ECOHYDROLOGY & HYDROBIOLOGY

DOI: 10.2478/v10104-012-0013-3

Vol. 12
No. 2, 137-152
2012

# An Ecohydrology approach to the Danube River, and the "enviroGRIDS" project

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## Abstract

The paper presents a review of research performed on the Danube River, Danube Delta and Black Sea area, carried out since 1990 by the National Institute of Hydrology and Water Management (NIHWM), Bucharest, and other institutes, and indicates how the main concepts and principles of Ecohydrology are being used and implemented. A closer view is given to the large scale research project entitled: "Building Capacity for a Black Sea Catchment Observation and Assessment System supporting sustainable Development", known as "EnviroGRIDS". Some of these ideas and principles of Ecohydrology were applied to the activities developed under the project. The paper gives an idea of a compatibility of the research and activities being undertaken with Ecohydrology theory and methods, and presents the way this can serve good management practices and sustainable river basin development.

**Key words:** principles of ecohydrology, water resources, hydrology, sustainable development, ecological reconstruction.

## 1. Introduction

Ecohydrology is a relatively new synthesis science, which is an interdisciplinary approach employing the specific tools of hydrology, water physics, chemistry and ecology (Zalewski, Wagner 2005). It can play an important role in the management and sustainable use of water resources. Taking into account the above mentioned characteristics, an Ecohydrology Group was created under the umbrella of UNESCO. The mandate of the group was to develop and apply specific Ecohydrology tools to estuaries, deltas, lagoons and coastal areas with a view to supporting the sustainable development of these areas. The main goals of the UNESCO Working Group were to develop:

- contributions on Ecohydrology as basis for planning for sustainable development in micro-tidal deltas, estuaries, coastal areas and lagoons (Chicharo 2006);
- different experiences in the control of eutrophication, hydrology, biology and pollution in various areas, utilizing modelling and different ecohydrological techniques (Chicharo *et al.* 2006);
- comparisons between different regions and different ecological conditions to determine the key parameters which control eutrophication, hydrology and biology, toxic algal blooms, invasions of new non-native species etc.;
- measures for the control and restoration of polluted and eutrophicated ecosystems;
- tests of the applicability of developed ecohydrological models in different areas;
- comparisons of the functioning of micro-tidal and macro-tidal deltas, estuaries, coastal areas and lagoons.

Some of these ideas and principles were applied in different projects, as well as in the activities developed under the 7th Framework Research Program financed by the European Commission, under a large scale project entitled: "Building Capacity for a Black Sea Catchment Observation and Assessment System supporting sustainable Development", also known as "EnviroGRIDS".

Other important aspects of the above mentioned research are the human activities which have caused many changes in physical and chemical parameters of the Danube River and Danube Delta. These activities have resulted in high water – flood regimes; low water – drought regimes – pond depletion; morphological evolution of flow paths and sediments at the exit point to the sea; density flows – lack of salt water; pollution phenomena; satisfying the necessities – drinking water supply, maritime navigation, agriculture, fisheries, ecology, tourism; and, modifying the hydrologic and hydraulic parameters as an effect of some hydraulic engineering works in the Delta – modification of the water bed, embankments, dams, new flow paths, ecological reconstructions (Jolev 2009). Some of the above mentioned changes and the approaches used to reduce their associated negative impacts are presented, taking into account both the hydrological and ecological aspects.

## 2. Materials and methods

### *2.1. Ecohydrology, a scientific tool in full development*

Ecohydrology "is the concept which aims to create a new interdisciplinary background for the assessment and sustainable management of fresh water resources" (Zalewski, Wagner 2005). Ecohydrology is "the science that studies the mutual interactions between hydrology cycle and ecosystems. It is a fast-growing science that is expected to explain important problems related to natural processes and provide engineering solutions with reduced environmental impact" (Porporato, Rodrigez-Iturbe 2004). "Ecohydrology bridges the fields of hydrology and ecology and proposes new unifying principles derived from the concept of natural selection. It also has potential application in determining the response of vegetation to slow variation in climate" (Eagleson 2002).

The theory of Ecohydrology is based upon the assumption that sustainable water resources management can be achieved by:

- restoring and maintaining the evolutionarily-established processes of water and nutrient circulation and energy flows at a catchments scale;
- enhancing the carrying capacity (robustness) of ecosystems against human impact;
- using ecosystem properties as water management tools (Zalewski 2006b).

In this respect, Ecohydrology represents an integrative low cost high-technology new tool for achieving the Millennium Development Goals: science, implementation, and society involvement. Its main target is an integrative system approach to:

- minimize threats (mostly from various types of water pollution) to human health and biodiversity;
- maximize water availability and ecosystem services for society (Zalewski 2006b).

Ecohydrology is an interdisciplinary field studying the interactions between water and ecosystems. These interactions may take place within water bodies, such as rivers and lakes or on land, in forests, deserts and other terrestrial ecosystems. The principles of Ecohydrology are expressed in three sequential components:

1. **Hydrology:** The quantification of the hydrological cycle of a river basin, which should be a template for functional integration of hydrological and biological processes.
2. **Ecology:** Due to the urgent need to reverse environmental degradation, the integrated processes at river basin scale can be steered in such a way as to enhance the basin's carrying capacity and its ecosystem services.
3. **Ecological engineering:** The "dual regulation" of hydrological and ecological processes, based on an integrative system approach, is thus a new tool for Integrated Water Basin Management (Zalewski 2006b).

The fundamental theoretical basis is this "dual regulation" of biota by altering hydrology and regulating hydrology by shaping biota. This presupposes the integration of various regulations acting in a synergistic way to stabilize and improve the quality of water resources, and on other side the harmonization of ecohydrological measures with the necessary hydro-engineering infrastructure (Zalewski 2000; Nuttle 2002; Zalewski 2006a). Their expression as testable hypotheses (Zalewski *et al.* 1997) may be seen as:

- hydrological processes that generally regulate biota;
- biota that can be used as a tool to regulate hydrological processes;
- the integration of these two types of regulatory processes that can be integrated with hydrotechnical infrastructure to achieve sustainable water and ecosystem services.

### *2.2. Study area description*

#### *2.2.1 The Black Sea*

The Black Sea is an inland sea bounded by Europe, Anatolia and the Caucasus and is ultimately connected to the Atlantic Ocean via the Mediterranean and Aegean Seas and various straits. The Black Sea has an area of 436 400 km$^2$ (not including the

Sea of Azov), a maximum depth of 2212 m, and a volume of 547 000 km$^3$. The Black Sea is located in an east-west trending elliptical depression which lies between Bulgaria, Romania, Ukraine, Russia, Georgia, and Turkey. It is constrained by the Pontic Mountains to the south and the Caucasus Mountains to the east, and features a wide shelf to the northwest (Fig. 1). The longest east-west extent is about 1175 km (Murray *et al.* 1989; UNEP 2001; UD 2003; EU 2011).

The Black Sea has a positive water balance; that is, a net outflow of water of 300 km$^3$ per year through the Bosporus and the Dardanelles into the Aegean Sea. Mediterranean water flows into the Black Sea as part of a two-way hydrological exchange. The Black Sea outflow is cooler and less saline, and therefore floats over the warm, more saline Mediterranean inflow, leading to the creation of a significant anoxic layer well below the surface waters. The Black Sea is the world’s largest meromictic basin where the deep waters do not mix with the upper layers of water that receive oxygen from the atmosphere. As a result, over 90% of the deeper Black Sea volume is anoxic water.

The current hydro-chemical configuration is primarily controlled by basin topography and fluvial inputs, which results in a strongly stratified vertical structure and the positive water balance. The upper layers are generally cooler, less dense and less salty than the deeper waters, as they are fed by large fluvial systems. The deep waters originate from the warm, salty waters of the Mediterranean. This influx of dense water from the Mediterranean is balanced by an outflow of fresher Black Sea surface-water into the Marmara Sea, maintaining the stratification and salinity levels. The Black Sea (Fig. 1) receives freshwater from the large Eurasian fluvial systems located in the northern part of the Black Sea basin. The most significant rivers are the Don, Dnieper, Dniester and Danube (source: enviroGRIDS project 2008).

### *2.2.2 The Danube River, its delta and catchment*

The watershed of the Danube River and its delta forms the largest part of the Black Sea catchment area. The Danube River is, after the Volga River, the second largest river in Europe and, at the same time, one of the

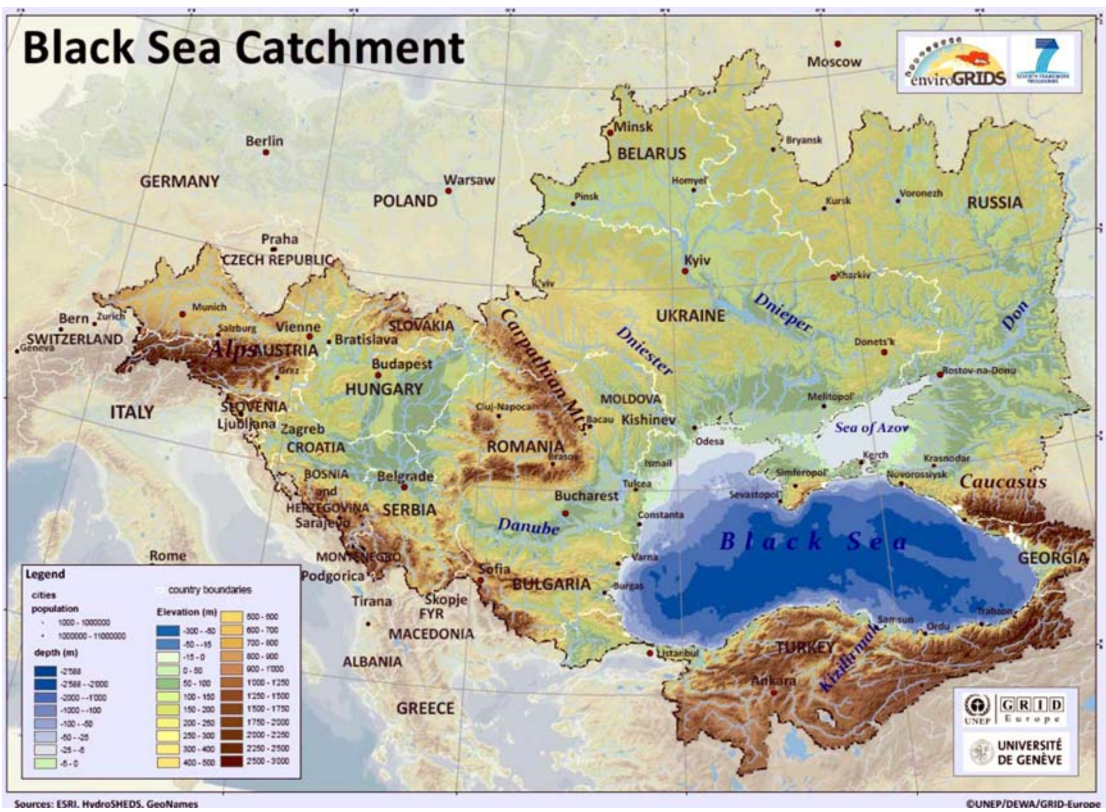


**Fig. 1.** The Black Sea receives river water from the large Eurasian fluvial systems to the north of the Sea. The most significant are the Don, Dnieper, Dniester and Danube (source: “enviroGRIDS” project 2008).

most important in the world, due to its length of 2872 km, its surface area of over 817 000 km$^2$, and its multi-annual average discharge of approximate 6300 m$^3$ s$^{-1}$ (Fig. 2). The Danube River, particularly the Danube Delta located at the interface between the Danube and the Black Sea provides habitat for a large number of species of wild flora and fauna. The area has received the status of a biosphere reserve and a natural world heritage site.

In addition, the Danube Delta is located both administratively and geographically at the nexus of two important regional environmental conventions: the Convention for Sustainable Management of the Danube River, and the Convention for the Protection of the Black Sea (Bucharest Convention). The Danube Delta, resulting from the interaction between the Danube River and the Black Sea, falls mostly under the auspices of the Danube River Convention. An interface task force (DABLAS) has been established to harmonize and correlate the objectives and targets assumed by the signatories of both conventions.

The ecological importance of the delta system, which is characterized by a large biological diversity with numerous endangered species of flora and fauna, is being exposed to increased pressure as a consequence of the economic activities that exceed the capacity of the ecosystem to sustain these activities. Nevertheless, since September 1990, the Danube Delta Biosphere Reserve has been declared a "wetland of international importance, especially as a water birds habitat", being one of the most extended areas of this kind. The EU Water Framework Directive (WFD) established a legal framework to protect and enhance the status of all waters and protected areas including water dependent terrestrial ecosystems, prevent their deterioration, and ensure their long-term sustainable use.

The WFD and other related water regulations provide a framework for development of an innovative approach to water resources management based on river basins, natural geographical and hydrological units, and ecohydrological approaches.

## *2.3. Legal and management framework*

The Danube and its tributaries, transitional waters, lakes, coastal waters and ground waters form the Danube River Basin District (DRBD). For the purposes of DRBD Management Plan (DRBM Plan), the DRBD has been defined as covering the Danube River Basin (DRB), the Black Sea coastal catchments in Romanian territory and the Black Sea coastal waters along the Romanian and part of the Ukrainian coasts. All Danube countries with territories greater than 2000 km² in the DRB are contracting parties to the Danube River Protection Convention (DRPC). The DRPC represents the legal as well as the political framework for cooperation and trans-boundary water management in the DRB.

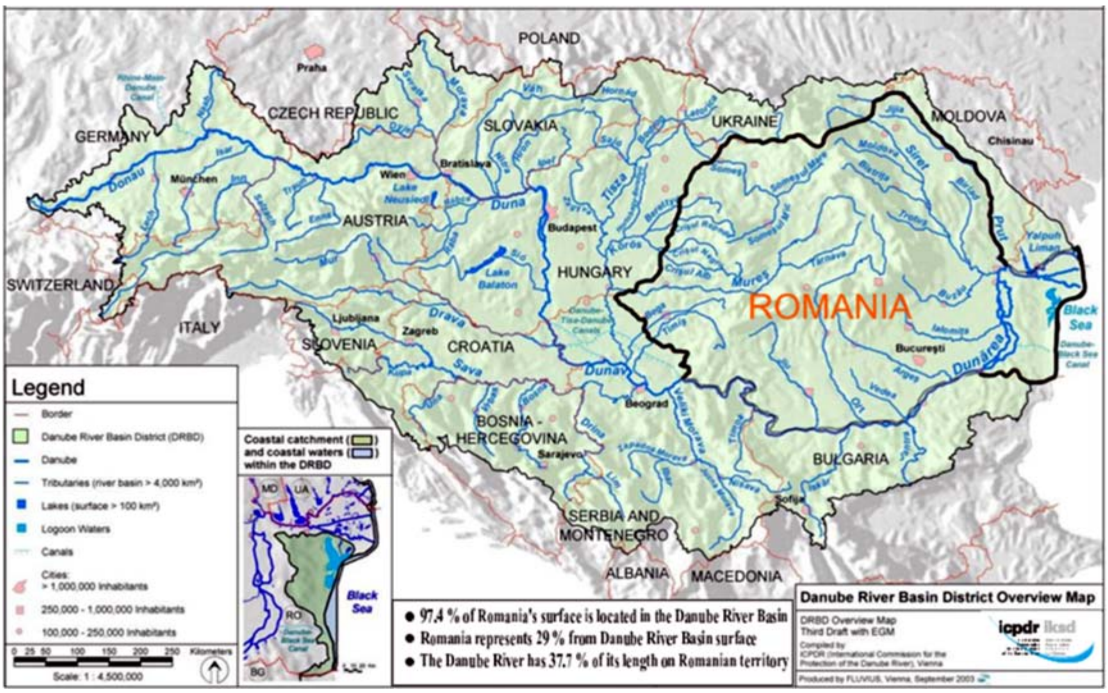


**Fig. 2.** The Danube River basin is located in 18 countries, and its delta is situated in Romania (southern part) and Ukraine (north-eastern part) (source: ICPDR 2009).

The International Commission for the Protection of the Danube River (ICPDR) serves as the coordinating platform to compile multilateral and basin-wide issues at the “highest level” of the DRB and facilitate the formulation of the DRBM Plan (Part A) (ICPDR 2009). The DRBD is not only characterized by its size and large number of countries but also by its diverse landscapes and major socio-economic differences that exist between the upstream and downstream countries (Table I). The content of the DRBM Strategic Plan is strongly based on findings and actions documented at the national/sub-basin level. So far, the Danube countries have agreed to develop sub-basin management plans for the Danube Delta, and the Tisza, the Sava and the Prut basins, which are to be elaborated at a higher resolution than that used at the regional strategic level. In addition to the DRPC, many bilateral/multilateral agreements between individual and/or subgroupings of countries are in place and enable trans-boundary cooperation below the regional level.

The key conclusions of the DRBM Plan focus on aspects of water management and the implementation of the WFD at the basin-wide scale. They have in view measures and aspects like: status assessment; organic pollution control; nutrient pollution management; hazardous substances pollution abatement; mitigation of hydro-morphological alterations including river and habitat continuity interruptions; reconnection of adjacent floodplains/wetlands; restoration of hydrological alterations; implementation of future infrastructure projects; groundwater quality and quantity management; flood risk and climate change management and formulation of responses to climate change and its potential effects within the DRBM Plan/Joint Program of Measures and public information and consultation. Complementary information on the considerable and important work taking place at the national level can be obtained from the national river basin management plans.

## 3.Results

### *3.1. Ecohydrological principles and some of their applications to the Danube River*

We can find some or all of the three ecohydrological principles of hydrology, ecology, and ecological engineering, applied in the recent studies and research performed on the Danube River, Danube Delta and Black Sea coastal area. The recent DRBM Plan, taking into account the quantity, quality and biota of the river basin, is based on such an integrative approach. Likewise, the interaction of the hydroengineering constructions, the liquid and solid substance transport, and the water quality and ecosystem responses reflect an ecohydrological approach.

**Table I.** Basic characteristics of the Danube River Basin District (ICPDR 2009).

| | |
|---|---|
| DRBD area | 807 827 $km^2$ |
| DRB area | 801 463 $km^2$ |
| Danube countries with catchment areas > 2000 $km^2$ | EU Member States (8): Austria, Bulgaria, Czech Republic, Germany, Hungary, Slovak Republic, Slovenia, Romania.<br><br>EU Accession Country (1): Croatia.<br><br>Non EU Member States (5): Bosnia & Herzegovina, Moldova, Montenegro, Serbia and Ukraine. |
| Danube countries with catchment areas < 2000 $km^2$ | EU Member States (2): Italy, Poland.<br><br>Non EU Member States (3): Albania, FYR Macedonia, Switzerland. |
| Inhabitants | approx. 80.5 million. |
| Length of Danube River | 2857 km |
| Average discharge | approx. 6500 $m^3 s^{-1}$ (at the Danube mouth). |
| Key tributaries with catchment areas > 4000 $km^2$ | Lech, Naab, Isar, Inn, Traun, Enns, March/Morava, Svratka, Thaya/Dyje, Raab/Rába, Vah, Hron, Ipel/Ipoly, Siò, Drau/Drava, Tysa/Tisza/Tisa, Sava, Timis/Tamiš, Velika Morava, Timok, Jiu, Iskar, Olt, Yantra, Arges, Ialomita, Siret, Prut. |
| Important lakes > 100 $km^2$ | Neusiedler See/Fertö-tó, Lake Balaton, Ozero Ialpug, Razim-Sinoe Lake System (Lacul Razim and Lacul Sinoe, which is also a transitional water body). |
| Important groundwater bodies | 11 trans-boundary groundwater bodies of basin-wide importance are identified in the DRBD. |
| Important water uses and services | Water abstraction (industry, irrigation, household supply), drinking water supply, wastewater discharge (municipalities, industry), hydropower generation, navigation, dredging and gravel exploitation, recreation, various ecosystem services. |

### *3.1.1. Refined Danube Delta monograph embodying Ecohydrology*

This approach is embodied in the update of the classical hydrological elements contained in the Danube Delta monograph of 1963 (Stanciu, Jelev 2005). The new monograph that has been prepared includes water flows through the Danube and its tributaries, taking into consideration morphological and pollutant dispersion elements.

An overall two dimensional hydrologic-hydraulic mathematical model of the Danube Delta, based on the Navier-Stokes equations includes the use of topographic-bathymetric profiles of representative channels, topographic mapping with a minimum density of 5 points per km$^2$ across the main waterbeds of the Danube, updated rating curves developed from measurements at all hydrological stations in the Danube Delta, and synthetic flash flood analyses with different recurrence interval probabilities that account for existing hydro-engineering works etc. In the current context, using the calibrated model, different scenarios based upon the optimal works required for maintenance of current ecological conditions in accordance with the main objectives of the Danube Delta Biosphere Reserve management plan can be identified. In addition, future scenarios can be evaluated prior to construction, including works such as the Chilia branch correction for maritime navigation, some eco-tourism developments (Caraorman, Roşu-Puiu, Sulina, Sf. Gheorghe) and specific pollutant dynamics and watershed morphology changes etc.

### *3.1.2. Wetland restoration*

Beginning in 1990, the Danube Delta Biosphere Reserve Administration initiated a large ecological reconstruction project to improve the situation in the Danube Delta area. The project includes wetland restoration and rehabilitation of the hydrological regime. The main objective was to restore existing habitats and ecosystems, thus saving endangered species and improving the ecological situation in degraded areas. First to have undergone ecological restoration were the Babina area (2100 ha) and Cernovca (1580 ha) in the northern part of the delta (Schneider *et. al* 2008; Schneider-Binder 2011). Work began in 1994 and two years later positive results were achieved. The project was highly regarded by international specialists, receiving the Eurosite Award from the European Commission and the Conservation Merit Award from the World Wildlife Fund (WWF). Next, the restoration of the Popina area (3600 ha) was started in 2000, after three years of monitoring and preparatory studies. The ecological reconstruction of the Fortuna rearrangement (2115 ha) was completed in November 2004. Currently in progress is an important project, addressing the old fisheries infrastructure in the Holbina-Dunavăţ area (5630 ha) (Schneider-Binder 2011).

From the ecohydrological point of view, in all of these reconstruction activities, the first and second principles of Ecohydrology (hydrology and ecology) can be recognised. The first step in promoting such projects was a large data collection activity required to quantify the hydrological cycle in the areas, and create a template for understanding the functional integration of hydrological and biological processes. Based on an integrated approach, the carrying capacity of the basin and its ecosystem services were determined and enhanced through application of the "dual regulation" principle of altering hydrology and regulation of hydrology by shaping the biota. Based on the recently implemented monitoring processes developed by the Danube Delta authority, important water quality improvements and better flood protection in the area also have been achieved, concurrently with biodiversity improvements, due to hydrological alterations. At the same time altered economic activities that are more compatible with the Delta's carrying capacity have contributed to this improvement (Stanciu, Jelev 2005).

### *3.1.3. Navigational improvements*

In a recent Environmental Impact Assessment study on the Danube-Black Sea Chilia Branch Navigation Route performed by the Ukrainian Scientific Research Institute of Ecological Problems (USRIEP 2008), the principles of Ecohydrology were utilized in the analyses and optimisation of hydrology and ecology cycles in interaction with hydraulic engineering works (Fig. 3-9). For over 90% of its length, the navigation route within the Ukrainian part of the Danube Delta runs along the Chilia branch, where depths and widths are sufficient to meet the requirements for an international waterway of the highest category, although dredging will be required in the shallow sections. For the Reni-Vylkove section, the total volume of material anticipated to be dredged is 5 785 000 m$^3$ (1 727 000 m$^3$ during Phase 1 and 800 000 m$^3$ per year on the average during remainder of the dredging operation). The estimated area of physical disturbance caused to the river bottom by dredging activities would be about 2 336 000 m$^2$ during construction and 1 020 000 m$^2$ during the on-going operations; i.e., 2.9% and 1.3% of the total area of river bottom, respectively. The most sensitive area is the final part of the route, affecting the so-called Bâstroe branch. The most important environmental aspect was to diminish the impacts, including the trans-boundary ones, of the planned interventions.

The project developed several modelling tools that were employed at the north-eastern part of the Danube Delta (Ukrainian part) (Fig. 3). These models include:

- A one-dimensional numerical hydraulic model based on the complete Saint-Venant equation used to evaluate flow distributions in the Danube Delta's river network (USRIEP 2008).
- A tested 2-dimensional hydrodynamic model adapted for the hydrodynamics calculations for the Ukrainian part of the Danube Delta downstream of Bâstroe branch, including the completed dam (Fig. 4). The modelled particle distribution pattern under the continuous dumping of excavated sand scenario is presented in Fig. 5.
- A 2 and 3-dimensional Lagrangian model used to simulate transport of non-cohesive and cohesive sediments using a mixture of fractions of different sizes (Fig. 5).
- A model to generate stationary surface and average velocity fields in the dumping area of the river mouth. The estimated average velocity is about 0.2 $ms^{-1}$ with a surface current of 0.3 $ms^{-1}$ (Fig. 6).
- A tool to simulate changes in bottom topography based on employed models (Fig. 7).
- A bathymetry simulation and flow velocity model for the river mouth. Figure 8 shows the bathymetric estimates for various options and sections of the

**Fig. 3.** The part of Romanian and Ukrainian Danube River Delta near Vylkove and C.A. Rosetti modelled within the USRIEP project. Arrows indicates Bâstroe, Chilia, and Starostambulske branches of the delta river network with computational sections and hydrological stations.

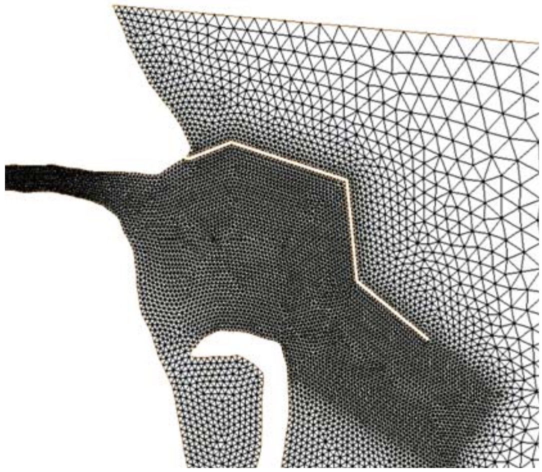

**Fig. 4.** The Bâstroe branch mouth of the Ukrainian part of Danube Delta modelled with grid data model in a scenario of completed dam. Grid represents computational nodes (USRIEP 2008).

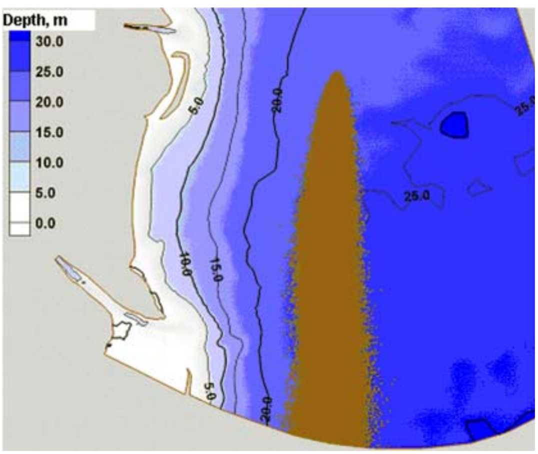


**Fig. 5.** The modelled Particle Distribution Pattern under the Continuous Dumping Scenario of excavated sand with the bathymetric map in the dumpsite (USRIEP 2008).

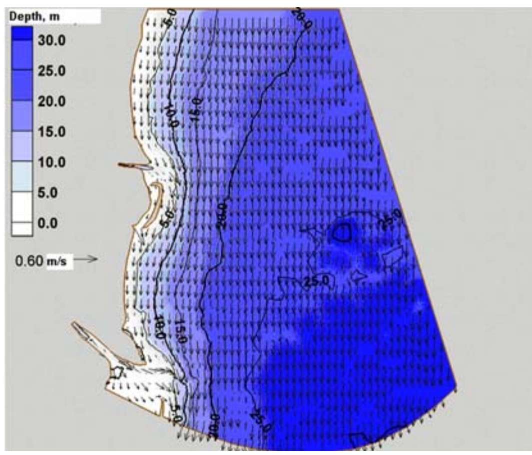


**Fig. 6.** The surface velocity field. The arrows show velocity direction and strength in the dumpsite (USRIEP 2008).

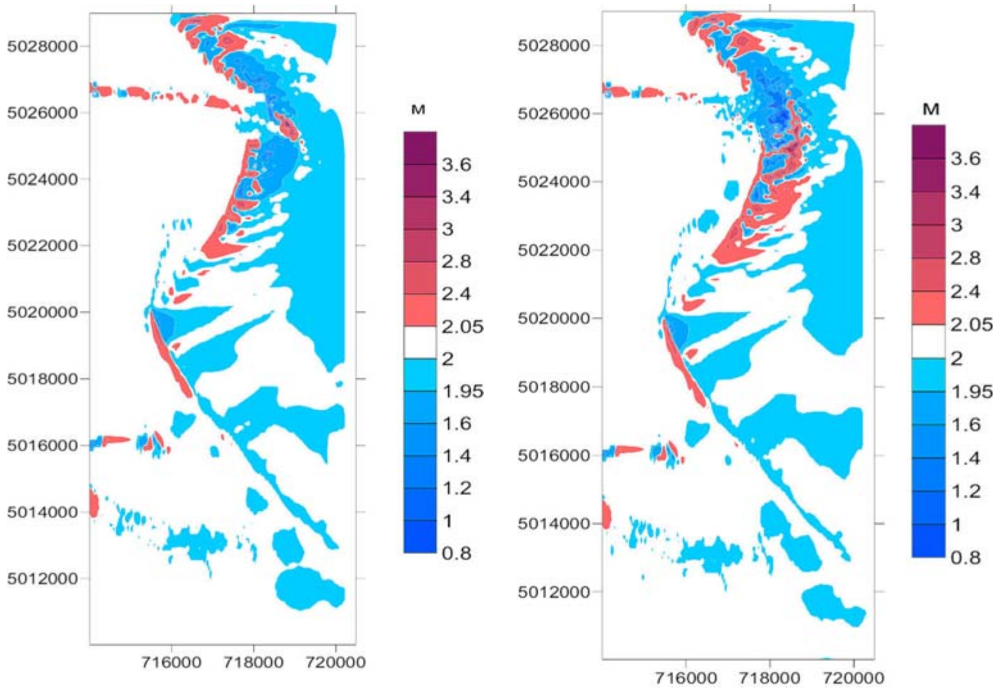


**Fig. 7.** Changes in bottom topography in the dumpsite of excavated sand (USRIEP 2008).

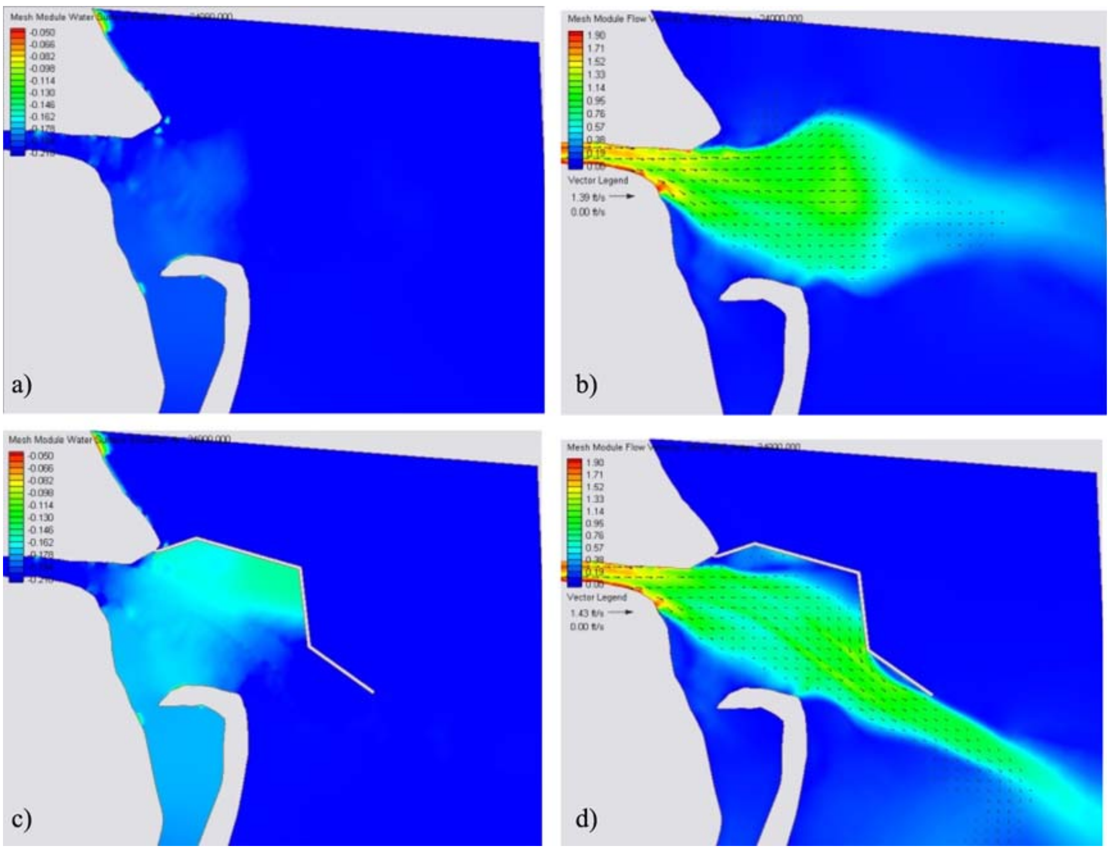


**Fig. 8.** Water levels (upper figures) and flow velocities (bottom figures) modelled at the Bâstroe branch mouth, with and without dam construction (USRIEP 2008).

navigation route before and after the construction of the retaining dam.

Comparisons of changes in water levels along the Starostambulske branch under various flow conditions were analyzed. The result for a flow rate of 7000 $m^3 s^{-1}$ near Chilia is presented in Fig. 9.

For quantifying the hydrological changes in the water regime and the impact of the navigation canal on the biodiversity of the Danube Delta biota, hydrological, ecological and ecological engineering aspects had to be taken into account. The results of hydrological change analysis were used as inputs in the ecological models used for assessing the impacts of these changes on the biodiversity. The integration of the various regulations, acting in a synergistic way to stabilize and minimise the impact on the quality of water resources, and the harmonization of ecological measures using the necessary hydro-engineering infrastructure, can be considered an ecohydrological approach.

### 3.1.4. Flood prevention

In relation to the high water levels in the Danube, another example of the application possibilities of Ecohydrology in relation to the latest floods is the case of the Danube River Rearrangements Plan (Mihailovici *et al.* 2006; Stanciu *et al.* 2009). The April-May 2006 Danube flood had a peak flow of 15 800 $m^3 s^{-1}$, the highest peak recorded between 1840 and 2006. It was necessary to open the dikes at two points, Călăraşi–Răul and Făcăieni–Vlădeni, in order to mitigate further damages and peak flow head cutting. The goal of this controlled flooding was to protect the cities of Călăraşi, Brăila and Galaţi, from which more than 15 000 people were evacuated.

Climate change, but also the hydraulic works constructed in the Danube basin (especially dikes), increased maximum discharges at Baziaş (Fig. 10, 11). The size of impact of climate change is not exactly known with respect to these hydrological alterations. In the last decade, the river and floodplain network was interrupted throughout the largest part of the Romanian Danube reach by embanked enclosures and specific flora and fauna have suffered (Fig. 12). Based on the studies, the rearrangement alternatives for this reach of the Danube River will take into consideration the following:

- important localities which must to be protected during the major floods,
- wetland restoration for biodiversity conservation, sustainable development and peak flow mitigation, as proposed by the National Institute of Research and Development, "Danube Delta" and the World Wildlife Fund,
- controlled flooding areas and those areas where the Danube has broken the dikes (non-controlled flooding areas),
- construction of a chain of polders in already flooded enclosures having the greatest differences between upstream and downstream water levels within the enclosures (differences of 2-2.5 m),
- number of people and value of goods protected by structural flood protection works including reservoirs, polders, dikes and water diversions.

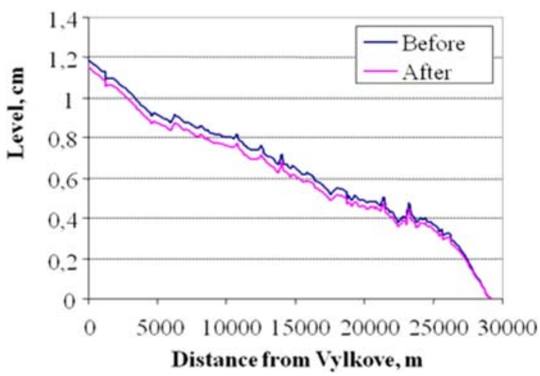


**Fig. 9.** Water plane levels along the Starostambulske branch, downstream of Vylkove, before and after the dam construction. Flow rate 7000 $m^3 s^{-1}$ near Chilia (USRIEP 2008).

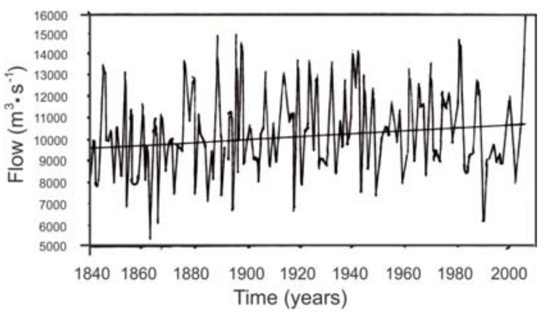


**Fig. 10.** Trend of increasing maximum discharges of the Danube at Baziaş, partially due to the climate change (Mihailovici *et al.* 2006).

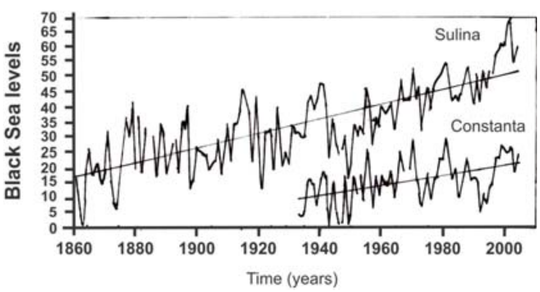


**Fig. 11.** Trend of increasing Sea level at Sulina and Constanţa, partially due to the climate change (Mihailovici *et al.* 2006).

Polders should be constructed (Fig. 13):

- upstream of the Jiu and Olt confluence with the Danube River, reducing the upstream peak flow and mitigating the pressure on the dikes in the whole downstream area;
- next to important infrastructure to be defended with a view to maximizing the effects of these pools in the downstream area;
- as a chain of polders: at Rast-Bistreţu-Nedeia, Dăbuleni-Potelu-Corabia, and Spanţov-Mănăstirea, or, as an alternative, at Borcea de Sus, augmented by construction of longitudinal dikes on the right side of the Danube between Brăila and Galaţi and placement of a dike on the channel from the first variant (Fig. 13);
- as circular dikes around human settlements or by removing settlements depending on the social and economic consequences of these actions.

### *3.1.5. Habitat improvements*

A good correlation between the diminished Cyprinidae fish population and increased impounded area can be observed in figure 12. This is mainly due to the reduction of spawning grounds. On the other hand it is possible to highlight other possible causes of diminished fish populations, including increased pollution of the Danube River and excessive fish capture. Figure 13 offers a synthesis of the present status of the former Danube River wetland area, where more than 400 000 ha have been impounded historically. After the 2006 floods on the Danube River, some of the dikes surrounding these areas were naturally or artificially destroyed in order to diminish the consequences of the floods on humans and property. Some of these areas can be proposed for future ecological reconstruction, and include converted wetlands (Fig. 13).

As in the case of the Danube Delta environmental reconstruction projects, in the above mentioned Danube River Rearrangement Plans, principles of Ecohydrology can be recognised. First of all, such plans are based on the quantification of the hydrological cycle in the river basin, including extreme flows. Secondly, such plans will contribute to the enhancement of the carrying capacity of the basin and its ecosystem services. Finally, the new polders will contribute to the "dual regulation" of hydrological and ecological processes by reducing flood impacts on one side and improving aquatic biota and water quality on the other side.

In the next section, a recent FP 7 project "EnviroGRIDS" will be summarised. It is a large scale project, focused on the larger Black Sea catchment area.

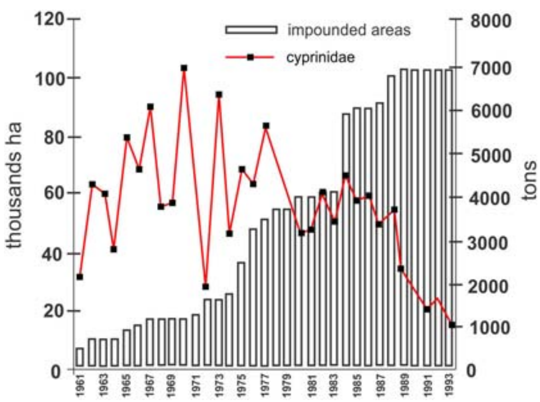


**Fig. 12.** Correlation between diminished Cyprinidae yield (tons) and the area of impoundments (thousands ha) (Stanciu *et al.* 2009).

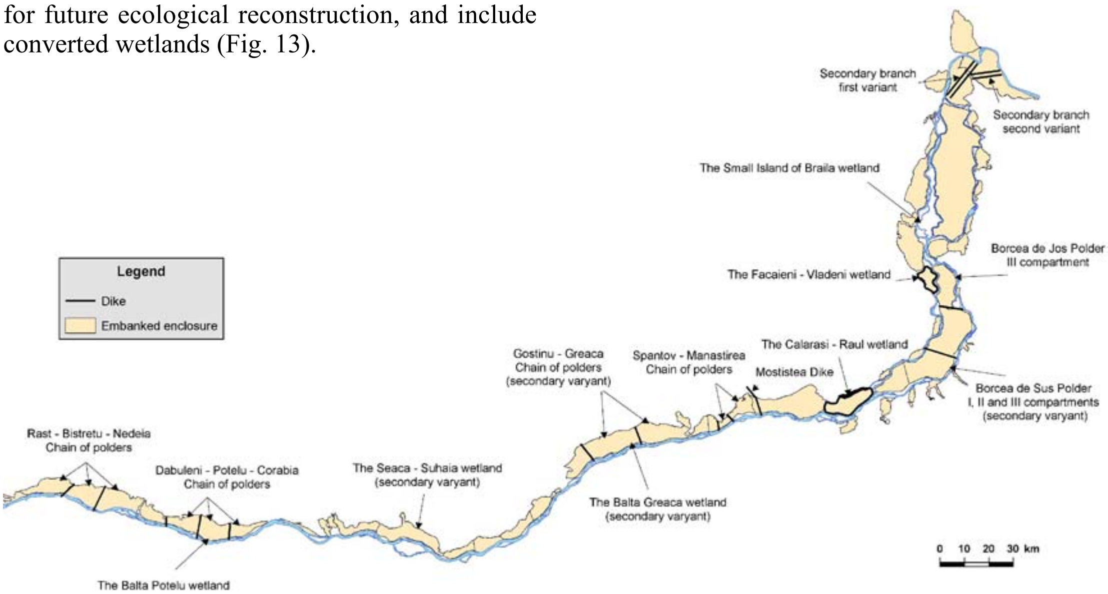


**Fig. 13.** The recommended placement of polders along the present impounded Danube River (Mihailovici *et al.* 2006).

### *3.2. “EnviroGRIDS”, an EU 7 Framework Research Project*

The “EnviroGRIDS” Black Sea Basin is a capacity building project to create the Black Sea Catchment Observation and Assessment System supporting sustainable development (Lehman, Ray 2008) which addresses the existing, non-sustainable manner of natural resources exploitation, by introducing several emerging information technologies used to observe our planet. The project aims to build the capacities of regional stakeholders to use new international systems to gather, store, distribute, analyse, visualize and disseminate crucial information on the past, present and future states of the environment, in order to assess its sustainability and vulnerability. “EnviroGRIDS” aims at building the capacity of scientists in order to utilise such a system in the Black Sea catchment, and at building the capacity of decision-makers to use it, and the capacity of the general public to understand the important environmental, social and economic issues at stake. To achieve its objectives, “EnviroGRIDS” will build Grid-enabled Spatial Data Infrastructure (GSDI) that will become one component in the GEOSS, compatible with the new EU directive on Infrastructure for Spatial Information in the European Union (INSPIRE). “EnviroGRIDS” will particularly target the needs of the Black Sea Commission (BSC) and the International Commission for the Protection of the Danube River (ICPDR) in order to help to bridge the gap between science and policy.

The main objective of “EnviroGRIDS” lies in developing the capacity of scientists to use such an extensive database, models and associated scenarios to explore the past, present and future, with application to the Black Sea area. The project involves 47 institutes from 15 countries. The general technical objectives of the “EnviroGRIDS” project are to:

- run a gap analysis of existing regional observation systems to prepare recommendations for the improvement of networks of data acquisition in each region/country;
- build capacity on observation systems in the Black Sea catchment;
- improve regional networks to coordinate the efforts of partners having active observation systems;
- link, gather, store, manage and distribute key environmental data;
- develop access to real time data from sensors and satellites;
- create spatially explicit scenarios of key changes in land cover, climate and demography;
- distribute large calculation efforts and datasets amongst large computer clusters;
- streamline the production of indicators on sustainability and vulnerability of societal benefits;
- provide a standard for integrating data, models and information and communication tools;
- provide policy-makers and citizens with early warning and decision support tools at the regional, national and local levels;
- produce innovative tools to visualize and interpret data and the results of integrated models;
- alert citizens concerning exposure to environmental risks;
- build capacities in the implementation of future standards and framework agreements (INSPIRE, GEOSS, OGC etc.).

Two of the seven Work Packages (WP) are especially of interest, namely WP4 “Catchment Hydrological Models” and WP 6, the “Black Sea Catchment Observation Systems”. WP 4 based on the “Model G-Water Balance Assessment” studies different possible hydrological processes that might occur as a result of political decisions to develop the area. The model was calibrated and validated using data on water flows, water quality, and land use including crops types. Based on the land use change analysis, agricultural practices, and climate change predictions, the model prepares forecasts of watershed developments based on various scenarios. The hydrological model Soil Water Assessment Tool (SWAT), operates on the same daily time step used for predicting water, sediment, and chemical yields in a specific watershed (Arnold *et al.* 1998). The input data are: weather conditions, soil properties, topography, vegetation, and land management practices of the watershed (Fig. 14). SWAT estimates the impact of land management practices on water quantity and quality in complex watersheds. The SWAT model must pass a careful calibration and its output is subjected to uncertainty analysis. The model also needs information about reservoirs in the catchment (Fig. 15, 16) (Paşoi *et al.* 2004; Stanciu *et al.* 2009). SWAT, a high-resolution water balance model, was applied to the entire Black Sea Catchment, including the Danube River.

There are two aspects addressed by the project related to reservoirs that reflect the principles of ecohydrology: necessity to create a large data base, and need for improvement of operation practice of these reservoirs in order to ensure good ecological status downstream of the dams. These aspects are consistent with the first principle of Ecohydrology (quantification of processes) and the third principle (regulation of biota by altering hydrology). In this respect the project will help to implement an ecohydrological approach in order to solve the hydrological and ecological problems created by these reservoirs. The variation and frequency of downstream flows can then be managed to ensure a good ecological status of the water ways downstream.

WP 6 includes the analysis of two case studies, one of which refers to the Danube River between the Black Sea and the town of Isaccea, and the other one to the Someş River in the north-western part of Romania. The latter is executed with the participation of the Romanian National Institute of Hydrology and Water Management (NIHWM) and Someş River Water Basin Authority. These case studies are coordinated by the UNESCO-IHE Institute for Water Education Delft, in the Netherlands. Overall this WP will be developed as a complex software interface that connects users (local authorities, Danube Commission, Black Sea Commission, the scientific community etc.) with GEOSS system, networking with the basic GRID supercomputer at CERN in Geneva, Switzerland. The main focus of this task is to develop adaptive components for custom-based content delivery to various actors and concerned citizens involved in Integrated River Basin Management (IRBM).

The work implies the proper description of the decision making context in a given river basin so that the main actors and their inter-relationships can be considered, together with the description of the physical system and the problems at hand. Translating these descriptions into useful information for citizens is the main thrust of this task. It will be developed for two main purposes:

- involvement of citizens in the long term river basin planning process, and

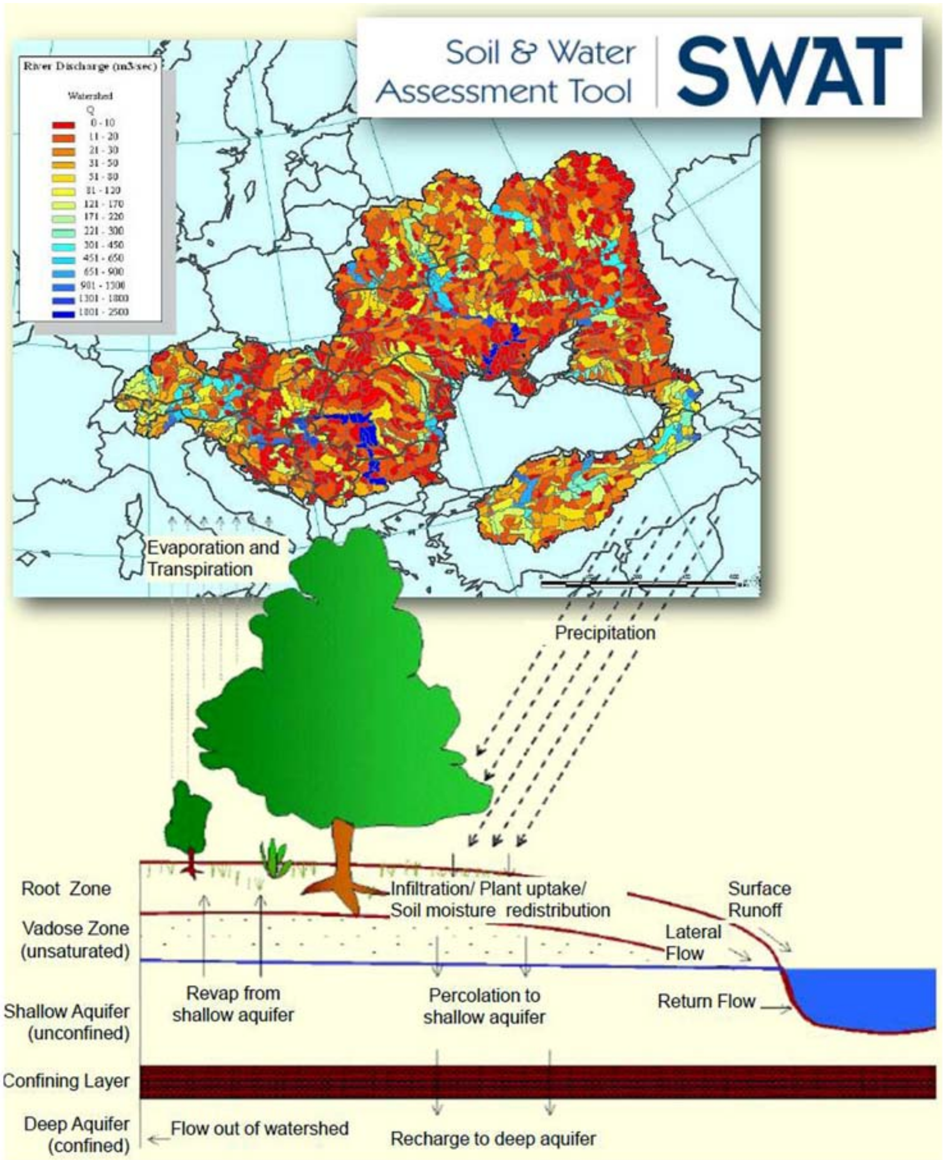


**Fig. 14.** The input data for the SWAT Hydrological Models: weather, soil properties, topography, vegetation, and land management practices of the watershed (Gorgan 2011).

- near real time dissemination of environmental data and information.

In this particular case, all the three main principles of Ecohydrology can be found in developing solutions to the above mentioned problems. This implies the integration of various regulations acting in a synergistic way to improve the carrying capacity of the river and its associated ecosystem services. The restoration of some lateral connectivity of the river will stabilize and improve the quality of water resources, while the harmonization of ecohydrological measures with the necessary hydro-engineering infrastructure will address water quantity concerns (Zalewski 2006a).

A conclusion can be drawn from the entire “EnviroGRIDS” project in which basic principle of Ecohydrology can be found: analysing at the same time hydrological aspects, vegetation and land use as well as the hydraulic engineering structures that impact the Danube catchment area. The influence of hydrology on the water biota must be taken into account to support a real ecohydrological approach.

## Discussion

The Black Sea is recognized as an area that faces many economic, environmental and social problems and often the natural resources of the area are not being used in a sustainable manner (Stanners, Boudreau 1995). At the same time, as climatic change becomes a worldwide concern that will affect many areas of human activities, the last report of the Intergovernmental Panel on Climate Change (IPCC 2007) predicts important changes in the coming decades that will not only modify climate patterns in terms of temperature and rainfall, but will also drastically change freshwater resources qualitatively and quantitatively, leading to more floods or droughts in different regions, reducing drinking water quality, and increasing the risk of waterborne diseases and/or irrigation problems. These changes may trigger socioeconomic crises across the globe that need to be addressed well in advance of the events in order to reduce the associated societal risks.

The European Community is addressing the crucial problem of water quality and quantity by adopting the Water Framework Directive that promotes water management based on watersheds rather than on administrative or political boundaries. The aim is to build river catchment management plans that define objectives based on ecological, hydrological and chemical values, as well as on a designated protected areas status regulatory strategy. River catchment analysis will integrate the analysis of the economic value of water use for stakeholders with the physical presence and characteristics of the river in order to understand the cost-effectiveness of alternative policy and technical measures. However, despite efforts to date, the vulnerability of different areas of Europe and beyond to the climate change remains poorly addressed.

The core environmental problem of the Danube River and Black Sea catchment area can be described as “ecological unsustainable development and inad-

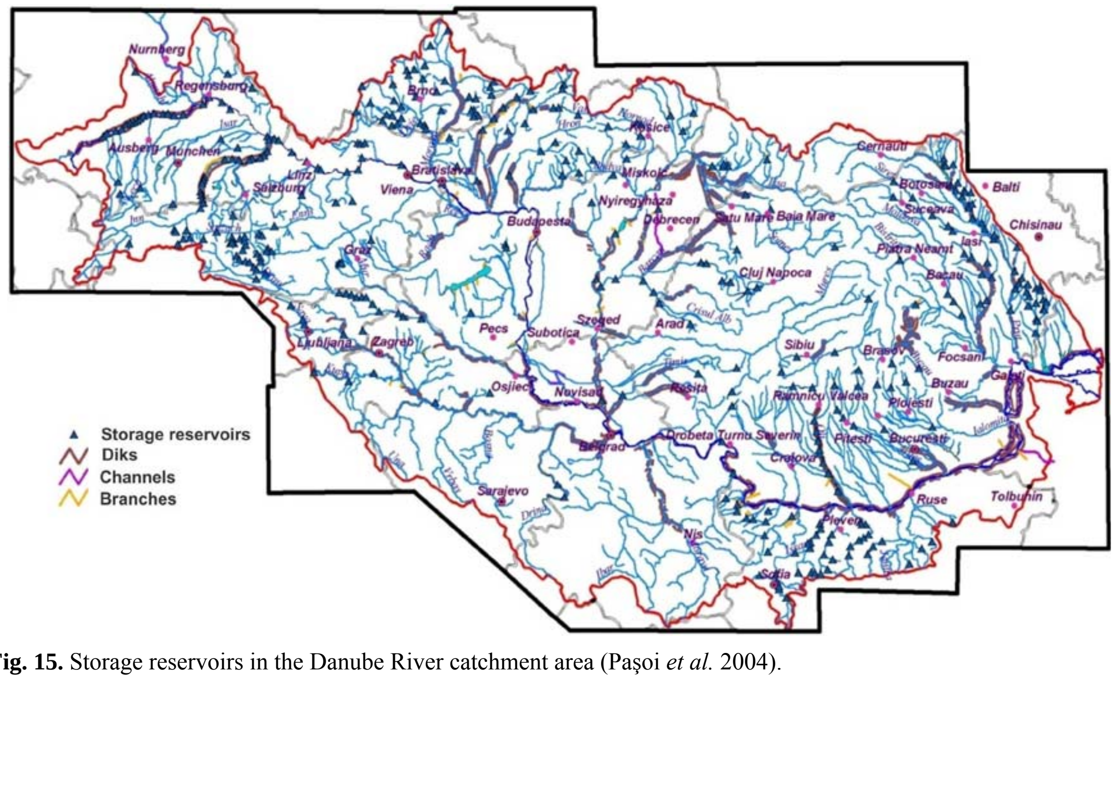


**Fig. 15.** Storage reservoirs in the Danube River catchment area (Paşoi *et al.* 2004).

equate water resources management" (PCU 1999). The problems are caused by different factors such as: inadequate management of wastewater/solid waste, ecologically unsustainable industrial activities, and inadequate land management and improper agricultural practices. They generate several direct consequences: pollution of surface/ground waters, eutrophication, and accelerated runoff/erosion. These consequences have, on the other hand, the following main effects: decline in environmental quality, increase in human health risks, degradation of biodiversity, economic decline, and reduced availability of water. Some signs of recovery have been observed in recent years, but eutrophication remains a severe problem.

In this analysis we can find solutions to the above mentioned aspects using the principles of Ecohydrology. In the research presented above the accent is put on these principles, however in the "enviroGRIDS" project, the main objective is the respect for the principles of sustainable development. In any case there are no contradiction between the principles of sustainable development and those of Ecohydrology. The three main pillars of sustainable development (environment, economy and social development) indirectly oblige countries to take into account the principles of Ecohydrology. "EnviroGRIDS" therefore provides an exceptional opportunity to demonstrate how major driving forces of change (in particular climatic change) can be analysed in a fully integrated way, using relevant integrated tools, to produce added value for citizens and decision makers at various territorial levels. The United Nations has followed a similar pathway and launched the UN Water Program 2 aimed at bringing a greater focus to water related issues at all levels and in the implementation of water related programs necessary to achieve the water related targets of Agenda 21, the Millennium Development Goals (MDGs) and the Johannesburg Plan of Implementation (JPOI).

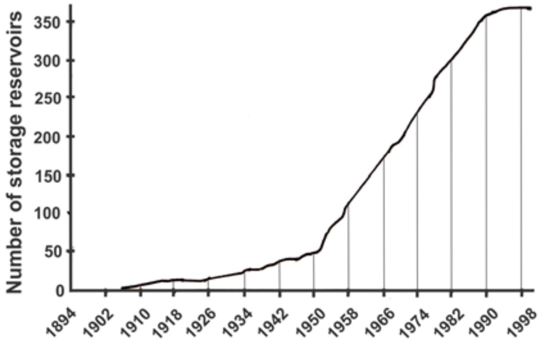


**Fig. 16.** Evolution of storage reservoirs in the Danube catchment area (Paşoi *et al.* 2004).

Environmental impact assessment research, like that completed by USRIEP (2008), clearly applied the principles of Ecohydrology: how the biota influence hydrology, how hydrology influences the biota and how we can better realize hydraulic engineering works to reduce their impacts on the biota, hydrology, stream morphology and water quality. In all the analysed research, aspects like climate change, sediment transport, water quality, and flood protection are the main concerns.

Particularly for the Danube and Black Sea area the tendency toward increased extreme flows, sea level rise, diminished sediment transport, loss of beach area, and an inland movement of the Black Sea shore line are put into evidence. The main causes are: the increased numbers of hydraulic structures throughout the Danube catchment area having consequences for diminished sediment transport (the main sand supplier for the creation and conservation of sea-side beaches north of Constanţa town, for example); sea side harbour constructions which act like barriers to sand transport from the Danube Delta mouth to the south; increased extreme phenomena such as the storms during recent years (due to climate change); and, specific very small ground movements in the area etc.

The Danube River and Danube Delta reconstruction of former wetlands is however a controversial issue. At present, these areas are separated from the river by dikes and are used mainly for agricultural purposes. The Water Framework Directive, properly reflected in the Danube River Management Plan, obliges countries to ensure the longitudinal and lateral connectivity of river waters, thus implying wetland reconstruction (ICPDR 2009). The main arguments of the opponents are related to the high agricultural productivity of the present-day irrigated soils, the former large investments in hydraulic engineering structures, including dikes, and the concern over introduction of nutrients into the polders, as the water of the Danube penetrates along, and having high concentration of nutrients in comparison with the situation existing before its embanking. This situation would lead to an emphasised algal bloom inside of these polders. At the same time the supporters of reconstruction argue that the other functions like fish farming, improved flood protection, moderation of extreme events and/or the nutrient control functions of the wetlands can be in the favour of wetland reconstruction.

Ecohydrology can offer the solutions in such debates, including those over the important economical mechanism of the Water Directive and the full water services cost recovery. The achievement of a good chemical and biological status of water is carried out by expensive structural measures. Ecohydrology represents less expensive solutions by the identification of some ways to operate for the existing hydro-engineering structures harmonized with the requirements of the aquatic ecosystem. These integrated action may result with a more reduced price of water. The research carried out for the Danube rearrangement plans using these principles, based on careful scientific analysis of each area along the Danube, and taking into account the soil productivity, fishery activities, reforestation, flood protection, water quality, ecological reconstruction potential and impact on the biota, can generate the proper answer to such debates. These efforts will also help to identify and provide early warning to vulnerable populations and identify the efforts needed to adapt and limit negative social, economic and environmental impacts in the future.

### *Conclusions*

Ecohydrological principles can be used successfully in certain applications for shaping better management of large scale watersheds, building at the same time the capacity of scientists to assemble the data, information and legislative instruments essential to such a system (for example in the Black Sea Catchment Area), the capacity of decisionmakers to use it, and the capacity of the general public to understand the important environmental, social and economic issues at stake.

In the research presented the following actions are consistent with ecohydrological approach:

- the monographic works of catchments support quantification of ecological and hydrological processes if they include hydrological, ecological and chemical parameters of the environment;
- the first action in any environmental restoration project is data collection necessary for quantifying the hydrological cycle in the area and to understand the interactions between hydrological and biological processes; water condition regulation should be used as a management tool to improve ecological conditions and carrying capacity of the ecosystems;
- the engineering modelling tools used for river navigation projects could be used for feeding ecological models to predict impact of engineering works on the environment;
- flood prevention based on polders restitution can be beneficial for both human (reduction of risk of floods) and ecosystems (carrying capacity); lateral connectivity of the river valley can be maintained or restored (NSFRM 2006); however, multi-faceted aspects of the issue should be addressed to properly assess the costs of interventions;
- well-developed river basin management plans prepared with recognition of ecohydrological principles support sustainable development.

### *Acknowledgements*

Figure 2 was reprinted from Danube River Basin District Management Plan, document number IC/151, final version, with the permission of Philip Weller, ICPDR. Figures 1 and 14 were reprinted from the "enviroGRIDS" project (FP7-ENV-2008-1, financed by EU Commission, through Grant Agreement Nr. 226740) with the permission of Nicolas Ray, manager of the project and Prof. Dorian Gorgan. The authors wish to express their gratitude to Mr.Viorel Chendeş for the digitizing of figure 13 and to Mr. Mihai Marinescu for his support in improving the quality of the figures in the paper.

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