

## THE ANALYSE OF THE FLOOD REGIME IN THE LOWER COURSE OF THE DANUBE RIVER FOR SECTOR GHIDICI-CORABIA\*

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*Abstract.* The Danube River and its affluents made a complex ecosystem which exiting natural balance equilibrium depends strongly on water courses, flow, sediment transport, water temperature and other physical variable with well defined role. The new policy concept "more space for rivers" of Europe meaning to give back river what "we've got" requires the harmonization of social and economical needs in order to preserve aquatic flora and fauna (conserving habitats-wetlands), mitigation of floods and retention of nutrients. The aim of the present paper is the analysis of the Danube flood area regime between Ghidici and Corabia in the wetlands restoration scenario of the agricultural polders (there are not dams and there is the possibility to re-establish the old Danube riverbed). For this it was made the 1D2D sketch (the use of the "Overland flow") that integrates hydraulic elements 1D of the analyzed area with the digital model of the land. The hydraulic description of the rivers discharge and the water management was made using SOBEK RURAL software package offering a high quality for the hydraulic modelling of the river flowing into low areas and in hilly lands of the irrigation and drainage systems. The scenarios were rolled for a minimum hydrological level of the Danube River (year-2003), medium (year-2004) and for the high level (year-2006). They made flood maps for low, medium and maximum levels of Danube River and was determined the flood degree on the analysed sector.

*Key words:* Sobek hydraulic modelling, flood mapping, flooding scenarios, Danube, wetland.

### 1. INTRODUCTION

Historic high flood of April-May 2006 on the Danube river was the cause of accidental breakage or directed breakage of embankments, of a number of 10 agricultural enclosures, summarizing an area of 73 144 ha. The damages caused by total or partial flooding of villages located in this enclosures, consisting of 50% damage houses and the necessity of relocation of a number of 16 350 inhabitants.

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The total impoundment of Danube, warned the great scientist Grigore Antipa in the work "Danube and its scientific, economical and political issues" (1921), "would lead to incalculable consequences", because "the large marshes form an organic whole with the river", that "separating them" "we will transform them in un-productive swamps" and "the fishery from the whole Danube and even across the entire Delta will be destroyed. Immediately as the migrants fishes will be deprived of their breeding and feeding sites". Based on lengthy researches, Grigore Antipa concluded that the Danube has distinct features to other rivers, and the economical interests and biodiversity conservation require a specific treatment. He emitted the theory that the Danube Valley is one of the great flood storage reservoir, which may take about 26 billion cubic meters of water, leading to the pressure decreasing on the downstream localities, on the one hand, and on the other hand, it would regulate the river flow during drought periods, making it easier navigation. To do this, the Danube embankment must be thought otherwise. On the one hand, with submersible dykes, behind which to set up crops, pastures, etc., that alternate with highly productive fisheries, with minimal costs. And on the other hand, with high embankments, insubmersible, on the border of towns and terraces, area which is destined to crops. The same great scientist suggested the use for tourism purposes of wild Danube landscapes.

Following the catastrophic floods produced on Danube in 1970, it was began a vast project of the flood plain damming and of aquatic surface draining, in most of them. In this way, the largest wet areas in Romania were removed and the lands rendered to agriculture.

In the past 50 years, the rivers from Romania like the most rivers in Europe, suffered profound transformations in order to use those functions for the development of economical and social activities. There are enough cases where the hydro morphological transformations of the rivers for the economical use, have affected their ecological functions, [1].

The new concept of development of the river is based on the principles of sustainable development which is based on the idea that "Water is a heritage that must be defended, preserved and treated as such". The Water Framework Directive (CE/60/2000), [2] and Flood Directive (2007/60/CE), [3] promotes a new concept of rivers management, having as primary goals the reduction of flood risk and the conservation of aquatic biodiversity.

The new river development strategy starts from the idea that the rivers and their corridors form complex ecosystems that include adjacent lands, flora and fauna and the watercourses. These ecosystems depend of the regime of watercourses in which flows, sediments transport, water temperature and other variables have a well defined role. In case of generating of some changes to this existing variables in natural way, the balance is disturbed. That is why the rivers planning through engineering works that should have as goal the keeping in time and space a global dynamic equilibrium of watercourses.

The damming of watercourses on the long sectors of the river have led to the reduction of aquatic biodiversity as well as to the dez-attenuation of maximum discharges.

“**More space for rivers**” are keywords, which illustrate the political idea that currently dominates the Western Europe (which supports the need of river reproduction of what “we’ve got” - **flooded plains** - so that they drain properly high floods, instead of **corset of rivers between dams**. To achieve this goal in some countries from western Europe, the state acquires lands in flooded plains, by purchasing or compensating with other lands. This new concept “**More space for rivers**” requires the economic and social needs harmonization such as water supply, protection against floods and other ecological requirements. For this it must be assured the river continuity and its link with flooded plain, for achieving some habitats (wet areas) for: aquatic flora and fauna conservation, mitigation of floods and nutrients retention. In this way the river can show its mobility and it can adapt to external disturbance pressures and to keep its self operation conditions.

In the new concept of development, the structural measures will be limited to those absolutely necessary, namely:

- accomplishment of some strategic accumulation lakes in areas of flooding, to provide water for utilization and to reduce the flooding risk. For the accumulation lakes located on the water courses with migratory species, it will accomplish corridors for biota.
- Polders accomplishment with conducted flooding, on middle and lower sectors of water courses, to mitigate peak flow of floods
- Damming accomplishment on the short sectors of the river, for protection against flooding of localities and of some economical and social objectives.
- Rivers renaturalization and creating some suitable habitats for the conservation and development of aquatic fauna and flora.

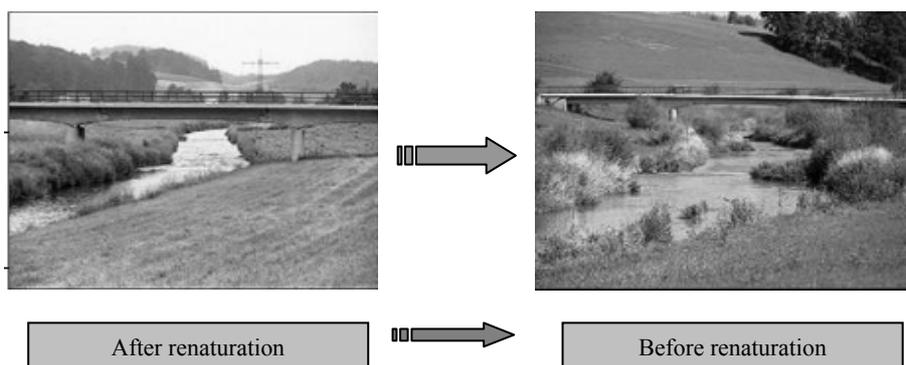


Fig. 1 – Image of rivers renaturalization.

By rivers renaturalization are providing some new spaces for floods mitigation and new spaces for nature, represented by flooded plains, where it will develop new ecosystems which provide optimum conditions for aquatic fauna and flora, as well as for recreation and tourism.

The program of ecological and economical re-dimensioning of assembled enclosures from Meadow and Danube Delta, was designed and launched to assist the Romanian Government in planning long term strategic objectives of Water Framework Directive, and the effective implementation of tasks relating to prevention, protection and flood mitigation, stipulated by the National Strategy of Flood Risk Management.

The study on “Ecological and economical re-dimensioning of Danube Plain” (REELD 2008), [4], based on the efficiency indicators analysis and on the cost-benefit report, the map of economical activities was drawn inside the agricultural enclosures from Lower Danube Plain – Romanian sector. Thus were established different functions of enclosures, as suitable for agriculture or water storage.

Hydrological scenarios were developed to quantify the Danube level decrease at maximum levels by:

- agricultural enclosures renaturalization
- the use of some agricultural enclosures for water storage at the maximum levels of Danube
- combined scenarios (renaturalization and water storage in some agricultural enclosures).

In the study it were used the results obtained in the ecological re-dimensioning project of Danube (REELD, 2008) which combine the requirements of Danube level decreasing by re-nature/ water storage in the areas suitable for such uses, to store a volume of water (degree of filing) as small as possible. Following the idea of renaturalization and based on these results we have made a script for hydraulic model SOBEK to simulate flooding in natural condition on sector Ghidici - Corabia.

The modeling hydraulic software used is SOBEK RURAL (Delft Hydraulics Software and some theoretical considerations related to software, are presented in Section 2 of the paper. Data for this model and the work method, to achieve flooding scenario, both for the module 1D FLOW and 2D OVERLAND, are presented in Section 3. The results and their discussion are presented in Section 4. The conclusions end the paper.

## **2. BRIEF THEORETICAL CONSIDERATIONS**

SOBEK, [5] is an integrated software package for describing hydraulic flow of rivers and water management in urban and rural areas. Seven software modules work together, to provide an overview of control flow. Is an integrated framework

which can connect rivers, canals and drainage systems, for total water management solutions. It has a friendly graphic interface, SOBEK is designed to interface with existing software. It can download information from a variety of data standard formats and GIS systems (**G**eographic **I**nformation **S**ystem).

In the study we used packet SOBEK RURAL, which offering a high quality tool for modeling fluid flow in rivers in the lowlands and hilly areas, for irrigation systems, and for drainage systems. Applications are usually related to flood control, water resources management in reservoirs, optimize agricultural production through the irrigation and the control of water quality. SOBEK-RURAL provide support for effective planning, designing and operating new water systems and existing ones.

The numerical model that make simulations (numerical calculations) one / bidimensional continuous flow/turbulent flow, is based on Saint Venant equations. Numerical modeling, based on solving the Saint-Venant equations, is a numerical problem with initial and boundary conditions [6], [7].

Water flow is calculated by solving the complete Saint Venant equations. For one dimensional flow, equations are solved, for continuity and equations of motion (simplified without terms containing wind speed and density).

Continuity equations:

$$\frac{\partial A_f}{\partial t} + \frac{\partial Q}{\partial x} = q_{lat}, \quad (1)$$

where:  $A_f$  = wetted area [ $m^2$ ], cross-sectional area that is watered by water;  $Q$  = flow [ $m^3/s$ ];  $t$  = time [s];  $x$  = distance [m];  $q_{lat}$  = lateral flow per unit length [ $m^2/s$ ], volume of water entering or leaving the model in a node or network segment.

Equations of motion:

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \alpha_B \frac{Q^2}{A_f} \right) + g A_f \frac{\partial h}{\partial x} + \frac{g Q |Q|}{C^2 R A_f} = 0, \quad (2)$$

where:  $Q$  = flow rate [ $m^3/s$ ];  $t$  = time [s];  $x$  = distance [m];  $\alpha_B$  = Boussinesq coefficient [-];  $M$  = wetted area [ $m^2$ ];  $g$  = acceleration due to gravity [ $m/s^2$ ];  $h$  = water level [m];  $C$  = coefficient Chézy [ $m^{1/2}/s$ ] (coefficient of friction to take account of bed roughness);  $R$  = hydraulic radius [m]. Hydraulic radius is defined as the ratio of wetted area and wetted perimeter in cross section of a watercourse).

The first term describes inertia. The second term describes convection. The third term describes the water depth gradient. The fourth term describes the friction.

Block diagram of the model consists of several modules. The first module represent the schematized network which can be in different settings and weather data also may be added, and could thus make the hydraulic model in a hydrological model. 1D schematization of the river is make by nodes, sections and subsections. A node is used for a fork, a junction or a border. Nodes are defined horizontally and coordinates  $x$  and  $y$ . Between two nodes, to define a segment He is the real value of the river between fork, junction or boundaries. Cross sections serve to help determine the different levels and widths of the river bed.

To simulate the flooding of enclosures or polders, making breach in dams, breaks of dikes or dams we have used 2D specialized module that allows a two-dimensional hydraulic simulation of hydrological regimes listed above.

When it comes to achieving schematization, run the simulation program. The results obtained can be viewed in different forms: maps, graphs, tables.

### 3. DATA AND METHODS

#### 3.1. 1D INPUT

##### a) Flow input and level output ( $Q \rightarrow H$ )

Model uses as input time series of flows for the entry border node (Fig. 2) and time series levels for exit border node.

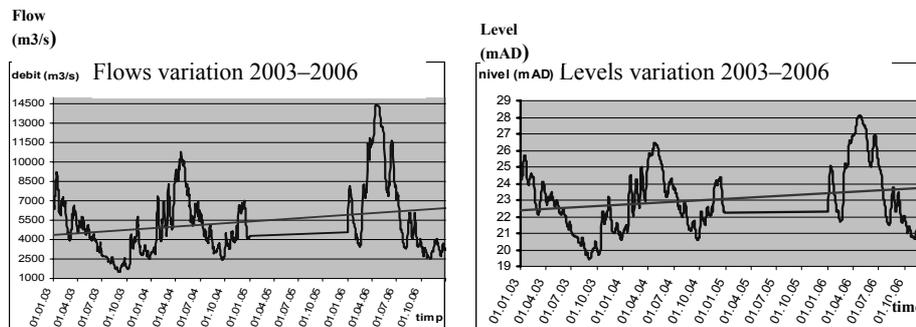


Fig. 2 – Representing the time series of entry flows and exit levels.

b) Cross sections I introduced in the model, cross sections of the river taken from the entire length, at distances of 1 km between them (Fig. 3).

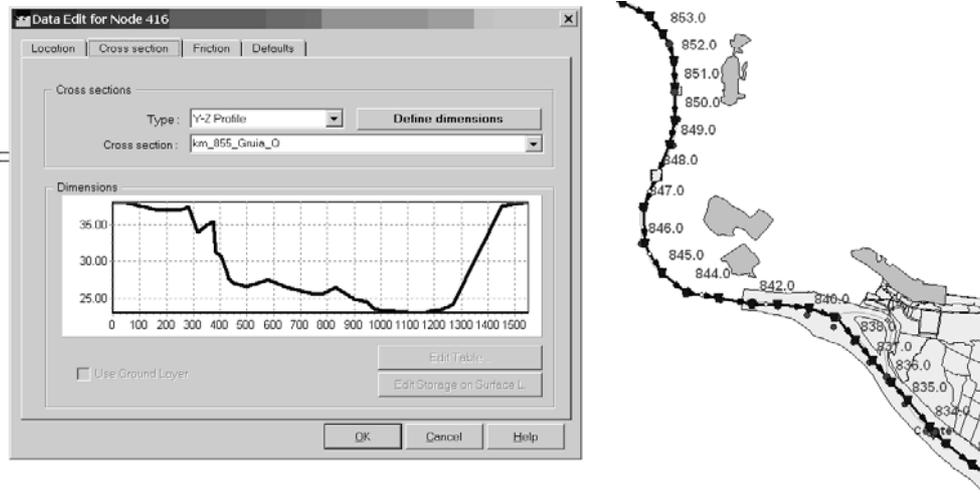


Fig. 3 – Image of model with cross-sections shape.

### c) Roughness coefficients

Roughness coefficients [8] represent the resistance to water flow in river channels and riverbeds. SOBEK module flow use value of the friction coefficient Chézy in solving the equations of motion.

$\gamma$  = friction parameter Bos-Bijkerk, can range between 20 and 40, resulting Chézy coefficient value depending of this parameter and the depth of water.

$$C = \gamma \cdot d^{1/3} \cdot R^{1/6}, \quad (3)$$

where:  $d$  = water depth,  $R$  = hydraulic radius.

A method to define the bed roughness Manning coefficient is used, the symbol  $n_m$  [ $s/m^{1/3}$ ]. Coefficient's value is linked to Chézy coefficient:

$$C = R^{1/6} / n_m. \quad (4)$$

Manning formula is

$$V = (R^{2/3} \cdot S^{1/2}) / n_m, \quad (5)$$

in which:  $V$  = average flow velocity;  $R$  = hydraulic radius;  $S$  = slope;  $n$  = Manning's roughness coefficient.

When you need more calculations Manning formula is used, it is sometimes convenient to use a transport term defined as:

$$K = (1 / n) \cdot A \cdot R^{2/3}, \quad (6)$$

where:  $K$  = transport channel in cubic meters per second;  $A$  = cross-sectional area of flow area in square meters;  $R$  = hydraulic radius in meters;  $n$  = Manning's roughness coefficient.

The term  $K$ , known as transport on channel section is a measure of transport capacity in that section [9].

#### d) Hydraulic schematization Maps

A schematic example containing the main hydraulic objects used (node, section, cross section) is shown in Fig. 4.

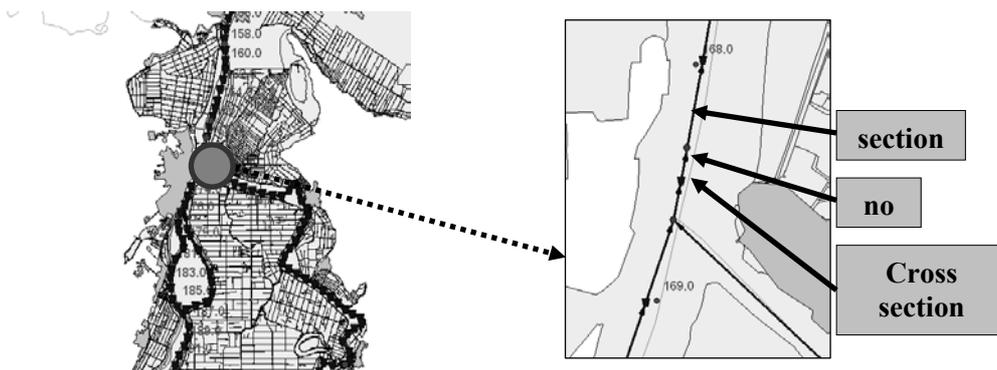


Fig. 4 – Picture of model schematization.

#### e) Time step

Time step used to run hydraulic simulations can choose a wide variety of time from seconds and reaching the day. In practice, the time step is not more than 1 day and for complex hydraulic schematic is indicated a smaller time step (1 to 6 hours). Simulation step time is set for 6 hours and the output data is 1 day.

### 3.2. 2D INPUT

In addition to data entered in the case of the 1D the new data is entered (Fig. 5 and Fig. 6): flooded area grid, Digital Terrain Model (DTM).

### 3.3. OUTPUT DATA

The output of the model can be obtained for each network node on each network segment, or the entire network behavior. Thus, can be obtained information about level, depth and water volume for each node. For sections of river can get information about water flow and speed on the section. Result maps containing information on the flooded area and depth of water on flooded area, speed of flooding.

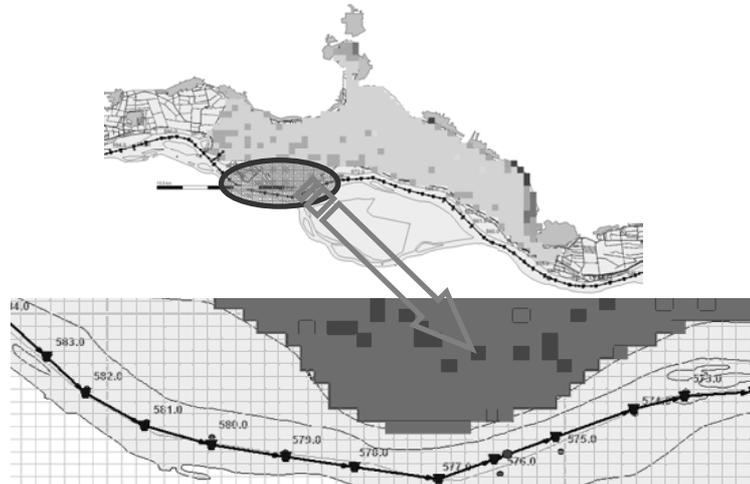


Fig. 5 – Flooded area grid.

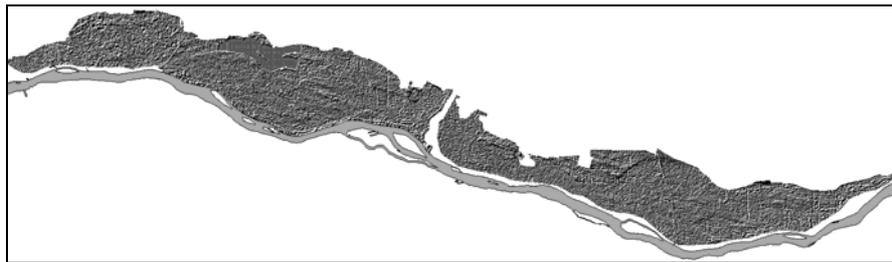


Fig. 6 – Digital Terrain Model.

A useful facility of this soft is representation the longitudinal sections of entire hydraulic schematic or selected only combined with the dynamic levels. Can be simulated and can view the dynamic water levels along the riverbed.

#### 4. RESULTS AND DISCUSSION

The purpose of this paper is to analyze the conditions of flooding area between Ghidici and Corabia (Fig. 7) in case of renaturalization of agricultural polders (no dams and restore the old floodplain of the Danube). The analysis was performed using a hydraulic schematization corresponding to this scenario.

To obtain boundary conditions (input flow, output levels) on Ghidici-Corabia sector, I have used the results obtained in the study on “Ecological and economical re-dimensioning of Danube Plain”, regarding the hydrological scenario with widths

of different threshold for each site that combines the requirements to reduce Danube level by renaturalization / storage of water in enclosures suitable for such uses to store a volume of water (degree of filling) as small (and thus stopping water drainage to be made within the shortest possible time) (REELD, 2008).

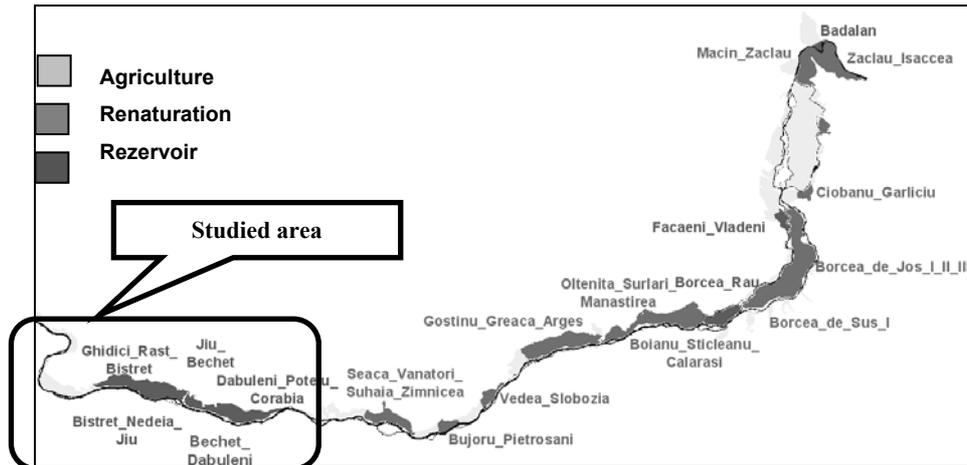


Fig. 7 – Ploders from studied area.

Three functions was established for furnished enclosures in the Danube, suitable for agriculture, water storage or renaturalization, thus:

- suitable locations for renaturalization (75,439 ha);
- agricultural enclosures (205,006 ha) (outside the schematization hydraulic);
- suitable locations for water storage (193,111 hectares).

Note that, the enclosures included in this paper, relative Ghidici-Rast-Bistret, Bistret-Nedeia-Jiu Jiu-Bechet, Bechet-Dabuleni, Dabuleni-Potelu-Corabia, are suitable for renaturalization. Hydraulic schematic of renaturalization was to include in the cross section of the Danube fairway a transversal profile corresponding agricultural enclosure (terrain model). Starting from the purpose of the study, to analyze the flooding regime of the area between Ghidici and Corabia in case of renaturalization, was done hydraulic schematization in this scenario. This was done schematization 1D2D (using the module "Overland Flow") that integrates hydraulic elements 1D of the area analyzed with digital terrain model. 1D2D hydraulic schematic is presented in Fig. 8, resolution grid used for 2D schematization is 250 m.

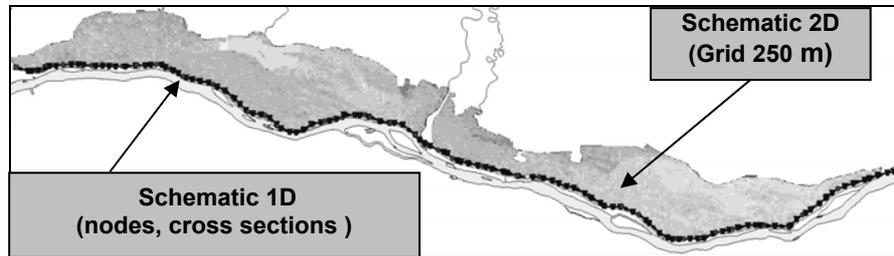


Fig. 8 – Schematic model 1D2D of Ghidici-Corabia polder in case of renaturalization.

Scenarios were run for a minimum hydrologic regime (2003-the minimum level was registered on 01/09/2003), medium (annual medium 2004) and maximum (2006-the maximum level was registered on 4/24/2006) of the Danube. After running the script 1D2D- Ghidici-Corabia sector (Fig. 9) maps have been developed for low levels of flooding.

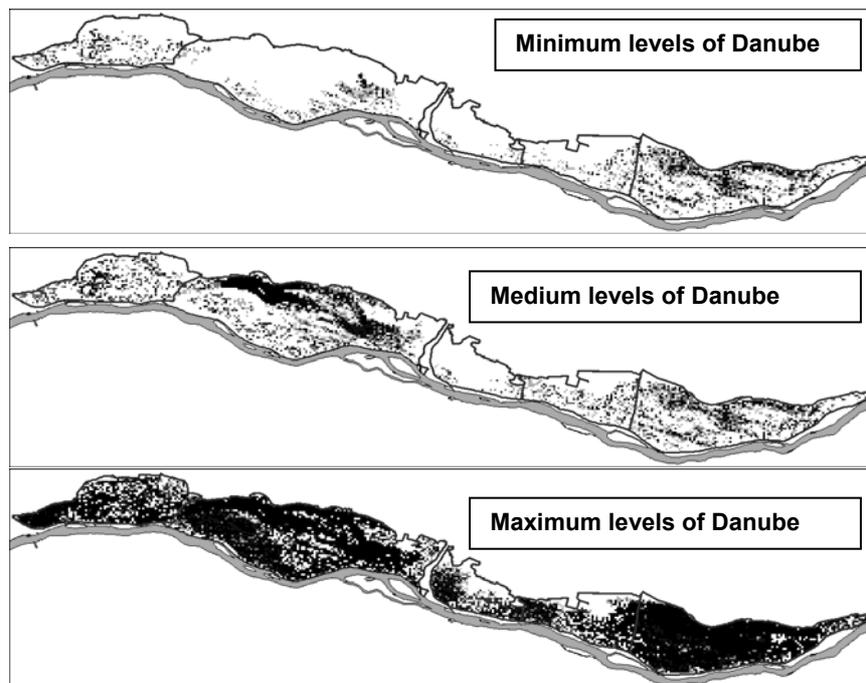


Fig. 9 – Maps with flooded area in different scenario.

Results of hydrological scenario simulation permitted to determine flooded areas and water depths for each value of flow on entry in the Danube sector studied. Flooding maps for significant hydrological regimes of Danube are presented in Fig. 9. It can get a distribution of flooded areas, where the three scenarios examined, using eight depth classes (Fig. 10, Table 1).

Table 1

Distribution of flooded areas on deep water class

Depth class (m)	MINIMUM	MEDIUM	MAXIMUM
0.01 – 0.5	2694	5656	975
0.5 – 1	269	438	2100
1 - 1.5	5919	9063	2063
1.5 – 2	119	313	3544
2 – 2.5	2813	4881	3831
3 – 4	1000	2169	10538
4 – 5	344	769	8988
> 5	200	2269	14319
Total	13356	25556	46356
Sector area 57732 ha			
Percentage	23%	44%	80%

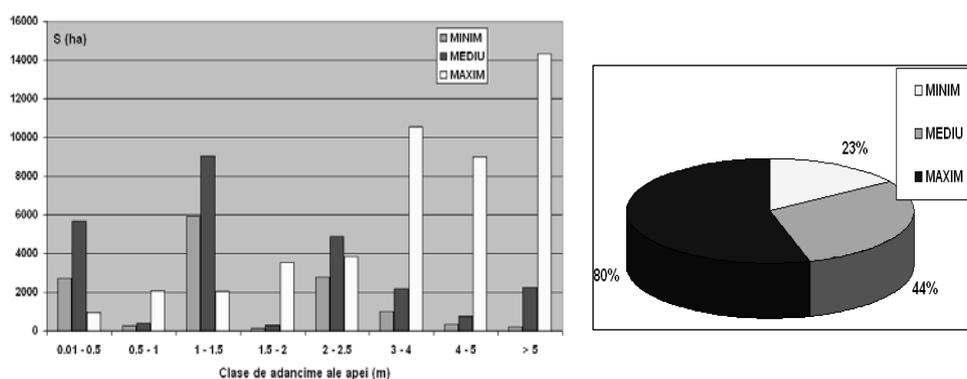


Fig. 10 – Representation of flooding degree.

## 5. CONCLUSION

Starting from study aims, to analyze the flooding area between Ghidici-Corabia in case of renaturalization of these agricultural polders (no dams and restore old floodplain of the Danube) was made corresponding hydraulic schematization scenario. Scenario was run for a minimum hydrologic regime (2003), medium (2004) and maximum (2006) of the Danube. They made maps of flooding to low levels (01/09/2003), medium (2004) and maximum (4/24/2006).

After determining the classes of depth and analyses of area ratio in different classes, I concluded that, if the scenario was for the maximum hydrological regime, within the total area of sector, flooded area is 80%.

Renaturalization of enclosures dammed to create wetlands is conservative interest, among objectives pursued being natural hydrologic cycle reintegration of Danube polders, the hydrological balance and ecological restoration and

development of traditional activities. To assess suitable enclosures arranged to determine their destination, (renaturalization, water storage or enclosures combined), which aims to establish arrangements directed to high water flooding, will also take into consideration the cost / benefit ratio for investments maintenance existing defenses dams and create ring dikes around the towns defense exposed to danger of flooding.

## REFERENCES

1. Nijland H., and Menke U., *Flood Risk Management and Multifunctional Land Use in River Catchments*, Conference Proceedings Mainz, Germany 17 th–19 th Oct, 2005.
2. \*\*\* The Water Framework Directive (CE/60/2000), 2000/60/CE (WFD).
3. \*\*\* Flood Risk Management Directive (2007/60/CE).
4. \*\*\* *Danube Delta National Institute for Research and Development, Ecological and economical re-dimensioning of Danube Plain*, Research Study Report, 2008.
5. \*\*\* Delft Hydraulics software SOBEK RURAL, <http://delftsoftware.delft.nl/>. Handout SOBEK, February, [www.citg.tudelft.nl](http://www.citg.tudelft.nl), 2007.
6. Horrit M.S., Bates P.D., *Evaluation of 1D and 2D Numerical Models for predicting River Flood Inundation*, *Journal of Hydrology*, **268**, 87–99, 2002.
7. Jia, Y., Affiliate, ASCE, Wang, S.S.Y., Fellow, ASCE, *Numerical Model for Channel Flow and Morphological Change Studies*, *Journal of Hydraulic Engineering*, pp. 924–933, 1999.
8. \*\*\* *An Australian Handbook of Stream Roughness Coefficients*; <http://www.rivers.gov.au/roughness/>
9. George J. Arcement, *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains United States Geological Survey Water*, Supply Paper 2339, 1989.
10. National Institute of Hydrology and Water Management, *Hydrological yearbooks*, 2003–2005.