

## DEVELOPMENT OF A BATHYMETRIC MODEL FOR DANUBE BALA BRANCH-OLD DANUBE BIFURCATION

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**Abstract:** *The study area is of particular importance in terms of the morphological complex processes of the riverbed. Bala branch is defined by intense hydro morphological dynamics areas. At the same time, Old Danube is characterized by sediment deposition processes, as evidenced by the presence of numerous islands and sandbanks, with negative implications for navigation. In this context, in order to create hydrodynamic and morphodynamic models using Delft3D software, it is necessary to develop a bathymetric model that allows to provide results that are in line with reality. At the basis of the bathymetric model are the results obtained from the single beam and multi-beam measurements and the optimized grid which was refined in the hydrotechnical construction area.*

**Keywords:** *Danube River, grid, bathymetry, morphodynamic.*

### 1. Introduction

The Danube River is the second largest in Europe after the Volga, with a total of 2857 km and a hydrographic basin of approximately 817,000 km<sup>2</sup> [1]. The Danube is of particular importance for Romania, the country being almost entirely in the Danube basin, covering about one third of the basin's surface and the total length of the watercourse [2].

In order to ensure navigation safety, there was the need to draw up bathymetric maps, indicating the Danube's fairway. At national level, on the basis of the bathymetric works carried out under the leadership of I. Ionescu, such maps were drawn up from 1905 to 1910 on the Danube River, the depths indicated being reported to the altitude of "0" from the local rod [3].

Nowadays, systems with single beam and multibeam echosounder equipment are used to determine the morphology of the riverbed.

Single beam bathymetric measurements are based on the principle by which the water depth is determined by measuring the time recorded from the signal emission to its reception after reflecting the bottom of the riverbed [4] [5]. The single beam system is equipped with a single transducer for both emission and reception. By using this system, you cannot get images of a large surface on the riverbed. However, single beam systems are useful and inexpensive when performing bathymetric measurements on a cross section of a watercourse [5].

The bathymetric measurement technology with multibeam equipment has been developed since the early 1990s. Through these measurements, a detailed image of the watercourse riverbed can be obtained, which are often not taken over by conventional measurements with single beam sonar [5].

In order to perform analysis regarding the watercourses hydro-morphological conditions, information resulting from the field measurements processing are used as input data by the numerical modelling software. It is possible to calculate hydrodynamic (water current velocity, water surface elevation etc.) and sediment transport variables, to determine water quality parameters, to observe trends in the riverbed morphology, etc. [6].

*Delft3D* is the world leader in three-dimensional modelling for hydrodynamics, sediment transport, morphology and water quality parameters for water courses, estuaries and coastal environments. This software has been used over 140 countries for a wide variety of commercial projects and research studies [7]. The use of this software allows the analysis and prediction of water flow dynamics, both bidirectional and three-dimensional, depending on the input conditions established on the basis of the riverbed parameters and water discharge. *Delft3D* offers the possibility to establish hydrodynamic variables (flow discharge velocities and water levels, turbulence properties, water pressure on the riverbed, etc.), to determine sediment transport characteristics, to analyse the hydro-morphological parameters of the watercourse, to model water quality parameters, etc. [8].

## 2. Bathymetric measurements

This research investigates the Danube sector represented by the Old Danube between Km 348 and Km 343 and the Bala branch between Km 10 and Km 7.5 (Fig. 1). The study area analyzed in this paper is of particular importance from the point of view of the complex hydro-morphological processes of the riverbed. The Bala branch is characterized by an alternation of areas with intense hydromorphological dynamics with relatively low energy areas. On the Old Danube, the fluvial energy is diminished, downstream of the bifurcation, thus sediment deposition processes predominate, as evidenced by the presence of numerous islands and sand banks that form sills with negative implications for navigation [9].

At the same time, in order to improve the navigation conditions on the Lower Old Danube, in the analysed area, a bottom sill, a guiding wall and a bank protection were built in order to redistribute discharges between the two branches.



Fig.1. Location of the study area

In order to obtain data regarding the bathymetry of the minor riverbed, measurements were made using equipment provided by INCDPM. Thus, for the achievement of the bathymetric profiles were used equipment based on Acoustic Doppler Current Profiler (ADCP) technique, namely *River Surveyor M9* and *RiverRay* system.

Through this technique, both single beam bathymetry and water velocity measurements can be performed on different sections. Based on these measurements, the discharges on these sections can be estimated. However, ADCP measurements are limited in cross-section coverage, namely [5]:

- Areas near the banks cannot be measured;
- The riverbed area cannot be measured, as the echosounds are disturbed by the bottom reflections over a distance of about 6% of the total depth.

However, by using the acquisition program, these unmatched areas are automatically estimated by extrapolation of measured data from proximity.



Fig. 2. *River Surveyor M9* bathymetrical system



Fig. 3. *RiverRay* bathymetrical system

The *River Surveyor M9* (Fig. 2) is a robust and extremely accurate system designed specifically to measure the water depths, velocities and directions of water flows using Doppler technology [10]. This system associates Doppler technology with a Windows-based software package, facilitating both acquisition and primary data processing [10].

A stationary or moving vessel can be used to carry out the measurements. In the present research the measurements were made using a low-speed vessel, perpendicular to the bank, so as to obtain a cross section. In order to verify the accuracy of the records, each profile is conducted from 2 to 4 crossings.

Using the ADCP technique, the *River Ray* (Fig. 3) is a single beam bathymetrical system, designed to measure real-time bathymetric profiles and water velocities of water flows in rivers with different hydrological regimes. It consists of a 600 kHz transducer on which a water temperature sensor is installed. The system is installed on the float and the connection to the field computer is done via the *WinRiver II* program.

Considering that echosound systems are the most efficient equipment for the riverbed bathymetry measurement [5], the data obtained by using the *Kongsberg Geoswat Plus* multibeam system (Fig. 4) were also used in the research. The obtained bathymetry is highly accurate, after processing the data resulting a 3D model of the riverbed (Fig. 6).

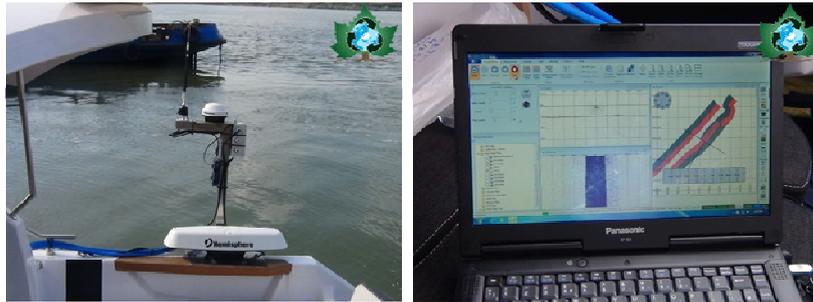


Fig. 4. *Kongsberg Geoswat Plus* multi-bathymetric system

This system was purchased from *Kongsberg Maritime*, a company that has been providing echosonar for more than 60 years and echosonic multibeam since 1986, being recognized as the world leader in echosonic multibeam systems used for water bodies of different depths. By means of this system, bathymetric data are acquired, with a profile coverage up to 12 times the depth of water [11].

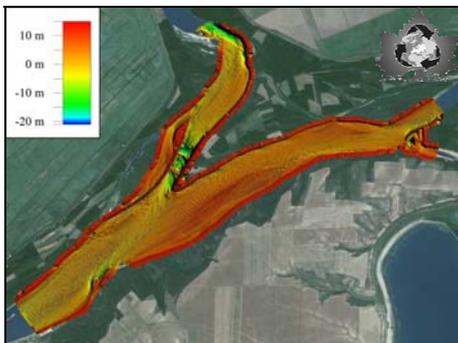


Fig. 5. Area covered by the bathymetric measurements of March 2016

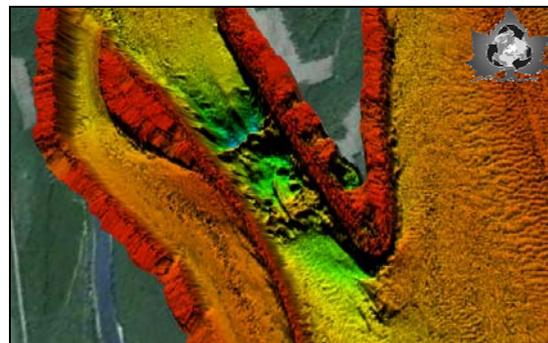


Fig. 6. Detail of bathymetric measurements at the Bala branch bottom sill

In the research, in March 2016, when an average discharge of  $12,300 \text{ m}^3/\text{s}$  was recorded at the Calarasi hydrometric station, bathymetrical measurements were carried out in the Bala branch – Old Danube bifurcation area (Fig. 5, 6). Multibeam measurements consisted in the performing of several cross-sectional profiles projected across the entire width of the riverbed, in order to have as much coverage as possible.

### 3. Computing network

After the field measurements and the processing of the information, in order to obtain the program input data for the numerical simulation, it was necessary to construct the

computing network related to the area of interest and to create the bathymetric model of the riverbed, based on the measurements in the field.

In order to build the computing network, the *Delft3D-RGFGRID* module was accessed. Depending on the area boundaries, this module allows to create, build, optimize and view the grids/networks to be used for bathymetry implementation [12]. The program offers the possibility to select the network where the hydrodynamic equations are solved: rectangular coordinates, orthogonal curvature coordinates (selected limit) or spherical coordinates. As for the three-dimensional simulations, for the building of the vertical network were selected  $\sigma$ -coordinates [13].

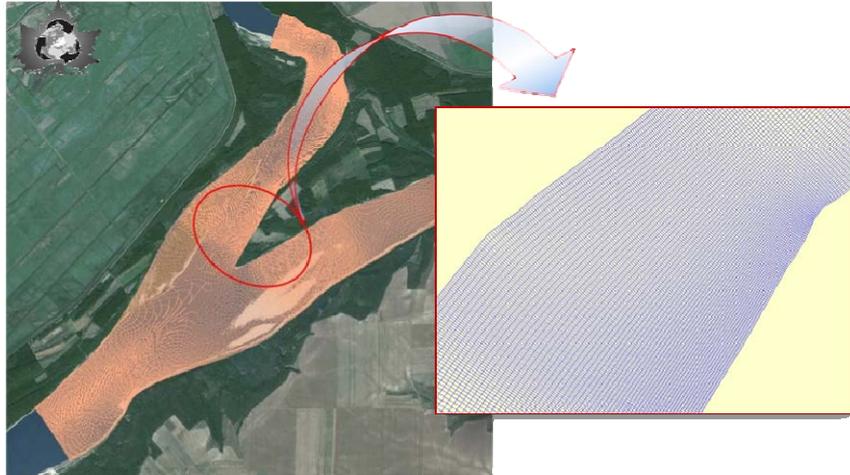


Fig. 7. Grid detail

A first step in the construction of the grid was the establishment of the study area boundaries. The inserted borders follow the line of the banks of the analysed sector, namely on the Bala branch between Km 10 and Km 7.5 and the Old Danube between Km 348 and Km 343. The limits imposed by the banks were made based on the information obtained from the topographical measurements conducted by INCDPM experts, as well as satellite data from high-flow periods (Fig. 1). Depending on these, splines are drawn and then the grid is generated (Fig. 7).

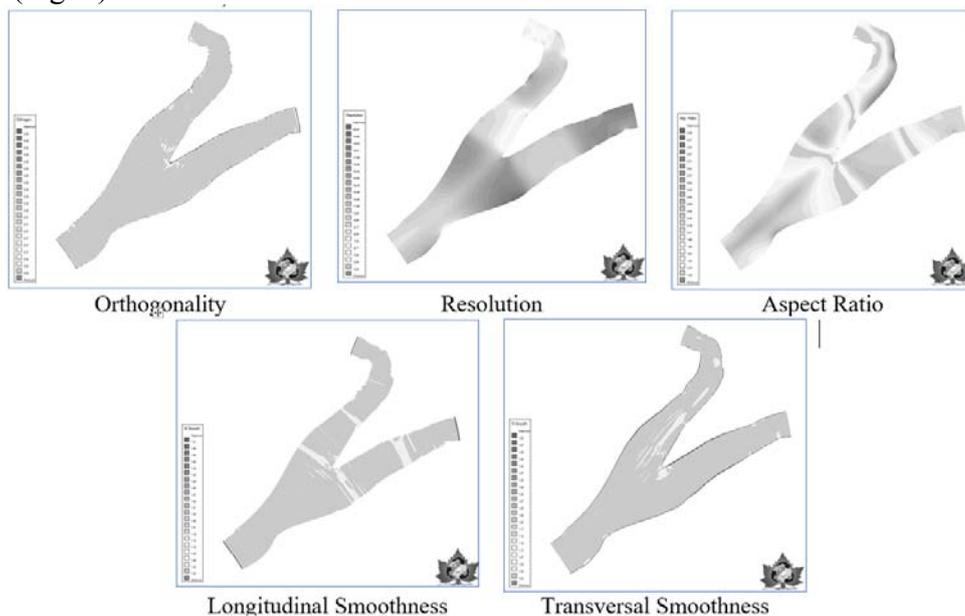


Fig. 8. The grid properties values

The grid thus constructed has 59024 cells, of which 528 longitudinally developed and 113 transversally. This was accomplished using polyhedral mesh cells with quadrilateral faces with dimensions ranging from 3.88 to 27.32 m in the longitudinal direction and 2.90 to 21.99 m in the transverse direction. These features provide the optimal proportion between mesh size, runtime and results.

In order to perform correct hydrodynamic calculations, the requirements imposed on the grid thus generated were analysed, namely: orthogonality, the rate for dimensional and directional changes (smoothness, curvature) and the ratio of meshing to different directions (Fig. 8).

After successive operations required to improve the grid properties, were obtained values that were optimized. The grid properties values provide the optimal proportion between model scale, runtime and results

On this grid will be implemented the bathymetry that will result from the processing of the data obtained from the measurements carried out in March 2016.

#### 4. Bathymetrical model

Based on the grid and the data obtained from the field measurements, the bathymetric model for the study area was created.

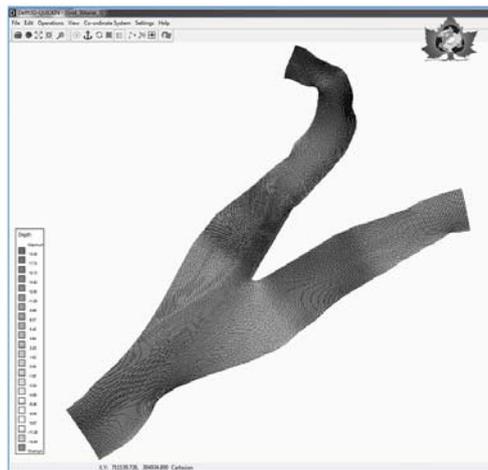


Fig. 9. The grid in the study area with bathymetric data

This operation was performed analytically by the automatic correlation between the coordinates of the computing cell centres and the georeferential information in the same coordinate system. The overlapping of the bathymetric data over the grid was accomplished by using the *Delft3D-QUICKIN* module and was an operation requiring a high volume of analysis.

Single-beam and multi-beam bathymetry data were processed so that each cell of the network was assigned the absolute elevation value - in Stereo 70 MNS (MNS – Altimetry System Black Sea – Sulina) - of the Danube riverbed.

The "depth" variable in the legend of Figure 9 does not have the meaning of depth but of absolute quota (relative to MNS - Black Sea Sulina) of the bottom of the Danube riverbed - bathymetric values obtained by interpolation at the respective cells. Figure 10 is a 3D detail with bottom sill in the Bala branch area.



Fig. 10. The bathymetric model exported from the *Delft3D* program. Detail the Bala branch

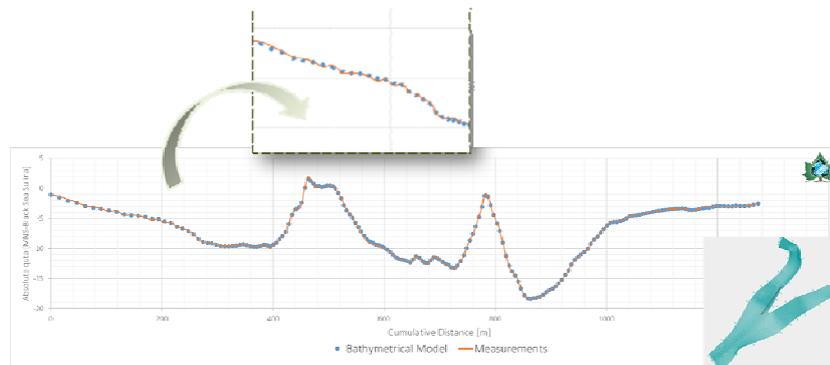


Fig. 11. Longitudinal control section - Comparison between the *Delft3D* bathymetric model and measurements

The bathymetric model data was compared with the data obtained from the measurements. In this regard, control sections have been designated, resulting an average difference of about 1.5 cm.

## 5. Conclusions

The bathymetric model represents the basis for the numerical model development process, through which information can be obtained regarding hydrodynamic and hydro-morphological variables, sediment transport characteristics, water quality parameters, etc. influenced by the hydrotechnical works conducted on Bala branch, in order to achieve the discharge redistribution towards Old Danube.

The development of the bathymetric model implied a high volume of analysis work and laborious calculations, using as primary data measurements carried out by experts with high-precision equipment.

To verify the bathymetric model accuracy, control sections were designated, in which the Delft3D model data was compared with the *in-situ* measurements, resulting an average difference of about 1.5 cm. The bathymetric model obtained using the Delft3D program fulfils the necessary criteria for performing numerical simulations.

Taking into account the morpho-dynamic phenomena occurring in the Bala – Old Danube branch bifurcation area it is necessary to periodically update the bathymetric model based on the results obtained from the measurements.

## 6. Acknowledgement

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