

# Chapter 10

## Reducing Water Related Risks in the Lower Danube Through Nature Based Solution Design: A Stakeholder Participatory Process



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### Highlights

- In the Lower Danube we identified that Nature Based Solutions co-benefits play a key role in enhancing social acceptance of the NBS considering the potential socio-economic benefits, even higher than in the reduction of flood damages.
- Contrarily to most of the existing approaches, in which the co-benefits are accounted for exclusively during the phase of NBS assessment, the Lower Danube taught us that the co-benefits need to be co-defined since the NBS design phase.
- The hydraulic models developed for the Lower Danube, based on the 2006 catastrophic flood, represented the base for envisaging the scenarios of the former floodplain restoration.
- A GIS infra-territorial indicator methodology to assess flood risk vulnerability was implemented in order to complement the current lack of available insurance data related to destroyed and affected dwellings.

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## 10.1 Introduction

The Lower Danube wetlands, one of the most important European wetland ecosystem, lost nearly 80% of its surface over the last century due to river dredging, land reclamation and flood control ([www.icpdr.org](http://www.icpdr.org)). Anthropogenic interventions along the Danube river water course, such as construction of the hydropower plants Iron Gates I and Iron Gates II and alterations along its banks through embankment, have generated high bank erosion processes as well as changes of the riverbed with negative impact on navigation. The negative effects induced by anthropic interventions coupled with climate change impact have intensified the flooding and drought events. Also there are problems with desertification, areas such as Dabuleni (called by the locals “Sahara of Oltenia”) are in continuous expansion while others are emerging. In addition, catastrophic floods like the one which occurred in 2006 that devastated Rast town, had major impact along the whole Lower Danube Sector. The ecosystem resilience after these hazards is even more weakened by less destructive but more frequent floods which occur at high water discharges and have mainly a local impact.

After the catastrophic floods from 2006 the Romanian government approved “the Program for Ecologic and Economic Reshape of the Danube Floodplain within the Romanian sector”. Among its priorities, it included a reconsideration of the defence lines against the flooding of settlements, by restoring some embanked areas to set up wetlands for biodiversity conservation, together with an evaluation of the economic potential within these embanked areas in the context of the wetlands restoration. Afterwards, a series of projects promoting Nature Based Solution (NBS) were implemented by National Administration Romanian Waters during 2006–2014 (Fig. 10.1).

In order to continue the abovementioned initiatives, NAIAD Project proposed the implementation of a wetland restoration project in the Lower Danube region (Romanian Case study) by designing NBS for dealing with water-related risk. For

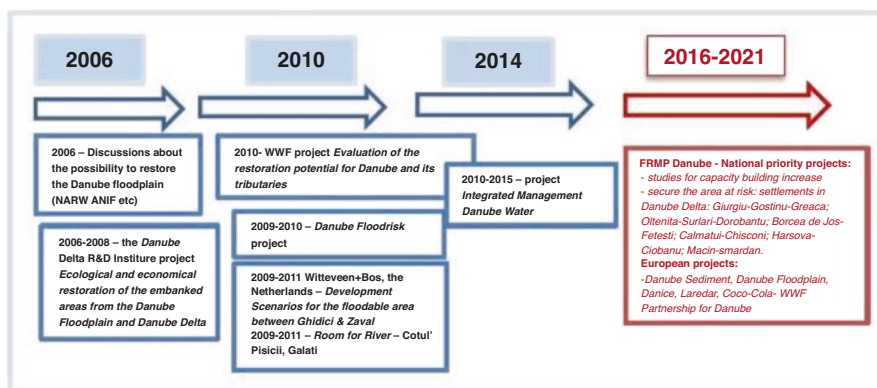


Fig. 10.1 Initiatives promoting NBS implementation in the Lower Danube

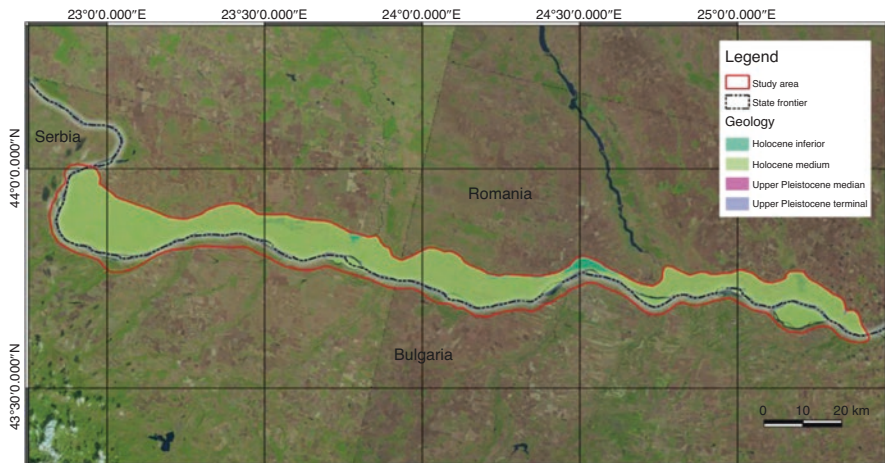
this objective, NAIAD implementation in the Lower Danube case study aimed at providing support to facilitate both local collaboration between the different stakeholders and the engagement of these local stakeholders in decision-making and policy setting, by integrating their (local) knowledge with the results of scientific models. This would contribute to build a strong cooperation and collaborative framework for the effective adoption of NBS for water risk management (as discussed in Chap. 6 this volume). Good governance of NBS requires creating local partnerships, facilitating cooperation, and identifying clear roles within those partnerships focusing on the local stakeholders knowledge of resources. In addition, local administrations need capacity building on implementation, management and monitoring interventions on the ground. Thus the process undertaken in the Lower Danube Case study is based on working with both communities at the local level and decision-makers at national level to align policy and practice.

The aim of this chapter is to describe the different steps for developing a Natural Assurance Scheme (NAS) for the Lower Danube Case Study (Zimnicea – Calafat sector) meant to improve the flood and drought management and capitalize the NBS co-benefits. This chapter is structured in the following way: first we present a physical risk assessment of the Lower Danube case study; second, we discuss the main results of the dedicated processes focusing on NBS design, with emphasis on active stakeholders engagement; and finally, we explore the possibilities to perform a damage assessment in areas vulnerable to flooding and without any access to insurance data.

## 10.2 Case Study Characterisation and Physical Risk Assessment

In terms of geology, the Lower Danube area, where our case study is located, is mainly characterized by newer formations, as expected, due to the high sediment influx from the Danube River. Most of the formations are young, ranging from the Upper Pleistocene fundament to the Holocene deposits that overlay it (Fig. 10.2). Since the construction of the Iron Gates dams, the sediment afflux has strongly decreased, although the main source of material is still being transported by the Danube. Geomorphologically, the case study area is part of the Oltenia terraced plain sector characterized by a sequence of terraced plains with sand dunes, bordered in the south by the large escarpment of the Pre-Balcanic Plateau (Constantinescu et al. 2015).

In hydrological terms, Danube River represents the most important component of the studied area, flowing for approximately 250 km between Zimnicea and Calafat. At Calafat, Danube has its largest meanders, starting from Cetate until Rast, with a change of direction up to 180°. The average slope of the Danube is only 0.043% due to a small difference in level, of only 7 m. The water flow in this area has been conditioned by both the reduced slope and some geological characteristics



**Fig. 10.2** Map of the local geology in the study area

of the area, such as the slow subsidence in the Calafat – Rast sector and ascending movements towards East at the confluence with Jiu River. Therefore, the flow velocity decreases together with the transport capacity, resulting in the intensification of the sedimentation processes which has a series of consequences on the water course. These consequences are first, a decrease of the river bed depth (up to 3 m at average level compared to the usual depth of 5–8 m) concomitantly with its broadening of up to 1.3–1.6 km; and second, the formation of spits and sand banks which generate a large number of water course unplaiting. This means that the level fluctuations of the Danube in the area of Calafat reach amplitudes of 8–9 m in direct connection with the large variation of the flow. The multiannual average flow is approximately 5500 m<sup>3</sup>/s at Cetate and 5460 m<sup>3</sup>/s at Calafat hydrologic stations (h.s.). Exceptional flows have been recorded in 1940 when a maximum flow of about 15,000 m<sup>3</sup>/s was reached and in 1946 when a minimum flow of approximately 2000 m<sup>3</sup>/s was measured.

The last catastrophic flood in the Lower Danube area was recorded in 2006. The estimated return period for this flood event in this specific region (Danube River, Gruia h.s.) is 100 years (Liška et al. 2008). For a period of three months (from April 2006 until June 2006) the water volume recorded during this event was  $116,000 \times 10^6$  m<sup>3</sup> (maximum values of 15,990 m<sup>3</sup>/s at Calafat h.s. and 15,970 m<sup>3</sup>/s at Bechet h.s.). The flood alert for the Lower Danube lasted more than 6 weeks and 13 dikes broke in Romania during the duration of the event from the 7th April to the 15th June 2006. Both overflow and infiltration caused dike breakage which led to the flooding of Rast – Bistret, Bechet – Potelu – Corabia, Tatina – Spantov – Manastirea, Calarasi – Raul, Oltina, Facaieni enclosures. In the studied area, one dike failure in Bechet has been recorded on the 24th April 2006 at 7:15 am.

Usually, during a year, the following variation can be observed: maximum flow in April–May–June and minimum flow in September–October; in between there is an autumn increase (November) and a winter decrease (January–February). The Danube River freezes across its entire width only in very frosty winters. The ice bridge forms usually at the half of January and its longest recorded duration was 54 days in 1954.

According to its chemical composition, the Danube water is carbonated-sulphated-chlorinated but its degree of mineralization is small, around 300 mg/l. Therefore, the water can be used for human consumption after treatment, for irrigations and for industry.

The Lower Danube experiences a temperate climate, with rains for the whole year, with hot and dry summers. Compared to the other areas of the country, this area is characterized by the highest temperatures, both in the summer and in the winter, with an annual average temperature over 11 °C. The studied area has some climatic peculiarities due to its location in the SW of the country being influenced by the Mediterranean climate, resulting in drought periods in the summer, with a maximum of two rain periods.

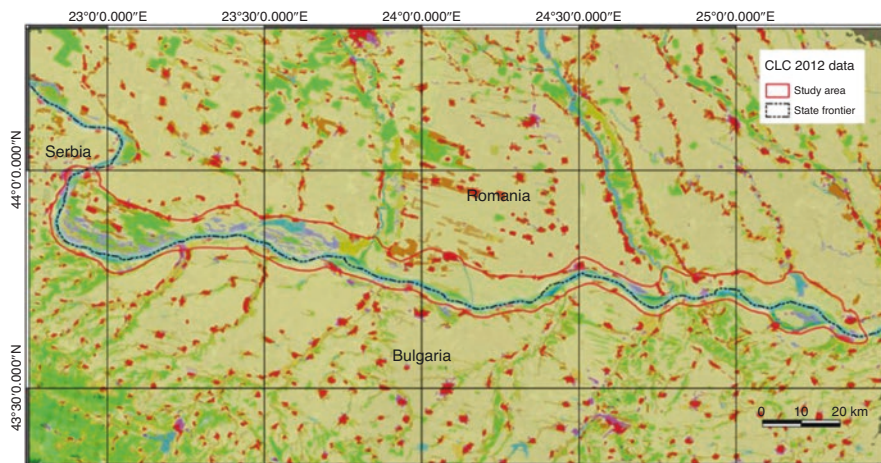
Average annual temperature during the 1991–2000 interval was 11.9 °C with the highest annual average temperature of 13.2 °C registered in 2000 while the lowest annual average of 11.0 °C was recorded in 1996. The highest monthly values are recorded in July and the lowest in January, therefore the highest monthly average value within this time interval (1991–2000) was recorded in July 1993 with 29.1 °C, and the lowest monthly average value was recorded in January 1996 with 27 °C.

The case study area is susceptible to severe droughts especially in the summer season, as mentioned above. Areas such as Dabuleni facing desertification, are in continuous expansion while others are emerging. Droughts result from a combination of meteorological, physical and human factors. Their primary cause is a deficiency in rainfall and the timing, distribution and intensity of this deficiency is in relation to existing storage, demand and water use. Temperature and evapotranspiration may act in combination with insufficient rainfall to magnify the severity and duration of droughts. Moreover, due to changes in land use, water demand and climate, the droughts may become more frequent and more severe in the future.

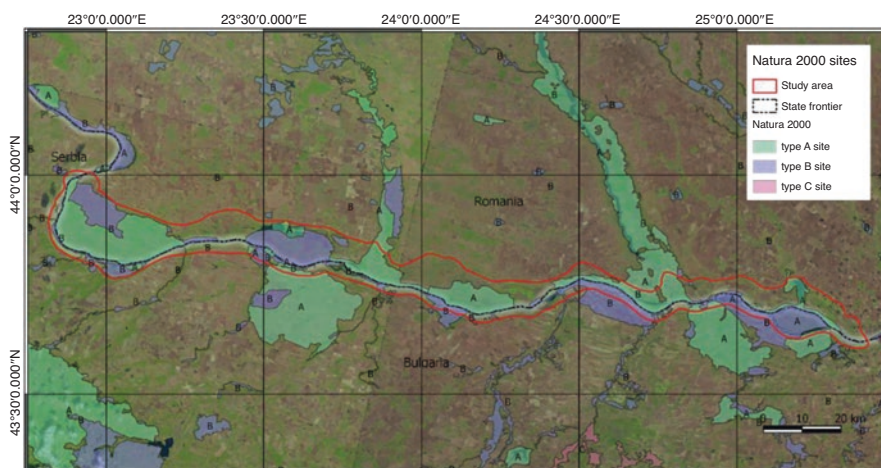
The Danube River is a major economic region reflected by the high percentage of cities located along its route. In our case study there are a number of major cities and rural areas starting from Zimnicea to Calafat. The distance between the Danube River and the settlements along its course varies between few hundred meters and one kilometre, with the exception of those settlements that have ports and where the infrastructure has been developed right up to the riverbank.

In between the populated urbanized areas, most of the land is being used for agriculture and pastures (Fig. 10.3) since this area is very fertile and produces very good yields. Initially this area corresponded to the former Danube floodplain, an area naturally flooded during high water levels, with a very important role in protecting the neighbouring settlements from catastrophic events by attenuating the flood peaks. The land use changes imposed by the agricultural and industrial evolution have altered the regulatory role of the floodplain resulting in the need for





**Fig. 10.3** Map of the case study site overlapping with cities, towns and agricultural fields



**Fig. 10.4** Map of the Natura 2000 sites in the case study region

implementing additional protection measures (grey infrastructure). The land along the riverbank is currently under the administration of private owners which therefore hinders the incentives that the local authorities could have regarding the maintenance and development of these areas.

However in the region, along the Danube riverbanks, some Natura 2000 sites listed under “Birds Directive” can be found (Fig. 10.4). These sites are strongly protected from human intervention and are strictly monitored by the National Agency for Environment Protection.

### **10.3 Nature Based Solution Design Process**

Nature Based Solutions (NBS) have become not only a complementary but a valid alternative to grey infrastructures for coping with climate-related risks in urban and rural areas alike. As defined by the European Commission, NBS are solutions inspired and supported by nature which are cost-effective, and capable to simultaneously provide environmental, social and economic benefits and help build resilience. Several examples of NBS for dealing with climate-related risks are cited in the scientific literature - i.e. restoring wetland, restoring and protecting forests, renaturing watersheds, creating natural retention areas, creating groundwater recharge areas, etc. Moreover, NBS are increasingly recognized for their capacity to support ecosystems functions and to generate ancillary environmental, economic and social benefits considered as essential backbones of actions for climate-change mitigation and adaptation. However successful NBS seem to be, starting from design to implementation, a challenge due to several barriers. One of the key barriers that need to be addressed concerns the low level of stakeholders and local community engagement in the NBS design process.

To this aim we have developed a stakeholders engagement process in order to design intervention scenarios based on NBS implementation. The research performed in the Lower Danube case study, within NAIAD project, aimed at understanding the role of natural assurance schemes in complex natural, economic and social contexts. To increase the relevance and the potential for replicable results, the large scale case study approach was complemented with a focus on the analysis of the Dabuleni-Potelu-Corabia enclosure (area drained for land reclamation) specific NBS. The downscaling was performed in order to allow the assessment of this specific NBS effectiveness based on a combined bottom-up interest of communities for diversification of economic activities and a top-down concern for reducing the pressure on the grey infrastructure for flood protection by means of a cascade system of green solutions.

The different phases of the NBS co-design process are described in the following sections.

#### ***10.3.1 Main Beneficiaries and Regulatory Framework***

The main beneficiaries from the process undertaken were the local communities, not only regarding the flood and drought protection, but also regarding the production of co-benefits related to the socio-economic and ecosystem dimensions. In contrast with grey flood prevention infrastructure that is already planned at river basin scale and has more solid financing sources, green infrastructure relies largely on local communities, first for acceptance, and second, for its implementation, monitoring and maintenance. Especially in Lower Danube case study, where NBS are in rural areas, and where farmers and local population are users, owners or

administrators of land resources and have their own way of using these resources. Therefore, to ensure the acceptance of NBS at the local level, local communities, as well as the local administrations need to be engaged in decision-making processes for design and implementation.

In the context of the Water Framework Directive 2000/60/EC and of the Flood Directive 2007/60/EC on the principle of “more space for river”, as well as the risk of climate change, specialized studies have been started since 2007 aimed at ensuring more favourable conditions for the drainage of flood events by repairing and restoring the ecological characteristics and regulatory functions of a part of the floodplain to the initial conditions that existed before the embankments construction, while at the same time ensuring the sustainable development of the adjacent areas in terms of income and revenue flows.

The principles of sustainable development focusing on green infrastructure aligned with the Water Framework Directive and the Flood Directive, have been applied in the general direction of the proposed scenarios developed for Dabuleni-Potelu-Corabia (DPC) enclosure, in order to reconnect this sector of the former Danube Floodplain with the Danube River to reduce water related risks (flood and drought) and to exploit the benefits and co-benefits generated by the implemented NBS. To this aim, local community knowledge and values were elicited and structured, to be used for the definition and assessment of the co-benefits to be produced.

### ***10.3.2 Stakeholders Engagement Process***

As already stated, a stakeholders process was implemented in the study area, with the scope of defining the key co-benefits to be produced through the NBS implementation and to support the assessment of its effectiveness. Three rounds of semi-structured interviews (approximate duration 1 h) with individual stakeholders (or group of stakeholders representing a single institution), one per stakeholder, were held first. The results of this activity showed that the whole area is increasingly affected by persistent droughts and, particularly in some locations, intense floods, both responsible for human and economic losses. Additional issues were also raised individually by the stakeholders, mainly related to the state of the environment and to the economic activities (e.g. agriculture, tourism, etc.), and identified as key elements to support the development of the area. Some problems were also discussed and highlighted by the stakeholders e.g. the negative effects associated to the lack of institutional cooperation and the limited stakeholders involvement in decision-making.

The first stakeholder workshop (approximate duration 3 h), was held in March 2018 at the headquarter of the River Basin Administration Jiu (Craiova), and oriented to the definition of a ranking among benefits and co-benefits. The main benefits were related to the reduction of the impacts of both floods and droughts, which were considered as equally important. Regarding the main co-benefits for the DPC enclosure, the highest-ranked ones were, in order of relevance: (i) the development



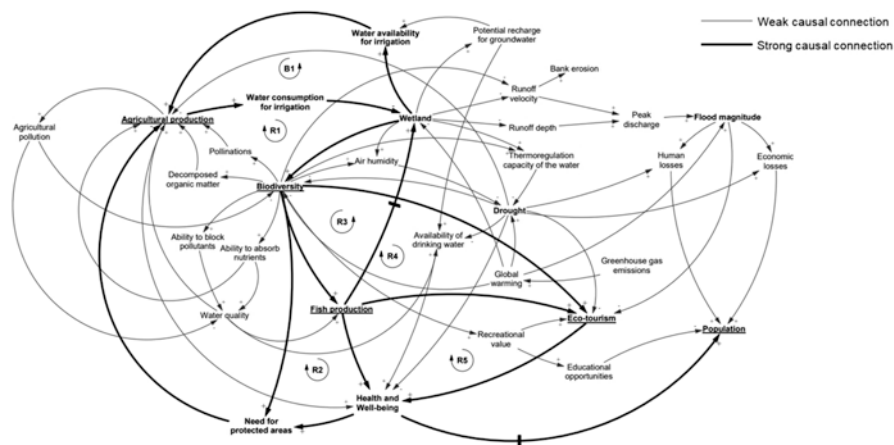
of eco-tourism; (ii) the limitation of migration/depopulation; (iii) the increase in biodiversity; (iv) the development of fishing and aquaculture activities; (v) the increase of agricultural production. Furthermore, the following NBSs were identified as potentially relevant for the area: wetland restoration, retention areas, river renaturation, and reforestation.

The second stakeholder workshop was held, with the same stakeholders, in December 2018 (approximate duration 3 h) at the headquarters of the River Basin Administration Jiu (Craiova). A Casual Loop Diagram (CLD) was collectively built, using the Vensim® simulation software, to describe the current state of the system. The main benefits associated with the reduction of water related risks (i.e. ‘drought’ and ‘flood magnitude’) and the selected co-benefits (‘biodiversity’, ‘eco-tourism’, ‘fish production’, ‘population’ and ‘agricultural production’) are drawn in bold (Fig. 10.5).

The developed CLD was used to support the discussion about the expected impacts of the NBS, according to the stakeholders understanding. A performance assessment matrix was developed, allowing the stakeholders to provide qualitative weight to the capability of the NBSs to produce the selected benefits and co-benefits (Table 10.1).

The Table 10.1 shows the comparison among four potential NBS. As shown in this table, stakeholders perceived the wetland restoration as greatly effective in reducing water-related risks, but also in producing important socio-economic and ecosystem-based co-benefits, such as increasing biodiversity and fish production, enabling eco-tourism initiatives.

The stakeholders engagement process was supported by the physical assessment, the flood and drought modelling and NBS effectiveness, as described further in the text.



**Fig. 10.5** CLD to describe the dynamics related to the benefits (“drought” and “flood magnitude”, in bold) and co-benefits (in bold and underlined) in current conditions in Dabuleni-Potelu-Corabia enclosure. (From Coletta et al. 2021)

**Table 10.1** The potential NBSs and the associated objectives/benefits and co-benefits

Alternatives/ NBSs	Objectives/Benefits and co-benefits					
	Water-related risks reduction	Biodiversity increase	Agricultural production increase	Eco-tourism increase	Fish production increase	Population growth
Wetland restoration	+++	+++	--	+++	+++	++
River renaturation	+	++	0	++	+	++
Retention areas	+++	+	-	+	++	+
Forested areas	+	++	--	+++	+	+



**Fig. 10.6** Dabuleni-Potelu-Corabia enclosure

### 10.3.3 Proposed NBS Scenarios for the Case Study Area of the Dabuleni-Potelu-Corabia Enclosure

The Danube River floodplain defence system was implemented between the years 1960–1966. Currently the existing structures for flood protection integrates a total area of approx. 4735.56 km<sup>2</sup>, representing 92.15% of the total area registered as floodable Romanian territory. This defence system is represented by approximately 1200 km of dykes arranged within 50 distinct land reclamation enclosures. An “enclosure” is the name given to the areas drained for land reclamation. DPC enclosure (Fig. 10.6) was dammed between the years 1965–1966 at the degree of protection against catastrophic floods of 1%, with a safety reserve height of 1 m. The dike length is 32.4 km, the cross section is trapezoidal with the following characteristics: crest width – 5 m and slopes 1:3 to the water and 1:(4÷5) to the enclosure. As a protective measure against erosion, hybrid black poplars were planted in the dike-river bank area.

The DPC enclosure was fully drained, representing a surface of 14,665 hectares and the area irrigated has a surface of 2.86 hectares (approx. 20% of the total drained area). The draining of the DPC enclosure was achieved by opening the Celeiu

channel that discharged the water with the help of five pumping stations: Corabia (3.2 m<sup>3</sup>/s), Stejarul (1.45 m<sup>3</sup>/s), Valcovia (10.75 m<sup>3</sup>/s), Racari (2.75 m<sup>3</sup>/s) and Celei (1.4 m<sup>3</sup>/s).

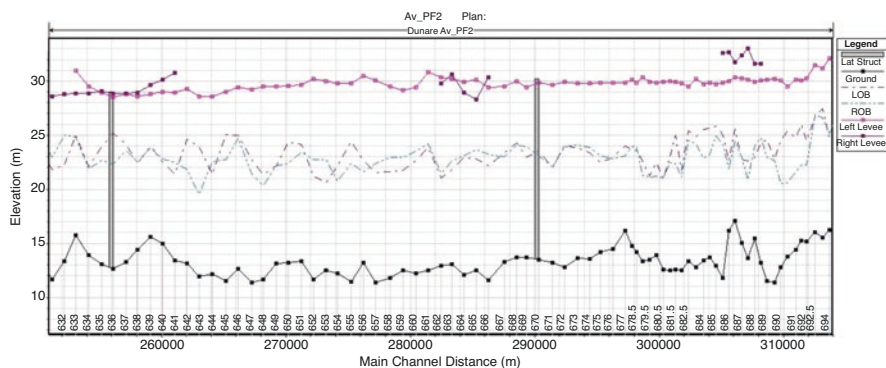
### Hydraulic Modelling of the Dabuleni-Potelu-Corabia Enclosure

Taking into account the particularities referring to land ownership and willingness to embrace the NBS implementation, we have developed two hydraulic models consisting on (i) partial flooding and (ii) total flooding of the enclosure surface. Further on, this two hydraulic models will represent the base for envisaging the scenarios for the restoration of the DPC enclosure.

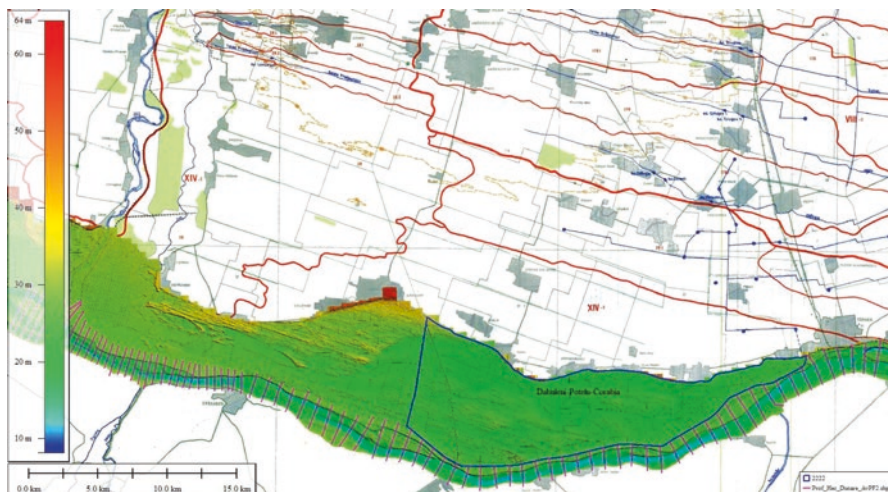
The hydraulic modelling of the water flow in the DPC enclosure considered the embanked Danube river, as well as the inside enclosure, and was performed using the HEC-RAS software (developed by the US Army Corps of Engineers). The hydrological parameters used in the modelling were those corresponding to the recorded flood of 2006.

The hydraulic model of the Danube riverbed and DPC enclosure was developed using the topometric and topobathymetric cross sections, plotted throughout the embanked Danube river (Figs. 10.7 and 10.8) and the numerical model of the land in the enclosure area (Fig. 10.8). The equidistance of the cross sections is approximately 1 km and their location corresponds to the Danube kilometre landmarks (Figs. 10.7 and 10.8). The numerical model of the terrain consists of a grid with a resolution of 5 × 5 m.

The hydraulic model developed for the studied area consisted of a one-dimensional model corresponding to the embanked area of the Danube river and a two-dimensional model corresponding to the enclosure area behind the dikes. For the two-dimensional model area, the overall grid cell size was 30 × 30 m. The connection between the one-dimensional hydraulic model (1D) and the two-dimensional hydraulic model (2D) was achieved considering two spills, corresponding to the areas where the breaches appeared in the defence dikes during the 2006 flood.



**Fig. 10.7** Longitudinal profile of the Danube River intersecting the plotted cross-sections within the Bechet – Corabia sector (Legend: Ground-river talweg, LOB-left overbank, ROB-right overbank, Left and Right Levees represent the defence dikes)



**Fig. 10.8** Cross sections locations

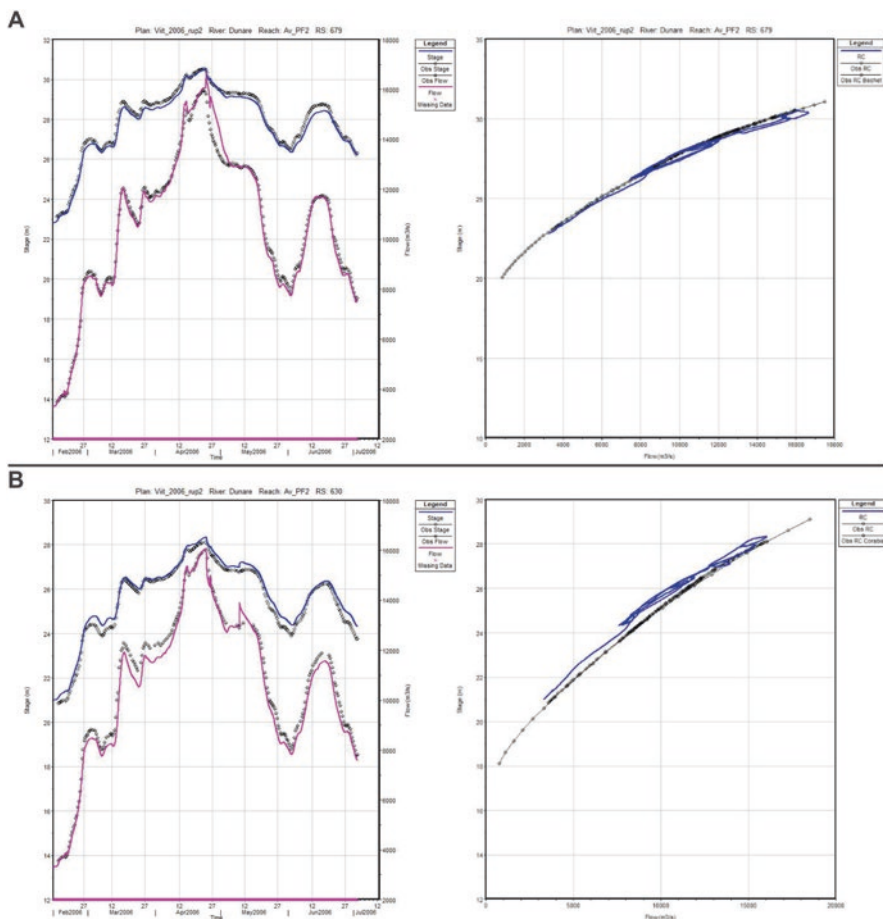
The calibration of the hydraulic model represents an important stage of the hydraulic modelling process and consists in validating the model results against the hydrological observations: flow rate and maximum level, total volume (increase and decrease) and rating curves (Fig. 10.9).

The main parameters that can be acted upon during the adjustment (calibration) process of the mathematical model that reproduces the flood waves propagation are:

- roughness coefficients ( $n_i$ ) (Fig. 10.10), which model the hydraulic resistance of the river channel;
- introduction of the accumulated mileage of the floodplain in the direction of the recorded flood propagation axis (ID);
- determining the higher areas and levels from where the floodplain begins to flood, detecting and modelling the local low level areas (located below the level of the riverbanks) of the floodplain with a polder effect that does not contribute to the flow, but influences the propagation and volume of recorded floods;
- detection and modelling of the backwater areas;
- optimal adjustment of the calculation coefficients of the model, by adjusting time and distance calculation steps along the river ( $\Delta T$ ,  $\Delta X$ ), and the number of cycles when integrating the equations.

The calibration of the hydraulic model took into account several dike breaches produced as follows, from upstream to downstream: the Bechet enclosure breach, followed by the division dike breach between Bechet enclosure and DPC enclosure, and lastly the Danube dike breach, created for evacuating the flood water from the DPC enclosure (Fig. 10.11).

The roughness coefficients resulted from the calibration process have values of 0.03 for the riverbed and 0.07 for the floodplain (Fig. 10.10).

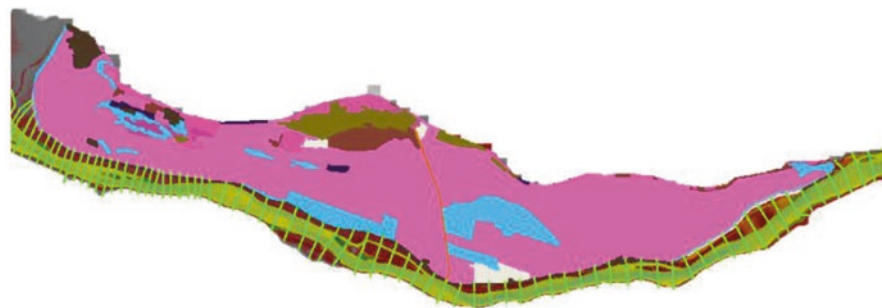


**Fig. 10.9** Calibration results of the hydraulic model (flow and level hydrographs, left side and the rating curves, right side) in the sections of Bechet (a) and Corabia (b) hydrometric stations

**Planning Scenarios for the Restoration of Dabuleni-Potelu-Corabia Enclosure**

The proposed restoration scenarios for the DPC enclosure integrated the conclusions of the meetings held with the stakeholders from our case study area. Based on the extreme flood from 2006 that recreated the Potelu Lake, the majority of our stakeholders have been in favour of restoring the former floodplain, mainly being driven by the potential benefits and co-benefits that the implementation of the NBS can bring. The new formed Potelu Lake was drained one year after, in 2007, causing the loss of the benefits and co-benefits associated with the wetland. The proposed planning scenarios were focused on the total flooding (optimistic planning scenario) and partial flooding (realistic planning scenario) of the enclosure, in order to recreate the former Potelu Lake that will act as a natural retention area to reduce the flood peak and promote additional uses such as fish farming and recreation.





Color	Value	Name	Default Manning's n
	0	no data	
	1	112 - Artificial surfaces/ Urban fabric/ Discontinuous urban fabric	0.03
	10	324 - Forest and semi-natural areas/ Shrubs and/or herbaceous vegetation associations/ Sclerophyllous vegetation	0.2
	11	411 - Wetlands/ Inland wetlands/ Inland marsh	0.03
	12	511 - Water bodies/ Inland waters/ Water courses	0.03
	2	121 - Artificial surfaces/ Industrial, commercial and transport units/ Industrial or commercial units	0.03
	3	211 - Agricultural areas/ Arable land/ Non-irrigated arable land	0.05
	4	221 - Agricultural areas/ Permanent crops/ Vineyards	0.035
	5	231 - Agricultural areas/ Pastures/ Pastures	0.035
	6	242 - Agricultural areas/ Heterogeneous agricultural areas/ Complex cultivation patterns	0.06
	7	243 - Agricultural areas/ Heterogeneous agricultural areas/ Agriculture mixed with areas of natural vegetation	0.06
	8	311 - Forest and semi-natural areas/ Forests/ Broad-leaved forest	0.08
	9	321 - Forest and semi-natural areas/ Shrubs and/or herbaceous vegetation associations/ Natural grasslands	0.2

**Fig. 10.10** Distribution of land use categories and roughness coefficient adopted. The roughness coefficients (Default Manning's n) used for the enclosure area were taken from Chow (1959), corresponding to the different categories of land use presented in Corrine Land Cover 2018

#### *Planning scenario 1 (optimistic scenario)*

This scenario is based on the modelling of flooding conditions without considering the existence of defence dykes.

The total area of the DPC enclosure is 14,665 ha its maximum estimated capacity would be  $75 \times 10^7 \text{ m}^3$  (at 28 m ground level). In normal retention conditions (at 24.5 m ground level) the estimated stored water volume will be  $24 \times 10^7 \text{ m}^3$  (Fig. 10.12).

The flooding simulation of the DPC enclosure was performed based on the recorded flood wave from 2006 (Figs. 10.13 and 10.14). The connection between the one-dimensional (1D) hydraulic model corresponding to the Danube river and the two-dimensional (2D) hydraulic model corresponding to the DPC enclosure was made through side spillways. The spillways crest level was extracted from the numerical terrain model of the DPC enclosure representing the lowest values identified at the base of the dykes.

The hydraulic modelling results of scenario 1, indicates a decrease of  $430 \text{ m}^3/\text{s}$  of the maximum water flow downstream of the DPC enclosure as well as a lowering with 36 cm of the maximum water level in the upstream part (Bechet hydrometric station).



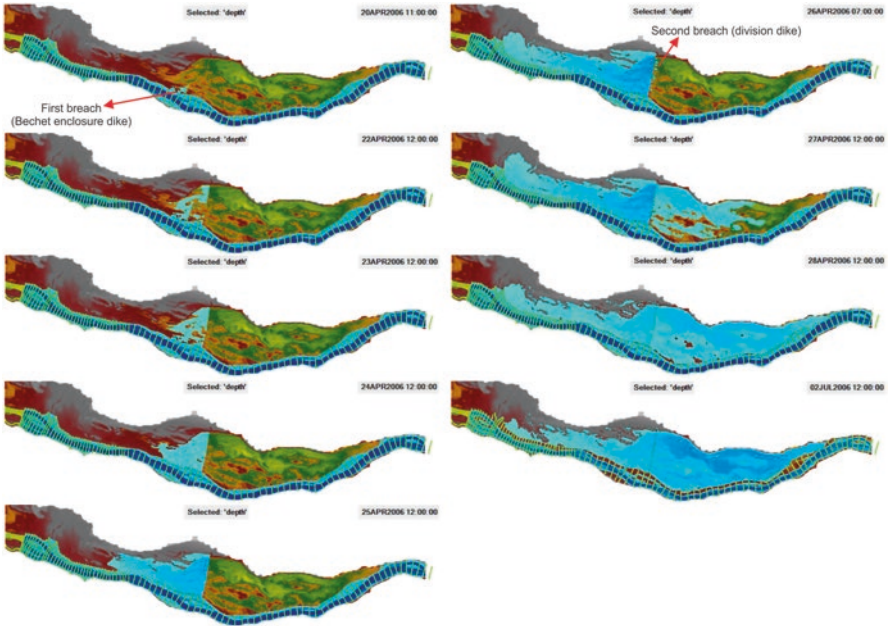


Fig. 10.11 The results of the flood wave propagation in the Bechet and DPC enclosures generated by the breaches in the Danube dike and the interior division dike, at different times

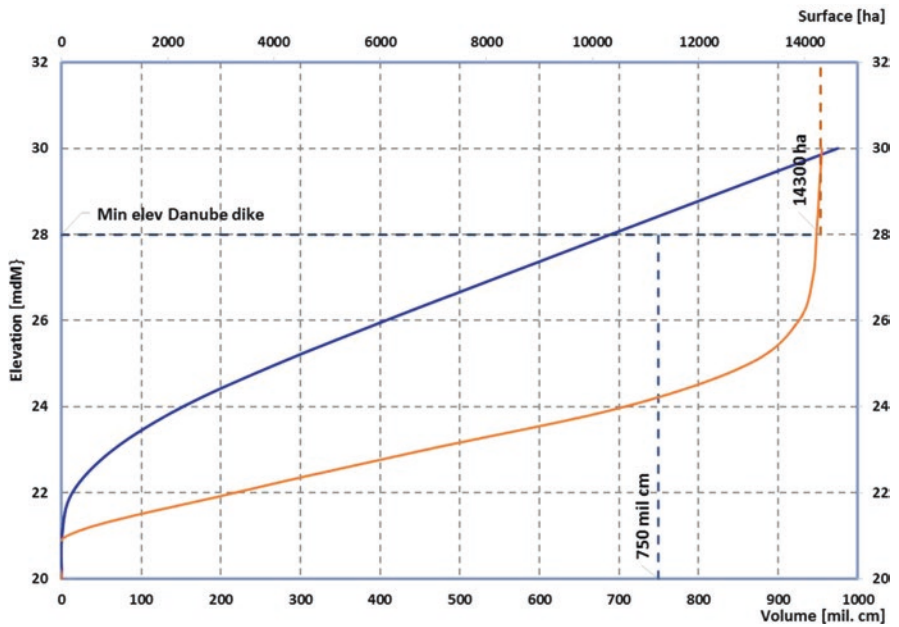
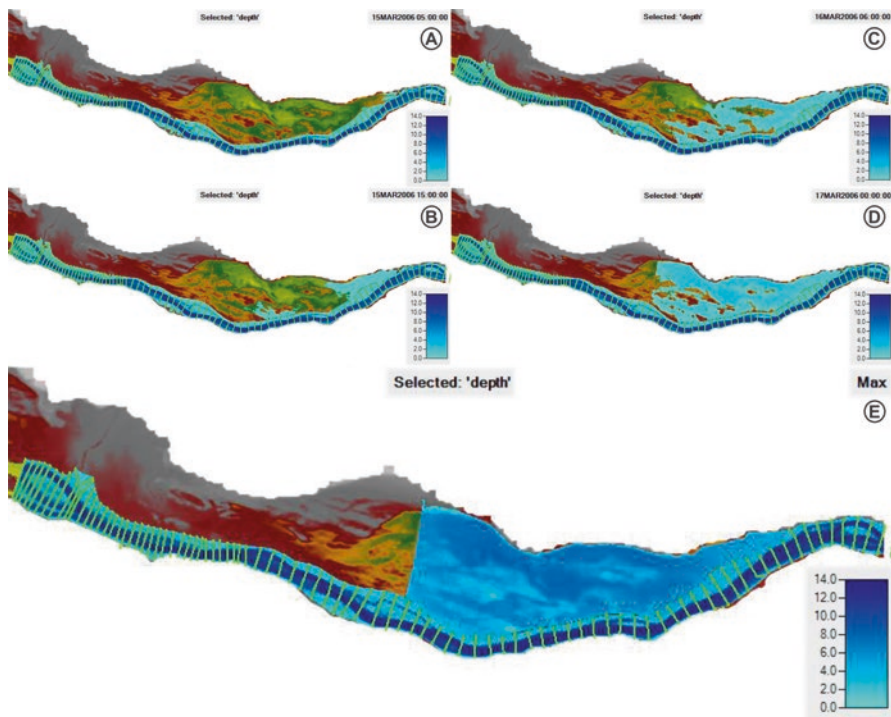
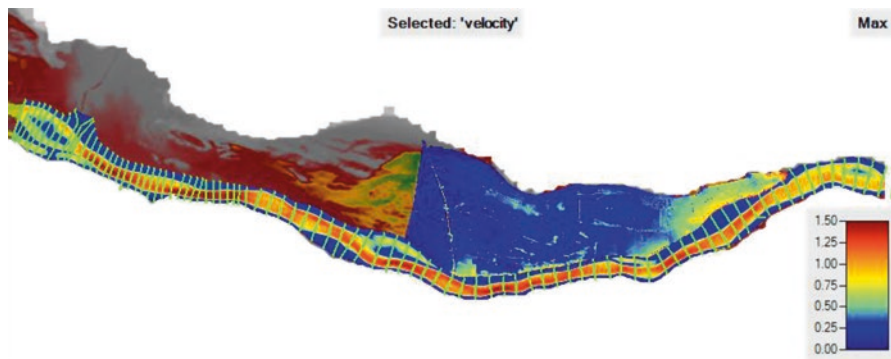


Fig. 10.12 Characteristic curves of Dabuleni-Potelu-Corabia enclosure (blue line – volume variation, brown line – water surface variation)



**Fig. 10.13** Flood wave propagation in the DPC enclosure without considering the existence of defence dykes



**Fig. 10.14** Water flow velocities in the DPC enclosure based on the recorded flood from 2006

The decrease of the maximum water flow of 430 m<sup>3</sup>/s is considered to be maintained downstream of the DPC enclosure until the confluence with the river Olt (the main tributary of the Lower Danube) (i.e. a stretch of about 60 km). This flow reduction generates a lowering of the maximum water level with approx. 20 cm according to the rating curve from the section of Corabia h.s.

The main effect generated by the water level decrease is represented by the reduction of the pressure on the existing defence dykes.

The estimated value of the engineering works proposed to be carried out within the framework of the planning scenario 1 was calculated taking into account the costs of similar investments. This calculated value is approx. M€ 8 and represents the total investment needed for implementing the engineering works without considering the costs of expropriation of land areas, permits and authorizations, as well as other commissions and fees; which means that the total costs would be higher.

#### *Planning scenario 2 (realistic scenario)*

This scenario is based on restauration of the former Potelu Lake (Fig. 10.15) which implied readapting the main irrigation and drainage channels.

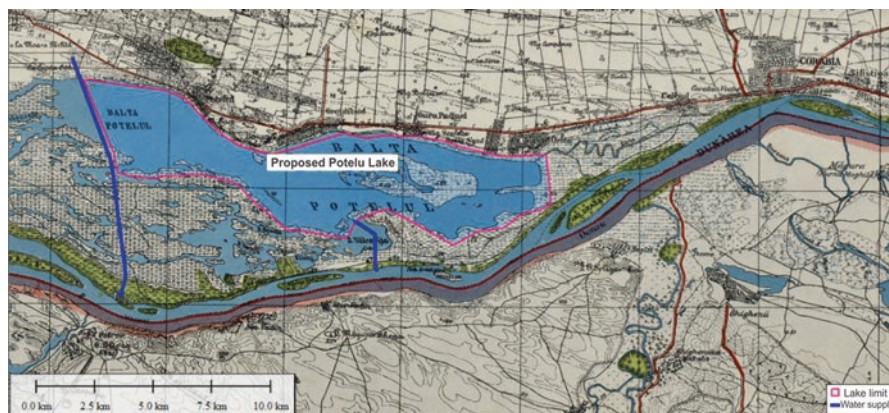
The limits of Potelu Lake will be represented by contour levees with the crest level corresponding to the level that will ensure a protection against catastrophic floods with the probability of 1%.

The total length of the contour levees surrounding the Potelu Lake will be 47 km, however, if the northern limit will be extended up to the base of the existing terrace, the total length will be reduced to 27 km.

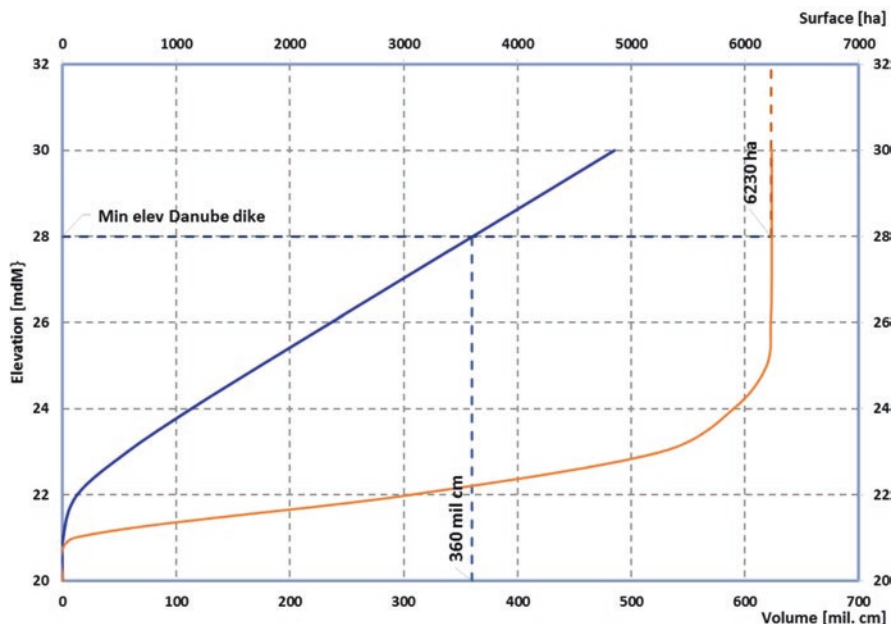
Based on our workshops and the inputs elicited from the local stakeholders, the main uses of Potelu Lake would be fish farming and recreation.

The total area of the proposed Potelu Lake would be 6230 hectares and its maximum estimated capacity will be  $36 \times 10^7 \text{ m}^3$  (at 28 m ground level). In normal retention conditions (at 24.5 m ground level) the estimated stored water volume will be  $14.5 \times 10^7 \text{ m}^3$  (Fig. 10.16).

The reduced transport capacity of the Potelu Lake supply/drainage channels, together with its small volume (approx.  $21 \times 10^7 \text{ m}^3$ ) reserved for the attenuation of the flood waves from the Danube River ( $116,000 \times 10^6 \text{ m}^3$ ) would have a negligible impact in reducing the water flow and flood peak.



**Fig. 10.15** The extension of the proposed Potelu lake



**Fig. 10.16** The characteristic curves of the proposed Potelu Lake (blue line – volume variation, brown line – water surface variation)

The value of the construction works proposed for the planning scenario 2 was estimated taking into account the costs of similar investments. The calculated costs would be approximately 47,000,000 Euros in the case of delineating the entire Lake Potelu with contour dykes (47 km in total length). However, if the northern limit of the lake would be extended up to the base of the existing terrace, reducing the length of the estimated dyke construction (down to 27 km), the calculated costs would be approximately 29,000,000 Euros. These costs refer only to the engineering works without considering the costs of expropriation of land areas, permits and authorizations, as well as other commissions and fees; which means that the final costs would be higher.

## 10.4 Economic Assessment

DPC enclosure has been largely damaged during the 2006 flood event. High population density and geographical constraints make the area extremely vulnerable to devastating consequences of flood events.

Considering the current lack of insurance data available to assess the insured damage and to calibrate damage curves specific for the Lower Danube area, we opt for a GIS infra-territorial indicator methodology to assess flood risk vulnerability.

In order to gather information on the economic assessment we performed a literature review to collect quantitative information about the 2006 flood damage. Consistent post-event research on the flood damage has been performed (Liška et al. 2008; Schwarz et al. 2006). These researches are the unique source of information concerning the damage, in terms of number of damaged houses, most damaged communities and global amount of losses.

### ***10.4.1 Literature Review on 2006 Flood Damage***

The estimation of the amount of damage for the 2006 flood is approximately M€ 400 for the Lower Danube area with 14,000 people displaced in Romania and 63 displaced in Bulgaria (Liška et al. 2008). For Romania the estimated damage are approximately M€ 200–300 with no human losses recorded. When focusing on the counties of the studied area, we obtained detailed information on the tangible direct damage (Table 10.2).

When comparing the affected Romanian counties, we observe that both Dolj and Calarasi (Calarasi is not located in the studied area) counties were amongst the most damaged ones. Dolj county represents the largest proportion of the total number of affected constructions (54.6% of the total destroyed dwellings) and railroads (87.8%). Olt county has not been strongly affected. Concerning agricultural damage, two of the four areas heavily impacted are located in the studied area: Potelu and Calarasi villages (not to be mistaken with Calarasi county and Calarasi town). It represents 41.184 ha of productive land flooded and 10.802 people lost their livelihoods. In terms of loss of productivity the studied area represents 54.9% of the total loss of hectare of productive land (Table 10.3).

Then, it is possible to define the average costs of a claim. We consider the total number of damaged infrastructures (10522) for the overall Romania for a total cost of M€ 250. The average costs of a claim is € 23,759. In this study we focus only on assessing the direct damage to the dwellings (destroyed and affected), for the overall Romania it represents 31% of the total damage, thus M€ 77.9. For the studied area, it represents 12%; so we consider the damage to the dwellings destroyed and affected for approx. M€ 30.8. So the average costs of claims for dwellings are € 9300 (total number in the area: 3279).

### ***10.4.2 GIS-Based Indicators***

The second step is to apply the GIS-based indicators methodology developed by CCR to perform a damage estimation in an area without any access to insurance data. The objective of this GIS-based infra-territorial indicator is to propose a vulnerability mapping method for disaster assessment in the NAIAD case studies. This indicator should be seen as a tool for decision-making process to assess the areas

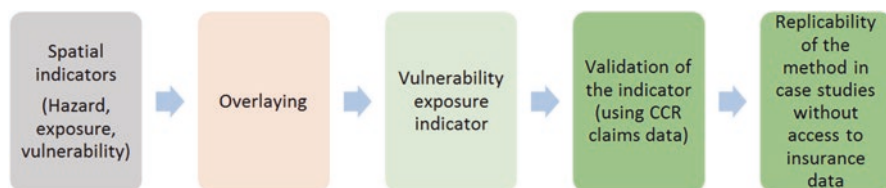
**Table 10.2** Affected and destroyed infrastructure in Romania, focus on the counties in the studied area (Liška et al. 2008)

County	Affected constructions				Railroads and roads				Other constructions
	Destroyed dwellings	Affected dwellings	Dependencies	Wells	Railroads (km)	Local, county and national roads (km)	Bridges and footbridges (km)		
Olt (ROU)	3	5	87	-	-	4	11	4	
Dolj (ROU)	372	919	596	2133	21.0	3	169	48	
Total of the ROU counties	681	2598	2763	3881	23.9	22	487	67	
Dolj proportion in the total (%)	54,6	35,3	21,5	54,9	87,8	13,6	34,7	71,65	

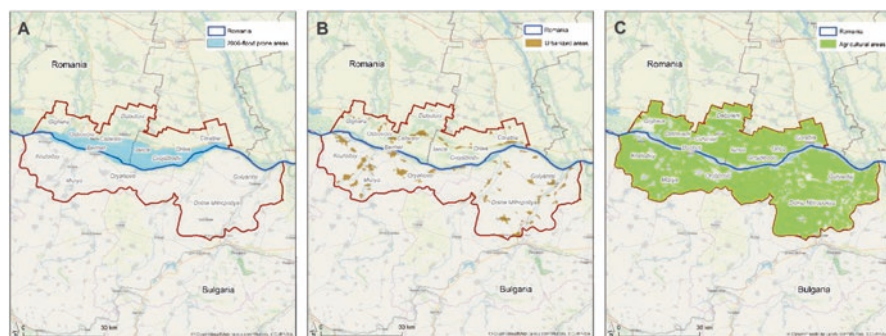


**Table 10.3** Damage done by floods on productive land and on human well-being; (Schwarz et al. 2006); focus on the studied area

	Evacuation	Loss of productivity
Balta Potelu	–	8.200 ha arable land flooded 5.900 ha forest flooded 2.600 ha pastures flooded
Balta Calarasi	2.480 displaced	1.222 ha arable land lost 4.686 ha arable land lost
Total	10.802	41.184 ha
Studied areas proportion in the total	23%	54.9%



**Fig. 10.17** Method to implement GIS-based risk indicator



**Fig. 10.18** Indicators used for the GIS-based methodology

vulnerability to water-related hazards and to select the more appropriate area for preventive measures implementation. The proposed methodology (Fig. 10.17) combines a range of geographically based input layers from physical (flood extent) to socio-economic (land-use) ones within DPC enclosure.

Indicator-based approach participates in the development of standard methods to assess flood damage potential for assets at risks (Eleutério et al. 2010). Thus, three types of input layers have been overlaid in ArcGIS, through the raster calculator (Fig. 10.18). The layers have not been weighted; the location is the common key between the different layers. The flood prone area (hydraulic models developed by Geocomar – Fig. 10.18a) and the urbanized areas (Corine Land Cover 2018 – Fig. 10.18b) have been overlaid for the vulnerability exposure of urban areas and in

a second step, flood prone area and agricultural areas (Fig. 10.18c) have been overlaid for the exposure of agricultural areas.

Following the development of the spatial analysis, the obtained exposure indicator is aggregated at the community scale using meshes of 250 m, 500 m and 1 km resolution.

The figures below show the result of the overlaying process with urbanized and with agricultural areas. We observed that the central area of Bechet and Calarasi are the most at-risk areas (Fig. 10.19). The orange areas considered as “moderate” risk are agricultural areas largely damaged during the 2006 flood event, as visible in the Fig. 10.20. The GIS-based indicator highlights the large exposure of agricultural areas to flood risk. This is consistent with the findings in the literature review on agricultural damage.

Furthermore, it is possible to define the percentage of the communities at risk of flooding taking into account their urban or agricultural exposure. When comparing the flood exposure, the results indicate that all of the agricultural areas are heavily at risk (from 80% to 98% exposure), the most exposed communities from Romania being Ostroveni, Bechet and Grojdibodu while regarding the urbanized exposure, the most exposed ones are Ostroveni, Ianca and Grojdibodu (Fig. 10.21).

The exposure of agricultural areas is largely more significant than the urbanized exposure, which is consistent with the elements found in the literature review.

When we performed the assessment using meshes of 250 m, 500 m and 1 km resolution, with urbanized and agricultural inputs layers, we observed the same pattern with agricultural areas being more exposed to flood risk than urbanized areas (Figs. 10.22, 10.23, and 10.24).

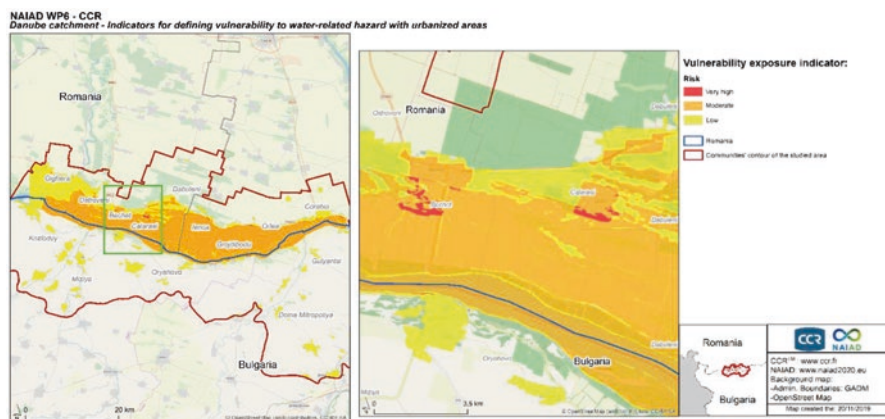


Fig. 10.19 GIS-based vulnerability exposure indicators of urbanized areas

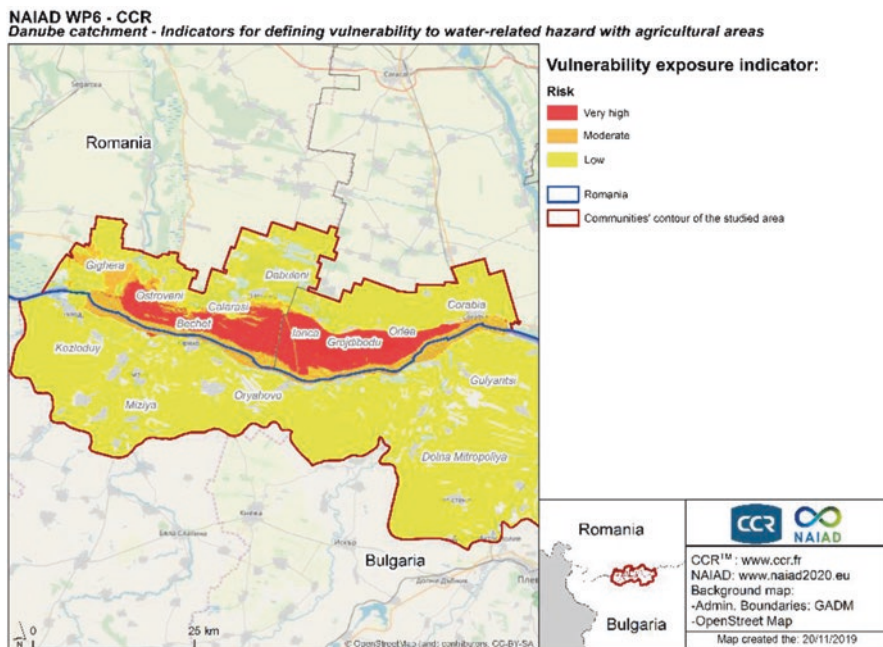
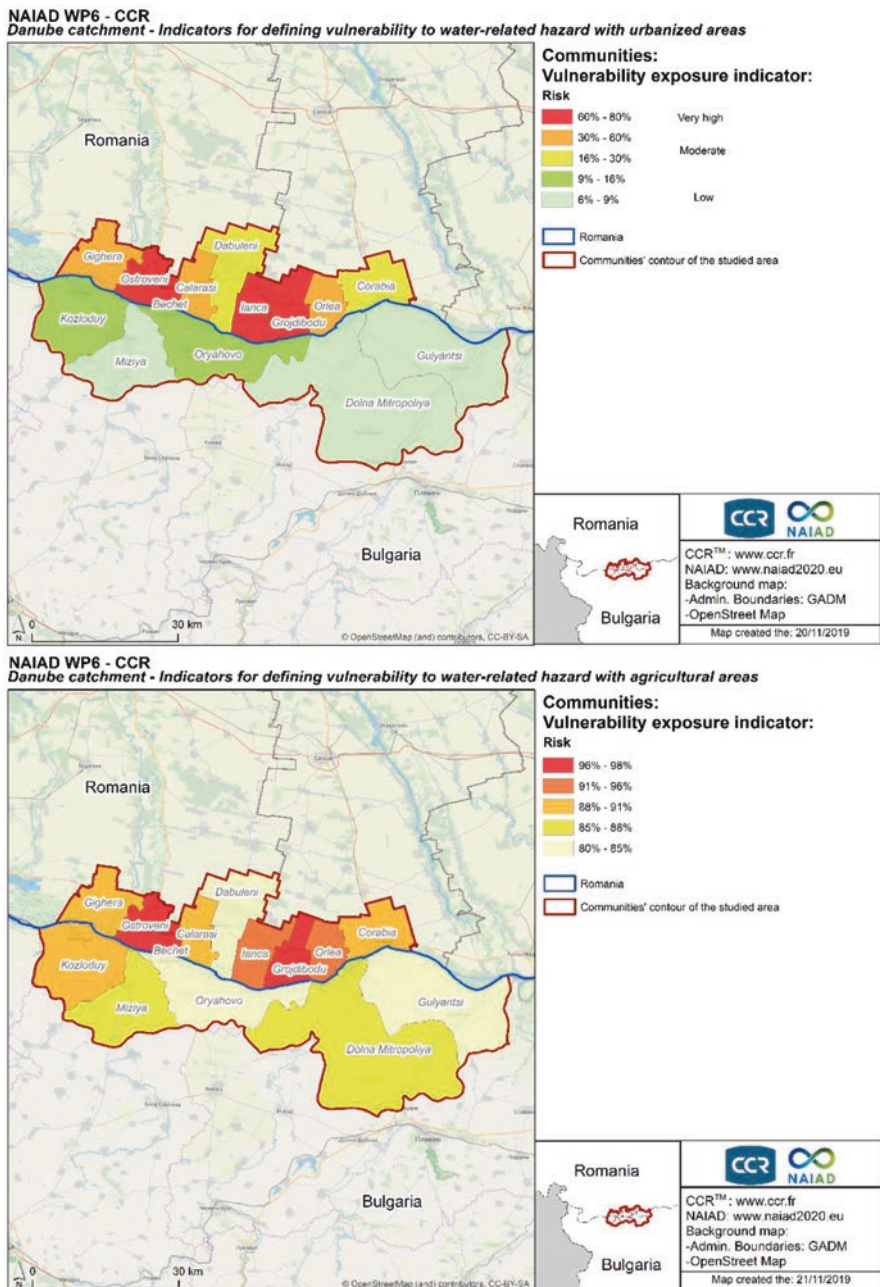


Fig. 10.20 GIS-based vulnerability exposure indicators of agricultural areas

## 10.5 Conclusions and Lessons Learned

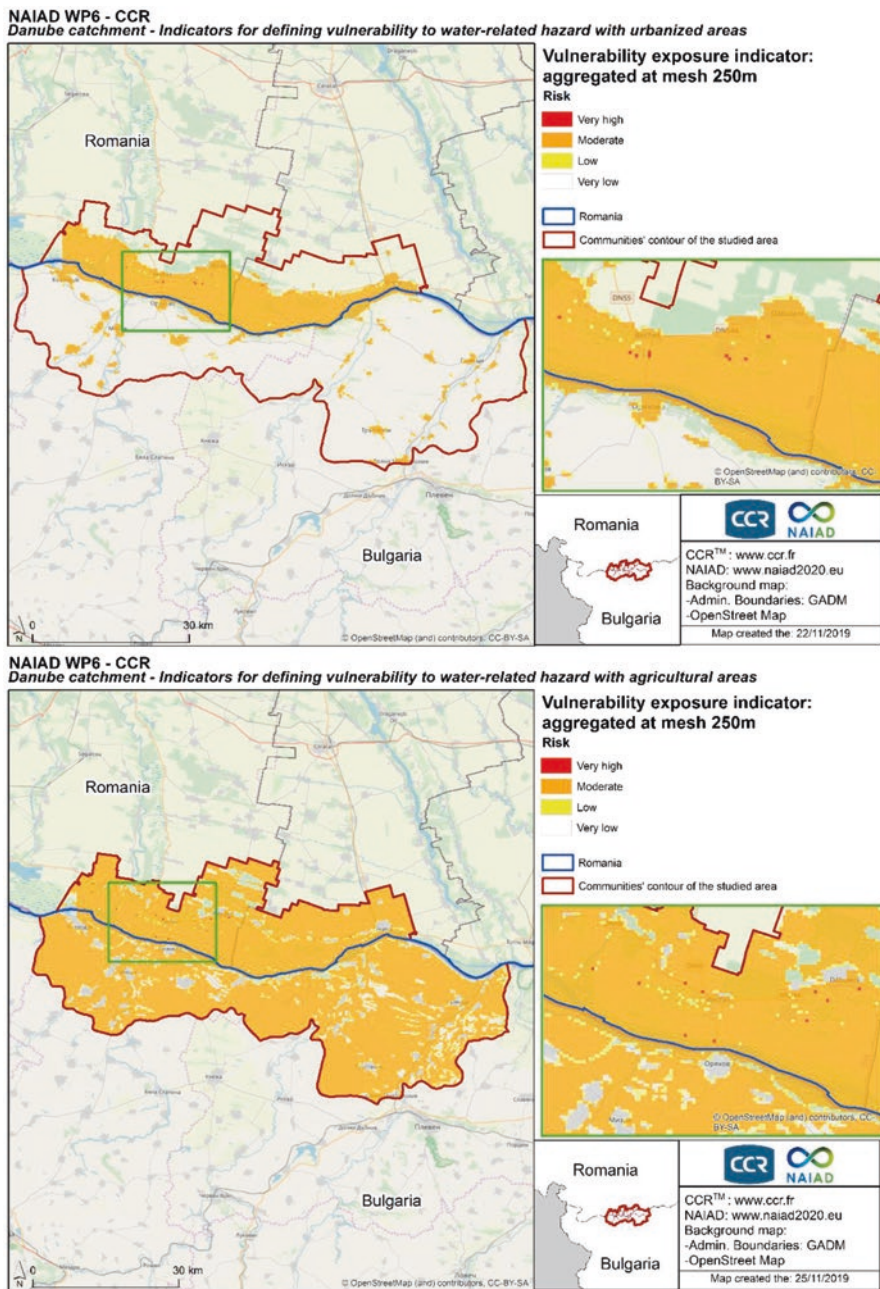
Besides the physical assessment of the NBS effectiveness in reducing the water-related risks at local level, the NAIAD implementation contributed to develop an integrated assessment framework, capable to account for the stakeholders preferences over the co-benefits to be produced. For a more detailed definition of the different phases of the implemented process, a reader might refer to Giordano et al. 2020. In this section, we would like to describe the key lessons learned during the whole process.

Firstly, we learned that rich and diverse knowledge is required for an effective NBS design and assessment process. To this aim, the adopted approach allowed to collect individual risk perceptions, to detect and keep track of the main differences among risk perceptions and problem framings, and to avoid pursuing immediate and unanimous consensus. Secondly, the experiences carried out in the Lower Danube demonstrated the key role that the co-benefits play in enhancing social acceptance of the NBS. Most of the stakeholders involved in the process expressed high interest in the potential socio-economic benefits – i.e. eco-tourism, fishery production, reduce de-population (Giordano et al. 2020) – even higher than in the reduction of flood damages. Therefore, we learned that contrarily to most of the existing approaches, in which the co-benefits are accounted for exclusively during

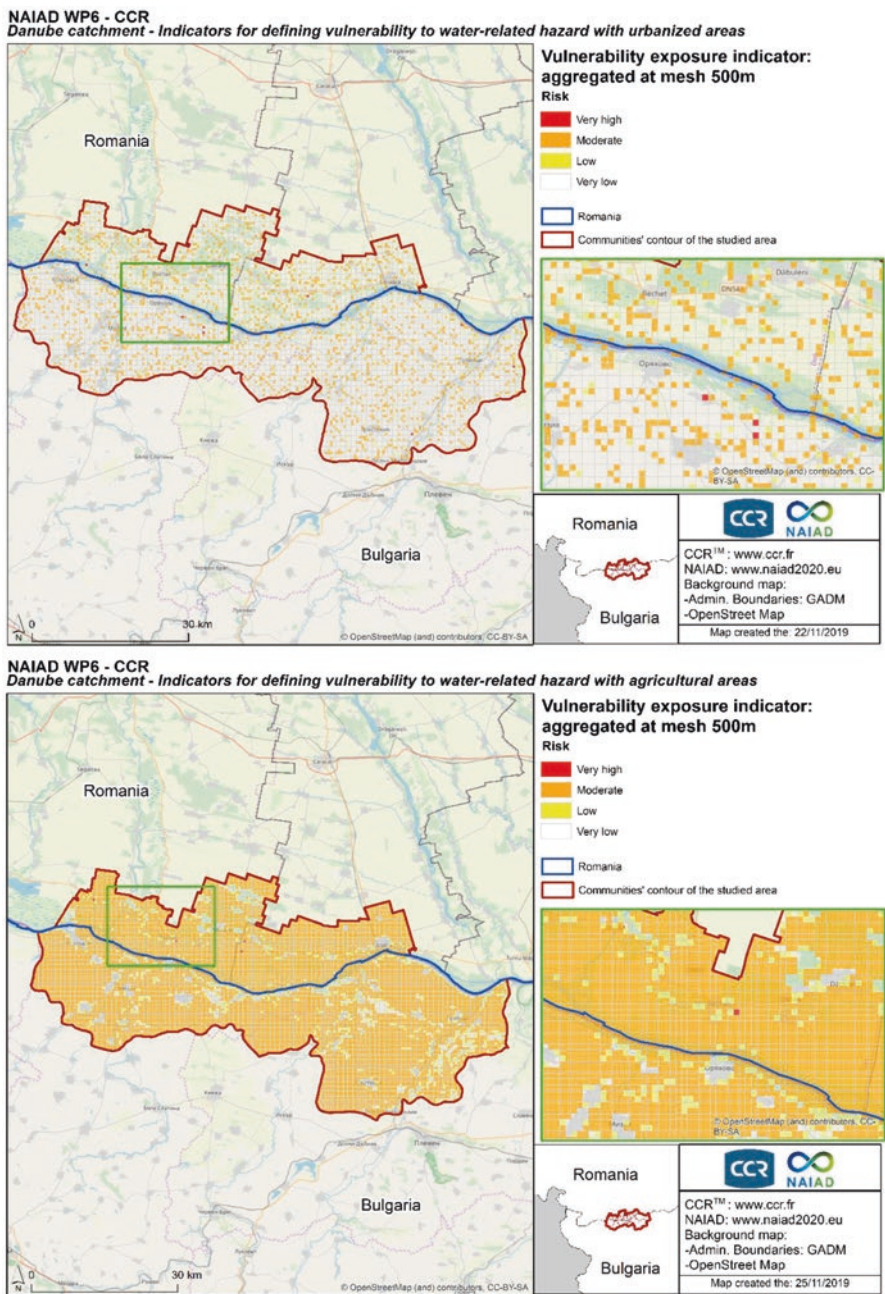


**Fig. 10.21** Percentage of the communities areas at risk of flooding: vulnerability exposure of urban (up) and agricultural areas (down)



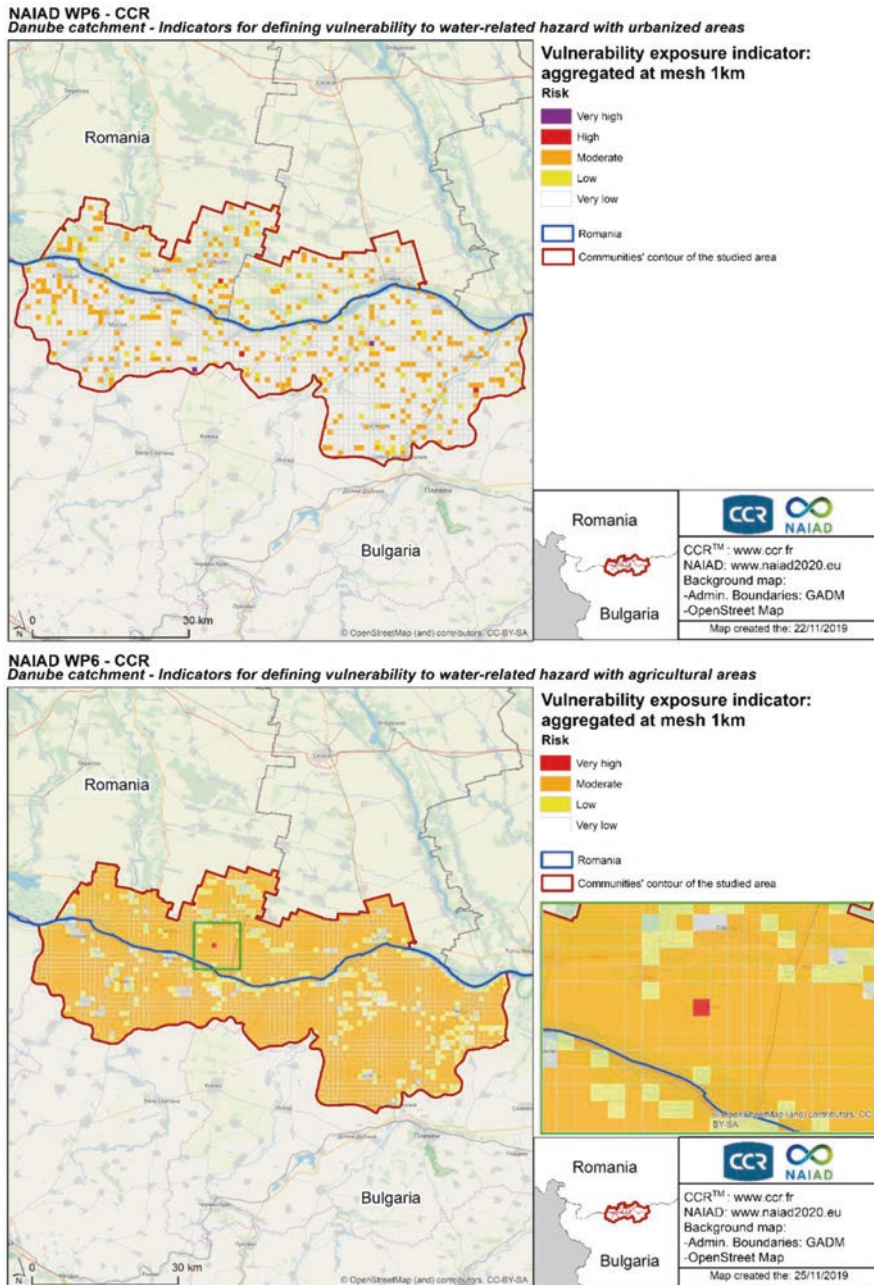


**Fig. 10.22** GIS-based indicators with urbanized areas (up) and agricultural areas (down) input layers – mesh of 250 m



**Fig. 10.23** GIS-based indicators with urbanized areas (up) and agricultural areas (down) input layers – mesh of 500 m





**Fig. 10.24** GIS-based indicators with urbanized areas (up) and agricultural areas (down) input layers – mesh of 1 km

the phase of NBS assessment, co-benefits need to be co-defined since the NBS design phase. Thirdly, given the importance of the co-benefits in enhancing the social acceptance of the NBS, guaranteeing the equality in accessing and benefiting the co-benefits is of utmost importance. Therefore, the detection and analysis of potential trade-offs and conflicts should be at the basis of the NBS design.

Moreover NAIAD Project attempted to assess the insured damage and to calibrate damage curves specific for the Lower Danube area associated with specific water related risks. For this, a GIS infra-territorial indicator methodology to assess flood risk vulnerability was implemented in order to complement the current lack of available insurance data.

The literature review on the 2006 flood in Romania provides relevant elements on the number of damaged assets. Nevertheless, the lack of data on the insured losses generates difficulties in the local damage assessment and furthermore to the avoided damage assessment. The GIS-based indicators can support the lack of insurance data, with the objective to define the most exposed areas. In the context of the Lower Danube case study, the GIS-based results demonstrate the prevalence of agricultural areas exposure to flood. The literature review together with the GIS analysis are able to provide a reliable cost estimation of the damage related to destroyed and affected dwellings.

**Acknowledgements** This work was funded by the H2020 project NAIAD (Grant 730497) from the European Union's Horizon 2020 research and innovation program. We acknowledge the support of our colleagues Iulia Puiu and Camelia Ionescu from WWF Romania. We thank Elena López Gunn for reviewing this chapter and providing many useful comments. Part of the data used within NAIAD Project was obtained through the Core Program (Program Nucleu) - "Developing integrated management for pilot areas of the Romanian Danube sector, influenced by climate change and anthropic interventions, by applying complex research methodologies", funded by the Romanian Ministry of Research and Innovation, contract no. 13N/08.02.2019. Sabin Rotaru was also supported by the Romanian Young Academy, which is funded by Stiftung Mercator and the Alexander von Humboldt Foundation for the period 2020–2022.

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