Hydrodynamic Modelling for the Chilia—Bystroe Danube Sector: Model Calibration and Validation

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Abstract Morpho-hydrodynamic changes are one of the major problems affecting the abiotic sphere and the ecological status of water bodies. In order to assess the impact of the works carried out in the Bystroe Channel on the hydrodynamic and hydromorphological conditions of the Chilia and Old Stambul Danube branches, solid scientific based tools are required. Using MIKE 3 Flow Model and input data provided by in situ campaigns carried out by the National Institute for Research and Development in Environmental Protection Bucharest, an 8.5 km river length hydrodynamic model was developed, calibrated and validated in two independent river flow conditions. The model shown to provide high—confidence results (>90%) by comparative analysis of modelled versus measured values for water discharge and similarity in water velocity distribution for transversal control sections.

Keywords Hydrodynamic modelling · Boundary conditions · Model calibration · Model validation · Danube river · Bystroe Channel

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1 Introduction

Over time, the Danube River has undergone alteration processes that have affected the dominant natural systems and created structures for economic purposes (navigation, hydropower, agriculture, ports, etc.) that have led to the reduction of floodplains and changes in morphological structures. The Chilia Branch status is particularly important due to the fact that it acts as natural state border between Romania and Ukraine and from it branches the Bystroe Channel, for which intended increased navigability, works have been carried out since 2004 that lead to international intense debate over the adverse transboundary impact on the local hydrodynamic and hydromorphological conditions [1] and habitat loss for fish and birdlife [2, 3].

It is necessary to use techniques and tools [4] to help determine the correct spatio-temporal evolution of hydromorphological properties with impact on water quality [5]. Currently, high-performance software programs are available that ensure the development of numerical models with a high level of confidence in simulating the hydrodynamic and hydromorphological conditions of rivers [6]. With the evolution of technology, a series of programs have been developed related to the hydraulic modeling of water flow [7]. Given that the numerical models take into account all the elements that can influence the water dynamics (flow, bathymetry, riverbed roughness, etc.), by 3D modeling can be calculated hydrodynamic variables and sediment transport, water quality parameters can be determined and trends in riverbed morphology can be monitored [8].

2 Materials and Method

In order to develop a hydrodynamic model for the Chilia-Bystroe area, the first steps carried out consisted of modelling domain delineation by implementing the measured bathymetry values into the dedicated computational grid and setting up the boundary conditions and simulation parameters. Considering the extent of the 3D riverbed bathymetry data set provided by the high resolution multibeam measurements carried out by the National Institute for Research and Development in Environmental Protection Bucharest (INCDPM), the modelling domain covered an 8.5 km length river sector, as seen in Fig. 1.

The in situ campaigns carried out by INCDPM [9] provided data sets (Fig. 2) that were used for setting up the geometric model, boundary conditions (discharge and water level values) and water velocity distributions in control sections for the model calibration and validation.

The developed geometric model for the study area consisted of 17680 triangular elements and 9446 nodes in the horizontal plane and 10 sigma layers with variable thickness (2, 3, 4, 6, 8, 10, 12, 15, 20, 20%) in the vertical plane. The data used for the boundary conditions resulted from Acoustic Doppler Current Profiler (ADCP)

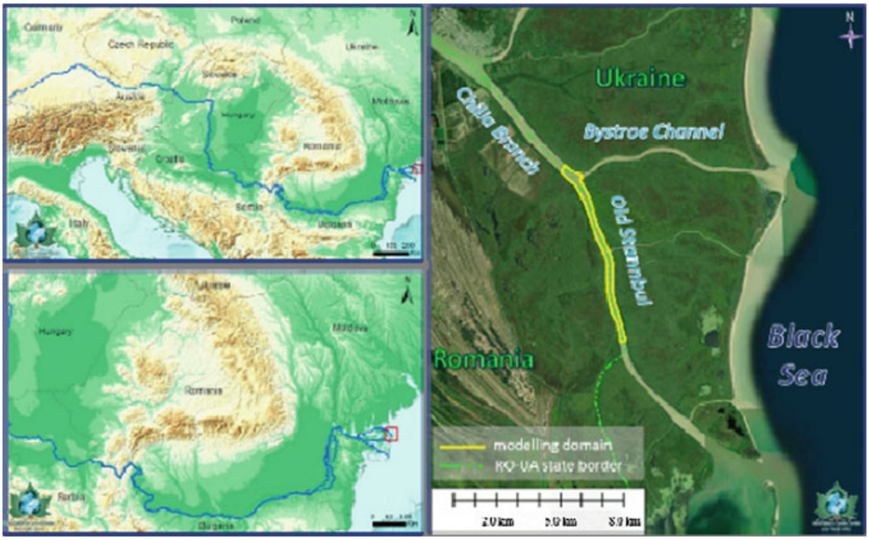

Fig. 1 Position of the hydrodynamic model domain in the Danube river basin

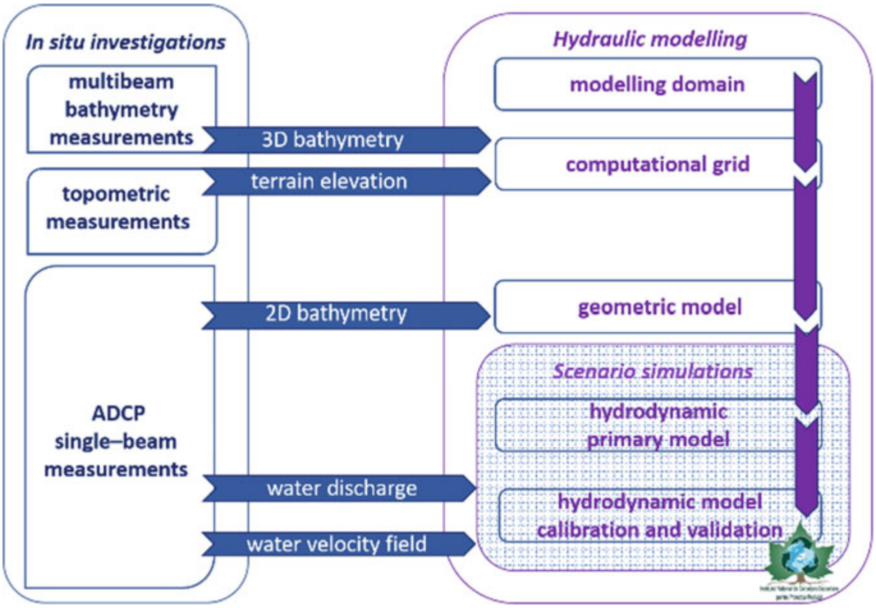

Fig. 2 Hydraulic modelling and measured input data sets (INCDPM 2020)

Table 1 Parameter values measured in situ campaigns used for boundary conditions

Control section	Water discharge values [m^3/s]		Water level values [m]	
	1st set	2nd set	1st set	2nd set
Upstream modelling domain (C1)	1434	2199	0.272	0.677
Bystroe channel access (C2)	658	1036	0.265	0.669
Downstream modelling domain (C3)	776	1163	0.202	0.592

single-beam measurements (water discharge) and from topometric measurements (water level) that were carried out in different hydrological conditions (Table 1).

The initial model was calibrated by gradually varying the parameters values until the modelling results were similar with the in situ measured values for the set flow conditions.

The model validation process consisted in setting up the boundary conditions for another data set recorded in different flow conditions and running the model by using the parameter values determined in the calibration process and compare the resulted modelled values with the measured ones.

3 Result and Discussion

The main simulation parameter that estimates the influence of the riverbed resistance in the Hydrodynamic module (HD) of MIKE 3 Flow Model is the *roughness height (RH)*. For different RH values, 15 test models were run and the modelled discharge values were compared with the measured ones (Fig. 3). With resulted relative errors of −1.38% (C3) and −1.74% (C2), the optimum value for RH was determined to be 0.09 m.

As seen in Fig. 4 for a cross-section located below the bifurcation (Fig. 4a), another step in the model calibration process consisted in the comparative analysis of modelled (Fig. 4b) and measured (Fig. 4c) water velocity distributions for transversal sections. Figure 4 shows the similarity of the two distributions.

In the model validation process, a numerical simulation was carried out using the second data set from Table 1 for the boundary conditions and the determined 0.09 m value for RH. The resulted relative errors for modeled discharge values being below 10% (Table 2) and the water velocity modelled and measured distributions being similar, the hydrodynamic model for the Chilia—Bystroe area was considered validated.

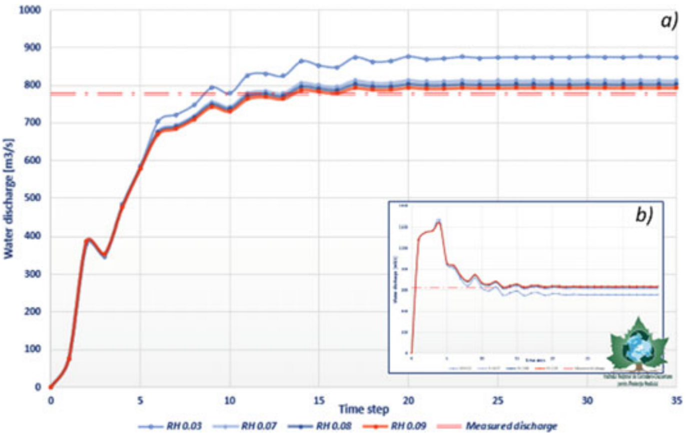

Fig. 3 Modelled discharge versus measured values—model calibration stage for C2 (**a**) and C3 (**b**) control sections

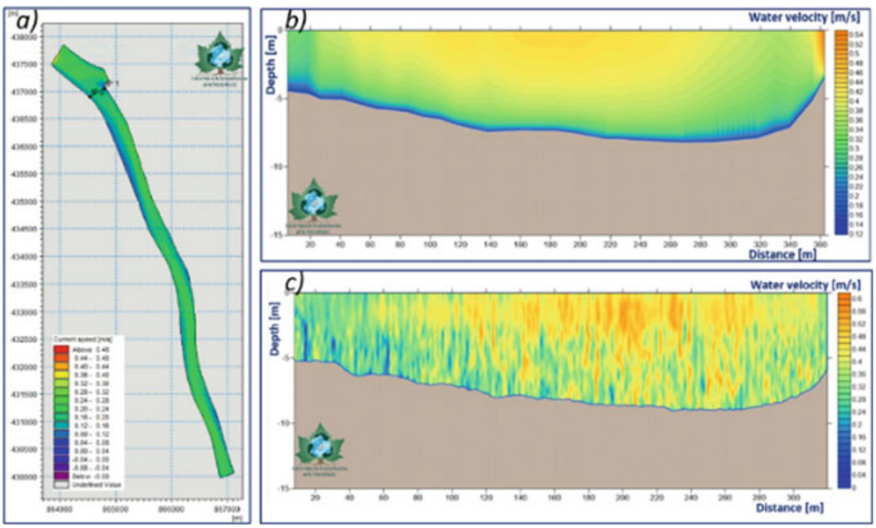

Fig. 4 Modelled water velocity versus measured distribution—model calibration stage

4 Conclusion

Using MIKE 3 Flow Model, a software with international repute on solving challenges in water environments and results of in situ measurement campaigns carried out by INCDPM for the 3D bathymetry on which the geometric model was developed, for the boundary conditions and reference values for the model calibration and validation processes, the hydrodynamic model for the Chilia—Bystroe area had

Table 2 Modelled versus measured values of water discharge in C3 and C2 control sections [m^3/s]

Test model	Control section	Measured [m^3/s]	Modelled [m^3/s]	Relative error [%]	Control section	Measured [m^3/s]	Modelled [m^3/s]	Relative error [%]
1	C3	776	951.839	−22.66	C2	658	479.33	27.15
2			874.716	−12.72			555.98	15.5
3			548.764	29.28			885.221	−34.53
4			694.489	10.5			738.72	−12.27
5			694.583	10.49			742.849	−12.89
6			674.369	13.1			758.902	−15.33
7			812.76	−4.74			617.977	6.08
8			837.771	−7.96			592.975	9.88
9			812.76	−4.74			628.48	4.49
10			802.701	−3.44			628.012	4.56
11			824.295	−6.22			606.449	7.83
12			798.894	−2.95			636.894	3.21
13			791.717	−2.03			653.431	0.69
14			793.795	−2.29			643.477	2.21
15			786.699	−1.38			669.428	−1.74
Model validation		1163	1048.72	9.83		1036	1133.91	−9.45

shown that it provides results with a high degree of confidence (>90%). The model will be updated with new data as it becomes available and it will be used for making short- and medium-term forecasts based on scenarios in order to assess the morpho-hydrodynamic changes for this area with strategic importance and their impact on migration routes and sturgeon habitats.

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