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THE LOWER DANUBE GREEN CORRIDOR". CONTRIBUTIONS TO THE ANALYSIS OF THE RESTORATION OPPORTUNITIES FOR CERTAIN SURVEYED WETLANDS IN THE DANUBE FLOODPLAIN, DIVERSIFIED BY TYPES OF POTENTIAL.

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Abstract
The Ministries of Environment of Romania, Moldova and Ukraine signed the "Lower Danube Green Corridor" Declaration on 5 June 2000. The declaration aims at identifying along the Danube the former wetlands that have a high ecological potential and may be subject to flooding from the economic and planning point of view. About 700 lakes covering 980 km ^{2} lie in the Danube Floodplain. Thus, along the entire Lower Danube, 17 major wetlands were identified, and in case of Romania there are proposed 7 major areas showing an appropriate economic potential, known under various toponyms: Pond Nedeia (between Bistret and Bechet); Potelu Pond (between Bechet and Corabia); Suhaia Pond (between Turnu Măgurele and Zimnicea); Greaca Pond (between Olteniţa and Giurgiu); Călăraşi Pond; Lower Prut Floodplain; Pardina Polder (between Chilia and Sulina). These areas have various potential effects, such as: to mitigate the flood impact; to provide a favourable environment for pisciculture; to generate local social, economic and ecological effects. This work tackles several aspects relating to the types of potential and the expected effects for certain surveyed wetlands in the Danube Floodplain, namely Bistreţ Polder and Zaghen Lake. The restoration of the wetlands in the Danube floodplain by appropriate technical and technological means depending on the expected purpose aims at restoring the natural balance, fulfilling the local community interests, as well as promoting feasible projects financed by stakeholders or by foreign funds. Consequently, the study of the processes occurring within the wetlands is important through the analysis of the optimal solutions for the use of their potential.

Keywords: wetland restoration opportunities, types of potential surveyed

1. INTRODUCTION
1.1. Danube wetlands proposed for restoration opportunities. General Characteristics

WWF (World Wide Fund for Nature) aims to reduce threats and pressures on wetlands, to reconstruct the Danube Delta and floodplain of the river and its tributaries by restoring habitats, protected areas and developing the organic agriculture. Already, WWF-Romania in conjunction with the Olt Environmental Protection Agency have failed to restore 950 ha of floodplain in the Lower Danube River Danube confluence Ramsar site; (*www.natgeo.ro - Three new wetlands Romanian-Bulgarian-WWF,15.03.2014* "). In this context, on 5 June 2000, the Ministries of Environment of Romania, Bulgaria, Moldova and Ukraine signed the Declaration "Lower Danube Green Corridor". The declaration aims at identifying the former floodplains along the Danube that have a high ecological potential and that are economically and urbanistically suitable to flooding. Thus, 17 wetlands along the entire Danube have been identified and seven areas with appropriate economic potential are proposed for Romania, namely: Nedeia Pond (between Bistret and Bechet); Potelu Pond (between Bechet and Ship); Suhaia Pond (between Turnu Magurele and Zimnicea); Greaca Pond (between Oltenia and Giurgiu); Lower Prut Floodplain, Calarasi Pond; Pardina Polder (Chilia branch). About 700 lakes stretching over 980 km^2, including the proposed wetlands lie in the Danube Floodplain. These wide lakes were formerly connected to the Danube by secondary arms and lay under the influence of its level oscillations. Figure 1 shows three maps of some Danube sectors as they used to be in 1929 (reference maps). (Constantinescu, "Geographical and Historical Atlas for secondary schools, Braşov, 1929").

At present, these floodplain lakes have been dammed, drained, such as Greaca lake, and part of them have been engineered and included in the dammed area (Figure 2). The following anthropogenic impacts that substantially changed the regime of the Danube Floodplain are worth mentioning: damming the Danube floodplain; hydro-power and navigation systems Iron Gates 1 and 2, improving the navigation conditions – riverbed dredging works; hydrotechnical engineering works for ports and shipyards; irrigation works and hydrotechnical facilities for the water intakes; dredging works; damming the riverbeds of some tributaries.

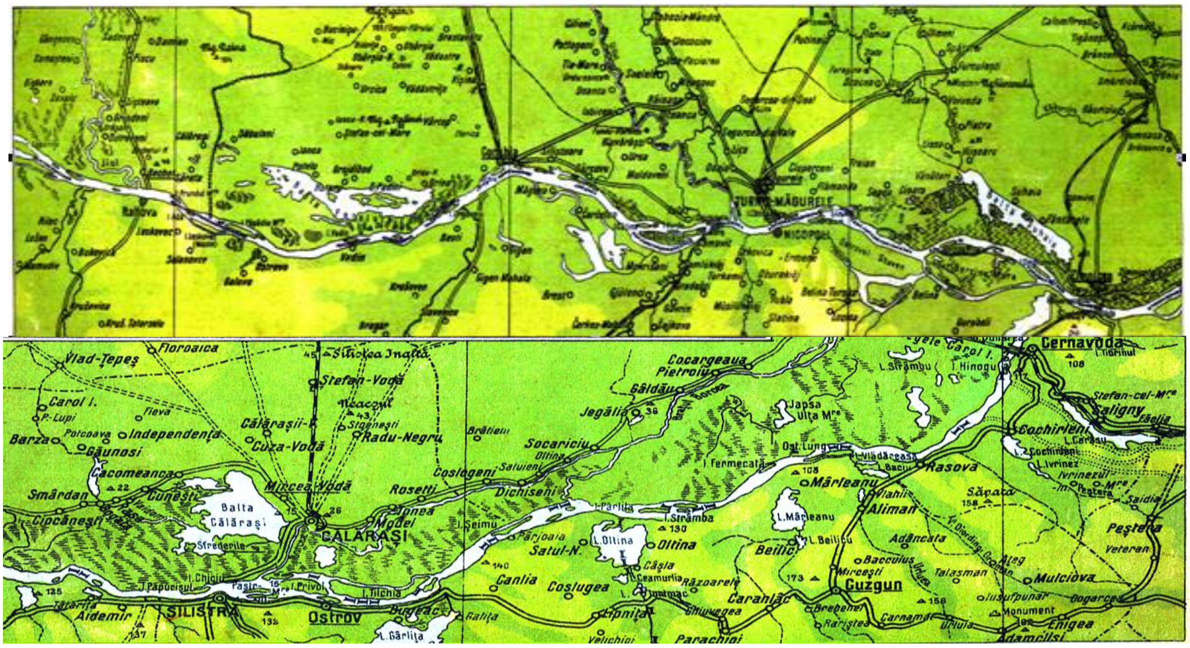

Figure 1. Map representing sectors of the Danube in the year 1929 - images

The farmland extension requirements determined the construction of some floodbanks as early as the XIXth century in order to prevent the Danube floodplain and some islets along the Romanian sector of the Danube from flooding. This action was enhanced during the interwar period and especially after the World War II, when the old floodbanks were restored and new ones were built. The evolution over time of the damming works on the Romanian bank of the Danube (including the Danube Delta) may be estimated according to the dammed areas, namely: in 1940 about 50000 ha, in 1960 about 101000 ha, and in 1964 about 375100 ha. The total length of the dikes exceeds 1000 km, up to about 1100 km. Dammed areas on the Romanian sector of the Danube were built from 1930 to 1972 from a cumulated area of 21715 ha in 1930 to 410227 ha in 1972. Figure 2 shows the dammed areas performed on the Romanian bank of the Danube and the location of the proposed wetlands *(Romproiect,1990, Site Plan for the dammed and drained areas in the Danube floodplain)*.

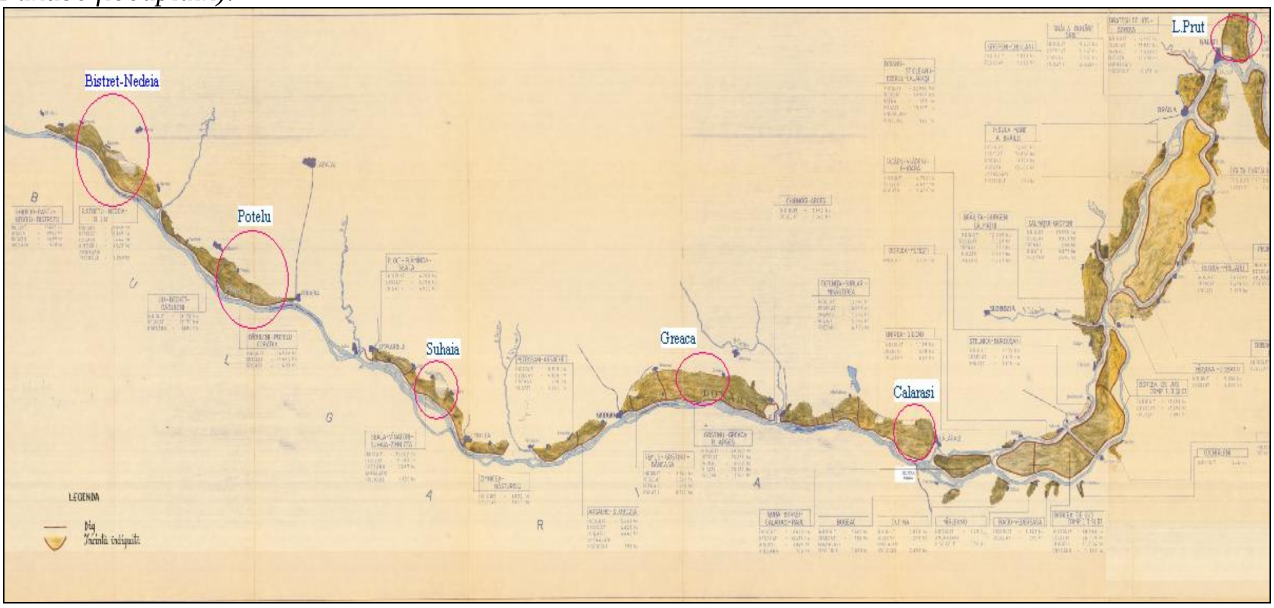

Figure 2.Engineering of the Romanian sector of the Danube, technical parameters..Location -dammed areas

The performed damming works (agreed by the riparian countries) have aimed at protecting certain social and economic objectives located along the Romanian sector of the Danube for certain maximum flowrates with the exceedance probability depending on their importance class, according to the respective legislation: for farmlands at the IV-th class according to the maximum flowrate with the probability of 5% , for urban agglomerations and economic objectives at the II-nd class according to the maximum flowrate with the probability of 1%.

1.2. Extreme Phenomena

Over the following period a major development of the rural localities, the expansion of the urban localities, as well as of the economic objectives has occurred within the dammed areas in the agricultural areas due to the flood protection effects. This in conjunction with the occurrence of some extreme phenomena of flood wave type with a probability of 1% resulted in the generation of record damage in the areas with a low protection degree in 2006. The breaches caused due to the crest overflow were due to the low transit capacity of the dammed areas according to the longitudinal profile of the Danube. *(Podani et al, 1985, Longitudinal profile on the Danube, C.N.A., supplements 2006-2010)*. The wetlands proposed for engineering consisting in the former ponds situated in the flood sections are generally located in the current dammed areas with a low protection degree and which caused damage in the high flood that occurred in 2006. The close connection between the river and the lakes makes their water volume to annually renew itself by the inflow during floods and the flow back to the Danube when the waters retreat. The main technical characteristics of the wetlands are shown in table 1.

Table 1

Wetlands Proposed	Dammed Area Location	Dammed Area	Drainage Systems	Volume Wetlands	Possible add. water supply
wetland name	area name	ha	ha	mil.m^3	river name
Nedeia Pond	Bistreţu-Nedeia-r.Jiu	22.000	14.000	340	Desnăţui
Potelu Pond	Dăbuleni-Potelu-Corabia	14.600	14.500	230	Jieţ
Suhaia Pond	Seaca-Vânători-Suhaia	13.600	11.800	210	Călmăţui
Greaca Pond	Gostinu-Greaca-r.Argeş	28.400	25.200	430	Zboiu,Argeş
Călăraşi Pond	Boianu-Ezeru-Călăraşi	23.000	21.000	350	Mostiştea
Lower Prut FP	Brateşu de Jos-Somova	14.500	12.000	220	Siret; Prut
Pardina Polder	Pardina –braţ Chilia	830	550	18	-

The maximum flows recorded in April 2006 reached levels higher than the values recorded in 1970, 1981, whose probability of exceedance was approximately 1% - the recurrence period – every one hundred years. (*Hydrological events, Ministry of Environment, Report of Min. Barby, S., Bucharest 2006*) The Figures 3 and 4 show the compared hydrographs of the average daily flows in various years at the specified hydrometric stations, highlighting situations where the water flows were higher than the water flow corresponding to the alert levels (therefore when major risks occur), as well as the months when such flows occur. (Borcia**,** Carsmariu et all., 2013)

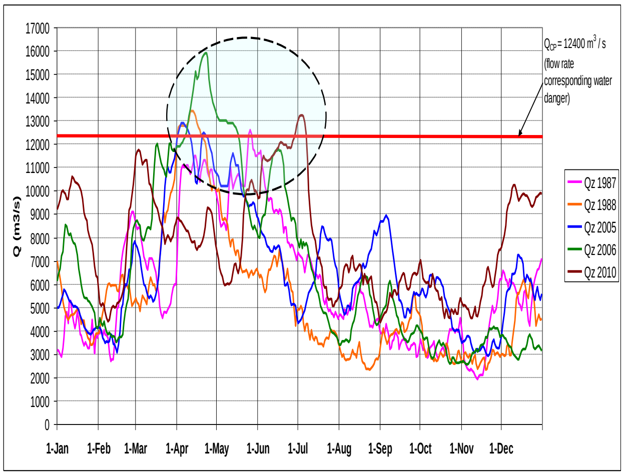

Figure 3. Compared hydrographs of daily average water flows at hydrometric station Bechet (1987, 1988, 2005, 2006, 2011)

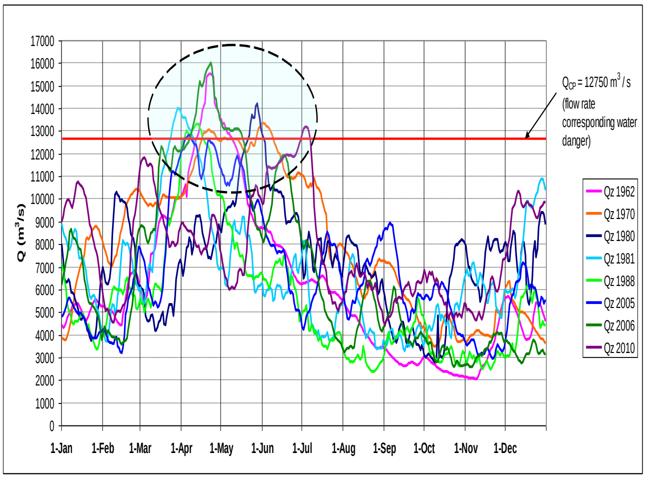

Figure 4. Compared hydrographs of average daily water flows at the hydrometric station Corabia (1962, 1970, 1980, 1981, 1988, 2005, 2006, 2011)

2. METHODS.

Mitigation of flood effects on the Danube. As abovementioned, 17 wetlands were identified along the Danube. For Romania seven areas with an appropriate economic potential are proposed, namely: Pond Nedeia (between Bistret and Bechet); Potelu Pond (between Bechet and Corabia), Suhaia Pond (from Turnu Magurele and Zimnicea) Greaca Pond (between Oltenia and Giurgiu), Lower Prut Floodplain, Calarasi Pond, Polder Pardina (Chilia branch) , with potential flood wave mitigation effects. The numerical simulation of the propagation of a flood wave recorded in the presence of a wetland has been performed in order to analyze the water intake in the wetlands, the operation mode under high flood conditions and estimations on the effects likely to be achieved along the Danube floodplain course. (Carsmariu & Dumitrescu,2012)

The analysis was prepared on a hydraulic type numerical model for unsteady state flow with various options imposed in the conditions of water intake in the wetland:

→ By arranging a stepped side weir depending on the peak flow levels with different probabilities of exceedance (Figure 8);

→ Setting gates for wetland water supply during average water periods and discharge into the Danube to supplement the minimum flows during the drought periods (Figure 8);

→ Use of typical recorded flood waves as input data (Figure 9).

The model works in one-dimensional diagram and can tackle one-line beds and beds in dendritic or ring network described by cross sections with points corresponding to georeferenced plans. It is based on the numerical integration of the Saint Venant partial differential equation system, according to a rectangular grid in the plane X, T, in default diagram, with the linearization of the equations, using for a time interval DT, the double sweep algorithm. *(2010, RiverAnalyses System, Hydraulic ReferenceManual-US ArmyCorps of Eng.*). The one-dimensional unsteady state flow with gradually varied free surface is governed by the system of Saint Venant partial differential equations. For a one-dimensional channel element dX, the component dynamic and continuity equations are:

$$\partial Z/\partial X + 1 / g * \partial V/\partial T + \alpha / g * V * \partial V/\partial X + JE = 0 \qquad (1)$$

$$\partial A/\partial T + \partial Q/\partial X = 0 \qquad (2)$$

The initial calculation condition may be a steady state determined by program, common in the basic flow rate of the flood, or an unsteady state taken from a previous calculation. The standard boundary conditions are flow hydrographs in the inlet sections and a limnimetric key (or hydrographs) in the outlet section.

The Saint Venant partial differential equation system is numerically integrated in finite differences according to a rectangular grid in X, T plane, in default diagram with linearization of the equations according to an algorithm inspired from (equation 3, Figure 5).

$$dZ + d(\alpha * V^2 / 2 / g) + JE * dX = 0 \qquad (3)$$

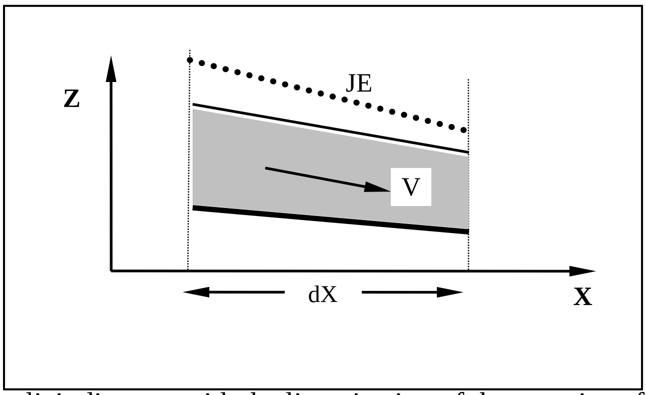

Figure 5. Implicit diagram with the linearization of the equations for an element of bed

Once all the necessary data on the geometry of the riverbed described by the cross-sections extracted from georeferenced plans are inserted, various constructions undertaken in the flow section may be described, namely: dikes or side intake structures provided with high water discharge equipment, as well as other works in the riverbeds likely to influence the hydrological regime (Dumitrescu & Carsmariu, 2010). In general, the analysis should be developed for a wetland which should have data on the georeferenced geometry (Figures 6, 7) of the Danube riverbed. The calculation sector should rather include hydrometric data, as well as the land model or at least the typical capacity and surface curves of the wetland V (volume) =

f (H), S (area) = f (H) for the correct estimation of the free surface curve level on the Danube, as well as of the wetland retention capacity.

The boundary and arrangement conditions of the wetland should also be (theoretically) specified in order to eliminate the potential damage (relative to the maximum level on the Danube) likely to affect the adjacent areas. This type of approach may also be allowed for a drought period, by using the wetlands as potential reservoirs (with natural or artificial fill) and by developing balance calculations on the estimated capacity to supplement the Danube flow.

It is important that the possibility to mitigate the floods impact by the directed retention of the flood wave volumes on the maximum flow sector in the wetlands (along the Danube) and to attenuate the flood waves should occur (as much as possible) successively up to the flow that can be transited by the Danube riverbed provided with floodbanks (Figures 2; 9). To achieve this goal the study must be extended to the proposed wetlands (as well as to other areas meeting the imposed requirements) along the entire length of the Danube river bed with the compliance of the optimal intake and attenuation conditions.

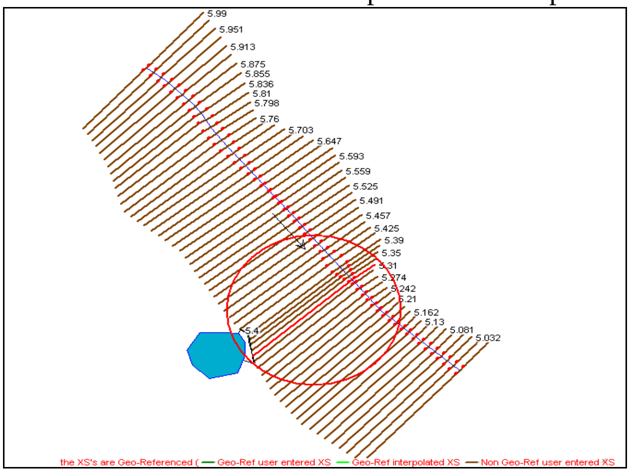

Figure 6. Plane location of the calculation sector with the bed geometry and the wetland analyzed

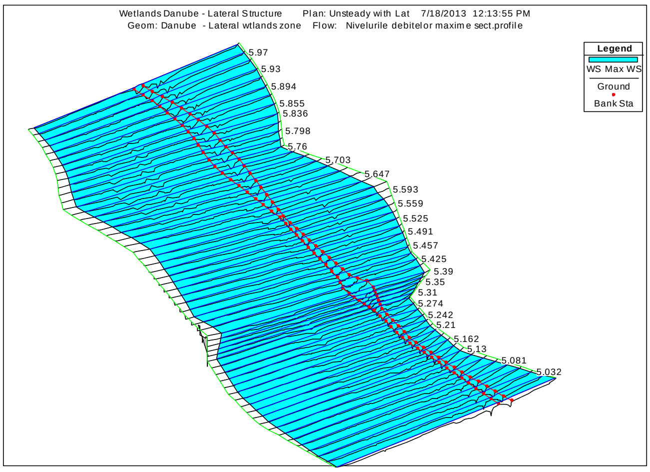

Figure 7. 2D representation of free surface curve calculated for the analyzed flood wave

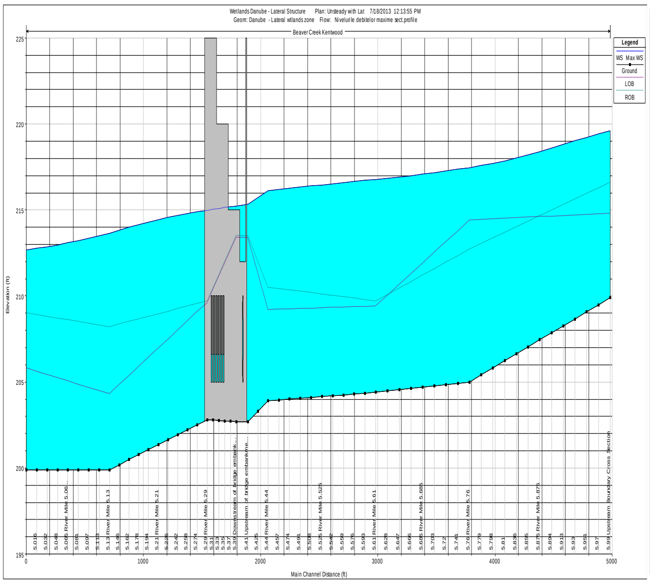

Figure 8. Longitudinal profile presenting the maximum level and the water intake in the wetland

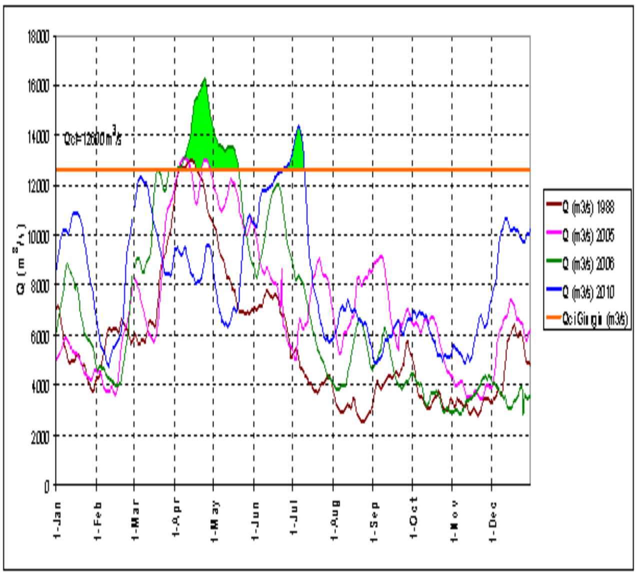

Figure 9. Graphical representation of the results on the flood wave attenuation.

The consequences of the floods that occurred in 2006 on the Lower Danube sector were especially due to the complete damming of the floodplain and consequently to the reduction of “the free space” intended for the flood wave attenuation by approx. 73%. The National Administration Romanian Waters based on the National Flood Risk Management Strategy has proposed solutions for the remediation of the situation, considering the European principles and practices in the field: ‚wetlands rehabilitation, aquatic habitat conservation, creation of cascade retention modules within the dammed areas in order to temporarily retain the water volumes during floods period. *(*Gâştescu, 2012; Mihailovici at al.,2006)

2. RESULTS AND DISCUSSION

Example of ongoing projects for the reactivation of some wetlands. These areas have various potential effects, such as: to mitigate the flood impact; to provide a favourable environment for pisciculture; to generate local social, economic and ecological effects. This work tackles several aspects relating to the types of potential and the expected effects for certain surveyed wetlands in the Danube Floodplain, namely Bistreţ Polder and Zaghen Lake.

2.1. Rehabilitation of the operational parameters of Bistreţ Polder

Bistreţ Polder lies on the Desnăţui river, in front of the localities of Plosca (right bank) - Bistreţ and Cârna villages (left bank)-Goicea village, Dolj county. Hydrologically, Bistret lake is located downstream of the Baboia river confluence and upstream of the Danube confluence *(Figure 10)* in the natural major bed between the embankment DN 55A and the Danube floodbank. It is worth mentioning that the Desnăţui river is a first order tributary of the Danube and transits the flowrates by means of Bistret polder and of the existing high water weirs, as well as of the connection channels. Due to the fact that the right (Romanian) bank of the Danube is provided with floodbanks, the flows in Bistret Lake are transited by means of the pumping stations.

The main initial purposes of the Bistret permanent reservoir are:

→ Fish farming by means of the four corresponding ponds *(Figure 11),*

→ Retaining, mitigating the flood waves of the Desnăţui river and discharging the volume accumulated in the Danube by means of Mălăeni and Dunăreni sluice gates according to the flowrates and of the connection channels linked to the pumping stations with the Danube *(Figure 12)*,.

→ Protection of the social and economic objectives in the localities of Bistreţ and Goicea,

→ Transiting the flows necessary for irrigations and piscicol ponds in Săpata- Nedeia area, by the SP1 Dunăreni pumping station

Figure 10. Plan of the location and of the major hydrotechnical works of Bistret Lake.

Bistreţ Reservoir was created in 1971, falling under the importance class IV, category C. In 2013 the lake was transferred to the „Apele Române” National Administration. The status of the main technical parameters at the level of the 4 piscicol ponds defining Bistret Lake is shown in table 2 and graphically in figure 12.

Table 2

Piscicol Ponds	NNR	Perim.	Surface NOL	Depth max NOL	Volume NOL	Dike level volume	Remarks Weir/gate location
name	mMN	m	ha	m	$mil.m^3$	$mil.m^3$	
Pond 1	25.70	11040	634	1.83	6.7	32	Sluice gate Mălăeni
Pond 2	25.70	9117	478	1.68	5.1	24	
Pond 3	25.70	8129	258	1.67	2.7	13	Sluice gate Dunăreni
Pond 4	25.70	7981	330	1.83	3.5	16	Weir-broad crested
Total lake	25.70	36267	1700		18.0	85	

NOL – Normal Operating Level

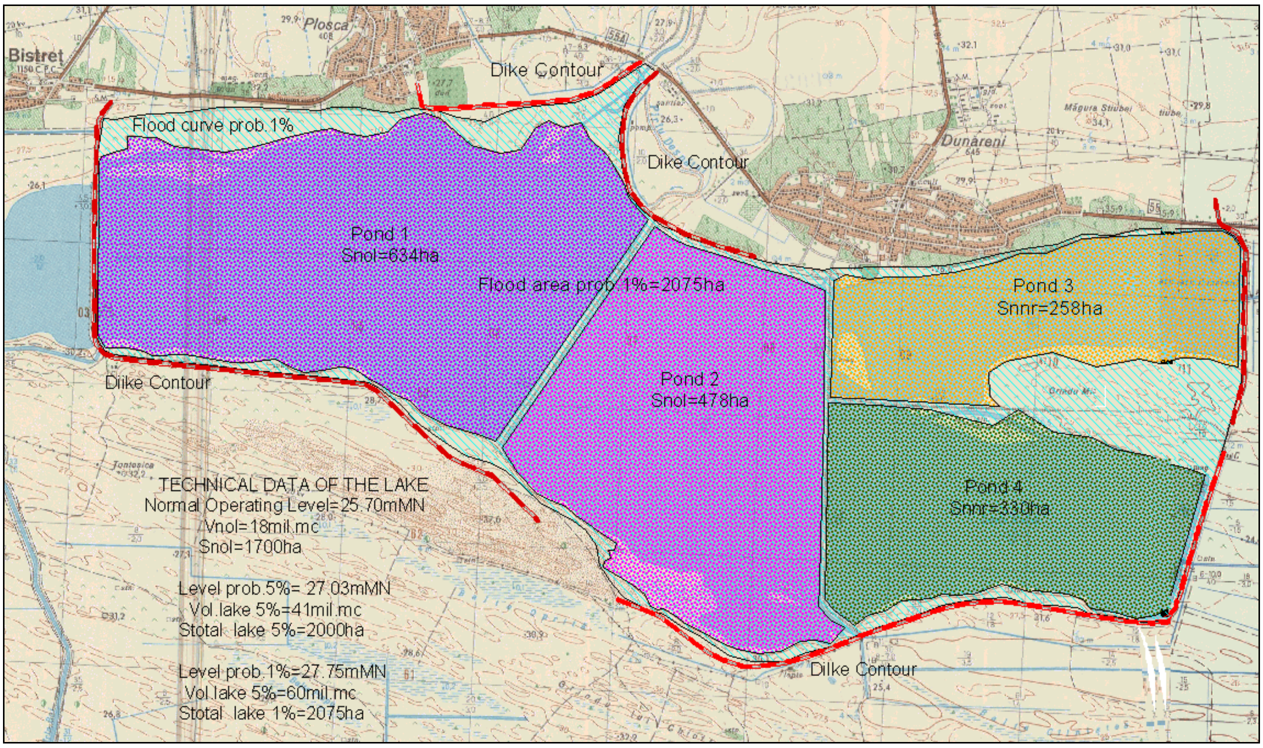

Figure 11. Layout of component ponds, contour dams, technical data and maximum level 1%.

Various works on the rehabilitation of the technical parameters and on fulfilling the purposes for which the work has been designed have been proposed following the prepared studies and the technical inspection report for Bistret lake submitted by the Jiu River Basin Administration (***2013, *Hydrological and hydraulic study on Bistreţ polder, on the Desnăţui river, Dolj county, D.A.Jiu).*

→ *Works on the superelevation of the crown level* in order to ensure a safety guard for the maximum control levels and not to exceed the crown level of the contour dams. According to the results of the hydraulic calculations *(Figure13)*, the levels of the maximum flowrates with exceedance probabilities of 0.5%, 1% and 5% achieved in Bistret reservoir are as follows: 28.18 md MN; 27.75 md MN and 27.03 md MN respectively. As an additional safety measure, the minimum level of the dams was allowed to be 28.50 md MN.

→ *Works on embedding the contour dams into the slope area*. The length of the Bistret lake contour is approx. 22.60 km of which the contour dams are located in the depression areas over a length of approx. 15.30km, and the remaining 7.30km is represented by slope areas and high bank. Works for embedding the contour dams into the slope area have been proposed for the safety of the works and of the social and economic objectives adjacent to the lake.

→ *Works on the restoration of the bankslope protection in the lake area and as a result of the erosion phenomena in the dam body*. The technical inspection report for Bistret lake has shown that the bankslope

protection in the lake area provided with a concrete slab pitching is about 85% destroyed, and the erosion phenomena have developed up to the crown in some areas.
→ *Lake desilting works* in order to achieve the optimal depth of the piscicol ponds at the normal retention level.
→ *Checking and ensuring the optimal operation of the hydrotechnical spillway systems* into the Danube: sluice gates, pumping stations, connection channels.
→ *Performing an information system* connected to the river basin system to be implemented in the integrated water management scheme and in the information flow system scheme at the national level and at the level of the Danube-Jiu river area.

Mathematical models for numerical simulation on the release of the flood waves in the reservoirs have been used for dams provided with fixed and controllable spillways *(Figure 12).*

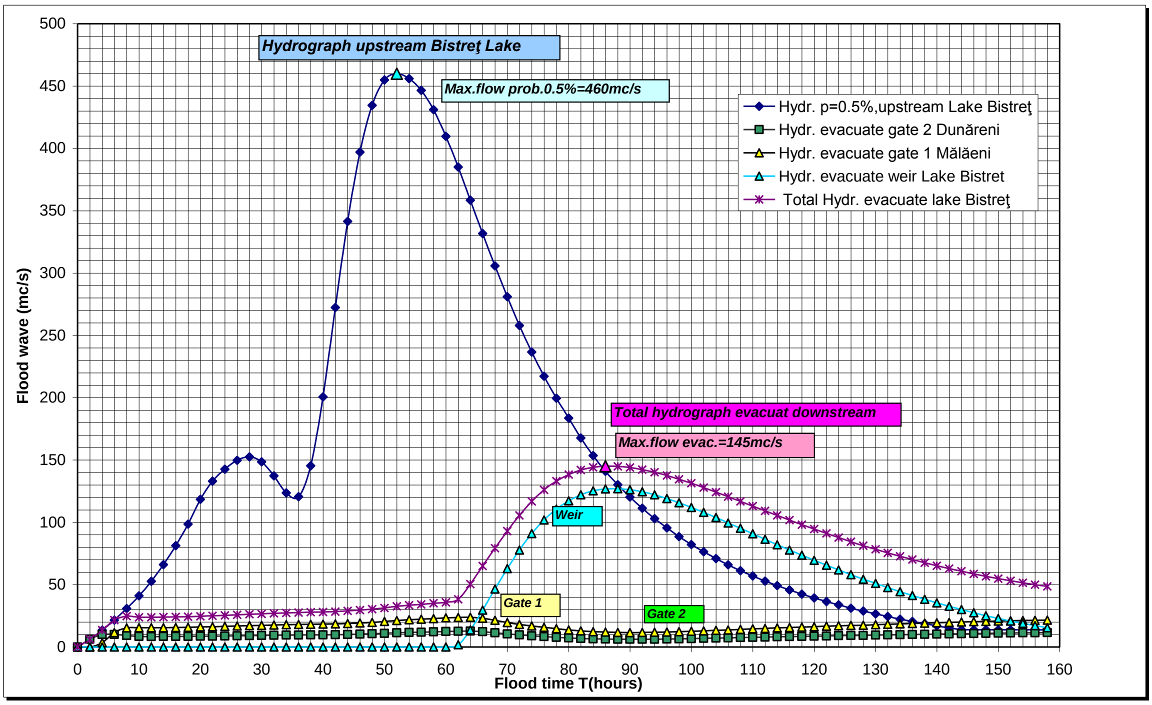

Figure 12. Graphic results of the flood wave attenuation in Bistreţ Lake. Flow hydrographs up&downstream

The method underlying the design algorithm consists in solving the classical continuity equation written in finite differences:

$$W_{t2} - (Qa_{t2} - Qd_{t2}) * (1-m) * dt = W_{t1} + (Qa_{t1} - Qd_{t1}) * a * dt \quad (4) \text{ where:}$$

W_{t1} , W_{t2} - values of the volume at the beginning and end of the calculation step,
Qa_{t1} , Qa_{t2} - values of the inflow on the same interval
Qd_{t1} , Qd_{t2} - values of the outflow on the same interval
a - coefficient regarding the division of the initial calculation step into intermediate steps.

The outflow through the spillway i is calculated depending on the height h of the water blade achieved over the spillway crest, at each calculation step, the width of the crest of the spillway b and of the flowrate coefficient md characteristic of the type of spillway, as follows:

$$Qdev(i) = md(i) * b(i) * 4{,}43 * h(i)^{3/2} \quad (5)$$

The outflow by releasing i is calculated depending on the level difference in the dam area h_{am}. - h_{av}. (read on the limnimetric key) performed at each calculation step, the area of discharge s and the flow coefficient mg, as follows:

$$Qgol(i) = mg(i) * s(i) * 4{,}43 * (h_{am} - h_{av})(i)^{1/2} \quad (6)$$

The total inflow is obtained by adding up the flows released by spillways for each calculation step. In addition, the possibility of mitigating the impact of the flood effects on the Danube has been analyzed. The Rast-Bistret-Nedeia area is a specific solution on the flow that can be transited between dikes. In relation to the maximum flow rate recorded in 2006, the volume required for storage is approx. 150-200 mill.m^3, which is the volume of those areas. The analysis was prepared on a hydraulic type numerical model for unsteady flow in various required options regarding the conditions of the water intake in the wetland.

II.2. Ecological restoration of Zaghen Lake

An example of ongoing project on planning the wetlands in the Danube floodplain which is the "Ecological restoration of Zaghen Lake in the Biosphere Reserve the Danube Delta, Romania / Ukraine". The wetland subject to ecological restoration lies in the eastern part of Tulcea municipality, respectively in the floodplain adjacent to the terrace on which the town is located. It is registered on the maps as Zaghen Lake (Figure 13). Zaghen lake is located within the dammed area Tulcea – Malcoci - Nufărul and is proposed for ecological reconstruction over an area of approx. 200 ha. The project intervention area of approx. 300 ha is wider. Without intervention, the lake will continue to silt until the total compromise and loss of flood attenuation function. The ecological restoration aims at restoring the natural balance through technical means and appropriate technology by a sustainable solution that fulfils the interests of the local community.

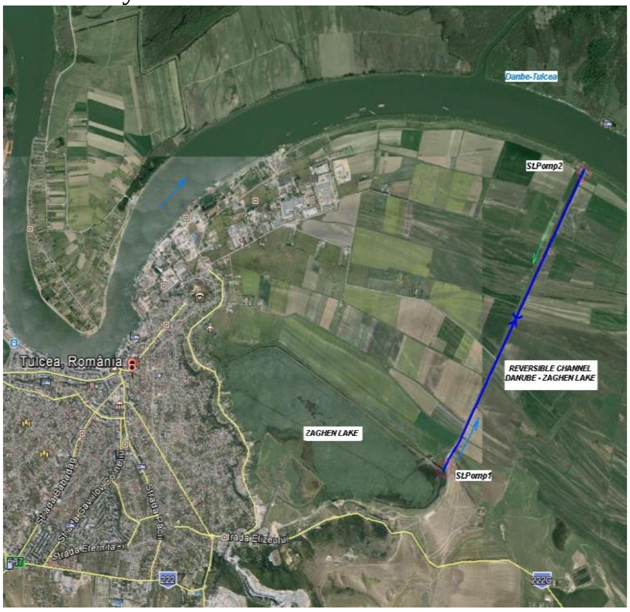

Figure 13. Plan of the location of Zaghen wetland proposed for ecological restoration

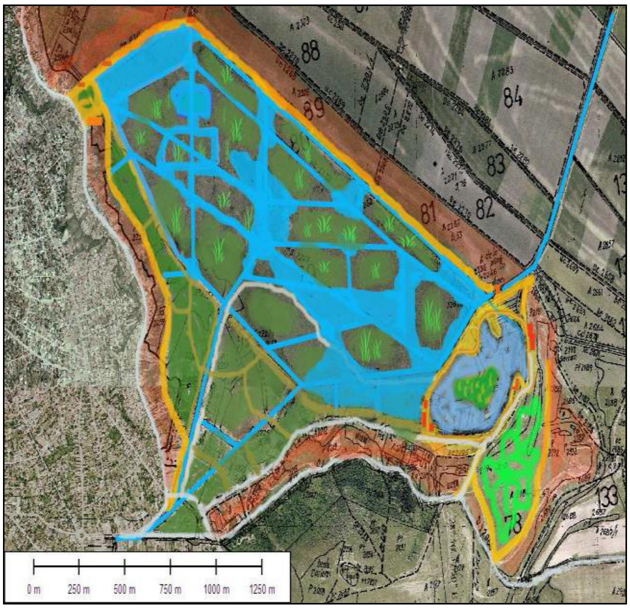

Figure 14. Restoration of the natural habitat mosaic, aquatic and terrestrial flora/fauna

The thematic program developed by ARBDD, in agreement with the Tulcea Town Hall, after the consultation of the public and of the interested local institutions the following requirements were formulated according to the the terms of reference:

→ Ensuring water supply of Zaghen lake from the Danube by pumping into Danube Zaghen channel.
→ Determining the critical inflows on the Danube, by ensuring the minimum level at the strainer of the Danube

→ Zaghen canal pumping station. Associating an annual probability of non-exceedance of the minimum flowrates for determining the probability for ensuring the supply of the Zaghen Lake with water from the Danube.

→ Determining the volumes lost by evapotranspiration in Zaghen lake, by seasons depending on the hydrometeorological, hydrogeological and pedological conditions.

Estimating the annual average silting rate of Zaghen lake as well as after the high flood periods.
→ Restoring a mosaic of natural habitats specific to wetlands (*Figure 14*) for the development of aquatic and terrestrial flora and fauna, for the development of natural resources: fish, reed, bulrush, wood, by establishing the appropriate hydrological regime (2011, *Feasibility study for ecological reconstruction in Zaghen polder, 2011)*

→ Ensuring (keeping) the existing function for the attenuation of high floods on Lipca, Baboianu rivers and the slope runoff by the existing polder and drainage system, which shall not affect the arranged area.

→ Proposing additional protection works for the inhabited area of Tulcea municipality according to the specific importance class.

→ Sizing the designed drainage system of Zanghen lake in order to release the rainwater flows, on the assumption of a uniform layer flowing in the studied river area. Determining the maximum flowrates and the flood wave volumes specific to the river basins adjacent to the drainage system canals.
→ Analyzing the possibility of transiting the high flood volumes retained in Zaghen lake by pumping into the Danube – Zanghen canal, simultaneously with the release of the drainage system flows, within the limit of the available pumping capacities.

Sizing the hydrotechnical works within the project of the Zaghen hydrotechnical complex shall be based on hydraulic, hydrological and water management calculations. Thus, numerical models on unsteady state shall be used (shown in chap. II). The model is needed for the propagation of the flood waves, for determining the free surface curve levels on the sector of the analyzed watercourse: r. Lipca sector – Zaghen lake – SP1- the Zaghen Danube canal – SP2- the Danube confluence and for sizing the hydrotechnical works by releasing the flows (Figure 13).

Consequently, the drainage networks, the contour dikes of the Zaghen lake, the two reversible pumping stations, as well as the ecological planning of the area adjacent to Zaghen lake shall be rehabilitated and commissioned by eliminating the unsuitable households and outbuildings.

3.CONCLUSION

There is a clear tendency to change the hydro-morphological parameters of the studied areas in the conditions of climate changes. The intensification of extreme phenomena in the Danube area will result in enhanced drought periods, in heavier floods. The reactivation of wetlands in the Danube floodplain by appropriate technical and technological means depending on the proposed purpose aims at restoring the natural balance, as well as the initial functions. The reactivation of the wetlands in the Danube floodplain according to the initial functions by appropriate technical and technological means depending on the proposed objective aims at restoring the natural balance, fulfilling the interests of the local community, as well as promoting the feasible projects financed by the interested beneficiaries or by external funds. It should be noted that agreements have already been concluded with the riparian countries, and projects on the local wetlands engineering have also been initiated. As a result, the study of the processes occurring within the wetlands is important and must be intensified by analyzing the optimal interconnection and reuse solutions.

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