHW, 2015

4.1. The study area location

The studied area in this research is represented by the Bala branch – Old Danube bifurcation, which is part of the Danube sector (*Figure 9*). It extends over a length of approx. 5 km on the Old Danube and approx. 2.5 km on the Bala branch. The investigated sector belongs to the Danube section Călăraşi - Vadu Oii, which is located in Oltina Plateau. At the upstream boundary of the study area, on the right bank of the Danube river is the Izvoarele locality, which belong to the Lipniţa village, located in the south-west of Constanţa County (Lipnica City Hall).

Figure 9 Bala branch – Old Danube bifurcation (INCDPM, 2011-2018)

4.2. Physical-geographic features

For the analysis of the physico-geographic factors were used historical data taken from the literature and data recorded during the monitoring period, being investigated both the Bala branch – Old Danube bifurcation zone and the area adjacent to it - the Danube section between Călăraşi and Brăila. The monitoring period was carried out over a 7 years interval, being segmented according to the following steps: before constructions, the construction of the hydrotechnical structures and after works completion, according to *Figure 10*.

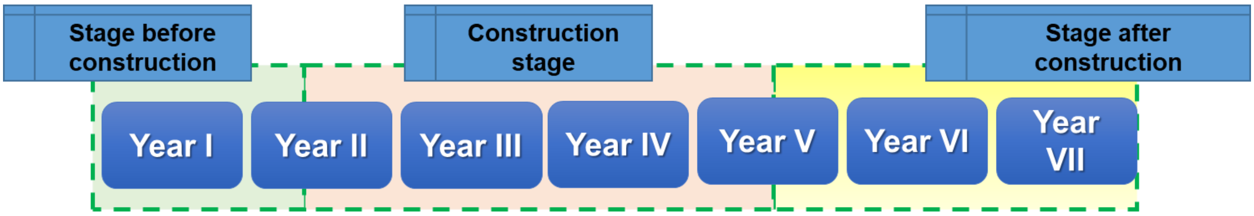


Figure 10 Monitoring period

4.2.1. Land relief

The Călăraşi - Vadu Oii sector is situated between the Dobrogea Plateau to the east and the high plain of the Hagiens to the west (INCDPM-ICIM, 2005). Vadu Oii - Brăila is located between Dobrogea Plateau to the east and the low Brăila Plain to the west, having an elongated depression from south to north on a length of 60 km, with a maximum width of 20 km (INCDPM-ICIM, 2005). The sector studied in this paper is located between the Oltina Plateau (subunit of Dobrogea Plateau) and Ialomiţa lake.

4.2.2. Riverbed relief

In the research, batimetric measurements were carried out in the Bala branch – Old Danube bifurcation zone. As can be seen in *Figure 11*, the results obtained from the multibeam bathymetric processing provide a clear three-dimensional image of the riverbed, the spatial resolution of the 1 x 1 m points providing the details of hydrotechnical structures.

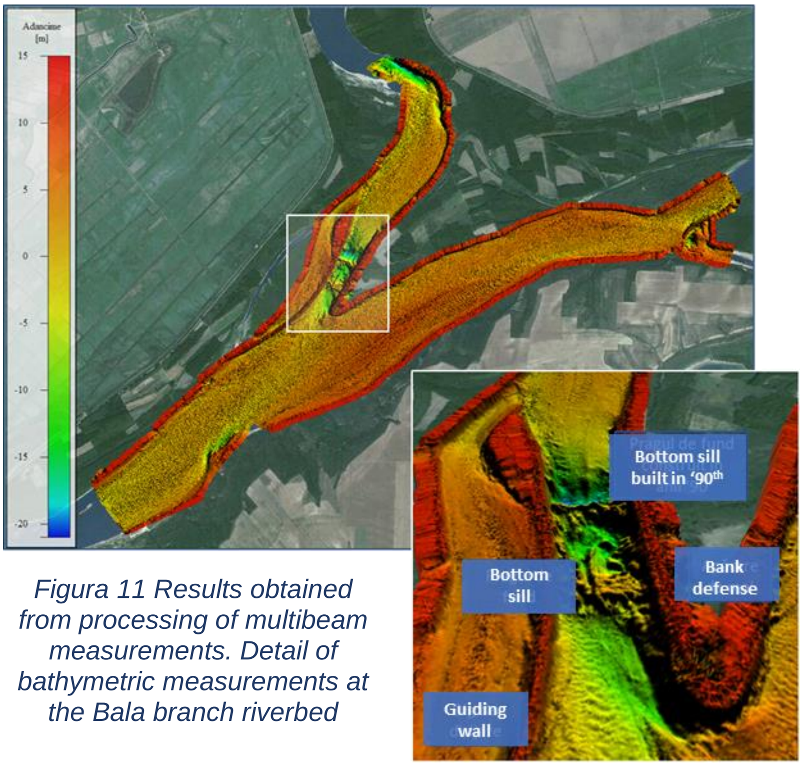


Figura 11 Results obtained from processing of multibeam measurements. Detail of bathymetric measurements at the Bala branch riverbed

During the study period, based on bathymetric measurements, the riverbed was investigated before and after the hydrotechnical construction. *Figure 11* shows an example in which a cross-sectional area located on the Bala branch was analyzed. It can be noticed that following the execution of the bottom sill, an erosion hole has formed downstream of it.

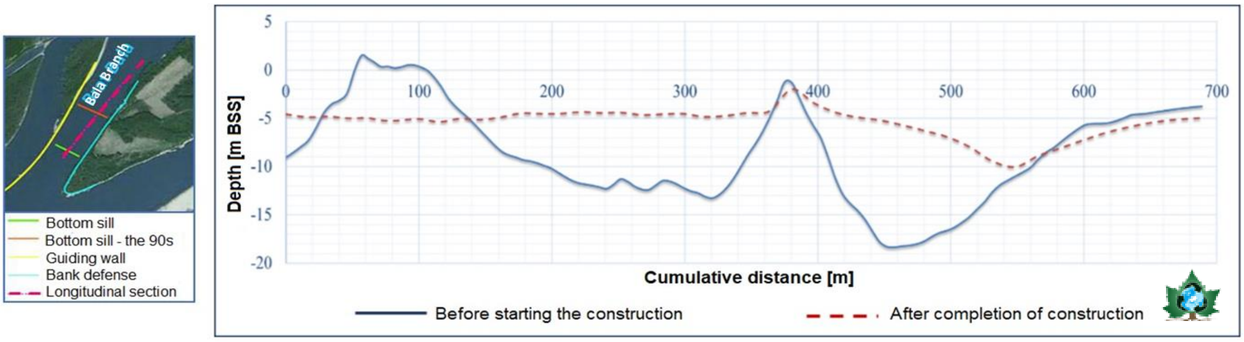


Figure 12 Longitudinal section representing the riverbed before and after the completion of hydro-technical constructions - Bala branch (Nicolae A.-F., Deak Gy., et al., 2017)

4.2.3. Geology

The area studied is part of the Călăraşi area, which belongs geologically to the Moesian platform. From a geological point of view, the left bank of the Bala branch consists largely of low-level landfills (sands, argillaceous meadows, sand dunes) and the right bank of high plateau deposits (loess clay, sand, gravel) (Egis, 2015) (Geological Institute, 1967).

4.2.4. Hydrodynamics

Regarding the discharge analysis, when the need to carry out hydrotechnical works for improving navigation conditions, the flow distribution in the bifurcation area was 40% on the Old Danube and 60% on the Bala (during the seasons with levels large waters), respectively 20% on the Old Danube and 80% on the Bala (during seasons with low water levels). With the activity reports [www.afdj.ro/ro/content/romomed] of the project *"Monitoring of Environmental Impact of the Works for Improvement of the Navigation Conditions on the Danube between Călăraşi and Braila, km 375 - km 175"* for the sector analyzed in this paper, data series on the discharges from the Călăraşi-Chiciu hydrometric station and the water levels from the Braila hydrometric station were used.

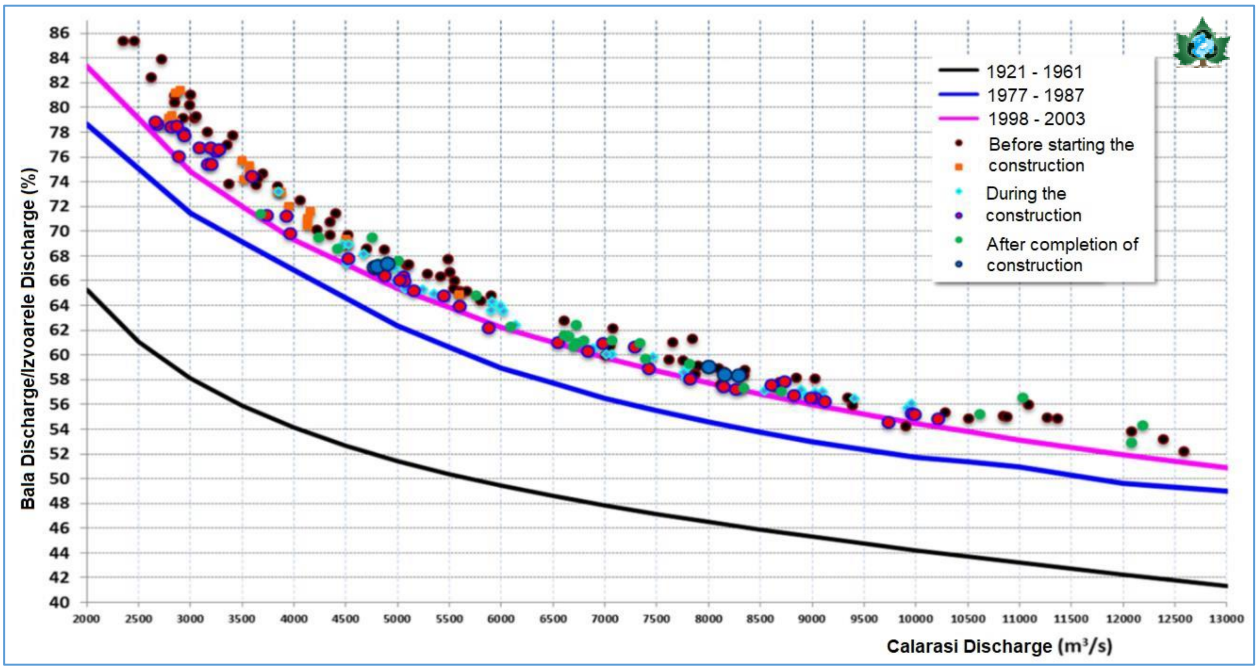


Figure 13 Percentage distribution of discharge flowing on the Bala branch at different time intervals, processing after INCDPM, 2011-2018

Following the processing of the data obtained from the measurements, the INCDPM experts carried out a comparative analysis regarding the distribution of discharges between Bala and Old Danube, for a period of 5 years. At the same time, these values were compared with the historical percentage distributions for the periods 1920-1961 and 1998-2003 respectively, values obtained from the literature (*Figure 13*).

In the following, hydrodynamic parameters of the analyzed sector are presented during 6 years of monitoring in three analysis sections, as shown in *Figure 14.*

Figure 15 shows the discharge distribution. If discharges of less than 4000 m^3/s are recorded in the upstream section, the flow is distributed on the two branches as follows: approx. 70-75% on the Bala branch and approx. 25-30% on the Old Danube. In the case of some 9500 m^3/s in the upstream section, the flow distribution is 57% on the Bala branch and 43% on the Old Danube.

Figure 14 Representation of the study area cross sections

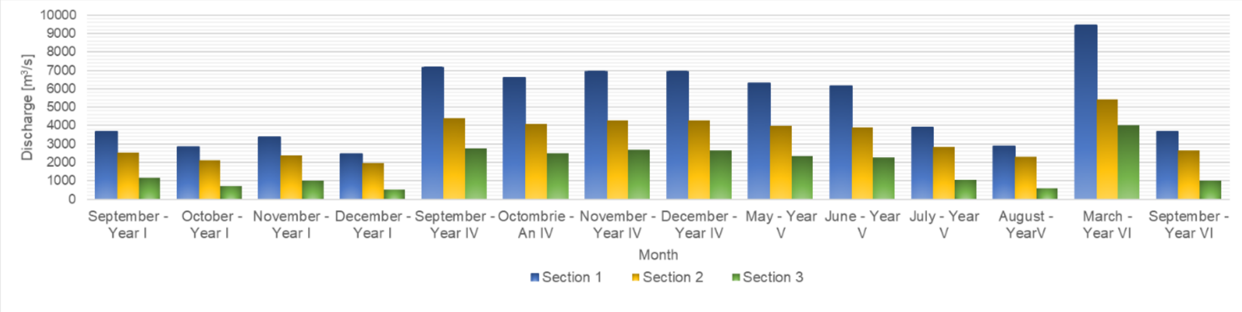


Figure 15 Discharges recorded in the analyzed cross sections (INCDPM, RI10, 2015) (INCDPM, RI1 2013) (INCDPM, RI12 2015) (INCDPM, RI 14 2017) (INCDPM, RI 16 2017)

Regarding to the water flow velocity, the values were recorded at 0.5 m depth in the center and in the right and left bank, for each section during the analyzed period. Compared to the other two sections, it results that in the section 2 located on the Bala branch the highest velocity values are recorded in the center of the channel (*Figure 16*).

Figure 16 Values of recorded water velocities (INCDPM, RI10, 2015) (INCDPM, RI1 2013) (INCDPM, RI12 2015) (INCDPM, RI 14 2017) (INCDPM, RI 16 2017)

4.2.5. Morphohydrodynamics

The Danube sector between Călăraşi and Braila is an area with a large morphohydrographic diversity (INCDPM-ICIM, 2005). The interest zone is of particular importance from the point of view of the complex morphodynamic processes of the riverbed.

The **Bala branch** detaches of the Old Danube near km 345 and flows into Borcea branch at km 68. This branch is characterized by an alternation of areas with intense hydromorphological dynamics with relatively low energy areas. The bottom sills area is also characterized by the presence of vortex currents and shore erosion phenomena (Egis, 2015). Due to the dynamic processes specific to sinuosities and confluences, the shape of the riverbed is asymmetrical. The banks of the Bala branch (*Figure 17*) are abrupt, with frequent traces of crashes due to increased erosion, produced in several cases by the presence of inverse currents near the banks (INCDD, 2004). Less dynamic areas are characterized by the shape of the flattened riverbed, lower depths and lower velocities compared to the rest of the branch (Egis, 2015).


Figure 17 Banks on Bala branch (Nicolae A.-F., Deak Gy., et al., 2017)

The **Old Danube** runs between km 373 and km 241, in this research being analyzed a 4 km long sector. Due to the fact that the Bala branch takes a large water volume of upstream, on the Old Danube, downstream of the bifurcation, the fluvial energy is diminished (*Figure 18*), with sediment deposition processes being prevalent. This is evidenced by the presence of numerous islands and sandbanks which form sills with negative implications for navigation (INCDPM, 2015). After the bifurcation with the Bala branch, the Old Danube manifests an obvious tendency of atrophy - reductions in the cross-section area, reductions in depths and discharges (the Caragheorghe sand bank) (Egis, 2015) (*Figure 19*).

Figure 18 Bank on Old Danube (INCDPM, 2011-2018)

Figure 19 Caragheorghe Sandbank (INCDPM, 2011-2018)

For the morphological analysis of the study area, Landsat satellite images were compared (*Figure 20*) using data from different time intervals (16 years), in the context of a similar discharge. In this regard, were used *Landsat 7* satellite images with a 30 m spectral resolution, which were brought at a resolution of 15 m, by applying the pan-sharpening using the panchromatic band 8. Satellite images were downloaded free of charge from the geo portal: https://earthexplorer.usgs.gov/. The analysis show that the biggest morphological changes occurred on the Bala branch. The guiding wall construction led to the change of the islet located on the left bank of the Bala branch (*Figure 20* - detail A). Following the hydromorphological processes, the tendency of the watercourse on the Bala branch is to develop eastwards. In the analyzed period of 16 years, on the right bank was eroded an area exceeding 8 ha over a maximum width of approx. 130 m, and on the left bank there are observed depositions on an area of 8.3 ha over a maximum width of cca. 150 m (*Figure 20* - Detail B).

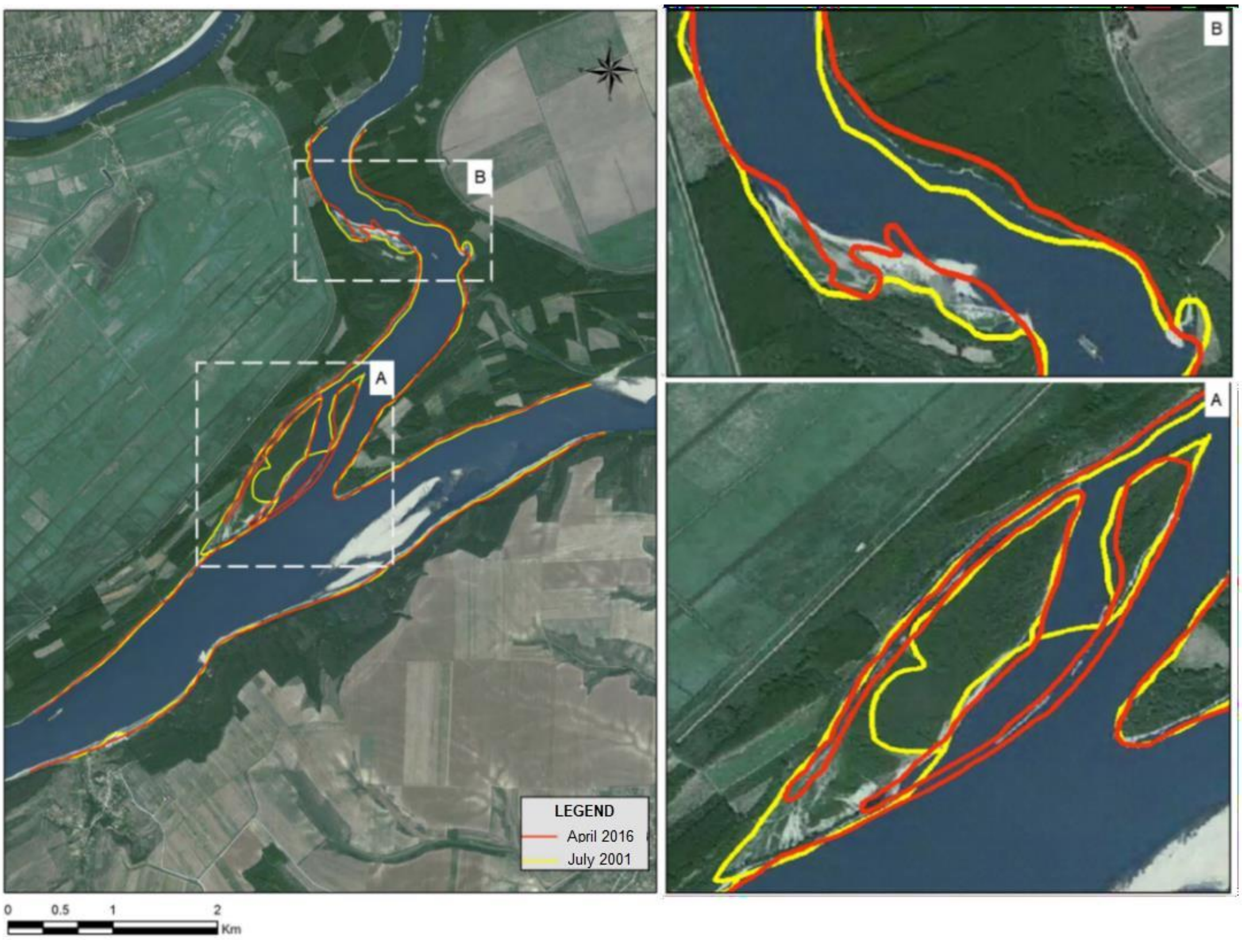


Figure 20 Evolution of bank morphology over a 16 years period

4.2.6. Sediments transport

In the channels dynamics, the sediments transport has a role as important as erosion and accumulation (Jipa D., 1987). In order to obtain the input data necessary for the numerical modeling, field campaigns were carried out which involved the sampling of sediments from control points *(Figure 21)*. The results obtained from the analysis were correlated with the water velocity, measured in that section (*Table 1*).

With regard to the mean size of the samples taken in the shores areas, during the analysis of the 7 months of year V (*Figure 22*), it can be seen that the D50 maximum values are obtained in the seventh month, framed within the range of 1.33 - 2.00 mm. In the second month the minimum values of D50 were obtained (0.10 - 0.24 mm). For most of the sediments samples, the D50 parameter exceeds the value of 0.20 mm, indicating that the particles are slightly eroded by aquatic currents (Inman DL 1949)

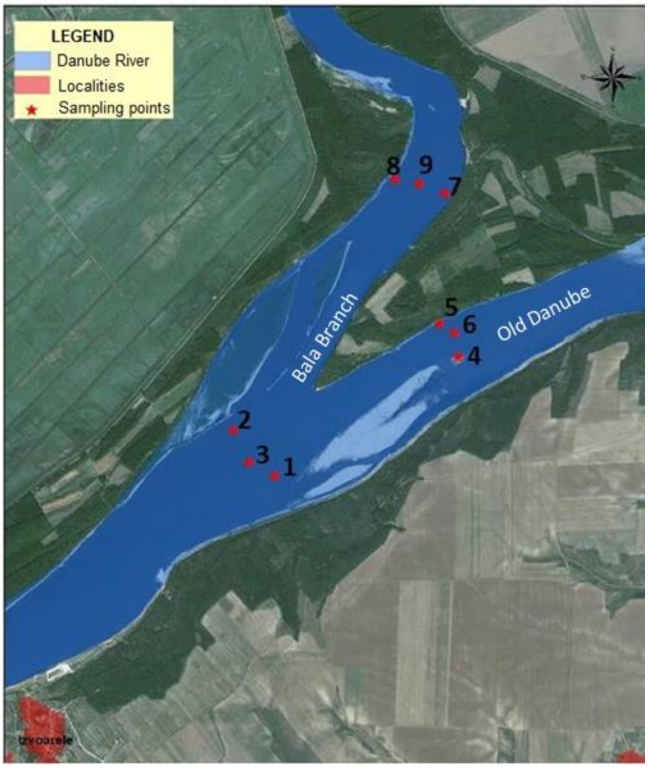


Figure 21 Sediments sampling

Table 1. Lithological characterization of sediments sampled from the riverbed

Point	Lithological description
1	Medium sand - coarse, tan-yellowish, micaceous, good sorting, with rare traces of small shells and very rare elements of fine gravel.
2	Medium sand - coarse, gray - brown, micaceous, good sorting, with small traces of shells, rare elements of fine gravel, mostly quartz. Rare *Corbicula* whole shells.
3	Medium - fine sand, tan-yellowish, micaceous, good sorting, with small traces of shells, fine gravel, rare ballast elements. Whole *Corbicula, Dreissena, Viviparus* shells.
4	Medium - fine sand, tan-yellowish, micaceous, well-sorted, with small traces of shells, rare *Dreissena* shells
5	Fine sand, gray - brown, micaceous, good sorting, with small traces of shells and plants
6	Fine - medium sand, tan - yellowish, micaceous, well sorted, with small traces of shells, rare elements of fine gravel.
7	Medium - coarse sand, brownish-gray, micaceous, well-sorted, with fine gravel elements, small traces of shells and *Corbicula, Dreissena, Viviparus* whole shells.
8	Medium - fine sand, brownish-gray, micaceous, well sorted, with fine gravel elements, with small traces of shells and *Drexena, Corbicula* whole shells.
9	Medium - fine sand, brownish-gray, micaceous, well-sorted, with rare grail elements, rare small traces of shells and rare *Drexena, Corbicula* whole shells.

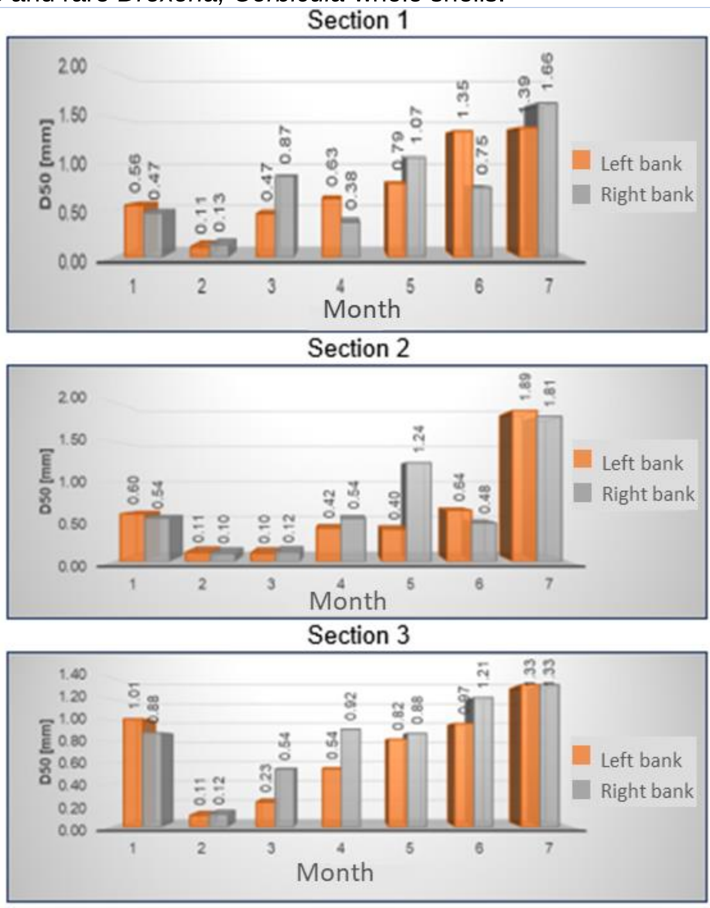


Figure 22 D50 mean sediment size - V year of analysis (INCDPM, 2011-2018)

Suspended sediment concentrations measured at different depths of the investigated sections have values ranging from 4.8 to 56.9 mg/l, with the highest concentrations being resulted on the Bala branch.

4.2.7. Climate regime

The climate regime of the area is of the continental-marine type and is due to the western air circulation over which the influence of the Black Sea overlaps. It is characterized by warm, sometimes torrid and dry summers, as well as slightly cold winters, often marked by strong blizzards in the continental area (Lipnica City Hall).

4.2.8. Ecological status of water bodies

For chemical assessment of the overall water bodies quality, series of water and sediment samples were taken in each analysis section (*Figure 14*). It was determined the average values for each quality indicator, the results being compared with the limit values of the quality classes provided by the *"Normative regarding the classification of the surface water quality in order to establish the ecological status of the water bodies"* (Official Monitor of Romania, 2006).

In order to determine the influence that anthropic interventions may have on the ecological status of the study area, the samples were taken in different series from a 6 years interval, which takes place before, during and after the structures construction.

In the water quality analysis, oxygen regime indicators particularly important because oxygen is the most representative parameter in assessing the functionality of ecosystems. In the studied sector, the CBO5, CCO-Mn, CCO-Cr values situate water in 1st and 2nd classes. Also, throughout the analyzed period, according to the limits specified in the "*Annex to Order of the Minister of Environment and Waters Management no. 161/2006 regarding the approval of the Normative regarding the classification of the surface water quality in order to establish the ecological status of the water bodies"* (Official Monitor of Romania, 2006), the values of the dissolved oxygen indicators and the saturation of the dissolved oxygen belong to the interval specific to the 1st and 2nd classes.

Nutrients are the chemical elements involved in phytoplanktonic production of organic matter (INCDM, 2012). The values of the ammonium, nitrates and total nitrogen indicators fall within the limits set by the above-mentioned normative, on the classification of water in 1st and 2nd grades and those for soluble orthophosphates, total phosphorus and chlorophyll belong to the limits corresponding to the 1st class of quality. Regarding the nitrites, they exceed the limits of 2nd quality class over some short periods.

Concerning the salinity indicators values (conductivity, dry filtration residue at 105^{0}C, chlorides, sulphates, calcium, magnesium, sodium), for the whole analyzed activity they belong to the interval corresponding to the limits of the 1st and 2nd classes.

Indicators of specific toxic pollutants of natural origin (total chromium, copper, zinc, arsenic, barium, selenium, cobalt, lead, cadmium, total iron, mercury, total manganese, nickel), the thermic regime and the acidification have values that place water in the 1st quality class. In the case of cobalt, in the first year of analysis the values were in the 2nd quality class, and for total iron, for short periods of the IV and V years were recorded values belonging to 3rd quality class.

Regarding the sediment assessment in the studied area, indicators of heavy metals, namely arsenic, cadmium, total chromium, copper, lead, mercury, zinc and nickel, have been investigated. At different points in the control sections, for copper, nickel and mercury they were recorded values exceeding the limits imposed by the sediment quality standard (INCDM, 2012). The highest concentration values for both copper and nickel were recorded in section 3 (Old Danube). Copper concentration exceeded 70 mg/kg at the right bank (standard limit 40 mg/kg) and the concentration of nickel was nearly 99 mg/kg near the left bank (the standard limit of 35 mg/kg).

4.3. Habitats

The studied area in this research is part of the Natura 2000 sites - the ROSCI0022 and the ROSPA0039 sites (INCDPM, 2011). The habitats found in the ROSCI0022 of the Bala branch are represented by Canadian poplar plantations (*Populus x canadensis*), anthropic communities with *Polygonum aviculare, Lolium perenne, Schlerochloa dur* and *Plantago major*, Danubian white willow forests (Salix alba), with blackberry (*Rubus caesius*) (*92A0 Salix alba and Populus alba galleries*) (INCDPM, 2011-2018).

ROSPA0039 also includes the sector studied in this paper, being important for nesting populations of the following species: *Coracias garrulus*, *Falco vespertinus, Aytya nyroca, Platalea leucorodia, Egretta garzetta, Nycticorax nycticorax, Plegadis falcinellus, Phalacrocorax pygmaeus*, *Ardea purpurea*, *Haliaetus albicilla*, *Ardeola ralloides*, *Lanius minor*, *Caprimulgus* *europaeus* and *Milvus migrans* (INCDPM, 2011-2018). (INCDPM, 2011-2018). *Figures 23*, *24* and *25* show examples of habitats formed in the Bala branch.

Figure 23 Habitats in the banks for the birds - Bala branch (INCDPM, 2011-2018)

Figure 24 Forest with black poplar (INCDPM, 2011-2018)

Figure 25 Echinochloa crus-galli, Portulaca oleracea, Polygonum lapathifolium, Portulaca oleracea species – Caragheorghe sandbank (INCDPM, 2011-2018)

The following habitats have been observed in the Turcescu area (the area between the Old Danube and the Bala branch): Canadian poplar plantation (*Populus x canadensis*), Danubian white willow forests (*Salix alba*) with *Rubus caesius* (92A0 *Salix alba* and *Galeries Populus alba*), anthropic communities with *Agropyron repens, Arctium lappa, Artemisia annua* and *Ballota nigra* (INCDPM, 2011-2018).

4.4. Terrestrial flora

In the Călăraşi - Braila sector the Canadian poplar plantations and the semi-natural habitats predominate. These are limited to narrow strips in riparian, temporarily flooded areas, with advanced degradation status, with many invasive species. In *figures 24* and *25* are represented black poplar forest and plant species located on the Caragheorghe sandbank.

4.5. Avifauna

From the avifaunistic point of view, INCDPM experts identified in the Danube sector between Călăraşi and Braila bird species protected by Council Directive 79/409/EEC (Directive 2009/147/EC, 2009), such as *Alcedo atthis, Aquila pomarina, Ardea purpurea, Ardeola ralloides, Chlidonias hybrida, Ciconia ciconia, Ciconia nigra*, *Circus aeruginosus, Egretta garzetta, Falco vespertinus, Haliaeetus albicilla, Milvus migrans, Nycticorax nycticorax, Platalea leucorodia, Plegadis falcinellus, Sterna hirundo, Accipiter brevipes, Chlidonias niger, Larus minutus, Phalacrocorax pygmeus*, *Picus canus* (INCDPM, 2011-2018).

The studied zone, represented by the Bala branch – Old Danube bifurcation, is part of the migration and nesting area for aquatic birds (INCDPM, 2011-2018). In this area, 4 protected species were identified: *Sylvia nisoria, Sterna hirundo, Tadorna ferruginea, Lanius minor* (*Figure 26*). (INCDPM, 2011-2018).

Sylvia nisoria

Sterna hirundo

Tadorna ferruginea

Lanius minor

Figure 26 Species of birds observed in the Bala branch – Old Danube bifurcation (SOR, Birds of Romania, 2017)

At the same time, the Bala branch – Old Danube bifurcation is part of the aquatic birds wintering area, important birds species like corvids (*Corvus sp*), large cormorant (*Phalacrocorax carbo*), mallard (*Anas platyrhynchos*) and yellow-legged gull (*Larus sp.*) being identified in this area (INCDPM, 2011-2018).

4.6. Aquatic flora and fauna

The ecosystem components - plant populations, animals, micro-organisms, and biotope structure - are subsystems between which are established multiple and complex relations that ensure the energy flow, the material circuit and the efficiency of the self-control mechanisms.

4.6.1. Phytoplankton

Phytoplankton data were obtained from monitoring activities performed during pre-construction, construction and post-construction periods.

Regarding the taxonomic composition of the phytoplankton, no major changes were noted during and after the completion of the constructions, compared to the stage before the start of the hydrotechnical structures.

During the monitoring period, the following quality indices were used to assess the ecological status of the aquatic ecosystem: Saprob Index, Simpson Diversity Index, Taxonomic Numbers Index and Numerical Abundance Index (INCDPM, 2011) (INCDPM, 2015) (INCDPM, 2014). Since it is very difficult to specify the accuracy with which each of these indices is one of the major pressures, according to GD 80/2011 (Decision No. 80/2011), the multimeter index, based on the values of all mentioned indices, was determined. For the calculation of the multimetric index, a weighting of the importance of the indices selected/used for the evaluation of the algae communities and the assessment of the ecological status was determined, as follows: Saprob Index (IS): 25%; Simpson Diversity Index (ID): 40%; Taxonomic Number Index (INT): 20%; Numeric Abundance Index (IAND): 15% (INCDPM, 2011).

The assessment of the ecological status based on the values of the multimetric index (IM) was performed according to the range of values obtained (*Table 2*) (INCDPM, 2011) (Decision No. 80/2011).

Table 2. Ecological status evaluation based on Multimetric Index (IM) values

Multimetric Index [IM]	**≥ 0,8**	**0,8 – 0,6**	**0,6 – 0,4**	**0,4 – 0,2**	**<0,2**
Ecological status	Very good	Good	Moderate	Low	Bad

According to *Annex 6.1. The system for classification and assessment of surface water bodies according to the Water Framework Directive*, for the compliance with the **very good ecological status**, the indicators for water body RO14 (of which the analyzed Danube sector is part of) must have the following values: Saprob Index: max. 2.35; Simpson Diversity Index: min. 0.85; Taxonomic Number Index: min. 10; index based on relative numerical abundance (proportion represented by *Bacillariophyceae*): max. 95%. Table 3 summarizes the values of the main qualitative and quantitative indicators for the studied area during the monitoring period.

Table 3 Qualitative and quantitative indicators - phytoplankton

Year	**Section**	**Saprob Index**	**Simpson Diversity Index**	**Taxon Number**	**Numerical abundance index** (*Bacillariophyta*)	**Multimetric Index** (HG 80/2011)	**Ecological status** (HG 80/2011)
Before construction							
I	**S2**	**1,7**	**0,676**	**20**	**99,2**	**0,825**	Very good
	S3	**1,6**	**0,674**	**12**	**100**	**0,811**	Very good
During construction							
II	S2	1,3	0,712	17	89,66	0,807	Very good
	S3	1,37	0,687	12	84,73	0,767	Good
III	S2	1,23	0,65	11	97,11	0,74	Good
	S3	1,53	0,656	10	94,6	0,76	Good
IV	S2	1,84	0,63	15	97,14	0,844	Very good
	S3	1,65	0,681	17	100	0,846	Very good
V	S2	1,68	0,678	16	100	0,848	Very good
	S3	1,77	0,675	16	100	0,858	Very good
Average	**S2**	**1,513**	**0,6675**	**17**	**95,978**	**0,81**	Very good
	S3	**1,58**	**0,675**	**17**	**94,833**	**0,808**	Very good
After construction							
VI	S2	1,57	0,704	15	100	0,848	Very good
	S3	1,30	0,705	14	95	0,810	Very good
VII	S2	1,5	0,734	16	100	0,852	Very good

Year	Section	Saprob Index	Simpson Diversity Index	Taxon Number	Numerical abundance index (*Bacillariophyta*)	Multimetric Index (HG 80/2011)	Ecological status (HG 80/2011)
	S3	1,53	0,728	16	88,89	0,85	Very good
Average	**S2**	**1,535**	**0,719**	**16**	**100**	**0,841**	Very good
	S3	**1,415**	**0,717**	**16**	**91,945**	**0,826**	Very good

S2 – Section 2; S3 –Section 3

According to the GD 80/2011, from the analysis of the multimetric index values for phytoplankton, it has been shown that throughout the monitoring period the ecological status of the Danube water is between good and very good. The quality indicators of the monitored phytoplankton recorded a variability dependent mainly on the sampling time, following the seasonal dynamics of the main algae groups (INCDPM, 2011) (INCDPM, 2015) (INCDPM, 2014) (INCDPM, 2016).

4.6.2. Macrophytes

In the area of interest, the presence of macrophyte species is reduced, but on the right bank the *Butomus umbellatus L.* is identified (*Figure 27*). The structure of Danube biocenoses and their functionality is mainly determined by the fluvial character of the ecosystem (INCDPM, 2015). Thus, the presence of small macrophytes is more frequent on the right bank, due to a profile with a slow slope where macrophytes are much easier to fix compared to the left bank with a very steep profile (INCDPM, 2011).

Figure 27 The presence of macrophytes in section 3 – right bank (INCDPM, 2015)

4.6.3. Macroinvertebrates

Generally, in the coastal area of the river there are more macronutrient communities and the number of individuals is usually very low in the deep-water area (Csányi B., et al., 2012). According to Csányi B. between km 347 - km 341 the right bank of the Danube is formed by sediment rich in fossils, as a solid substrate in the habitats of the coastal zone. In the paper "Methods on Macro-Vertebrate Research in Large Rivers: Case study Lower Danube, Romania" in order to analyze the taxonomic distribution, a series of samples from the studied sector were taken in May first year of analysis

In the section located upstream of the Bala branch – Old Danube bifurcation, the number of members of the insect group (*Chironomidae*) is remarkable and dominant in the fine sediment along the left bank (400 ind./sample), and the number of individuals is usually very low in the depth zone. In the cross section located on the Old Danube, an extremely large number of crustaceans (1547 ind./sample), mainly formed by *Chelicorophium curvispinum* (1100 ind./sample) living on the solid substrate of the riverbed (Csányi B., et al., 2012).

4.6.4. Ichthyofauna

Because the hydrotechnical structures designed to improve navigation conditions can affect the benthic reophilic species, at the level of the first year of analysis (before the start of the construction), the Bala branch was investigated. In this regard, the abiotic attributes of fish habitats (water depth and temperature, meteorological characteristics, riverbed material) were analyzed. During the summer campaign of the first year of analysis, 22 species and 657 fish were captured on the Bala branch, which is the subject of this paper. The most abundant species were *Z. streber* - 43% and *R. albipinnatus* - 14%.

At the same time, in the Lower Danube there are 4 species of sturgeon: beluga (*Huso huso*), stellate sturgeon (*Acipenser stellatus*), sterlet (*Acipenser ruthenus*) and Russian sturgeon (*Acipenser gueldenstaedtii*) (INCDPM, 2011). The scientific and economic importance of these species is given both by their unique value for biodiversity and by the growth of caviar market demand (INCDPM, 2016). Overexploitation, anthropic interventions, habitat loss and pollution have severely affected all sturgeon species, and it is necessary to ensure long-term conservation

(Djikanovic V., et al., 2015) (INCDPM, 2016). Since 1998, all sturgeon species have been protected by the "C*onvention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES)".

Beluga (*Huso huso* Linnaeus, 1758)

Stellate sturgeon (*Acipenser stellatus* Pallas, 1771)

Sterlet (*Acipenser ruthenus* Linnaeus, 1758)

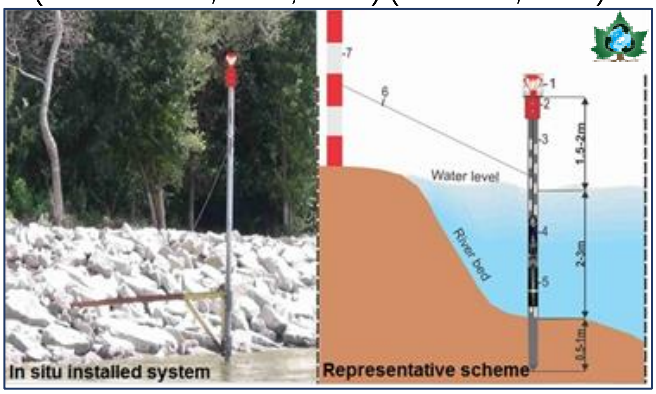
Russian sturgeon (*Acipenser gueldenstaedtii* Brandt & Ratzeburg, 1883)

Figure 28 Species of sturgeons identified in the Lower Danube (INCDPM, 2011-2018) (INCDPM, 2016)

In this regard, the INCDPM experts have carried out monitoring activities of the ultrasonic tagged sturgeons in order to determine the possible impact that the construction of the hydrotechnical works could have on them (INCDPM, 2011-2018). This could be achieved by developing monitoring systems that provide data about the migratory route of ultrasonic marked sturgeons. Sturgeon monitoring activities began in the first year of analysis, with the first surveillance systems developed by INCDPM (Raischi M.C., et al., 2016) (INCDPM, 2016).

In order to create monitoring gates, stationary (Deak, Badilita, et al., 2012) and mobile (Deak, Raischi, et al., 2014) stations were installed in the areas of Călăraşi - Braila sector where hydrotechnical works were performed monitoring of ichthyofauna and especially of ultrasonic tagged sturgeons.

These stations are used to determine water quality parameters and migratory route of ultrasonic tagged sturgeon.



(1) light warning system; (2) metal protective cover with special closing system; (3) slotted pipe; (4) multiparameter used to monitor water quality parameters and water levels; (5) ultrasonic signal receiver; (6) anchor cable; (7) pole anchor

Figure 29 DKTB ichthyofauna monitoring station, especially sturgeons, through remote sensing, with ultrasonic tags in different hydrological conditions (Deak, Badilita, et al. 2012)

The DKMR-01T mobile station to monitor through remote sensing, the ichthyofauna, especially sturgeons with ultrasonic tags in difficult hydromorphological conditions (Deak, Raischi, et al., 2014) (*Figure 30*) operates on the basis of the flotation pressure principle that offers mobility both vertically and horizontally and the possibility of using under any conditions: hydromorphological, hydrodynamic and meteorological, eliminating the risk of stations loss and implicitly of the volume of recorded information (Deak, Raischi, et al., 2014)

(1) light warning system; (2) floating sheet tank; (3) connecting system between tank and protection pipe; (4) protective cover; (5) protective tube provided with slots; (6) multiparameter used for the quality parameters monitoring; (7) automatic ultrasonic receiver for ichthyofauna monitoring.

Figure 30 DKMR-01T mobile station to monitor through remote sensing, the ichthyofauna, especially sturgeons with ultrasonic tags in difficult hydromorphological conditions (Deak, Raischi, et al. 2014).

The use of the two stations has led to the achievement of unique information regarding the conservation status of sturgeon species in the Lower Danube. As a result of the monitoring activities carried out during the 6 years of the analysis, 349 sturgeons from 4 species were captured, marked and monitored (INCDPM, 2017).

4.7. Anthropic interventions on the Lower Danube sector

The first hydrotechnical structures in the Danube basin began in the 16th century in Hungary, following with the first hydrotechnical construction in Austria, in 1930 and the first dam in southern Bavaria, in 1927 (ICPDR). The first works to improve navigation conditions were begun in the Upper Danube sector in the 19th century. At present, both the Danube and some of its main tributaries are navigable.

In Romania, the first engineering works were initiated between 1834 and 1837. These consisted of riverbed regularization to improve the navigation conditions (Egis, 2015).

In order to generate electricity and to improve the navigation conditions, on the Romanian Danube sector, they were implemented Hydropower and Navigation Systems Iron Gates I (*Figure 31)* and II (*Figure 32*), built in collaboration with the Serbian partners (Hidroelectrica, 2010).

Figure 31 Hydropower and Navigation Systems Iron Gates I (Hidroelectrica, 2010)

Figure 32 Hydropower and Navigation Systems Iron Gates II (Hidroelectrica, 2010)

Another important example is the Cernavodă Nuclearoelectric Power Plant (*Figure 33*). This ensures safe operation of Nuclear Units 1 and 2, each with 700 MW of installed power (EnergoNuclear, 2011).

Figure 33 Cernavodă Nuclearoelectric Power Plant (Nuclearelectrica, 2014)

Regarding the works to improve navigation conditions, the most important such intervention is the Danube-Black Sea Channel, which extends from Cernavodă to Agigea (Egis, 2015).

In order to maintain the navigable channel and to exploit the sand and gravel from the riverbed, dredging works were carried out. From the Lower Danube riverbed, a volume of sediment is annually dredged, with an average value of between 1.5 and 3.5 Mm^3/year (Egis, 2015).

4.8. Description of hydrotechnical constructions in the study area

On the Danube sector between Călăraşi and Braila, the rules established by the Danube Commission recommend that the waterway should have a depth of 2.5 m under the waterway and regulation level and a width of 180 m (INCDPM, 2011-2018).

In this sector, the navigation conditions are not ensured throughout the year given the existing context in the Bala branch – Old Danube bifurcation area: in low water situations, the distribution of the water flow between Bala and Old Danube has become unfavorable to the Danube's main branch (INCDPM, 2011-2018), (Egis, 2015), (Tractebel Development Engineering, 2012).

Therefore, the decrease of the discharges and water levels on the Old Danube affects all the downstream river use. At the same time, this situation leads to a prolongation of the drought period for the wetlands located in the Danube main branch area, to the increase of the sedimentation on the Old Danube and the erosion phenomena on the Bala branch, to the reduction of the availability of cooling water insurance for the Cernavodă Nuclear Power Plant and to the ever-increasing annual need for dredging maintenance of the waterway (Tractebel Development Engineering, 2012).

Regarding the issue of the flows redistribution from the Bala branch – Old Danube bifurcation, there were several stages in which different solutions were proposed (Buzuloiu Gh. And Chirila C. 2003):

- In the 1950s the following works were proposed: moving the mouth of the Bala branch upstream of the submerged rock at Pârjoaia; implementation of a guiding dike on the left bank of the Bala branch to annihilate the submerged groin effect of the Pârjoaia rock and direct the water current on the Old Danube; the barring of the Bala branch through a pier. In addition, to increase the water depths at low discharge levels, calibration works were planned on the Danube between 345-238 km. Abandoning works on the Danube-Black Sea Channel in 1953 also led to the abandonment of the aforementioned constructions.
- From 1979 to 1986, on the basis of model studies carried out at the Institute of Hydrotechnical Research (current INCDPM), the design documentation was prepared, which included, among others, in the area of Bala branch, the construction of a closure and routing dike on the left bank, a right bank protection and the constructions of two submersible bottom sills in order to reduce the liquid flows.
- After 1990, the project was updated, proposing the execution of a single bottom sill on the Bala branch at km 9.5 with a share of -1.85 m from the Călăraşi local low water level, in order to increase the flows on the Old Danube. In addition, a guiding wall was constructed on the left bank of the Danube - Bala branch area, so that the width of the channel at the entrance on the branch was reduced.

Stopped again, at the end of 1995, unfinished works in the upstream area of the Bala branch led to the acceleration of the small flow absorption on this branch as a result of the narrowing section. At the same time, the incomplete constructions led to the modification of the riverbed geometry at the entrance to the Bala branch as a result of the erosion caused by the increase of the discharges (Tractebel Development Engineering, 2012).

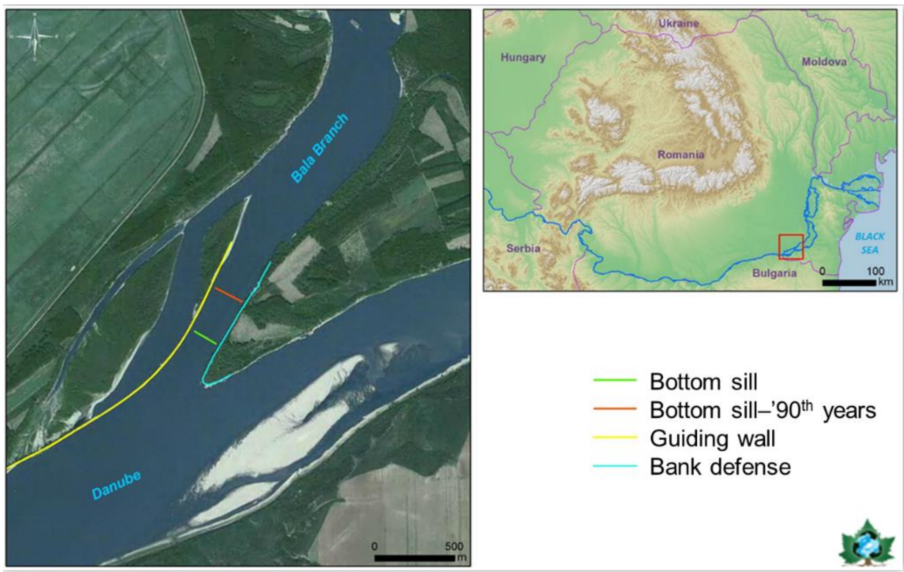


Figure 34 Hydrotechnical constructions location (Nicolae A.-F., Deak Gy., et al., 2017)

This led to the drastic reduction of the depths necessary for the needed and the non-assurance of the necessary catchments for the Cernavodă NPP units (Buzuloiu Gh. And Chirila C., 2003). In this context, it was imperative to propose a new series of hydrotechnical works to ensure optimal conditions of navigation throughout the year. These constructions are represented by: a bottom sill, a routing wall and shore defense, all performed on the Bala branch (*Figure 34*) (INCDPM, 2011-2018) (Nicholas A.-F., Deak Gy., Et al., 2017).

By implementation of these hydrotechnical constructions, it is intended to modify the flow distribution between the Old Danube and Bala branch, thus contributing to the improvement of the navigation conditions on the Lower Old Danube.

The bottom sill is provided across the width of the Bala branch. It is embedded in the guiding wall (left bank) and in the shore defense (right bank). The bottom sill is located approximately 300 m upstream of the site of the old submersible structure, whose construction began in the early 1990s, but has not been completed. It was designed to have a length of 195.30 m between the slopes of the two hydrotechnical constructions (the guiding wall and the shore defense). According to the project, the structure is built in steps, in the central area there is a ditch at a height of -3.48 m from the ENR. The width of the canopy ranges from 10 m in the ditch area to 40 m in the sector where the elevation is -1.85 m from ENR (Tractebel Development Engineering, 2012).

Figure 35. Construction of hydrotechnical structures to improve navigation conditions on the Danube (INCDPM, 2015)

The constructive solution of the guiding wall consists in the construction of a stone digging with a share of 11.28 MNS, 5 m wide and 2164 m long (Tractebel Development Engineering, 2012). The shore defense has as a constructive solution the building of a protection from raw stone layers. It has a share of 10.78 MNS. The stone used in the construction of the hydrotechnical works is a pillow-lava diabase, brought from the "Revărsarea" quarry (Tulcea) (Telarmed, 2011).

Chapter 5. NUMERICAL MODELING

In order to carry out investigations on the morphological changes of the studied sector riverbed, within the research it was applied as a method of study the numerical modeling, using the *Delft3D* program.

5.1. Grid set up

The medium-scale model was developed for the area which covers the Danube sector on a length of 5 km on the Old Danube and 2.5 km on the Bala branch. The construction of the cellular network was accomplished with the help of border boundaries generated by geographic data processing and map analysis programs.

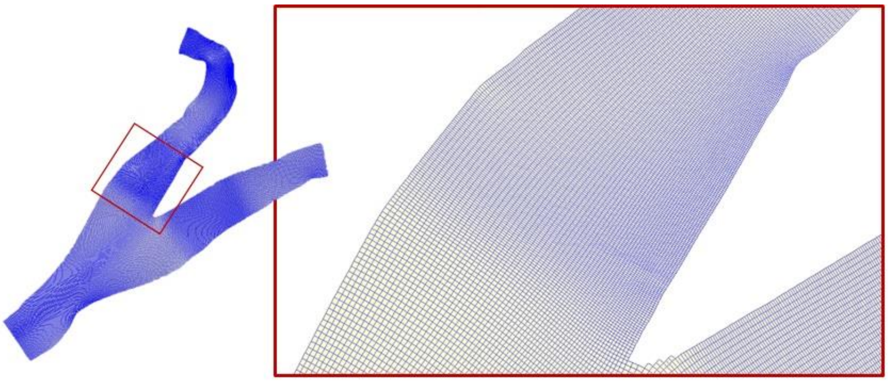


Figure 36 Grid detail

The limits imposed by the banks were established on the basis of both the information obtained from the topographical measurements carried out by INCDPM experts as well as the satellite data from the high flow periods. Depending on this, initially, the cellular network was schematized manually through splines, and subsequently generated automatically. In order to integrate the hydrotechnical structure geometry into the model and allow a better interpretation of the results, the grid was refined at the entrance to the Bala branch and the Bala – Old Danube bifurcation zone (*Figure 36*). The grid thus constructed has 59024 cells, of which 528 longitudinally and 113 transversally developed. This was accomplished using polyhedral meshing cells with quadrilateral faces with dimensions ranging between 3.88 - 27.32 m in the longitudinal direction and 2.90 - 21.99 m in the transverse direction. These features provide the optimal proportion between grid size, runtime and results.

5.2. Geometric model set up

The geometric model for the study area was created based on the grid and the data obtained from the field measurements carried out in March (the 6th year of analysis), when a discharge of 12,300 m^3/s was recorded at the Călăraşi hydrometric station. The geometric model (*Figure 37*) was performed analytically by automatically correlating the coordinates of the grid cell centers and the georeferential information in the same coordinate system, by using the *QUICKIN* module. Multibeam bathymetry data was processed so that in each cell of the grid it was assigned the value of the absolute quota - in Stereo 70 MNS - of the Danube riverbed. *Figure 38* is a 3D detail with the hydro-technical works in the Bala branch area (exported from *Delft3D*, viewed in *GlobalMapper*).

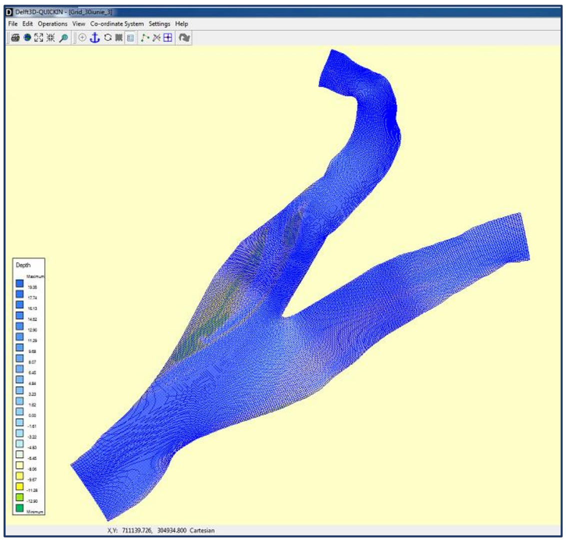


Figure 37 Grid in the study area with bathymetric data

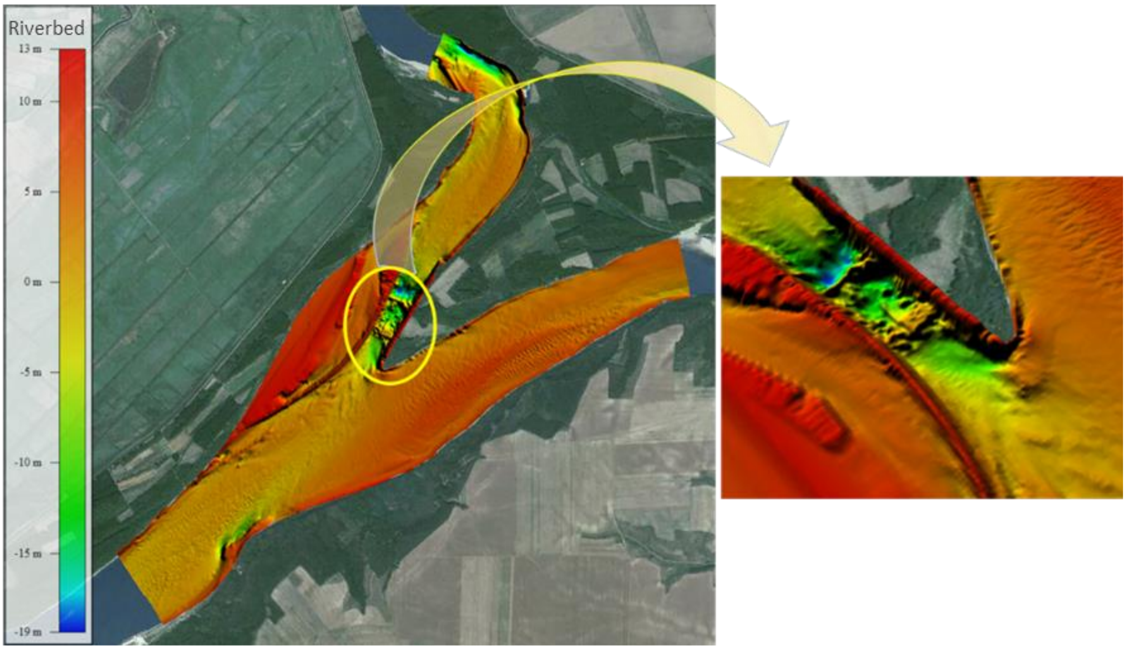


Figure 38 The geometric model exported from the Delft3D program. Detail - Hydrotechnical structures in the Bala branch area

5.3. Configuration of the hydrodynamic test model

In order to obtain a numerical model to provide highly reliable results, a σ hydrodynamic test model was developed in the *FLOW* module, which implied the use of the data obtained from the hydraulic parameters monitoring.

In the first stage, the model domain was created by loading the grid and the geometric model. At the same time, 10 vertical layers of computation were selected, this procedure being attributed to the quasi-three-dimensional characteristic model, which allows the parameterization of vertical velocities sections (Yossef M. and Becker A., 2015).

Regarding the time interval, a two-day analysis period was selected in which the time step was 15 seconds. The required limit conditions were discharge in the Danube upstream section and the water level at the downstream model boundary, both on the Bala branch and on the Old Danube. These limits (*Table 4*) represent the values obtained from field measurements from the date of the multibeam bathymetry.

Table 4. Limit conditions used to configurate the hydrodynamic model

		Discharge [m^3/s]	H [m]*
Upstream	Danube	10800	12,9
Downstream	Bala branch	5781	12,5
	Old Danube	5019	12,6

** relative to BSS - Black Sea Sulina*

After selecting the physical and numerical parameters, the control and analysis points and sections were designated for the studied sector. The results obtained from the runs were visualized using the *Delft3D-QUICKPLOT* module. In order to obtain highly reliable results with the measured values, the test model was calibrated and validated, these steps being set out below.

5.3.1. Calibration of the hydrodynamic model

The hydrodynamic test model was calibrated according to the water level, discharge and flow velocities. The calibration process was carried out gradually by changing the value of the roughness and viscosity parameters. Depending on the result of the first model, the values of the calibration parameters for the second model were modified, following that, the values of the hydrodynamic parameters (water level, discharge and flow velocities) were similar to those obtained from measurements. Therefore, it was imperative for the models to be verified with the measured data. Comparisons were made both at the upstream and downstream limits and in the control sections. Taking into account these aspects, models were developed in which the time step and the roughness formulas and values varied. In the case of roughness, the formula developed by Manning was used.

In the calibration stage, 7 models were analyzed. The results obtained from the rolling process of these models were compared with those obtained from field measurements. Following these comparisons, in all variants, the water level values provided by the model were equal to those obtained from the measurements. Conversely, in the case of discharge, the same equivalence is not maintained, thus the relative percentage error was calculated at the downstream boundary of the studied area:

$$A = \frac{P - Ps}{P} \times 100, \ [\%] \qquad (2)$$

Where: A - percentage relative error; P - parameter resulting from measurements - Qr, Hr; Ps - parameter resulting from numerical simulations - Qs, Hs.

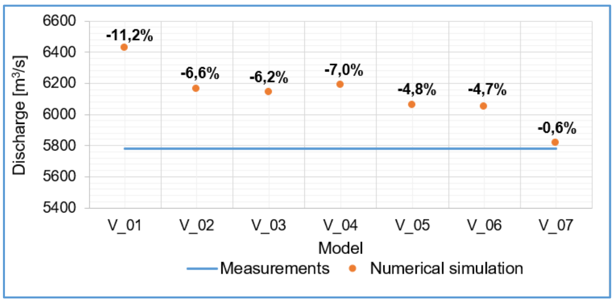


Figure 39 Calibration stage – Discharge comparison - Bala branch

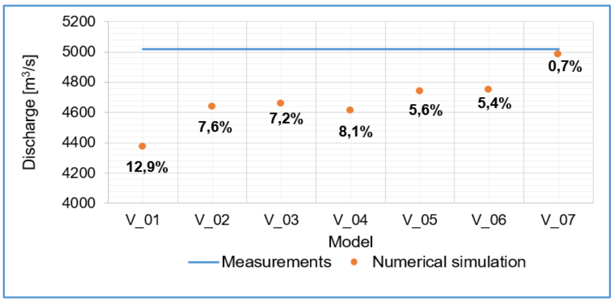


Figure 40 Calibration stage – Discharge comparison – Old Danube

As a result of these comparisons (*Figures 39* and *40*), the V_07 has provided results close to those obtained from the field measurements (at the downstream boundary deviations of approx. 0.6% on the Bala branch and approx. 0.7% on the Old Danube). To achieve the V_07 model, the value of 0.0001 m^2/s of vertical viscosity was assigned and a **rgh* file was used in which different values were allocated to the analyzed river sector (0.03 $s/m^{1/3}$ on the Bala branch and 0.025 $s/m^{1/3}$ on the Danube).

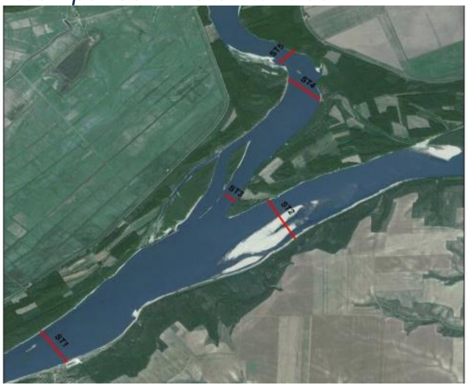
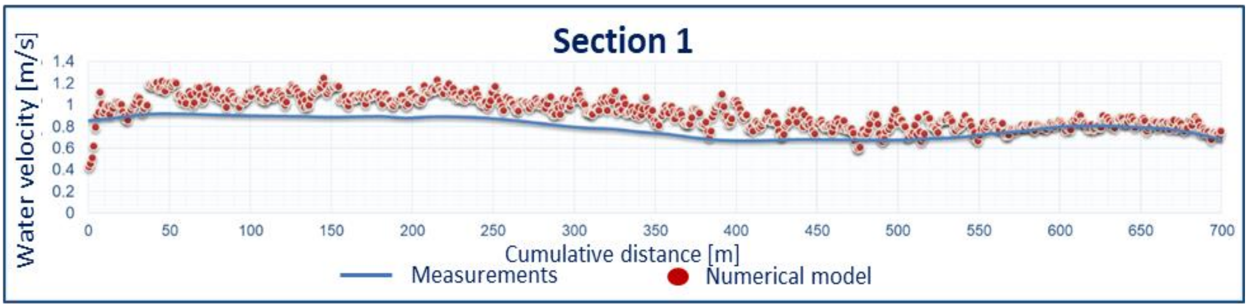


Figure 41 Cross sections analyzed for velocity comparison

Also, in the calibration stage, the water velocities provided by the V_07 model were compared with the water velocities measured by ADCP in the analyzed sections of the field (*Figure 41*). Generally, in the analyzed sections a similar trend is maintained between the vertically-mediated values of the water velocities obtained from the measurements and those resulting from the numerical modeling, thus confirming that the model can provide results similar to the situation on the ground.



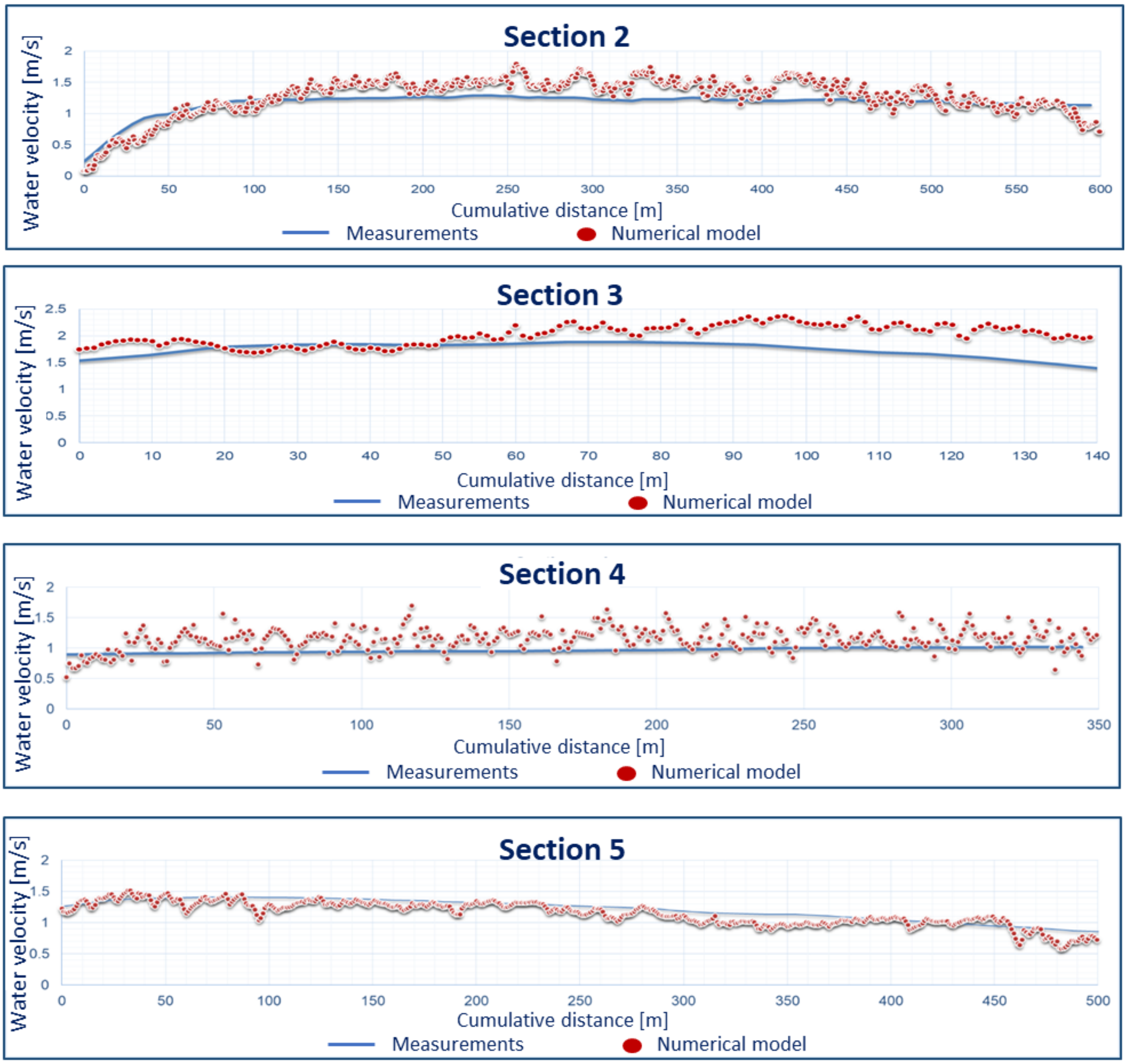


Figure 42 Differences between vertically-mediated values of water velocities obtained from in situ measurements and from numerical modeling

In order to reduce the processing time, it was developed a model through which the calculations for the vertical average velocity were automated with the help of a development module form the *Microsoft Excel* application through the *Visual Basic* programming language (*VBA*).

5.3.2. Validation of the hydrodynamic model

In order to verify the accuracy and precision of the mathematical calculations it was necessary to pass the validation step, which involves the use in the numerical modeling of sets of hydrological data different from those used in the calibration stage.

The validation of the model was based on the discharge and water level values. In this regard, two discharges values, different from the one used in the calibration step (3000 m^3/s and 11200 m^3/s), were applied as upstream limits. Both water discharges were recorded at the upstream boundary of the model, in October of the V year of analysis and June of the IV year of analysis, respectively. In *Table 5* are the input data used in the numerical modeling performed for the hydrodynamic model validation. At the end of the calculations they were checked the parameters related to the distribution of the discharges on the Bala branch and the Old Danube and the water levels at the downstream end of the studied sector.

Table 5 Hydrological data used in the validation step

UPSTREAM LIMIT		DOWNSTREAM LIMIT			
Danube		Bala branch		Old Danube	
Q, [m³/s]	H, [m]*	Q, [m³/s]	H, [m]*	Q, [m³/s]	H, [m]*
3000	6,5	2315	5,94	685	6,03
11200	13,1	5943	12,70	5225	12,79

** relative to BSS - Black Sea Sulina*

For the 3000 m^3/s discharge recorded at the upstream boundary, the distribution of the flows on the two branches obtained from the simulations is in accordance with the one determined by measurements, the difference between them being a 0.5% deviation at the downstream boundary of the Bala branch and 1.7% downstream of the Old Danube. For the discharge of 11200 m^3/s, the difference between the simulated values and those determined by measurements is 0.9% on the Bala branch and 0.8% on the Old Danube. With regard to water level, the values obtained from numerical modeling are equivalent to those resulting from the measurements.

The results obtained in the calibration and validation steps confirm that the built-in numerical model can provide data with a high degree of confidence.

5.4. Configuration of the morphohydrodynamic model

Based on the data obtained from the measurements and the quasi-3D hydrodynamic model presented previously, using the *FLOW* module of the *Delft3D* program, the *"Sediments"* component was accessed from the *"Process"* section, allowing analysis of the parameters defining the sediments transport process. The *Dleft3D* program allows analyzes of sediment transport for both sediment in suspension and bed-load sediments, for cohesive and non-cohesive sediments (Deltares, 2011). In this case the advection-diffusion formula was used.

Relative to the analysis of the mean sediment diameter, a D50 constant value of 0.25 mm was used in the program. Considering the data from the literature and the results obtained from the analyzes, the value of 0.07 kg/m^3 of the sediment concentration was applied.

5.4.1. Hydrodynamic characteristics of morphohydrodynamic model

In order to develop a model that provides clear information with a high degree of confidence, it was necessary to calibrate the morphohydrodynamic model. In this regard, it was intended that the results obtained by numerical modeling would be similar to those obtained from field measurements.

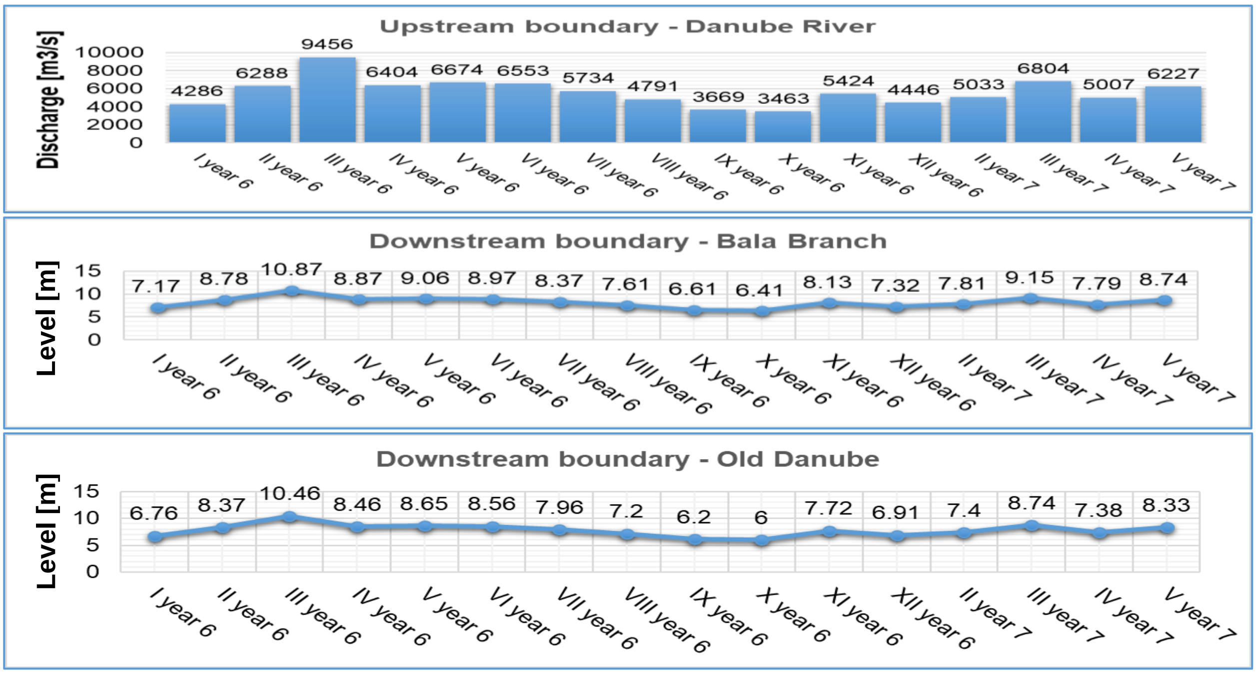


Figure 43 Hydrodynamic parameters used as input data for the morphohydrodynamic model

The morphohydrodynamic model was designed in order to follow the morphological changes taking place in the analyzed sector over a period of 16 months. Thus, the results to be obtained following the running model (which was created on the basis of the measurements of the VI year of the analysis), must provide an image of the riverbed similar to that resulting from the multibeam measurements in the Spring of the VII year of analysis. Consequently, based on the results of field campaigns conducted over 16 months, a hydrograph was used as the upstream limit of the model (*Figure 43*). In the downstream sections, for boundary conditions, the water level values for that hydrograph have been assigned.

One of the advantages of using the *Delft3D* numeric modeling software is that the riverbed's relief is updated at each calculation step (Deltares, 2011).

5.4.2. Results obtained from the calibration process of the morphohydrodynamic model

In general, the calibration of a morphohydrodynamic model is carried out in two steps. The first stage aims to reproduce, on a large scale and on a long-term basis, the morphodynamic characteristics of the watercourse. The second step involves a detailed analysis of a water sector over a short period of time (Yossef M. and Becker A. 2015). At present, information on riverbed relief in the analyzed sector is not sufficient to make a large-scale and long-term comparison of the results from numerical modeling with those resulting from measurements.

Using the parameters that define the hydrodynamic and sediment transport processes, whose values were obtained from the monitoring during January (VI year) - May (VII year), as input data, it was intended that the resulting model would provide an image of the relief of the riverbed similar to that obtained from the multibeam measurements made in the Spring of the VII year of analysis.

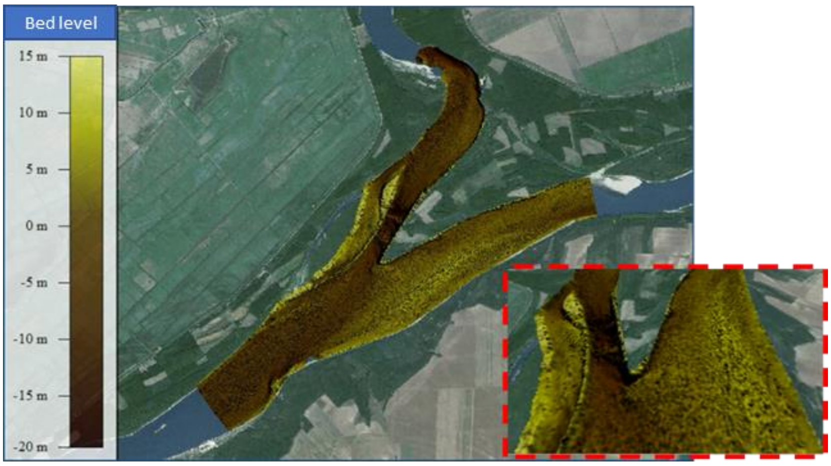


Figure 44 The riverbed relief resulted from bathymetric multibeam measurements performed in the VII year of analysis. Bifurcation area detail

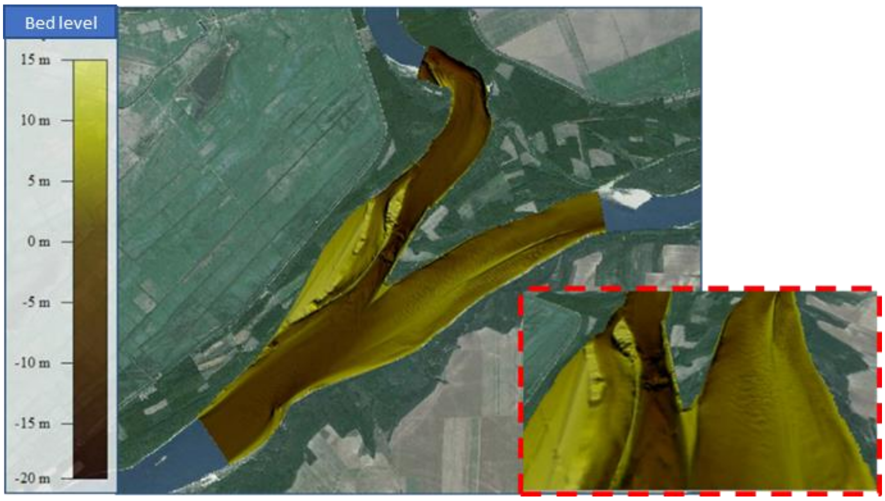


Figure 45 The riverbed relief resulted from the morphohydrodynamic model - calibration step. Bifurcation area detail

In *figures 44* and *45* are represented the images of the riverbed relief resulted from the measurements compared to the one obtained from the numerical modeling, the three-dimensional details of the bifurcation zone being outlined. From these images it can be observed the similarities between the bathymetric terrain model and the riverbed relief from the numerical modeling

In addition, in order to calibrate the morphohydrodynamic model, sections of analysis (*Figure 46*) were selected both in the transversal and longitudinal directions, in which the bathymetric profiles of the riverbed resulted from the numerical modeling were compared with those obtained from the multibeam measurements after 16 months (*Figures 47* and *48*).

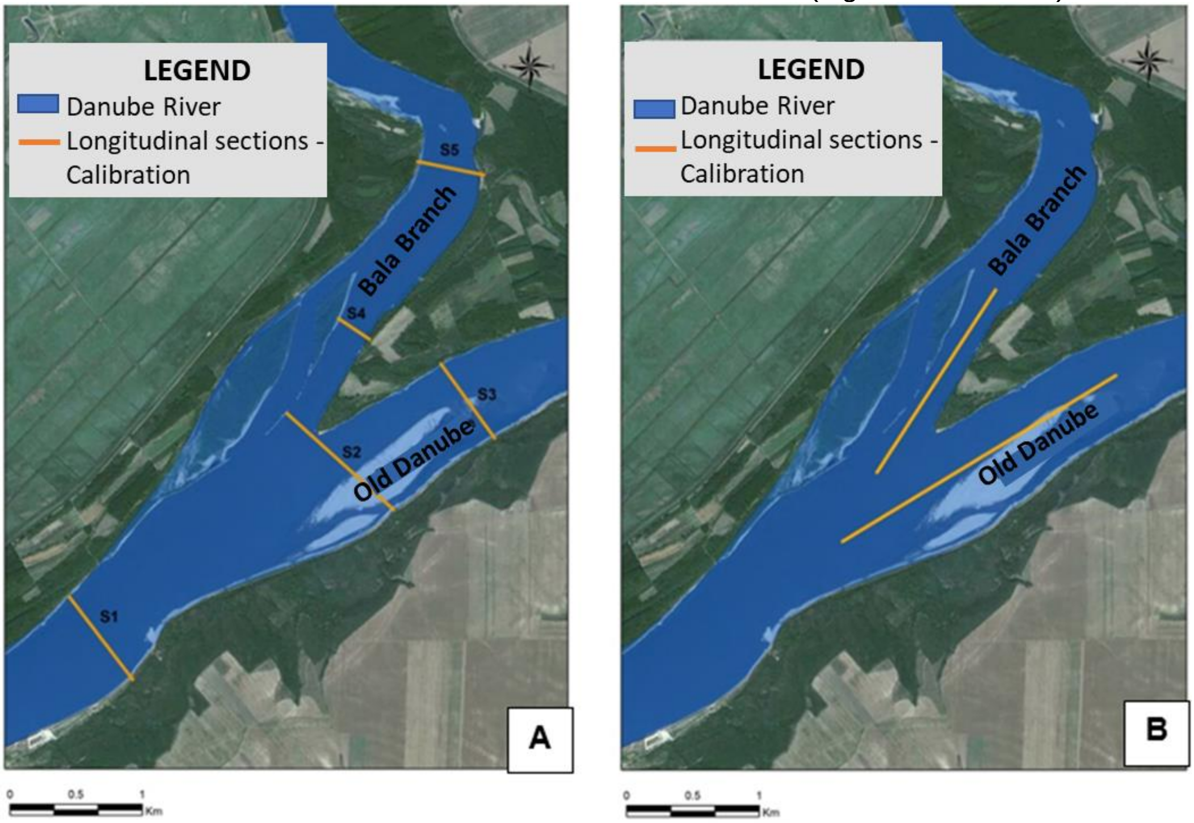
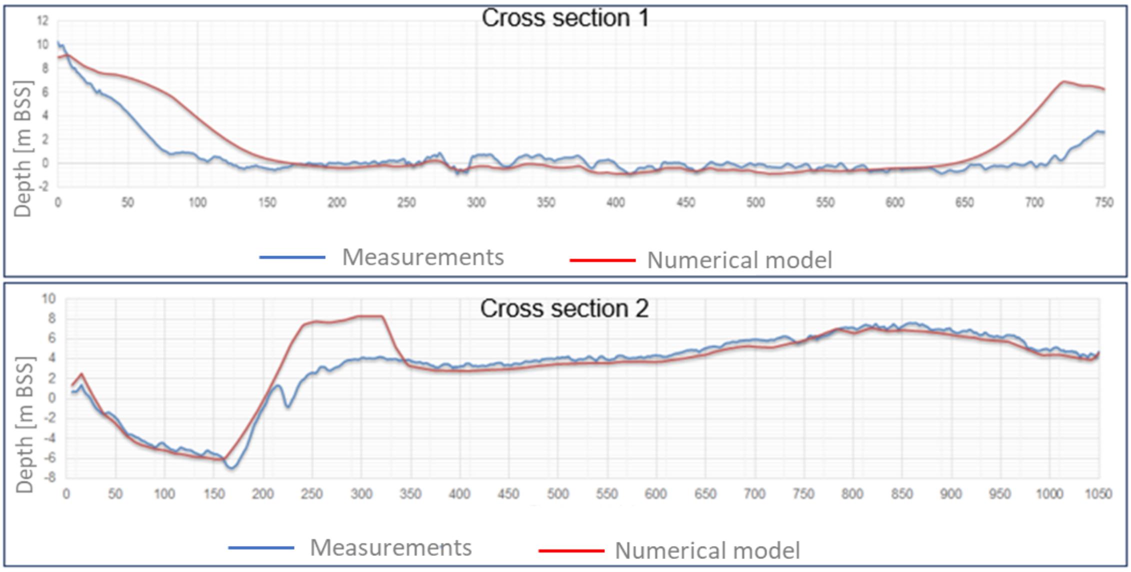


Figure 46 Calibration of the morphohydrodynamic model - Cross section (A) and longitudinal sections (B)



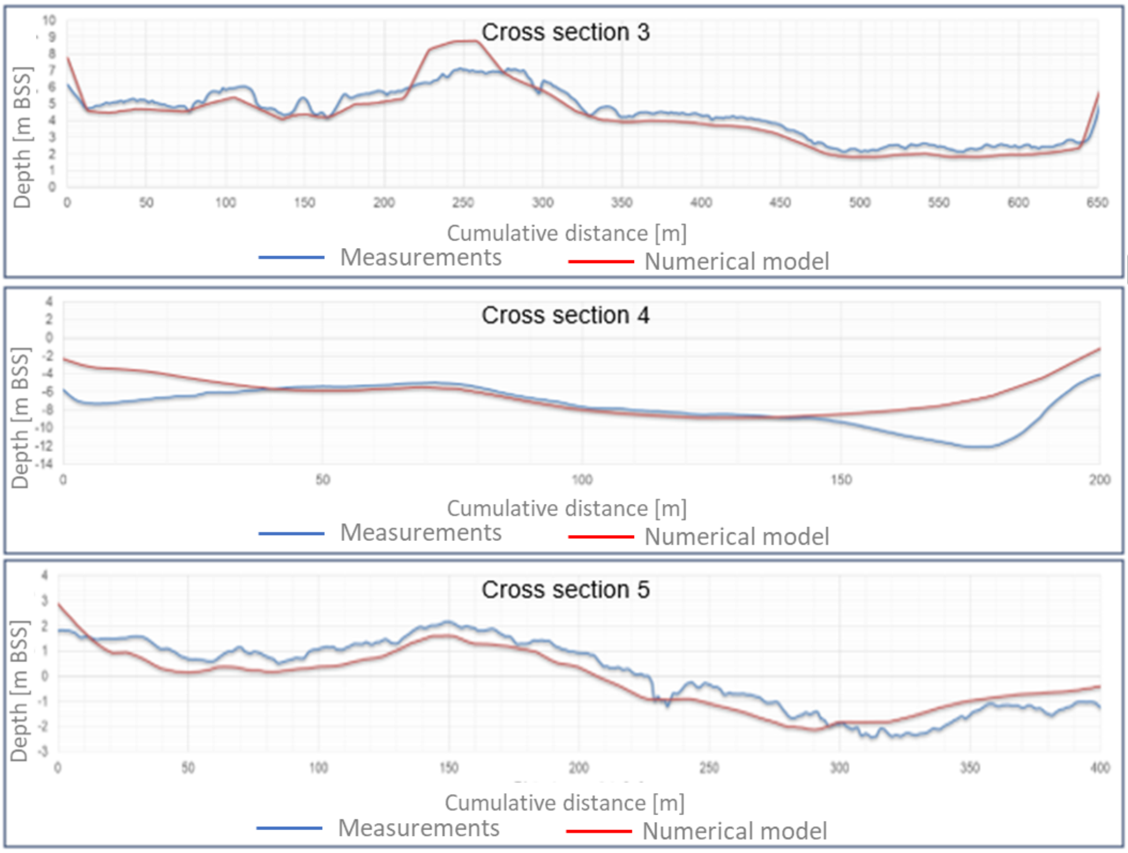


Figure 46 Cross sections representing the Danube riverbed - results obtained from in situ measurements and results from numerical modeling

In the case of cross-sections, the same trend is maintained between the results obtained from the numerical modeling and the data from the field measurements (*Figure 47*).

Figure 48 shows the riverbed in the longitudinal sections corresponding to the Bala branch and the Old Danube. For both sections there are no significant differences between the numerical model and the field situation.

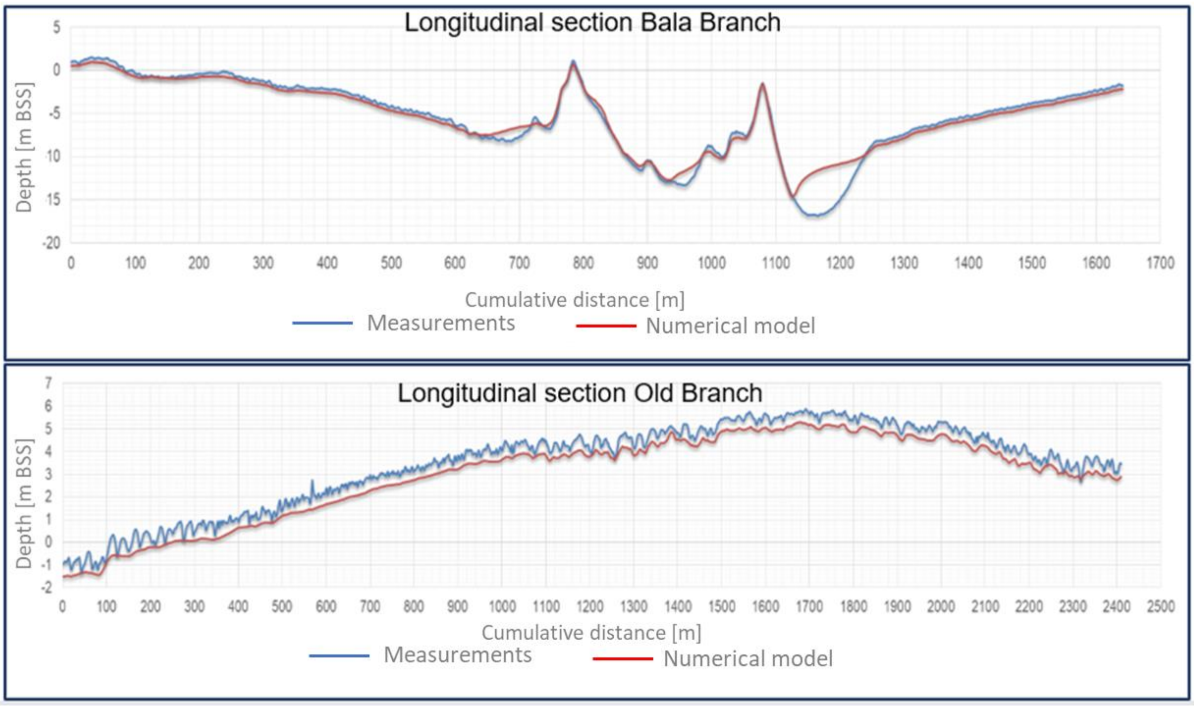


Figure 47 Longitudinal sections representing the Danube riverbed - results from in situ measurements and results from numerical modeling

From these representations it can be noticed that the riverbed geometry resulting from the numerical modeling is similar to that obtained from the processing of the bathymetric measurements. Differences in cross-sectional control are primarily due to the dimensions of the computing cells. The evaluation of the scenarios should take into account the results obtained in the calibration stage, in the sense that these deviations can also be propagated in the context of medium and long-term analysis.

The setting up of a numerical model through which to analyze on a small and medium scale the morphohydrodynamic processes of the watercourse and the correlation of these data with the biotic elements of the aquatic ecosystems, is the main objective of the doctoral thesis. The novelty of this paper follows from the technique used to achieve a three-dimensional numerical model that delivers clear, highly reliable results. Using the *Delft3D* numerical modeling program, based on the huge volume of data obtained from field campaigns, it was possible to develop a numerical model that would allow, for a detailed approach, the morphohydrodynamic evolution trend of the analyzed sector.

Chapter 6. NUMERICAL SIMULATIONS REGARDING THE MORPHOLOGICAL CHANGES OF THE RIVERBED

In order to analyze in the short and medium term the trends of morphological modification of the analyzed riverbed, a series of scenarios have been proposed, through numerical simulation. An essential element in assessing the morphodynamic changes of a watercourse is the inclusion in the analysis of sufficient seasonal variations (Yossef M. and Becker A. 2015). Taking this into account and, also, the effects of climate change, morphohydrodynamic investigations were performed using scenarios for short and medium time periods. This was due to the fact that, within a general framework, for long datasets, numerical simulation is limited in the use of extreme meteorological data such as floods and drought, a long-term scenario being, in this case, implausible.

For short and medium-term scenarios, a variable edge upstream hydrograph, constructed to represent full discharge variation in a schematic manner, was used. The schematic hydrograph is made up of several periods, each having a constant flow, correctly ordered to represent a typical year. The typical year was deduced from historical flow record analysis. Thus, a gradual hydrograph, which is based on measurements and is representative of the complete hydrological cycle

The input data used to determine the boundary conditions required for numerical simulations are represented by the discharge in the upstream section and the water level value in the downstream sections (*Table 6*)

Table 6. Input data used in numerical simulation

Month			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Upstream limit	Danube	Q [m^3/s]	3908	3908	7234	10800	9523	7234	5649	3908	3908	3908	3908	3908
Downstream limit	Bala branch	H [m]*	6,98	6,98	10,03	12,5	11,82	10,03	8,63	6,98	6,98	6,98	6,98	6,98
	Old Danube	H [m]*	7,01	7,01	10,06	12,51	11,85	10,06	8,66	7,01	7,01	7,01	7,01	7,01

** relative to BSS - Black Sea Sulina*

Starting from the updated model with the hydrodynamic parameters mentioned above, scenarios were developed in which the morphohydrodynamic character of the studied sector was analyzed at the interval of 3 years and 5 years. The results obtained were reported in the baseline situation, namely the calibrated model.

6.1. Scenario 1 - Reference Scenario

Scenario 1 is represented by the calibrated morphohydrodynamic model. The results provided by this model are used as references in the morphological analysis of the riverbed after 3 and 5 years. In this situation, the riverbed has the same tendency as the bathymetric relief that is outlined on the basis of the multibeam measurements (*Figures 44* and *45*). In order to evaluate the interaction between the riverbed geometry and the water flow, three situations were analyzed, in which the discharge value varied (*Figure 49*).

In this regard, besides the batimetric relief characteristic of scenario 1, in *Figure 49* are presented the details concerning the analyzed sector in the situation where, at the upstream limit, a flow with the minimum, average and maximum values is applied (*Table 7*).

Table 7. Data used at the upstream boundary of the studied sector

Situations	Discharge [m³/s]	Water level [m]*
Minimum discharge	3000	6,5
Medium discharge	7200	9,9
Maximum discharge	11400	13,1

** relative to BSS - Black Sea Sulina*

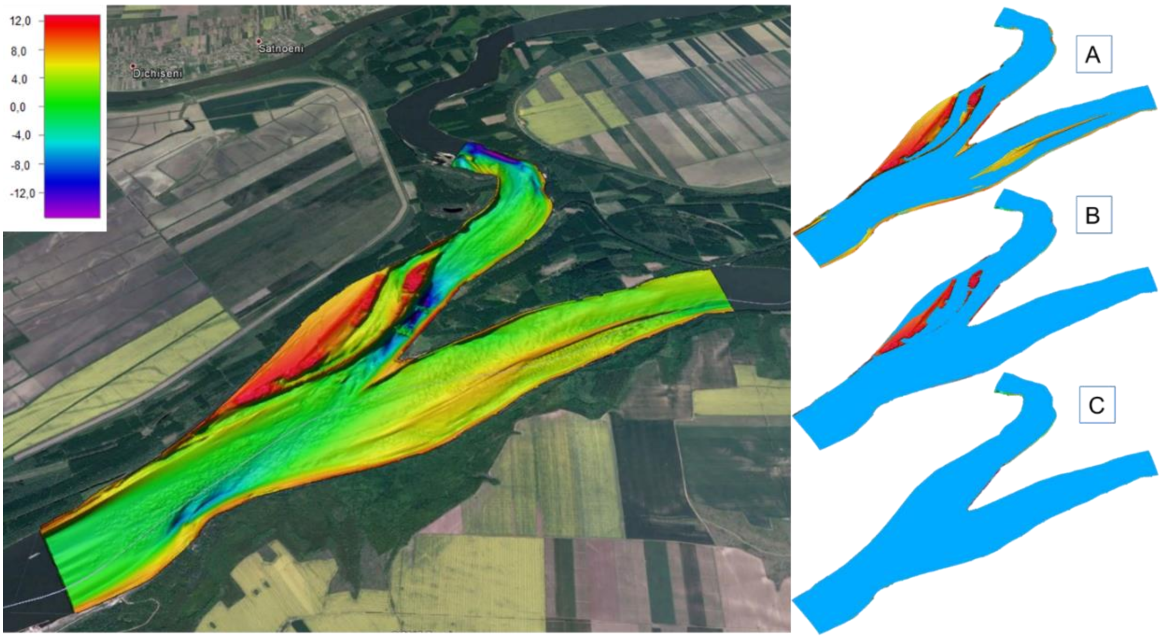


Figure 48 Scenario 1 – Riverbed relief in analyzed sector. Details on the interaction between the bathymetric relief and the water flow in the case of the discharge values (A) Q_{min}=3000 m³/s, (B) Q_{med}=7200 m³/s, (C) Q_{max}=11400 m³/s

In the context of a minimum discharge, land surfaces in the areas of the guiding wall, shore defences, Bala branch - Old Danube bifurcation, part of the Caragheorghe sandbank and the islet located in the west of the Bala branch are highlighted. In the case of the average flow, there are visible surfaces of the island and the shore defence corresponding to the Bala branch. In the case of the maximum flow, the whole sector is covered with water.

Since the water velocity is an important parameter in assessing aquatic ecosystem components, mainly in the analysis of the sturgeon migration route, in *Figure 50* were represented the vertically-mediated velocities values, in the case of a discharge of 3908 m³/s. In the area of the two bottom sills the maximum values of this parameter were obtained, which are below 2.0 m/s. This discharge is the minimum value used in the numerical simulations to represent a typical year. The typical year was deduced from historical flow record analysis.

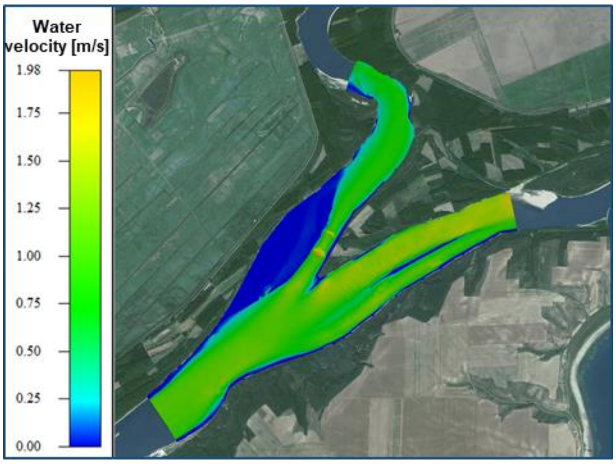


Figure 49 Scenario 1 - Distribution of vertically-averaged values of water velocities

6.2. Scenario 2 - The riverbed after 3 years of morphohydrodynamic simulation

Scenario 2 is the model resulting from the simulation of morphohydrodynamic processes for a period of 3 years. From a morphological point of view, the model provided information that revealed the erosion tendency in the area of the bottom sill and lateral accretion in the shoreline area (*Figure 51*).

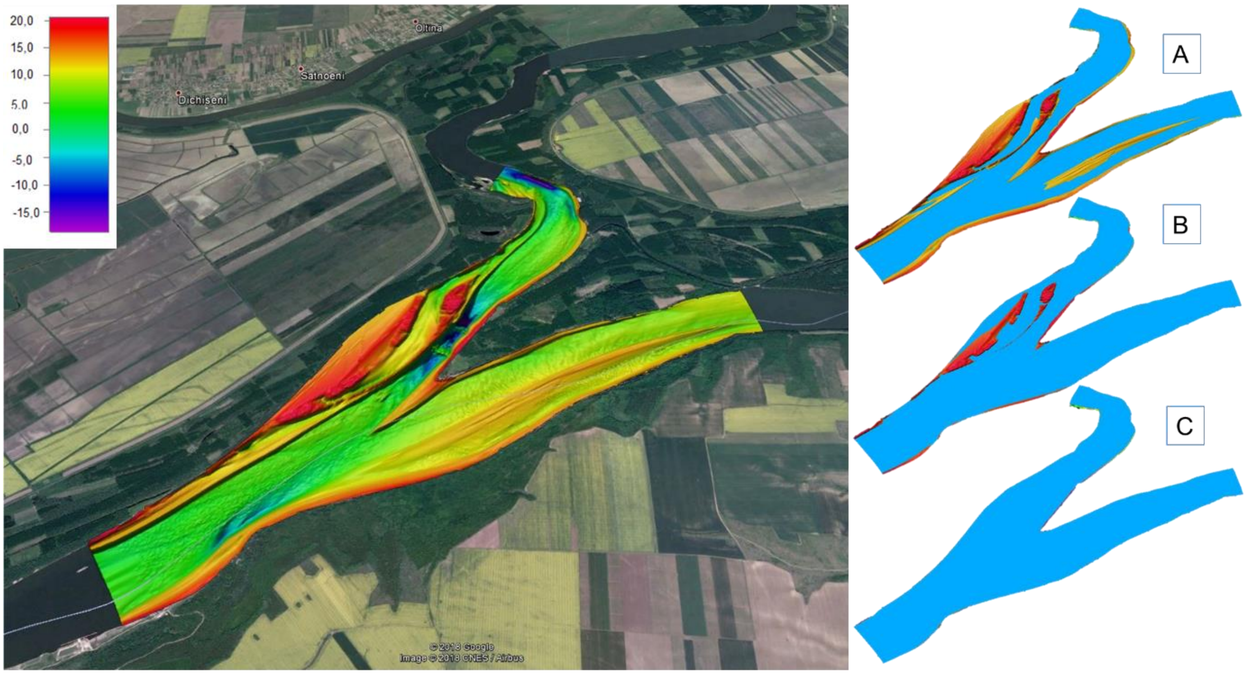


Figure 50 Scenario 2 – Riverbed relief in analyzed sector. Details on the interaction between the bathymetric relief and the water flow in the case of the discharge values (A) Q_{min}=3000 m^3/s, (B) Q_{med}=7200 m^3/s, (C) Q_{max}=11400 m^3/s

In order to investigate the interest area from hydrodynamic point of view, three situations were analyzed, in which the discharge varied, by applying to the upstream model limit a minimum, medium and large value (*Table 7*). In the case of a minimum discharge, the water level, which is 6.5 m MNS, covers the analyzed sector, but less a part of the guiding wall, shore defence, the deposit area at the Bala branch - Old Danube bifurcation, part of the Caragheorghe sandbank and significant areas of the isled located at west of the Bala branch. At the same time, unlike the reference scenario, in the case of low discharge, the lateral accretion on the right bank of the Old Danube is highlighted. In the context of an average discharge is outlined a reduced area with deposits from the bifurcation zone and the Bala branch shore defence. In the case of maximum discharge, the entire sector is covered with water.

Concerning the analysis of the water velocity distribution, the vertically-mediated values are highlighted throughout the sector of interest. For this scenario, for a discharge of 3908 m^3/s, the maximum values exceed 2.5 m/s in the bottom sill area.

Compared to the baseline scenario, due to the deposits on the Old Danube, in the Caragheorghe sandbank area, the vertically-mediated values of the water velocity are almost zero.

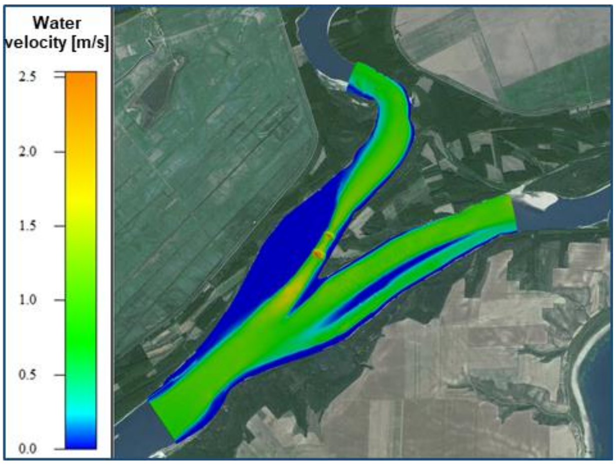


Figure 51 Scenario 2 - Distribution of vertically-averaged values of water velocities

6.3. Scenario 3 - The riverbed after 3 years of morphohydrodynamic simulation

Scenario 3 refers to the model resulting from the simulation of morphohydrodynamic processes over a period of 5 years (*Figure 53*). In this situation, information was obtained on the erosion processes that occurred especially in the area of the bottom sills and between the Caragheorghe sandbank and the Old Danube right bank. At the same time, following the analysis of the data provided by the model, the tendency of lateral accretion was observed, both on the right bank and on the left, especially on the section upstream of the Bala branch - Old Danube bifurcation.

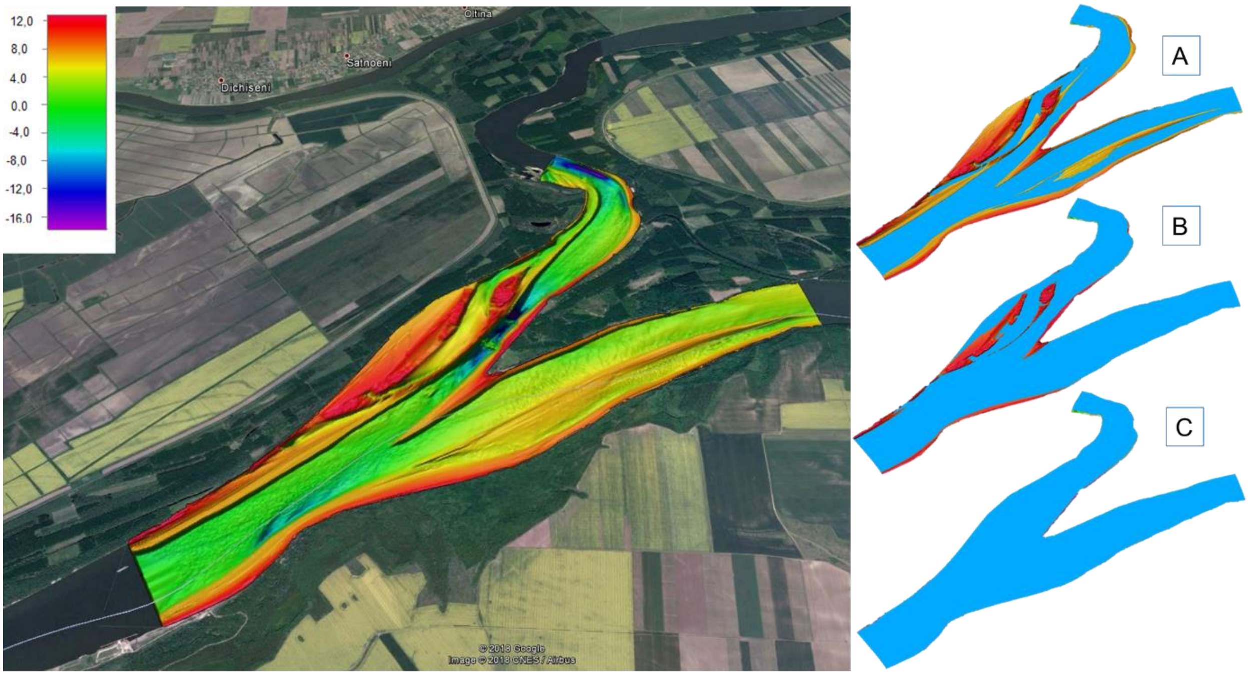


Figure 52 Scenario 2 – Riverbed relief in analyzed sector. Details on the interaction between the bathymetric relief and the water flow in the case of the discharge values (A) Q_{min}=3000 m^3/s, (B) Q_{med}=7200 m^3/s, (C) Q_{max}=11400 m^3/s

If a minimum flow rate of 3000 m^3/s (*Table 7*) it applies at the upstream limit of the Scenario 3 model, it can be seen that the land areas fills much larger surface compared to the scenarios described above. These areas are outlined by the guiding wall, shoreline protection, sediment accumulation in the bifurcation area, a longitudinal area of the Caragheorghe sandbank and the shoreline sediment deposits.

In the case of an average discharge of 7200 m^3/s, where the water level at the upstream boundary is 9.9 m MNS, the lateral accretion area related to the right bank of the Danube/Old Danube is displayed. Similar to previous scenarios, in the case of a discharge of more than 11400 m^3/s, the entire sector is covered with water.

From the point of view of the velocities distribution on the studied sector, in case of a discharge of 3908 m^3/s, they resulted maximum values of approx. 2.7 m/s in the bottom sill area (*Figure 54*).

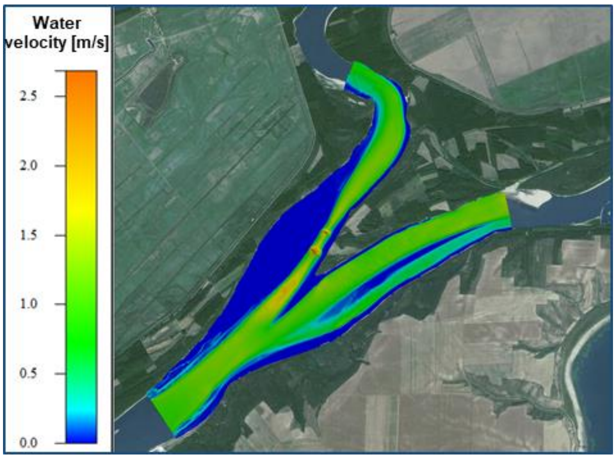


Figure 53 Scenario 3 - Distribution of vertically-averaged values of water velocities

Chapter 7. EVALUATION OF THE RIVERBED MORPHOLOGICAL CHANGES

In order to assess the anthropic interventions impact on aquatic ecosystems components, they were performed comparative analyzes regarding the morphological changes that occurred at the riverbed over the analyzed time intervals (3 and 5 years), through numerical simulations.

The results of the numerical simulations were reported to the reference situation - scenario 1. In order to perform the analysis of the morphological changes, a series of transversal and longitudinal analysis sections (*Figure 47*) were taken into account, which revelated the bathymetric profile during the investigated periods.

Also, based on the results provided by the simulation models, there were 4 sections in which the surfaces of erosion/deposition areas were analyzed.

Given that numerical simulations provide approximate results on the identification of small- and medium-scale morphology changes, this comparative analysis is of a qualitative nature.

7.1. Cross section 1 - Comparative analysis of the scenarios

Cross section 1 is located on the main Danube, upstream of the Bala branch-Old Danube bifurcation area. As a result of simulated on small and medium-time morphohydrodynamic processes, cross-section 1 mainly shows sediment deposits in the lateral side of the flow channel (lateral accretion) (*Figure 55*).

In the scenario where the morphohydrodynamic processes have been simulated for a period of 3 years, left-bank deposition results, followed immediately by erosion portions. After simulating the morphohydrodynamic processes for a period of 5 years, erosion processes are highlighted (*Figure 55*).

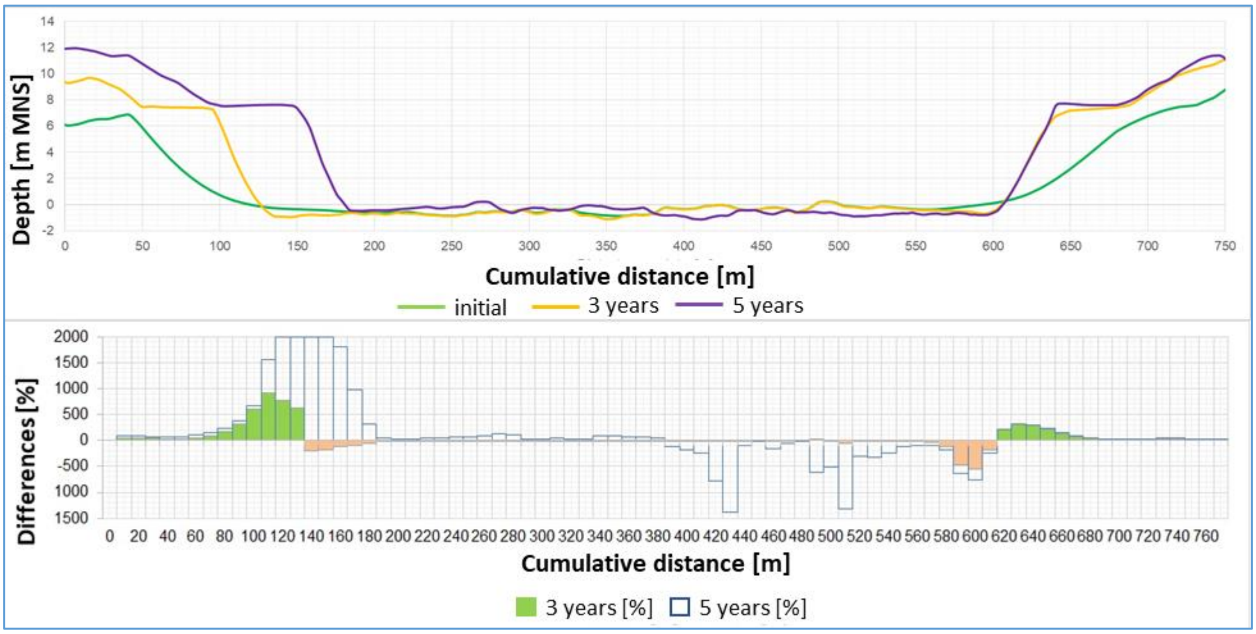


Figure 54 Cross section 1 representing the riverbed in the reference period, after 3 and 5 years of morphohydrodynamic processes simulation

7.2. Cross section 2 - Comparative analysis of the scenarios

Cross section 2 is located next to the Bala branch - Old Danube bifurcation. Following the simulation of the morphohydrodynamic processes, sediment deposits on the right bank are evidenced. Also, in *Figure 56* it can be notice the tendency of lateral development of the sandbank. After simulating the morphohydrodynamic processes for a 3 years period, an erosion area near the left bank was highlighted, and in the bifurcation area, close to the shore defence, a deposit area was developed. The same trend is preserved in the scenario where the morphohydrodynamic processes have been simulated for a 5 years period. In addition, in this case, a small area with deposits is observed near the right bank (*Figure 56*).

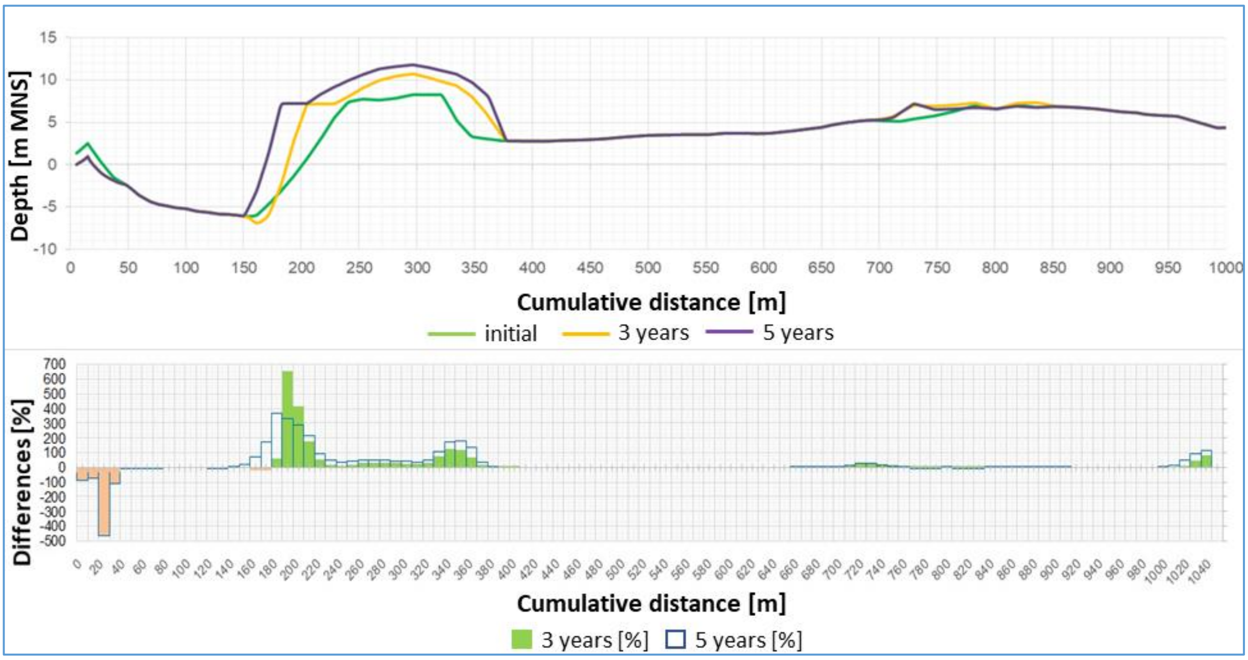


Figure 55 Cross section 2 representing the riverbed in the reference period, after 3 and 5 years of morphohydrodynamic processes simulation

7.3. Cross section 3 - Comparative analysis of the scenarios

This section is located on the Old Danube, downstream of the bifurcation. The results obtained from the morphohydrodynamic processes simulation revealed the tendency of the sediment accumulation to the left bank and the modification of the sandbank geometry through erosion (*Figure 57*).

The model built for morphohydrodynamic simulation for 3 years indicates mainly the sedimentation tendency at the two banks, a trend maintained for the 5-year analysis scenario (*Figure 57*).

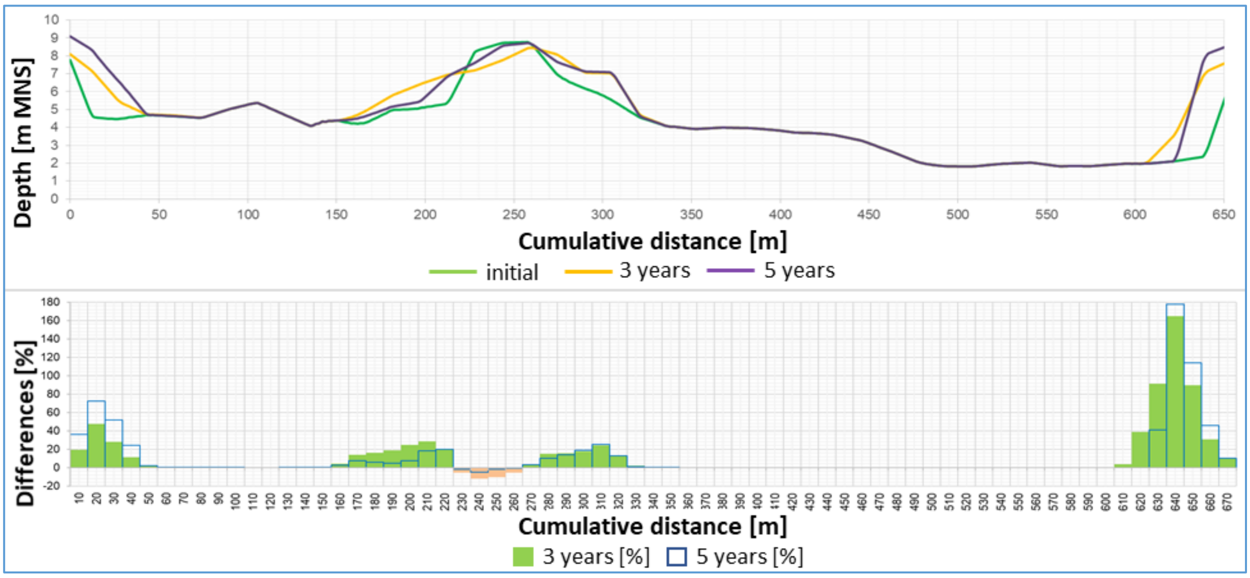


Figure 56 Cross section 3 representing the riverbed in the reference period, after 3 and 5 years of morphohydrodynamic processes simulation

7.4. Cross section 4 - Comparative analysis of the scenarios

In the case of the cross section 4, located in the hydrotechnical construction area, the lateral accretion process is highlighted (*Figure 58*). From the percentage differences between the relief of the riverbed obtained from morphohydrodynamic simulation for 3/5 years and the reference situation, there are lateral deposits on the banks and an erosion area near the right bank.

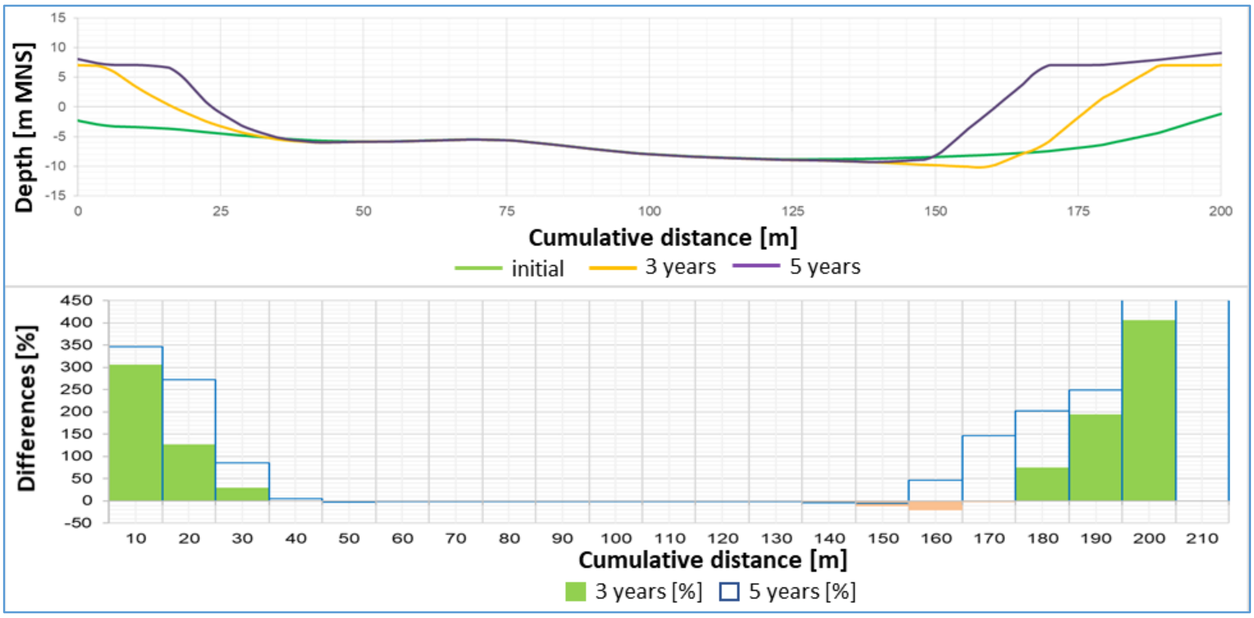


Figure 57 Cross section 4 representing the riverbed in the reference period, after 3 and 5 years of morphohydrodynamic processes simulation

7.5. Cross section 5 - Comparative analysis of the scenarios

The cross-section 5 is located on the Bala branch, downstream of the hydrotechnical works. The results obtained from morphohydrodynamic simulations for 3 and 5 years indicate the trend of sediment accumulation on the left bank and near the right bank (*Figure 59*).

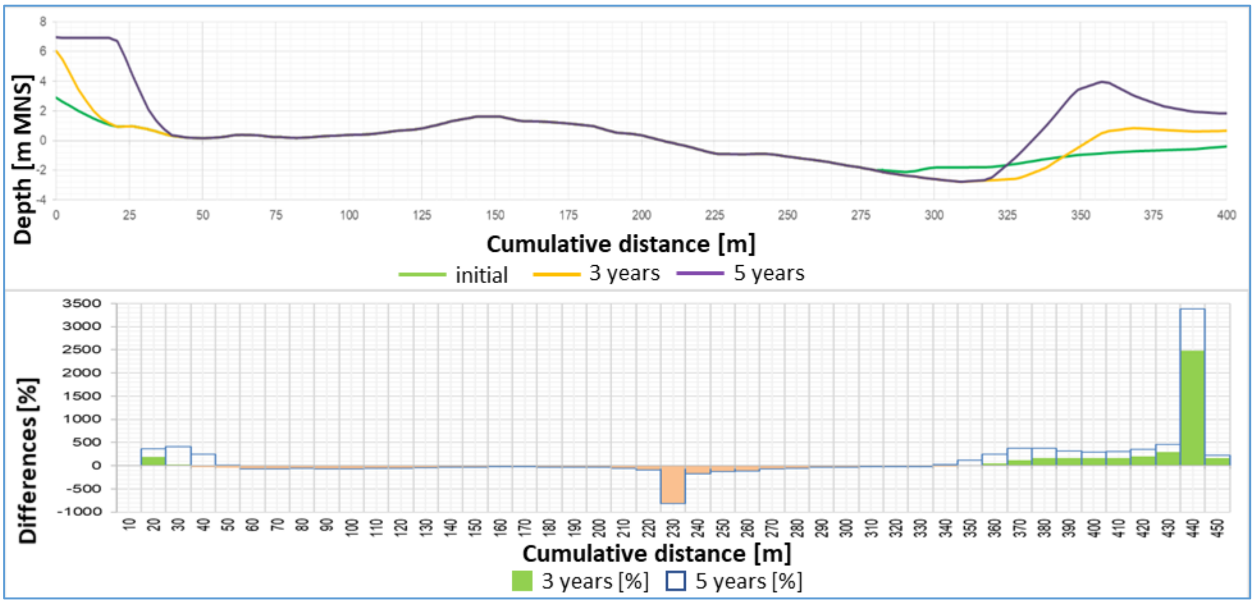


Figure 58 Cross section 5 representing the riverbed in the reference period, after 3 and 5 years of morphohydrodynamic processes simulation

7.6. Longitudinal section 1 - Comparative analysis of the scenarios

As a result of the simulation of small and medium-scale of the morphohydrodynamic processes, it can be noticed, in *Figure 60*, that the main changes in the riverbed geometry occurred in the area of the two bottom sills. The results obtained from the morphohydrodynamic simulation for a period of 5 years highlighted the erosion trend immediately downstream of the two submerged structures.

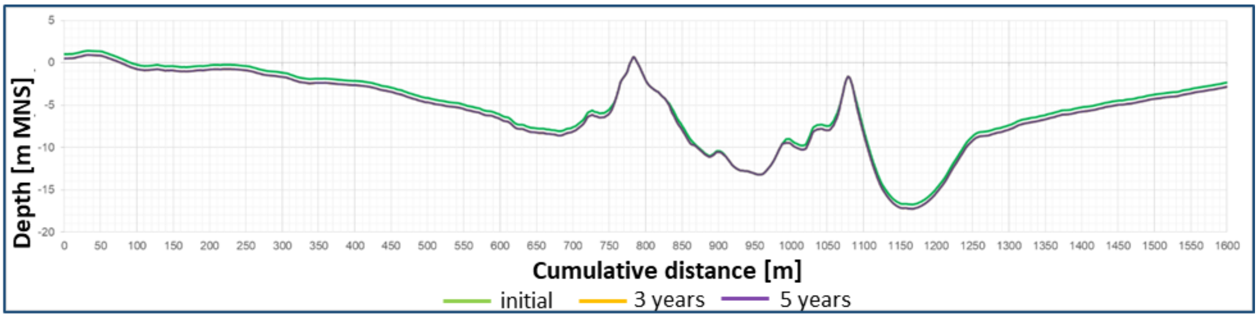


Figure 59 Longitudinal section 1 representing the riverbed in the reference period, after 3 and 5 years of morphohydrodynamic processes simulation

7.7. Longitudinal section 2 - Comparative analysis of the scenarios

In the case of the longitudinal section 2, located on the Old Danube, after the morphohydrodynamic simulation, a uniform image of the riverbed resulted (*Figure 61*). The bathymetric profiles obtained from the simulations for 3 and 5 years indicate the tendency to uniformize the riverbed, by depositing in low areas and by erosion in high areas.

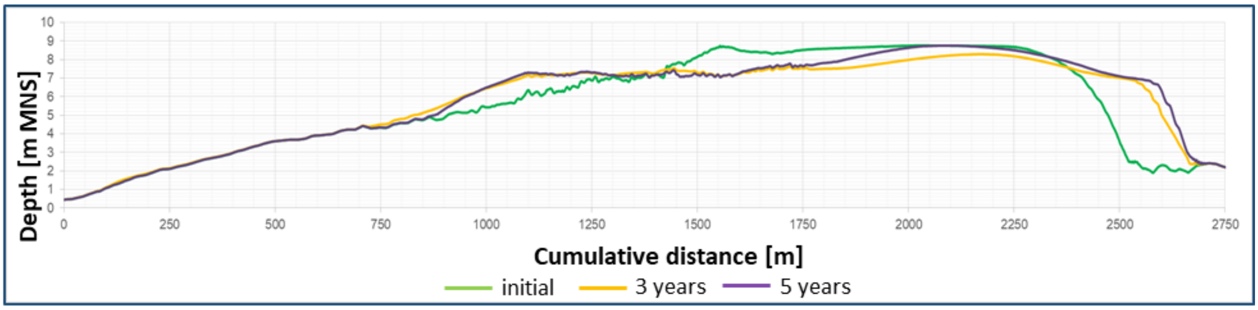


Figure 61 Longitudinal section 2 representing the riverbed in the reference period, after 3 and 5 years of morphohydrodynamic processes simulation

7.8. Analysis of control areas

For the detailed analysis of the obtained results, four control areas (*Figure 61*) were outlined, in which the bathymetric changes of the riverbed were investigated by evaluating the erosion/sedimentation areas. This analysis was performed by comparing the reference data obtained from the calibrated model with those resulted from the morphohydrodynamic simulations over the 3 and 5-year time intervals.

The *Figures 62-65* show, in detail, the riverbed geometries resulting from numerical simulations in the four control areas. In these details the isobaths are outlined, in order to evaluate the erosion/ deposition surfaces formed after the numerical simulations, on a small- and medium-time scale.

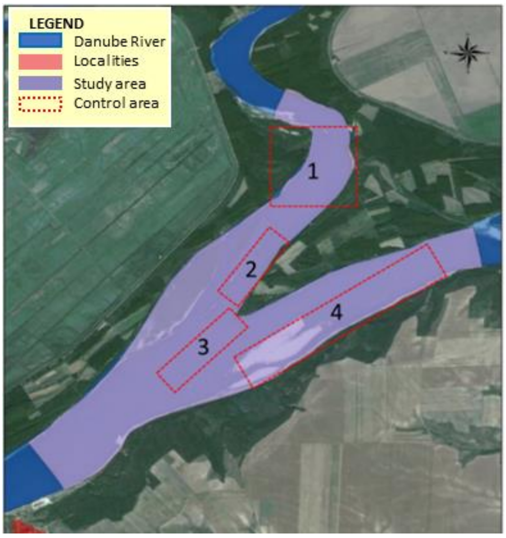


Figure 60 Control area localization

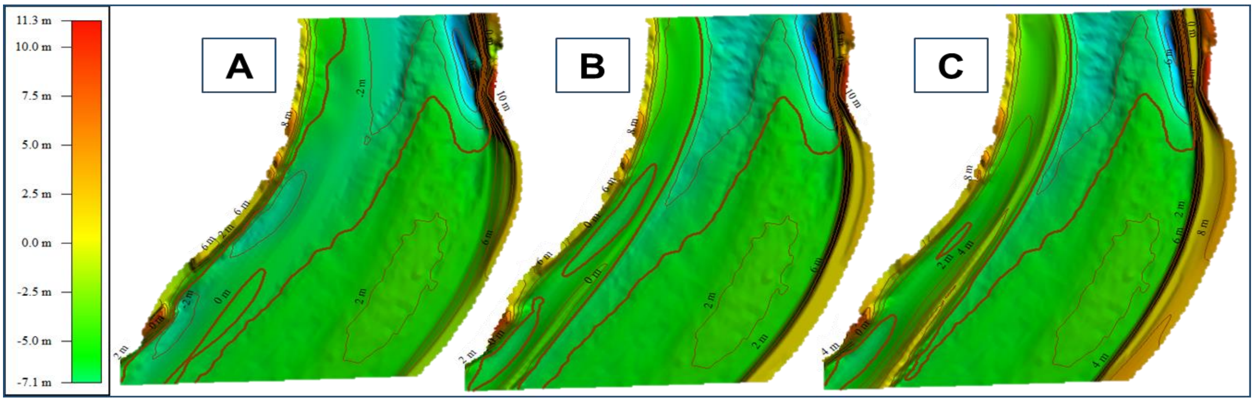


Figure 61 Comparative analysis of control area 1: (A) Scenario 1 - Reference; (B) Scenario 2 - Riverbed after 3 years of morphological evolution; (C) Scenario 3 - Riverbed after 5 years of morphological evolution

In the control zone 1 (*Figure 62*), located on the Bala branch, downstream of the hydrotechnical works, an erosion area near the right bank was revealed. This zone tends to develop towards the base of the right bank, which coincides with the field observations. The area near the left bank is characterized by sedimentation processes.

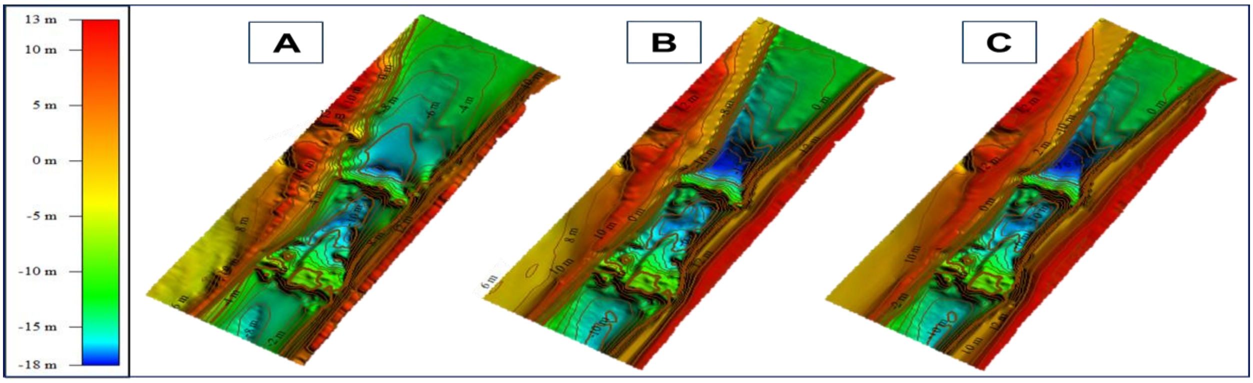


Figure 62 Comparative analysis of control area 2: (A) Scenario 1 - Reference; (B) Scenario 2 - Riverbed after 3 years of morphological evolution; (C) Scenario 3 - Riverbed after 5 years of morphological evolution

The control area 2 (*Figure 63*) is located in the sector where hydrotechnical structures were implemented. It is noted the tendency of lateral accretion developed from the scenario in which the morphohidrodinamic processes have been simulated for 3 years. Immediately upstream of the bottom sills, scenarios 2 and 3 highlight the erosion trend of the riverbed. The erosion scour formed downstream of the bottom sill has changed its geometry, evolving towards the base of the old sumberged structure built in the 1990^{s}. The lateral deposits made changes to the shape of the 1990^{s} bottom sill and the erosion scour formed downstream of it.

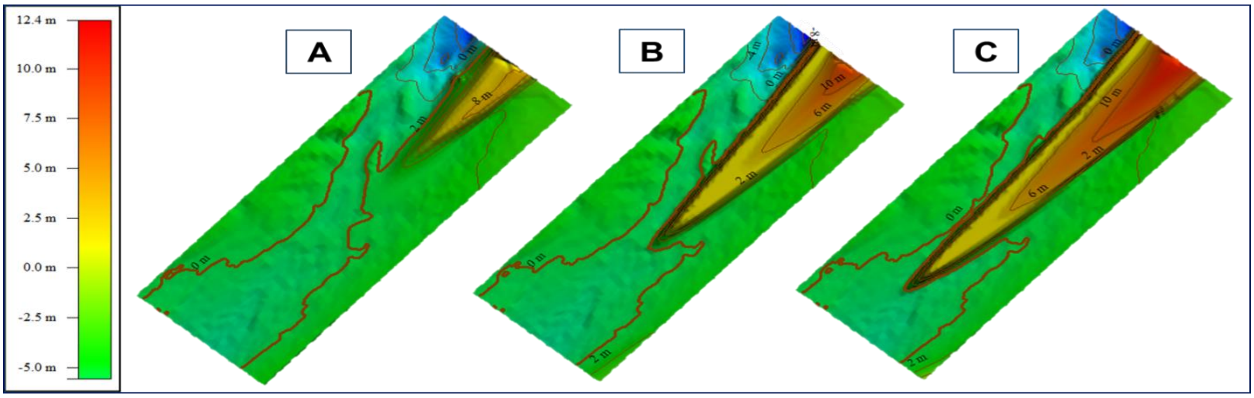


Figure 63 Comparative analysis of control area 3: (A) Scenario 1 - Reference; (B) Scenario 2 - Riverbed after 3 years of morphological evolution; (C) Scenario 3 - Riverbed after 5 years of morphological evolution

In the control zone 3 (*Figure 64*), located at the Bala branch-Old Danube bifurcation, the sedimentation phenomenon was highlighted in the shore defence area. The sediment deposits zone has evolved over time, upstream. Near the sedimentation area, at the entrance to the Bala branch, an erosion scour was developed, whose geometry did not change during the analysis period.

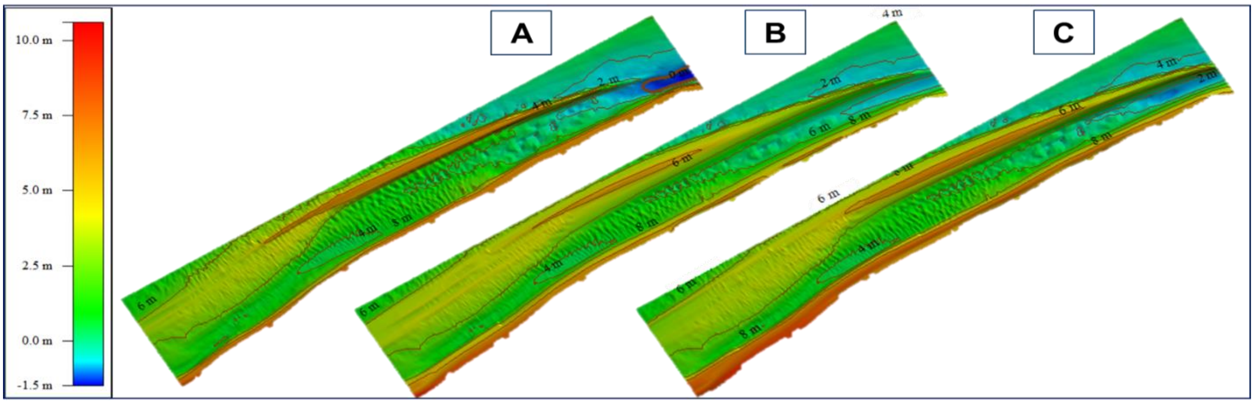


Figure 64 Comparative analysis of control area 4: (A) Scenario 1 - Reference; (B) Scenario 2 - Riverbed after 3 years of morphological evolution; (C) Scenario 3 - Riverbed after 5 years of morphological evolution

In the control area 4 (*Figure 65*) the evolution of the Caragheorghe sandbank is analyzed. Over time, it tends to advance downstream, in the form of a stripe which is parallel with the right bank.

The results obtained from the assessment of the riverbed morphological changes represent the starting point in analyzing the influence that these processes may have over the components of the aquatic ecosystem, over time. The investigations carried out have generally revealed erosion processes on the Bala branch and sedimentation on the Old Danube.

Chapter 8. INTERACTION BETWEEN ABIOTIC ELEMENTS AND ACVATIC ECOSYSTEM COMPONENTS

In general, the structures implemented to improve navigation conditions can have an impact on aquatic ecosystems both during the construction period and in the subsequent period.

Construction activities may involve the occurrence of erosion/sedimentation processes, which affects organisms in the site and downstream of it. Indirectly, these processes can lead to the destruction of the micro-habitats needed for food, shelter, migration, reproduction, and so can the communities of invertebrates and fish.

8.1. Hydrotechnical structures material

Starting from the geological characterization of the area, it is necessary to investigate, from the chemical point of view, the interaction of water with rocks used as material in the hydrotechnical structures. In addition to the landscaping change of the river sector, there was a question regarding the solubilization degree of some chemical compounds from the rock composition. As a result, several stone samples from the structures (*Figure 66*) were taken to be used for physical and chemical laboratory tests.

Figure 65 Rock samples

The analysis of the rock mineralogical composition showed that feldspars and pyroxenes occupy the highest percentage. From the chemical point of view, the analyzes revealed that SiO_2, Al_2O_3 and CaO are found in high percentage in the rock composition (*Table 8*).

Table 8. The chemical composition of hydrotechnical structures rocks

	SiO_2	FeO	Na_2O	Al_2O_3	MnO	K_2O	Fe_2O_3	MgO	TiO_2	S	P_2O_5	H_2O	CO_2	CaO
[%]	42,8	4,24	3,10	15,95	0,17	1,65	3,39	6,59	1,92	0,063	0,35	2,71	4,06	12,15

The processes by which the rocks are put into operation as well as the environmental conditions during the operation have been modeled in the laboratory. Thus, the samples were crushed and subjected to a solubilization test in the centrifuge device. The ratio of rock/distilled water was 1/2. The leachate resulting from these tests was analyzed for heavy metal content and the results are shown in *Table 9*.

Table 9. Analytical measurements - heavy metals from leachate

No.	Quality indicator	UM	Total Metal*	Dissolved metal**
1	Lead	μg/L	8,300	2,700
2	Cadmium	μg/L	0,400	0,200
3	Cobalt	μg/L	5,002	0,495
4	Nickel	μg/L	16,300	8,900
5	Zinc	μg/L	18,600	0,600
6	Copper	μg/L	5,300	4,200

** The total concentration of metal present in the sample, namely the metal in the water and in the solid suspension.*
*** Concentration of metal only in water (ionic form).*

8.1.1. Interaction of water with rocks

Rocks of the hydrotechnical structures are constantly washed by the river water. At the same time, the rainwater (rain and snow) have a great ability to dissolve some chemical compounds from the rocks. Considering the two aspects and the results obtained from the analyzes, in the sections located downstream of the hydrotechnical structures, there is the possibility that the elements that are solubilized from the rocks can modify the chemistry of the Danube water.

Consequently, concentrations of dissolved metal from rock to leachate (*Table 9*) may lead to contamination of water. Based on these considerations, the variation of the heavy metal concentration in water during the construction and after completion of the hydrotechnical works was analyzed in relation to the median values analyzed during the pre-construction monitoring period (reference). In this investigation, it was taken into account the section 2, which is located downstream of the hydro-technical works on the Bala branch.

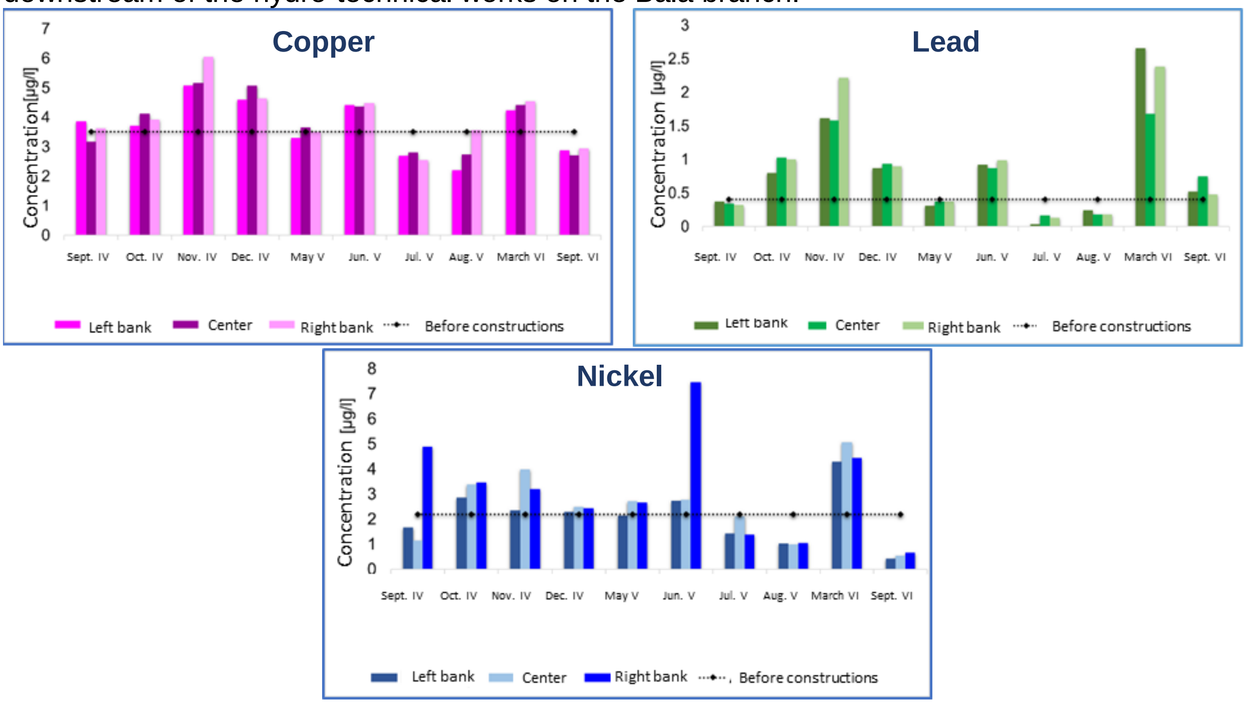


Figure 66 Variation of the heavy metal concentration in water

From the analyzed indicators, it was observed that for copper, lead and nickel, the mean values of the initial concentration are exceeded, compared to the values during the period of the hydrotechnical works execution. For the other indicators (zinc, cobalt, cadmium), the values resulting from the analysis of water samples taken during and after the structures completion were much lower than those in the reference period.

In order to highlight the differences, the results obtained from the analyzes of water samples taken from the center, left and right bank, for copper, lead and nickel were represented graphically (*Figure 67*). The time interval displayed in the graphs is part of the construction period (September – December, year IV of the analysis) and after the completion of the construction (May year V - September year VI of the analysis). The values corresponding to the reference period are the mediation of the concentrations resulting from the September-December I-year monitoring period.

As a result of water analyzes, copper concentration values have exceeded the initial average concentration over the reference period, with the exception of the months of July - year V and September - year VI of the analysis. In comparison with the average reference value, lead concentrations in water generally showed higher values over the analyzed interval, less in the months of May, July and August of the V year of analysis (post-construction period). Also, from the analyses of the water samples taken during and after construction, they were resulted higher values of nickel concentration compared to the reference range, except for July, August of V year and September of VI year of the analysis (*Figure 67*).

8.1.2. Changing the heavy metals concentration in sediments

Following the hydrotechnical structures construction on the Bala branch, the material of the riverbed changed with significant contribution of fine components resulting from rocks.

As a result of the chemical composition of the rocks used for the hydrotechnical structures implementation, it was necessary to conduct sediment investigations in order to observe the variation in concentration during and after construction. This research was carried out according to the average of the sediment concentrations resulting from the samples taken before the constructions began.

Based on the results obtained from the monitoring period, graphical representations were made, in which the concentrations of heavy metals (cadmium, copper, lead, zinc, nickel) from sediments in the control section of the Bala branch were compared (*Figure 68*). In this investigation, the construction period is represented by September - December, the fourth year, and the one after the completion of the constructions, May, V - September VI (the works were finalized in March of the 5th year of analysis).

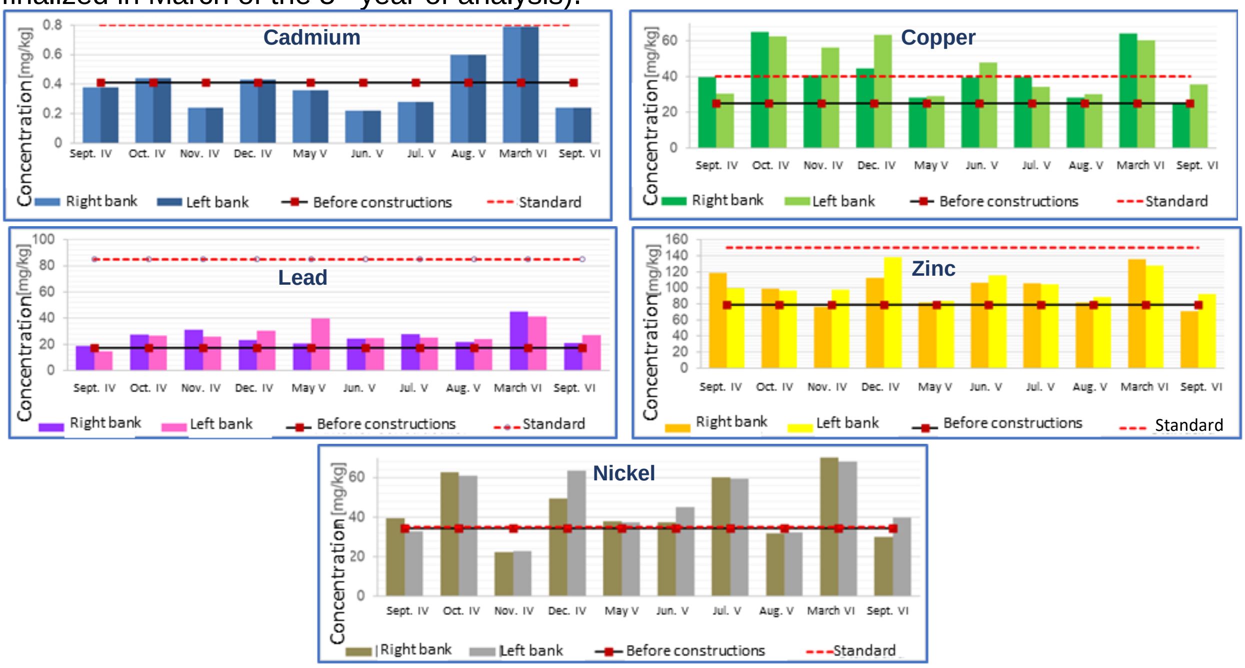


Figure 67 Variation of heavy metal concentration in sediments

Generally, during the period under review, the cadmium concentration variation in sediment exceeds the median value resulting from the reference period, except for the May-August, V-year analysis period. The copper concentration in the sediment samples analyzed during the construction period and after construction completion exceeds the mean value resulting from the analyzes performed during the reference period, except in May of the V analytical year. On the analyzed range, the lead concentration in the samples taken exceeded the reference value. As regards zinc and nickel, the median value resulting from the reference period is exceeded, except in August of the V year of analysis.

At a first observation, it is obvious that both for water and sediments values of the heavy metal concentrations increased during and after the execution of the hydrotechnical works and a possible cause, is represented by the composition of the rocks used in the construction of the hydrotechnical structures.

However, it is difficult to quantify the theory that the heavy metal contribution in water and sediments is due to the rocks, because, at the same time with the solubilization of heavy metals from rocks, there is also a dilution of the river flow and their leaching. Performing point-based analyzes is not sufficient to determine the influence of rocks on water quality parameters. At the same time, the solubilization of heavy metals in the rocks used for the construction of hydrotechnical structures increases in proportion to the temperature and water flow, but it is difficult to find a relationship between these parameters, since in the analysis it is necessary to take into account the upstream anthropic interventions, shipping, etc.

8.2. Correlation of the biotic components with the results obtained from the morphohydrodynamic simulations

In order to assess the impact of hydrotechnical constructions on aquatic flora and fauna, the results obtained from the monitoring period correlated with those provided by the simulation of short and medium-term morphohydrodynamic processes.

The substrate is an important biotope of the watercourse, its characteristics influencing the water properties, the sediments being a reservoir and supplier of nutrients for water. At the same time, the substrate represents the basis for the development of benthic flora and fauna, the physical and chemical structure of the substrate determining the type of benthic biocenoses (UGAL, 2018).

Regarding the aquatic flora and fauna, these are components that may become of interest as they are sources of food for fish belonging to one of the rare, vulnerable, endangered, endemic species (Chiriac G., 2010). Consequently, it is necessary to investigate these components, since in the Lower Danube, including the studied sector, there are 4 species of sturgeon (INCDPM, 2011), of which the beluga, stellate sturgeon and Russian sturgeon to the "Red List of Threatened Species" in accordance with the International Union for the Conservation of Nature (IUCN), and the sterlet is considered to be a vulnerable species (Dănălache T., et al., 2017).

Generally, during the construction period and after the completion of the hydrotechnical works, no major changes were made in the phytoplankton composition compared to the period before the construction began. The biggest differences were noted for the number of taxons: in the construction stage, on the section corresponding to the Old Danube, the number of taxons increased by approx. 41.67% compared to the previous stage of hydrotechnical works execution. In the post-construction period, with regard to the saprob index, decreases of 9.71% on Bala branch and 11.56% on the Old Danube were observed. Over the same period, the values of the other studied indices increased.

According to the analyzes carried out by the INCDPM experts, within the *"Laboratories"* department, throughout the monitoring, the ecological status of the Danube water in the study area was good and very good.

Microphytobenthos is a permanent but not exclusive component of the water bank area, fixed on the substrate by roots or strong rhizomes, which, in most cases, cross the water column coming into contact with the atmosphere (INCDPM, 2011).

Analyzing the information obtained from the morphohydrodynamic simulations, it can be noticed that sediment deposits occurred in the proximity of the banks. In these areas the water velocities are reduced. At the same time, following the analysis of the scenarios in which the discharge in the upstream section was varied, low water levels were recorded in the case of small and medium flows on important areas in the vicinity of the banks. Theoretically, these results could favor the development of macrophytes.

8.3. Morphohydrodynamic parameters analysis based on migratory behavior of sturgeons

In the last decades, sturgeon populations have fallen due to several factors, including irrational and excessive fishing and poaching (Deak Gy., Et al., 2014). Considering that beluga, stellate sturgeon and Russian sturgeon are species belong to the "Red List of Threatened Species," according to the IUCN, and the sterlet is considered a vulnerable species, the interest in their behavior has increased due to the high need for elaboration of the conservation action plans (Dănălache T., et al., 2017).

The results obtained from the simulation of morphohydrodynamic processes can be the starting point in the short and medium-term analysis of the influence of hydrotechnical effects on sturgeon species. However, given that the available information on the sturgeons behavior and their migration and wintering routes on the Lower Danube is not fully known (Deak Gy., Et al., 2014), it is difficult to assess the impact of hydrotechnical works on the sturgeons migration route.

The INCDPM experts investigated the aspects of sturgeon behavior, resulting a unique database at European level. There were carried out researches that had as main objective the association of the abiotic components of the ecosystem with the migratory route of ultrasonically tagged sturgeons (*Table 10*).

Table 10 The number of sturgeon specimens captured over a period of 6 years (INCDPM, 2017)

Year	Species			
	Beluga	**Stellate sturgeon**	**Russian sturgeon**	**Sterlet**
Year I	25	1	17	52
Year II	13	0	36	7
Year III	13	1	30	6
Year IV	4	1	44	3
Year VI	13	1	4	0
Total	**98**	**5**	**178**	**68**

According to the results obtained from the monitoring, the Bala branch was transited by sturgeon both during the pre-hydrotechnical works and in the periods during and after the constructions were completed (INCDPM, 2017).

At the same time, due to the riverbed geometry, the Bala branch is a favorable site for the wintering of the sturgeon species, during the monitoring period, several sturgeon specimens were recorded in successive days (INCDPM, 2011-2018).

8.3.1. Influence of the riverbed morphological changes on the behavior of sturgeons

The literature information indicates that the morphology of the watercourse is an important factor in the behavior of sturgeons.

Species of sturgeons specific to the Lower Danube prefer scours and deep areas of the river for hibernation, fact confirmed by the results obtained by INCDPM experts as a result of the monitoring of ultrasonic marked wild sturgeon specimens.

At the same time, studies indicate that sturgeon reproduction areas are characterized by hard substrates (up to 26 m), whose granulometry varies from gravel to rockfill, with crack networks where water velocity is usually low. The importance of the riverbed is also due to the fact that breeding areas are frequented by sturgeon species every year.

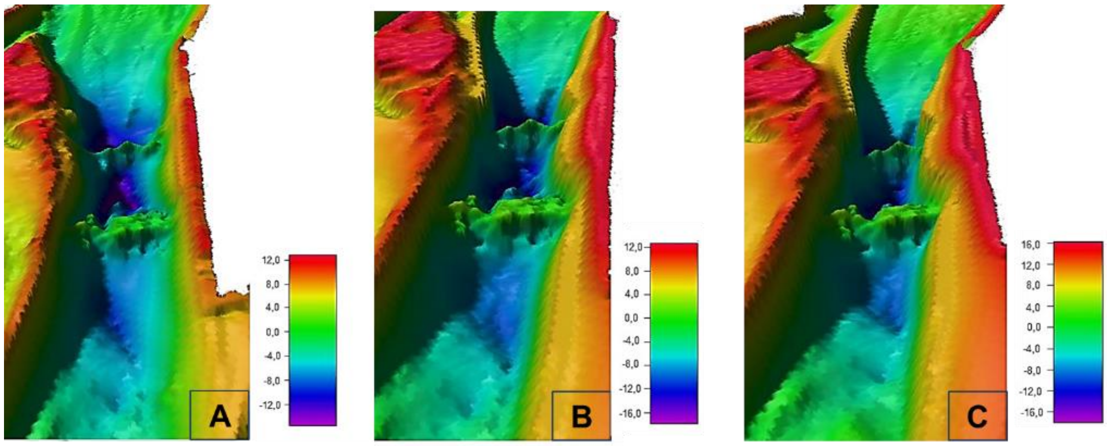


Figure 68 Comparative analysis of the bottoms sills area: (A) Scenario 1 - Reference scenario; (B) Scenario 2 – Riverbed after 3 years of simulation; (C) Scenario 3 – Riverbed after 5 years of simulation

Changing the bedside relief can have an immediate impact on habits related to breeding, wintering, feeding and, ultimately, can lead to the disappearance of habitats.

As mentioned above, during the monitoring activities, it was observed that the Bala branch is a favorable site for the wintering of the sturgeon species due to the presence of erosion scours, downstream of the two bottom sills (INCDPM, 2011-2018). In this regard, the area corresponding to the two bottom sills was investigated, in order to analyze the riverbed resulting from the simulations of the morphohydrodynamic processes (*Figure 69*). The obtained results indicate the tendency to modify the riverbed relief.

It has been observed that after the simulations performed over a period of 3 and 5 years, they resulted higher depths of erosion scours. Compared to the data obtained from the monitoring activities, in terms of riverbed, no significant changes are made to affect the wintering and reproduction habitats of the sturgeon.

8.3.2. Influence of hydrodynamic parameters resulting from numerical simulations on the behavior of sturgeons

The migration behavior of sturgeons is influenced by the variation of hydrodynamic parameters. Reproduction of sturgeon species depends on hydrodynamic conditions - the large discharges are leading to higher water velocities at riverbed level, which significantly reduces the reproductive success.

According to the literature, in the breeding areas the water vertically-mediated velocity ranges from 0.5 to 2.2 m/s, allowing the dispersion of the fertilized eggs.

Regarding the sturgeons swimming capacity, there is a lot of information on this issue in the literature, but none of them refers to *in situ* conditions. During the monitoring period, following the correlation of the data provided by the DKTB and DKMR-01T monitoring stations with the water velocity measurements, it emerged that they were ultrasonic tagged sturgeon specimens that crossed the upstream bottom sill in the situation of average velocities ranging from 0.83 to 2.64 m/s (INCDPM, 2017).

In order to investigate the influence that water velocity distributions can have on the migration behavior of sturgeons, the results obtained from the simulations of morphohydrodynamic processes with the information from the sturgeon monitoring were combined.

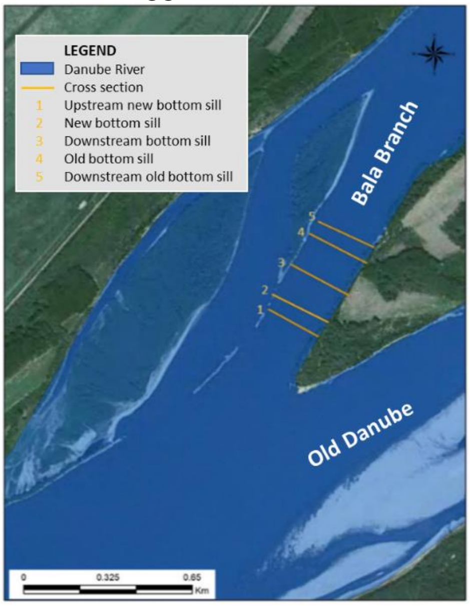


Figure 69 Location of analyzed cross-section

The discharge at which these analyzes were performed was 3908 m^3/s in the upstream section of the analyzed sector. This discharge is the minimum value used in numerical simulations to represent a typical year.

For this purpose, in the first phase, five cross sections were selected, in which were represented the distributions of the average values of the water velocities resulting from the numerical simulations (*Figure 70*).

For the section located upstream of the new bottom sill (*Figure 71*), there are no significant differences in scenarios for 3 and 5 years compared to the reference situation. In these cases, the maximum values are between 1.05 - 1.4 m / s.

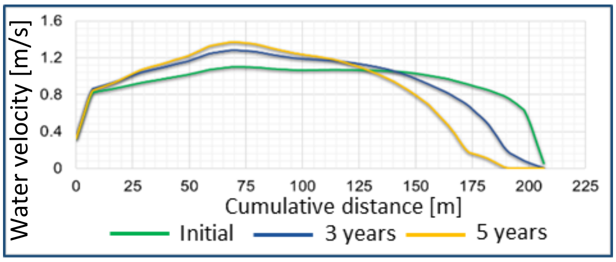


Figure 70 Water velocity distribution - Section 1

Above the bottom sill (*Figure 72*), the average values of the water flow velocities are higher compared to the reference situation. Thus, for scenarios in which the morphohydrodynamic processes were simulated for a 3- and 5-years period, they were resulted maximum values of water velocity of approx. 2.5 m/s and 2.7 m/s.

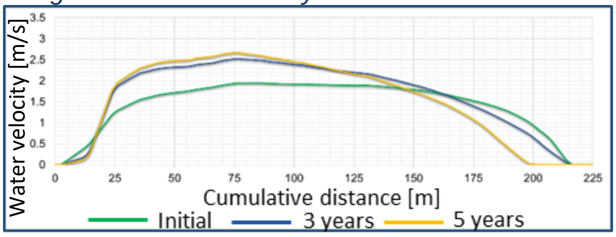


Figure 71 Water velocity distribution - Section 2

In the bottom sill downstream (*Figure 73*), the distribution of average water velocities presents a similar trend in the scenarios where morphohydrodynamic processes have been simulated for a period of 3 and 5 years, with maximum values of approx. 1.5 m/s.

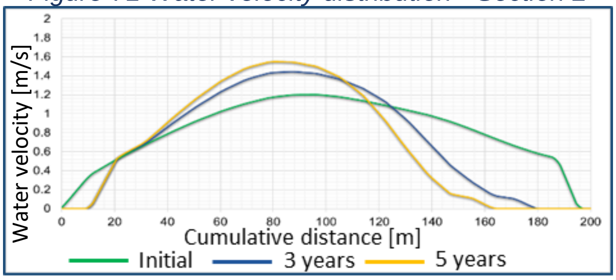


Figure 72 Water velocity distribution - Section 3

In the case of the section located above the submerged structure built in the 1990s (*Figure 74*), the average values of the water flow velocities are higher compared to the reference situation. For scenarios in which the morphohydrodynamic processes were simulated for a 3 and 5 years, they were resulted maximum values of water velocity of approx. 2.2 m/s and 2.4 m/s.

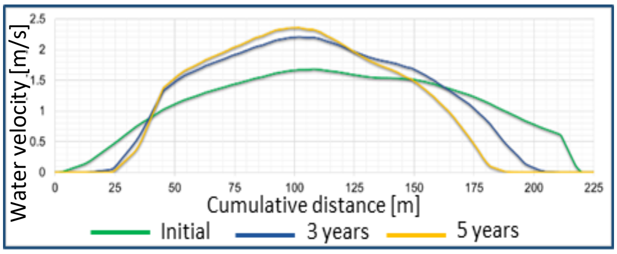


Figure 73 Water velocity distribution - Section 4

In the section located downstream of hydrotechnical structures (*Figure 75*), the distribution of average water velocities has a similar trend, in both scenarios (3 and 5 years) the maximum value being of approx. 1.3 m / s.

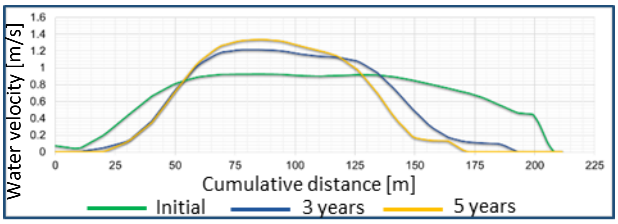


Figure 74 Water velocity distribution - Section 5

It can be noticed that, for all analyzed sections, the morphohydrodynamic simulations performed for 3 and 5 years showed lower values of the water velocities in the areas near the banks and higher in the central area of the channel.

For a more detailed search regarding the velocities resulting from the numerical simulations performed in the short and medium term, in the Bala branch were designated areas of analysis in which the velocity frequency was calculated. These areas were located upstream, above and downstream of the bottom sill and above and downstream of the submerged structure built in the early 1990s.

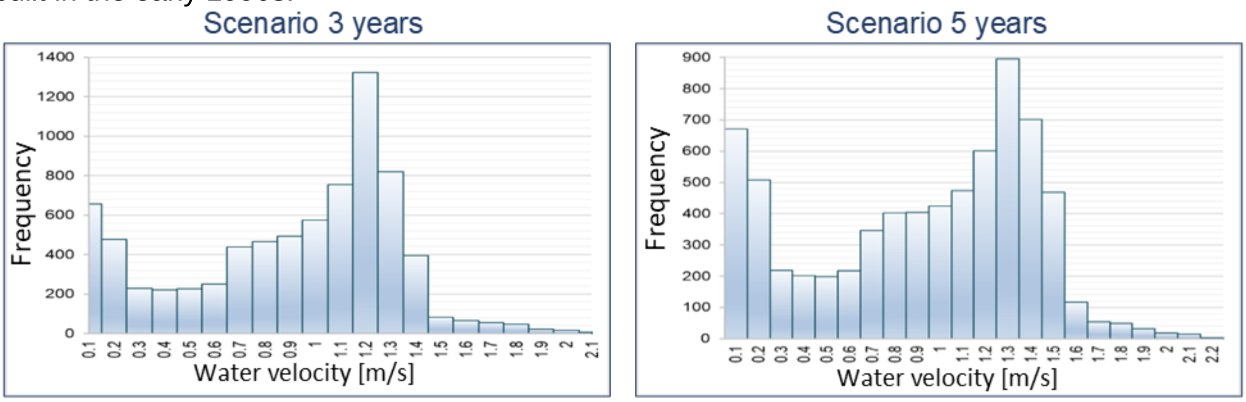


Figure 75 Velocities histograms - upstream of the bottom sill

Figure 76 shows the velocities histograms for the bottom sill upstream zone. In the scenario where the morphohydrodynamic processes were simulated for a period of 3 years, it was observed that the velocities between 1.1 and 1.2 m/s are the most frequent. For the scenario where the results for the 5-year period have been taken into account, the most frequent are the velocities ranging between 1.1 and 1.5 m / s.

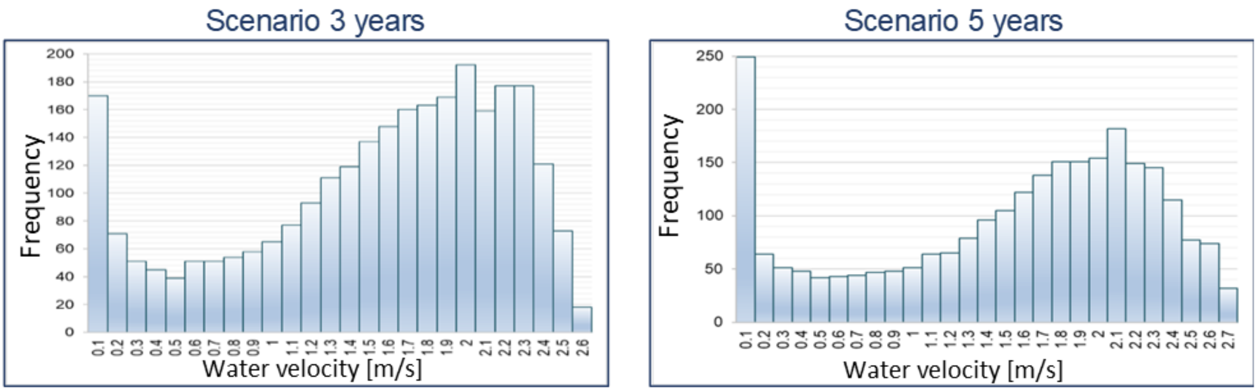


Figure 76 Velocities histograms – above the bottom sill area

In the case of the area above the bottom sill (*Figure 77*), the velocities histograms showed that for the scenario where the morphohydrodynamic processes were simulated for a period of 3 years, the most frequent water velocities have the mean values between 1.3 - 2.4 m/s. For the scenario where the results for the 5-year period were taken into account, the most frequent are the velocities whose values are less than 0.1 m/s and whose values fall within the range of 1.5 and 2.4 m/s.

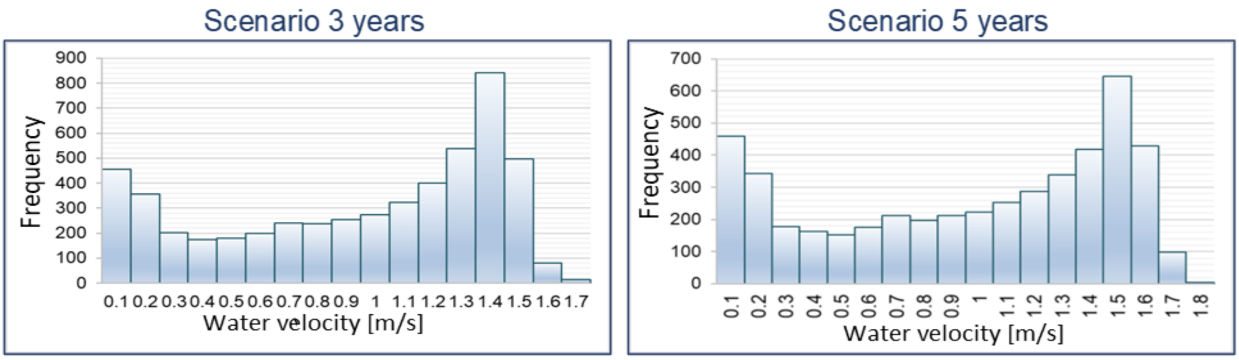


Figure 77 Velocities histograms - downstream of the bottom sill

In the area located downstream of the bottom sill (*Figure 78*), the results obtained from the scenario in which the 3-year simulation was taken into account indicate that the most frequent water velocities are between 1.3 - 1.5 m/s. In case of numerical simulation performed for the analysis of morphohydrodynamic processes for 5 years, the most frequent water velocities are between 1.4 - 1.6 m/s.

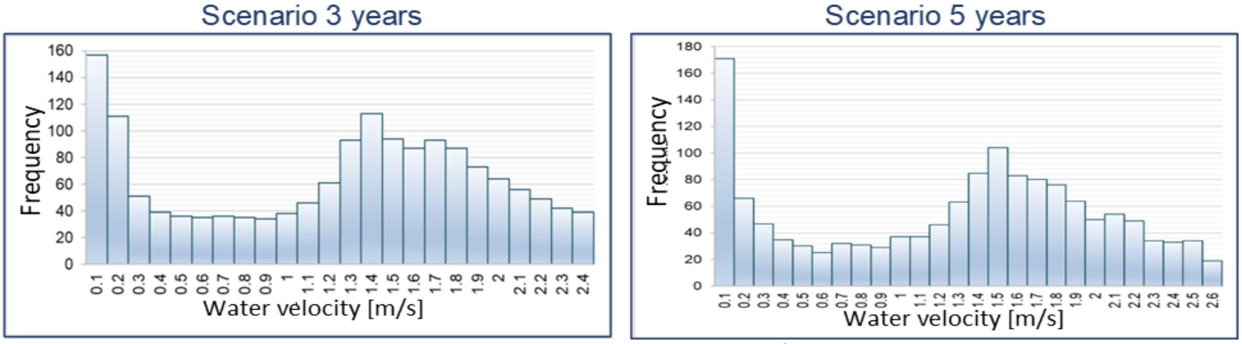


Figure 78 Velocities histograms – on the 90th bottom sill area

Figure 79 shows the velocities histograms for the area above the submerged structure built in the '90s. For scenarios where the morphohydrodynamic processes have been simulated for a period of 3 and 5 years, it has been observed that the velocities between 1.2 and 2.0 m/s are the most frequent. At the same time, for both scenarios, the velocities frequencies are less than 0.1 m/s.

In the situation of the area located downstream of the submerged structure built in the 90s (*Figure 80*), the velocities histograms have a similar shape. In the case of the analyzed scenarios, the maximum frequencies for this area are found for both the low (0,1 - 0,3 m/s) and the high (1.2-1.4 m/s - Scenario 3 years, 1.4 - 1.5 m/s - Scenario 5 years) water velocities.

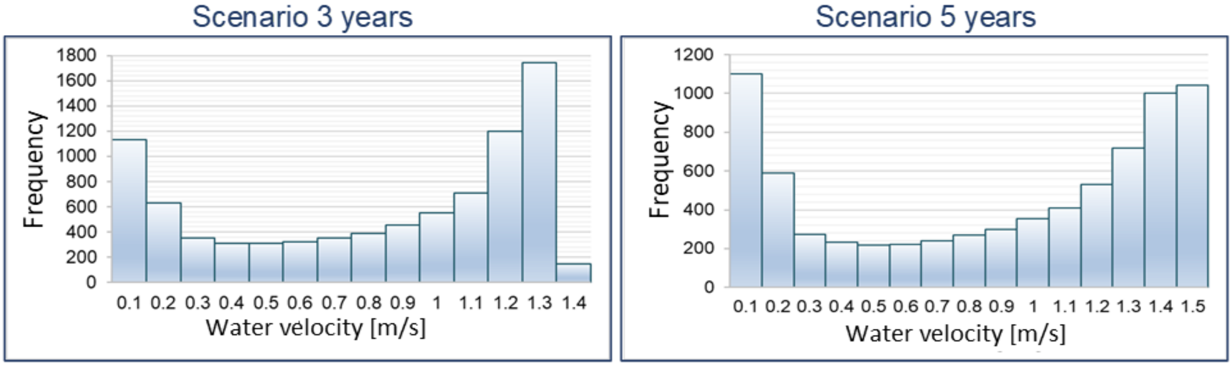


Figure 79 Velocities histograms – downstream the 90th bottom sill

Consequently, the correlation of the results obtained from the numerical simulations with the results from the monitoring campaigns derives from the fact that, from the morphohydrodynamic point of view, the building of the hydrotechnical structures does not negatively influence, in the short and medium term, the migratory behavior of the sturgeons.

Chapter 9. CONCLUSIONS, PERSONAL CONTRIBUTIONS AND PERSPECTIVES

Necessity to elaborate the doctoral thesis

The studied area, represented by the Bala branch - Old Danube bifurcation, is of particular importance from the navigation transport infrastructure point of view. This sector is part of the Pan-European Corridor no. VII, ensuring the connection between the Danube River and the Danube-Black Sea Channel. Taking into account the strategic position of the Danube as a transport corridor from the river ports to the Constanta port, in order to ensure the optimum navigation conditions throughout the year, on this area were implemented hydrotechnical structures.

At the same time, this area is part of the Natura 2000 sites - the ROSCI0022 and the ROSPA0039 and is an important sector in the sturgeon migration route.

To these considerations is added that this section represents an area with a great morphohydrodynamic diversity due to the influence of the hydrotechnical constructions build in the last years and the riverbed geometry, because the Bala branch is deeper compared to the Old Danube.

In this context, there was a question about the impact that anthropic interventions needed to improve the navigation conditions may have, over time, on aquatic ecosystems in terms of morphological changes in riverbed.

Thus, it has been developed a morphohydrodynamic numerical model that includes the Danube sector in the Bala branch - Old Danube bifurcation area (5 km on the Old Danube and 2.5 km on the Bala branch).

Through this model, numerical scenarios have been carried out which have allowed the small- and medium-scale analysis of the morphohydrodynamic evolution trends of the Danube.

The results of these investigations were correlated with the biotic elements, thus obtaining an overview of the impact that hydrotechnical structures can have on the components of the aquatic ecosystems specific to the area of interest, from morphohydrodynamic point of view.

Analysis of the morphological trend evolution of the riverbed by using numerical modeling

- ✓ Analysis of channel dynamics over a period of 16 years;
- ✓ Study regarding the modification of riverbed geometry as a result of anthropic interventions;
- ✓ Quasi-three-dimensional numerical medium scale model;
- ✓ Numerical simulations regarding the morphological changes of riverbed (3 - 5 years);
- ✓ Erosion processes on the Bala branch and sedimentation on the Old Danube;
- ✓ The results obtained following the evaluation of the riverbed trends changes (cone erosions at the entrance to the Bala branch, erosion scours downstream of the bottom sills, sedimentation areas on the Old Danube) were associated with the biotic elements of the aquatics ecosystems.

Assessing the impact on the aquatic ecosystem

- ✓ Analyzing the solubilization degree of some chemical compounds which are in the composition of these rocks;
- ✓ Correlation of the results obtained from the monitoring period with those provided by the numerical simulation to assess the impact that hydrotechnical effects may have on aquatic flora and fauna;
- ✓ In the case of simulations carried out for a period of 3 and 5 years, they resulted higher depths of the erosion scours;
- ✓ The most frequent values of the water flow velocities range from 1.5 - 2.0 m/s;
- ✓ From the morphohydrodynamic point of view, the construction of the hydrotechnical structures does not negatively influence, in the short and medium term, the migratory behavior of sturgeons

Original elements and author's contributions

Based on the results obtained in the research undertaken for the PhD thesis, the original contribution of the author can be summarized as follows:

- Conducting a comprehensive bibliographic study on the current state of research on alluvial transport, aquatic ecosystem analysis and morphological analysis of water courses using numerical modeling programs;
- Processing and interpretation of data concerning the characterization of the study area;
- Carry out comparative analyzes regarding the:
  - water and sediment quality parameters during monitoring periods;
  - riverbed in the periods before and after completion of hydrotechnical works;
  - water levels and water velocities, in different analysis periods;
  - morphological evolution of the study area over a period of 16 years, based on *Landsat* satellite imagery.
- The development of a medium-scale numerical model that can deliver highly reliable results:
  - grid cell set up;
  - geometric model development;

- analysis of several variants of hydrodynamic models;
- optimizing the hydrodynamic model;
- calibration and validation of the hydrodynamic model so that it can deliver results with a high degree of confidence;
- automation of the calculation process for verifying the vertical water flow velocity in the calibration step, in order to reduce the processing time;
- configuring the morphohydrodynamic model by accessing the sediment transport component;
- calibration of the morphohydrodynamic model;

- Performing numerical scenarios for the analysis of morphohydrodynamic processes, in the short and medium term;
- Evaluation of the morphological changes of the riverbed:
  - Selection of sections and control areas;
  - Qualitative analysis of the morphological changes which take place in the selected areas;
- Correlation of the results obtained from the morphohydrodynamic simulations with some elements of the aquatic ecosystem:
  - Analysis of the interaction of water with rockfills used for the construction of hydrotechnical structures;
  - Correlation of biotic components with the results obtained from morphohydrodynamics, by analysis of phytoplankton, macrophytes and macro-invertebrates;
  - Analysis of the influence of the morphological changes of riverbed on the behavior of ultrasonic marked sturgeons;
  - Investigations regarding the influence of hydrodynamic parameters resulting from numerical simulations on the behavior of ultrasonic tagged sturgeons, from the point of view of the ability to cross the investigated area.

Using the results in the investment strategy

One of the topics addressed in the doctoral thesis *"The anthropic impact on aquatic ecosystems components specific to the Danube" refers* to the migration behavior of ultrasonic tagged sturgeon species.

The scientific and economic importance of these species is given both by the unique value they represent for biodiversity and by the increasing demand for caviar on the market.

In the last decades, sturgeon populations have fallen due to several factors, including irrational fishing and poaching, or unidentified factors to date. In the Lower Danube there are 4 sturgeon species, namely beluga, stellate sturgeon and Russian sturgeon which are species belong to the "*Red List of Threatened Species*," according to the IUCN, and the sterlet which is considered a vulnerable species.

Given the exceptional economic importance of these species, the data provided by the correlation between the results obtained from numerical simulations and those resulting from monitoring campaigns can be the prerequisites for finding the best measures for the conservation of sturgeon stocks and identifying the causes that led to their decline.

The results provided by the simulations of the morphohydrodynamic processes, in the short and medium term, indicate the trends of erosion/sedimentation modification of the riverbed. Thus, given that the studied section is of particular importance from the point of view of the shipping transport infrastructure, these data can be used in the implementation of the intervention plans for the maintenance of the Old Danube waterway.

Also, the results obtained from the research can be a useful data base for the development of other hydrotechnical solutions in order to ensure the discharge required for navigation on the Old Danube.

To these considerations it is added the fact that using the *Delft3D* program, it is possible to update the configurated numerical model, in order to elaborate studies regarding the morphohydrodynamics long-term analysis and the evaluation of water quality parameters.

Perspective of the subject development

In the present paper are correlated the data obtained from the monitoring campaigns with the results provided by the numerical simulations. For the next period, the following research directions can be designed as follows:

- Continue to perform field measurements in order to obtain a database allowing the calibration of the morphohydrodynamic model, over a large scale;
- Performing numerical scenarios through which to analyze the trends of morphological evolution of the riverbed, in the conditions of climate change;
- Continue the monitoring activities of sturgeon species because the available information regarding the wild sturgeons behavior and their wintering and migration routes on the Lower Danube are not absolutely known;
- Updating the numerical model so that scenarios can be set up by which to analyze the water quality parameters in case of accidental pollution. This goal is to be developed under the Nucleu Project PN 18 26 02 01/2018: "*Research on the evaluation of water quality parameters by using numerical models in order to simulate the pollutant dispersion on Danube River".*

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2. A/2018/00099 - *Electrochemical method for diagnosing alkaline-aggregated reactions in the laboratory*, G.Poteraş, Gy. Deák, **A.-F. Nicolae**, A.I. Dăescu, I.F. Burlacu;
3. A/2018/00179 - *Prefabricated elements with photovoltaic cells embedded for facade and non-circular terrace roofing*, G.Poteraş, Gy. Deák, **A.-F. Nicolae**, A.G. Baraitaru, M.V. Olteanu;
4. A/2018/00180 - *Glazed roofing tiles with photovoltaic potential*, G.Poteraş, Gy. Deák, A.G. Baraitaru, M.V. Olteanu, **A.-F. Nicolae**.
5. A/2018/00577 - *Prefabricated parapets for roads, bridges and highways which incorporate photovoltaic cells,* G.Poteraş, Gy. Deák, **A.-F. Nicolae**, A.G. Baraitaru, M.V. Olteanu.

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1. **A.-F. Nicolae**, P.L. Georgescu, M.C. Raischi, Al. Petrescu, M. G. Boboc, *The Influence of Hydrotechnical Structures on the Minor Riverbed Morphology of the Danube, In the Bala Branch - Old Danube Bifurcation Area*, TEHNOMUS JOURNAL, no. 23, pg. 13-17, 2016;
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