Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XII, 2023
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

DRAMATIC REDUCTION OF THE WATER AND SEDIMENT FLUXES IN A HUMAN MODIFIED MEANDERING ECOSYSTEM FROM THE DANUBE DELTA, ROMANIA

Florin DUȚU, Laura TIRON DUȚU, Irina CATIANIS

National Institute for Research and Development for Marine Geology and GeoEcology (GeoEcoMar), 23-25 Dimitrie Onciul Street, Romania

Corresponding author email: florin.dutu@geoecomar.ro

Abstract

The pressure control of the anthropogenic factors has consequences on the fluvial systems, generating structural changes. The hydrology, hydraulics and sediment load of the rectified meandering systems depend on the hydrologic connectivity with the main stem of the river. The former meanders can be permanently, temporarily disconnected with the main channel producing interruptions in the transfer of fresh water and thus affecting the morpho-sedimentological processes and the biodiversity. This paper aims to investigate the distribution of the water and suspended sediment fluxes between the former meanders and the artificial man-made canals along the St. George distributary and thus, the hydrological connectivity. Understanding these complex human pressures are of high importance for reaching/ maintaining the ecological status of the Danube. Herein, we made investigations along the St. George branch on many sub-systems river-channel-lake site type, formed by cutoff meanders, connective channels and lakes to observe how much the water and sediment inputs to the delta depressions is affected by the structural changes of the meander's physiography.

***Key words**: ADCP, cut-off meander, Danube Delta, hydrologic connectivity, human pressure.*

INTRODUCTION

The good functionality of a deltaic system is represented by the hydrological connectivity developed by hydrologists to better understand the importance for water quantity and quality (Pringle, 2001; Bunn & Arthington, 2002; Karim et al., 2015). The water hydrology and hydraulics and the sediment load characteristics of river-channels- floodplain lakes from deltas depend on several natural coupled with human factors; however, the main driver of these characteristics is represented by the hydrologic connectivity with the main stem of the river (Junk et al., 1989; Pringle, 2003; Bracken et al., 2013; Covino, 2017). The reduction of the sediment load is generally due to the human activities, such as landscape engineering, construction of reservoirs, hydrotechnical works, dredging (Zaharia et al., 2011; Habersack et al., 2016; Nistor et al., 2021).

Since the 16th century, people have been changing the natural course of the rivers in the Danube River Basin, mainly for flood defence, hydropower generation and navigation. More than four-fifths of the Danube is regulated for flood protection, while approximately 30% of its length is additionally impounded for hydropower generation. Over 700 dams and weirs have been built along the main tributaries of the Danube (ICPDR, 2008; 2015). Moreover, to the upstream anthropogenic changes along the Danube River are added the downstream ones localized in the delta itself (Pacioglu et al., 2022a). The decrease of the sedimentary discharge started before the construction of the Iron Gates dams, and has been accelerated after their construction (1972, 1984, respectively). Since the middle of the 19th century, the direct anthropic changes within the Danube Delta began, after the establishment of the Danube Commission in 1856. The works consists in meander bends cut-offs, construction of dikes, jetties, groins, construction of a very large network of canals, river bank stabilization, substitution of natural ecosystems into large polders (Vădineanu, 2001). Along the St. George branch six free meanders were rectified between 1984 and 1994 diminishing the length by 32 km from the previous 108 km. Such river training works caused a change in the distribution of the solid as well as the streamflow in the whole delta, enhancing fluxes through the rectified channels (Bondar & Panin, 2000; Pojar et al., 2021; Vasiliu et al., 2021;

Tiron Duţu et al., 2022). Inside the meander systems, strong modifications were developed by acceleration of the liquid and solid fluxes through the artificial canals combined with sedimentation of the former meanders, as demonstrated by Popa (1997), Duţu et al. (2022a); Tiron Duţu et al. (2022); Trifanov et al. (2022). The changes of the river bed morphology, water and sediment fluxes produce a decrease of the fresh water and sediment fluxes to the former meanders and forward, to the interdistributary depressions, affecting the hydrological connectivity (Pacioglu et al., 2022b). This leads to the lake's eutrophication by the low intake of fresh oxygenated water, and thus, to habitat changes or even their loss (Trifanov et al., 2022).

This paper aims to investigate the distribution of the water and suspended sediment fluxes between the former meanders and the artificial man-made canals along the St. George distributary and thus, the hydrological connectivity between the branch and the former meanders and interdistributary depressions. Understanding theses complex human pressures are of high importance for reaching/ maintaining the ecological status of the Danube. Herein, we made investigations along the Saint George branch on many sub-systems river-channel-lake site type, formed by cutoff meanders, connective channels, and lakes to observe how much the water and sediment inputs to the delta depressions is affected by the structural changes of the meander physiography.

Figure 1. The St. George branch with the position of the investigated cross-sections. The lines in red represent the artificial canals of the rectified meanders (Global Mapper v17)

MATERIALS AND METHODS

The hydrological data were acquired in September 2020, with a powered boat-mounted acoustic Doppler current profiler (ADCP, RiverRay 600 kHz, manufactured by Teledyne Marine). Reported water depths are expressed in local values. During the field campaign, 55 transverse ADCP profiles were completed (Figure 1), distributed in key locations such as bifurcations, junctions and apex, in order to observe the water fluxes distribution along the rectified systems. In addition to the bottom-track reference used for ADCP velocity and path measurements, the data were continuously georeferenced by a vessel-mounted DGPS. The bathymetry, water velocity, and discharge were handled by means of WinRiver II Teledyne RDI software.

Suspended sediment concentrations were measured in 55 locations in laboratory using the filtration methods. In all the selected cross-sections, water samples were taken using a 5 L horizontal Niskin-types bottle. The water samples were filtered with a Millipore filtration unit, using 4.7 cm acetate cellulose filter membranes of 0.45 µ porosity, according to STAS 6953-81.

RESULTS AND DISCUSSIONS

The upstream rectilinear sector (between P01 and P06) had relatively constant flow rates, between 1382 and 1330 $m^3.s^{-1}$, mainly due to the presence of the lateral canal Litcov, on the left bank, linking the branch with the Gorgova, Isac, and Isacel lakes. Generally, the velocities are homogenously distributed along the cross-sections (0.48 and 0.54 $m \cdot s^{-1}$) (Figure 2).

Along the first large meander (Mahmudia meander, M1) the water flow is unequally distributed between the former meander (receiving a very small part of the upstream flow, 14 $m^3 \cdot s^{-1}$, representing 1% of the upstream flow of 1330 $m^3 \cdot s^{-1}$). At the junction (P13) very low velocities are found (between 0.01 and 0.04 $m \cdot s^{-1}$ on the natural channel of the former meander and between 0.52 and 0.58 $m \cdot s^{-1}$ along the artificial canal) (Figure 3).

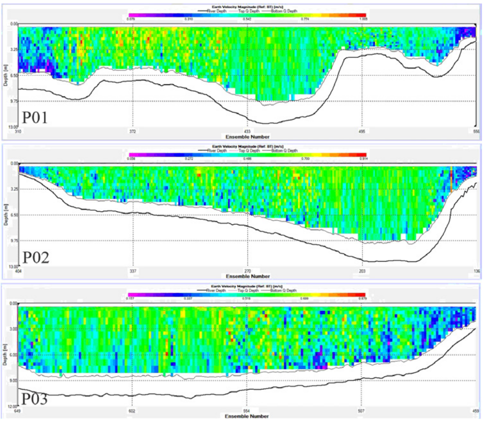

Figure 2. The velocity distribution on cross sections situated along the upstream rectilinear sector of the St. George branch

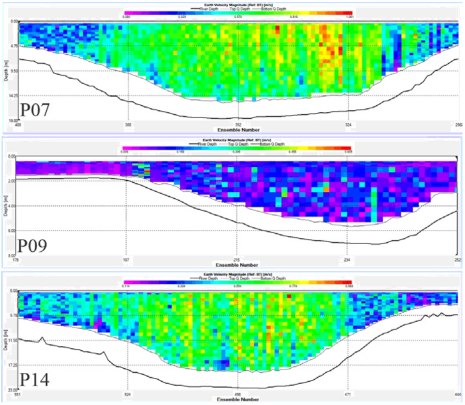

Figure 3. The velocity distribution on cross sections situated along the Mahmudia meander (M1), on the natural channel (P08 and P10) and on the artificial canal (P07 and P14)

On the Dunavăţ de Sus meander (M2), the water flow circulates mainly on the natural channel of the cutoff (1025 $m^3 \cdot s^{-1}$ i.e. 76% on the P19 profile), with mean velocities between the values of 0.31 and 0.46 $m \cdot s^{-1}$ on the natural channel and between 0.50 and 0.62 $m.s^{-1}$ on the artificial canal; the velocities are uniformly distributed on the cross section (Figure 4) except for the profile located in the apex (P20) where a more pronounced dynamic is observed in the area of the convex bank.

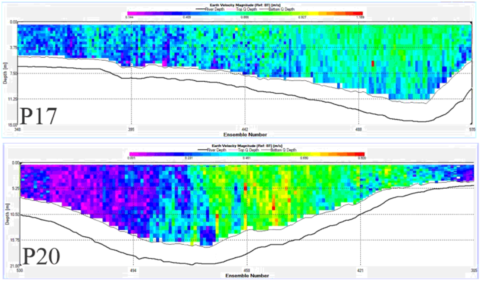

Figure 4. The velocity distribution on the cross sections situated along the Dunavăţ de Sus meander (M2)

Along the Dunavăt de Jos meander (M3), the water flow has a different/opposite distribution comparing with the previous meander, with a preponderance on the artificial canal (99%, 1294 $m^3 \cdot s^{-1}$); the natural former meander transported approximately 0.8% (11.5 $m^3 \cdot s^{-1}$) from the total upstream flow (Figure 5). The average speeds were situated between the values of 0.08-0.19 $m \cdot s^{-1}$ on the natural channel and between 0.64 and 0.66 $m \cdot s^{-1}$ on the artificial canal.

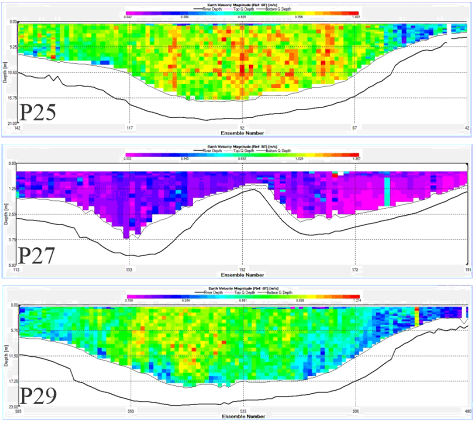

Figure 5. The velocity distribution on the cross sections situated along the Dunavăţ de Jos meander (M3)

Going downstream, on the Dranov de Sus meander (M5), the main water flow passes mainly on the artificial canal (1069 $m^3 \cdot s^{-1}$, i.e. 86% on the P33 profile) to the detriment of the natural channel with approximately 14% (204 $m^3.s^{-1}$ on the P34 profile) of total upstream flow. The average speeds ranged between the values of 0.29 - 0.35 $m \cdot s^{-1}$ on the natural channel and between 0.65 and 0.66 $m \cdot s^{-1}$ on the artificial canal (Figure 6). On the profiles situated on the artificial canal, high current speeds can be observed in the central part of the cross-sections.

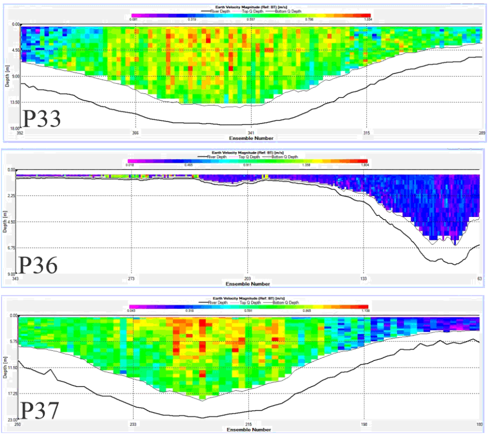

Figure 6. The velocity distribution on the cross sections situated along the Dranov de Sus meander (M5)

Along the Dranov de Jos meander (M6), the main water flow is taken by the the artificial canal (95%, 1237 $m^3.s^{-1}$) while the natural former meander transported approximately 5% (62 $m^3.s^{-1}$) of total upstream flow (Figure 7). The average speeds were very low along the natural channel of the former meander (between the values of 0.06 - 0.26 $m \cdot s^{-1}$) and higher along the artificial canal (between 0.57 and 0.61 $m \cdot s^{-1}$).

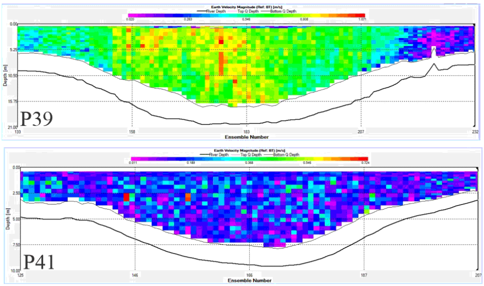

Figure 7. The velocity distribution on the cross sections situated along the Dranov de Jos meander (M6)

On the Ivancea meander (M7), situated near the distributary mouth, the distribution of water between the two channels is approximately equal (with 46% from the total upstream discharge passing through the natural channel) (Figure 8). The average speeds ranged between the values of 0.23-0.36 $m \cdot s^{-1}$ on the natural channel and between 0.49 and 0.60 $m \cdot s^{-1}$ on the artificial canal. High current velocities can be observed in the central areas of the investigates profiles.

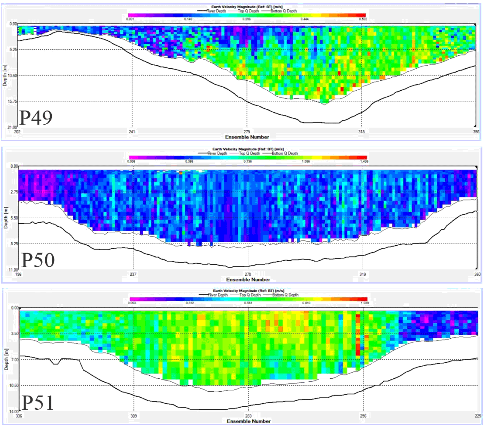

Figure 8. The velocity distribution on the cross sections situated along the Ivancea meander (M7)

Downstream, along the rectilinear sector of the branch, the discharge remained constant between 1215 and 1229 $m^3 \cdot s^{-1}$, without significant water flow losses to the Gârla Turcească canal, located on the right bank. The speeds are homogeneously distributed on the cross-sections, with the average between the values of 0.42 and 0.48 $m \cdot s^{-1}$) (Figure 9).

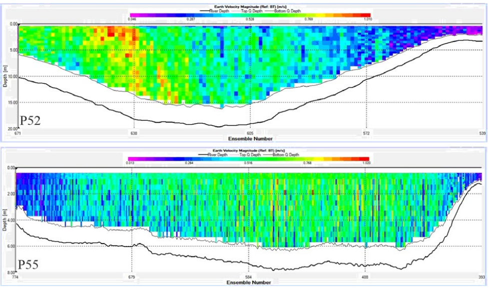

Figure 9. The velocity distribution on the cross sections situated along the downstream rectilinear sector of the St. George

Table 1 presents the evolution of the percentages of liquid flows taken over by the artificial canals after the rectification works (performed between 1984 and 1994).

The changing of water fluxes distribution between the natural channels of the former meanders and the artificial canals between 1993 and 2020 has been accelerated on M1, M3, and M6, and currently some of these canals take more than 95% of the upstream water flow.

Table 1. Long-term evolution of the percentages of liquid flows taken over by the artificial canals after the rectification works

Year	M1	M2	M3	M5	M6	M7
1993	39.3	8.3	13	21.7	14.7	14.5
1994	54	13	24	27	28	27
2006	82	15	56	-	-	-
2016	96	22	97	-	-	-
2020	99	24	99	86	95	54

The role of cut-off canals depends mainly on how much the slope of the water free surface has been increased due to the cut-off canal and, in even greater extent, on the angle between the natural course and the cut-off canal at its beginning (Tiron Duţu et al., 2022).

Previous research studies mentioned the importance of the channel bed slope ratio, the sinuosity, the bottom sediments grain size, the water surface elevation at the bifurcation areas, the diversion angle, on the flows taken over by the artificial canals after rectification works (Law & Reynolds, 1966; Hager, 1984; Duţu et al., 2022a; Duţu et al, 2022b). Along the cutoffs of the St. George branch three former meanders (Mahmudia, Dunavăţ de Jos, and Dranov de Jos meanders) are dramatically affected by the changes of the physiography and express an obvious inequality in the repartition of the liquid fluxes between the natural and artificial channels that obviously explain the infilling processes. It is a certitude that the meandering system is very sensitive to the meanders cut-off programme, by acceleration and fast response in decreasing of its water discharges and in the changes of hydro-morphological and sedimentological processes.

To better understand the impact of the human pressure along this complex meandering system, the suspended sediment discharge was calculated using a common formula based on correlating the sedimentary concentration in suspension with water velocity and section area (Carvalho et al., 2000):

$$Qs = SSC \cdot v \cdot A$$

where:

- Qs is the suspended sediment discharge ($kg \cdot s^{1}$),
- SSC is the mean concentration of suspended sediment for the considered section ($mg \cdot l^{-1}$),
- A is the area of the section (m^2),
- v is the average water velocity per cross-section ($m \cdot s^{-1}$).

The concentrations of suspended sediments (SSC) measured on the investigated sections range between 7.0 and 36.0 $mg \cdot l^{-1}$ (Figure 10).

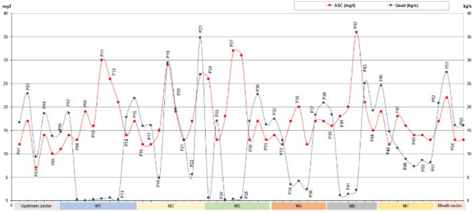

Figure 10. SSC ($mg \cdot l^{-1}$) mean values within cross-sections of the St George branch meanders (red line) and the SS fluxes (kg·s-1) (blue line)

At the bifurcation of the St. George branch, at Ceatal St. George (on profile P01) the suspended sediment discharge of the St. George distributary was of approximately 16.7 $kg \cdot s^{-1}$. Downstream, to the mouth (on profile P55) the suspended sedimentary discharge was estimated at 16.1 $kg \cdot s^{-1}$. At the scale of the entire branch the difference is not significant, but, along the former meanders, the accumulation of sediments and erosion of the riverbed occur locally as follows:

On the Mahmudia meander, from the sedimentary discharge of 14.7 $kg \cdot s^{-1}$ at the upstream bifurcation (cross-section P06), a very small part, 0.2 $kg \cdot s^{-1}$ passes through the natural course of the meander. On the cut-off channel (between P06 and P15) the sedimentary flow in suspension is significantly enriched (from 14.7 $kg \cdot s^{-1}$ to 21.9 $kg \cdot s^{-1}$) showing erosion processes along the artificial canal. Within the meander natural course, the suspended sediment discharge is low until the confluence with the cut-off canal (0.3 $kg \cdot s^{-1}$ on P13). At the exit of the meander a part of the discharge measured on P15 is settled down immediately downstream, the sedimentary discharge in P16 was 15.9 kg·s^{1}.

On Dunavăţ de Sus meander, the most part of the suspended sedimentary discharge is taken over by the meander natural course. Additionally, at the bifurcation area, a supplementary volume of suspended sediments (18 kg·s^{-1}) are locally eroded and deposed just downstream on P20. In the second half of the former meander, the sedimentation is dominant, expressed by a lower sediment discharge, of 13.9 kg·s^{-1} on P21. At the exit from the cut-off canal (P23) the discharge is higher than the sum of the sedimentary fluxes P22 + P21 indicating erosion at the junction area.

Downstream, on Dunavăţ de Jos meander the situation is reversed, but similar as for Mahmudia meander. The sedimentary discharge captured by the cut-off canal is around 99% of the total discharge of the distributary. Along the former meander the sedimentary discharge is maintain with a very low value (between 0.21 kg·s^{-1} and 0.6 kg·s^{-1}). Along the artificial canal the sedimentary discharge in maintain constantly around the value of 17 kg·s^{-1}.

Downstream, the two meanders of Dranov de Sus and de Jos have the same behavior, the most part of the sedimentary discharge (95-99 %) is taken by the artificial canals. The sedimentary discharge is very low along the former meanders (between 1.1 and 4.8 kg·s^{-1}), while along the artificial canals the values are situated between 18.3 and 20.0 kg·s^{-1}).

As for the Ivancea meander the sedimentary discharge is distributed almost equally between the two canals (11.3 kg·s^{-1} on the artificial canal and 8.6 kg·s^{-1} on the natural channel).

Downstream, going to the branch mouth area, (between P52 and P55), the sedimentary discharge is reduced from 20.1 kg·s^{-1} to 16.1 kg·s^{-1}.

The distribution of SS concentrations and fluxes varies and depending on the local morphology and water dynamics. It is a clear disparity between the sections situated on the former meanders and those situates near the bifurcations /confluences characterised by steep slopes and most intense hydrodynamic activity.

The concept of hydrological connectivity was widely employed in different environments and defines the water-mediated transfer of matter, energy and organism within the hydrological cycle (Pringle, 2001; 2003; Zhang et al., 2021).

Human activities have generally altered hydrological connectivity (Pringle, 2001) by small to large interventions that can disturb the entire ecosystems. Loss of the connectivity will diminish the fresh transfer between upstream and downstream. The longitudinal connectivity is important for the nutrients transport and the migration of aquatic organism (Zhang et al., 2021).

The reduction/interruption of the fresh water transfer influence the biogeochemical fluxes. The consequences on the ecological equilibrium of the delta territory are various with important influences on a variety of aquatic ecosystem processes (Covino, 2017) including: solute transport (Ren & Packman, 2005), nutrient (Mulholland et al., 1997), carbon (Wagner & Beisser, 2005), streamflow dynamics (McGlynn & Seibert, 2003), aquatic biota and biological habitat (Stanford & Ward, 1988), and water resource management (Oxtobee & Novakowski, 2002).

The hydrotechnical works carried out along the St. George branch to improve navigation produced negative effects on the exchange of water and sediments with the lakes in the delta through the connecting channels (Figure 11). Most of the natural channels of the above-mentioned rectified meanders are currently heavily clogged and the sediments accumulated in the bed create sediment blockages.

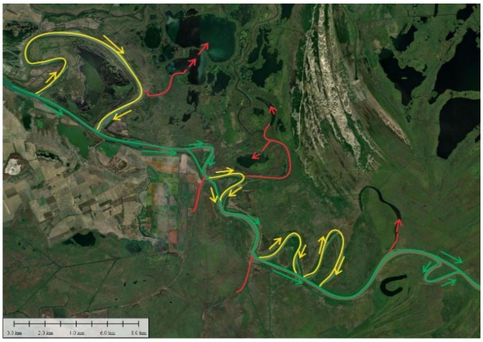

Figure 11. The rectified meanders of the St. George branch and the areas affected by the interruption of the hydrological connectivity (with green is the main stream, with yellow are the natural channels of the former meanders, with red are the areas disconnected when the hydrological connectivity is lost

Therefore, at low water levels, these areas are isolated from the main distributary producing interruptions of the liquid fluxes transfer with consequences on the hydrological connectivity.

Over time, this process tends to separate the former meander channel from the main branch and isolate the interdistributary areas. As in a chain processes/effect, the partial or complete disconnection of the lateral natural channels from the former meander (red line on Figure 11) will produce the physically separation of the interdistributary depressions (deltaic lakes).

CONCLUSIONS

River-floodplain hydrologic connectivity is important to be maintained to facilitate the exchange of water, sediment and nutrients between streams and floodplains.

The results shows that the water circulation along the study area is very complex. The hydrological changes are related to the human interventions, mainly by shortening the length of natural river courses, producing an increase of the water-free surface slope and therefore the water flow velocity along the artificial canals. The most dramatic situation is on Mahmudia meander (M1), Dunavăţ de Jos meander (M3) and Dranov de Jos meander (M6), where the cut-off canals take over 95-99 % of the upstream water and sediment flows, while the natural courses of the rectified meanders suffer infilling process, with the almost complete stopping of the water circulation on them therefore compromising the hydrological connectivity with the interdistributary depressions.

Efforts to rehabilitate the ecosystem must be assumed to maintain the restoration, and the redevelopment of the affected areas, based on the principle of sustainable development and ensuring 4D connectivity. One suggestion for future research is to investigate and monitor with specific equipment the water transfer and how storage of water occurs in different catchments to produce (dis)connected flow.

ACKNOWLEDGEMENTS

This research was financially supported by the Romanian Ministry of Research, Innovation and Digitization in the framework of the projects: PN19200401 (Contract no. 13N/08.02.2019), PN23300304 (Contract no. 4N/30.12.2022), and Project AMBIACVA (Contract no. 23PFE/30.12.2021).

The authors thank Gabriela Vlad and Naliana Lupaşcu from GeoEcoMar for collecting and analysing the suspended sediments samples.

REFERENCES

Bondar, C., & Panin, N. (2000). The Danube Delta Hydrologic Database and Modeling. *Geo-Eco-Marina, 5-6*, 5–53.

Bracken, L/J, Wainwright, J., Ali, G.A., Tetzlaff, D., Smith, M.W., Reaney, S.M. & Roy, A.G. (2013). Concepts of hydrological connectivity: research approaches, pathways and future agendas. *Earth-Scrience Reviews, 119*, 17–34.

Bunn, S. E. & Arthington, A. H. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management 30*, 492–507.

Carvalho, N.O., Filizola, N., dos Santos, P.M.C., & Lima, J.W. (2000). Guia de Práticas Sedimentométricas. *Ed.ANEEL/PNUD/ OMM, Brasília*, pp. 154.

Covino, T. (2017). Hydrologic connectivity as a framework for understanding biogeochemical flux through watersheds and along fluvial networks. *Geomorphology*, *277*, 133–144.

Duţu, F., Duţu, L., Catianis, I., & Ispas, B-A. (2022a). Sediment dynamics and hydrodynamical processes in the Danube Delta (Romania): A response to hydrotechnical works. *Zeitschrift fur Geomorphologie, 64*(4), 365–378.

Duţu, L., Duţu, F. & Iordache, G. (2022b). Intensive infilling processes of a cutoff meander in the Danube Delta. *Transylv. Rev. Syst. Ecol. Res., 24*(3), 1–10.

Habersack, H., Hein, T., Stanică, A., Liska, I., Mair, R., Jager, E., Hauer, C., & Bradley, C. (2016). Challenges of river basin management: Current status of, and prospects for, the River Danube from a river engineering perspective. *Science of the Total Environment, 543*, 828–845.

Hager, W.H. (1984). An approximate treatment of flow in branches and bends. *Proceedings of the Institute of Mechanical Engineers, 198*, 63–69.

ICPDR (2008). Joint Danube Survey 2, Final Scientific Report, pp. 242.

ICPDR (2015). Joint Danube Survey 3, A Comprehensive Analysis of Danube Water Quality, pp. 369.

Junk, W. J., P. B. Bayley & R. E. Sparks. (1989). The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences 106*, 110–127.

Karim, F., D. Dutta, S. Marvanek, C. Petheram, C. Ticehurst, J. Lerat, S. Kim & A. Yang. (2015). Assessing the impacts of climate change and dams on floodplain inundation and wetland connectivity in the wet-dry tropics of northern Australia. *Journal of Hydrology Elsevier 522*, 80–94.

Law, S.W. & Reynolds, A.J. (1966). Dividing flow in an open channel. *Journal of the Hydraulics Division, American Society of Civil Engineers, 92*, 207–231.

McGlynn, B.L. & Seibert, J. (2003). Distributed assessment of contributing area and riparian buffering along stream networks. *Water Resour. Res. 39*(4).

Mulholland, P.J., Marzolf, E.R., Webster, J.R., Hart, D.R. & Hendricks, S.P. (1997). Evidence that hyporheic zones increase heterotrophic metabolism and phosphorus uptake in forest streams. *Limnol. Oceanogr. 42*(3), 443–451.

Nistor, C., Savulescu, I., Mihai, B-A., Zaharia., L., Virghileanu, M. & Cacablaisa, S. (2021). The impact of the large dams on fluvial sedimentation; the Iron gates reservoir on the Danube River. *Acta geographica Slovenia, 61(*1), 41–55.

Oxtobee, J.P.A. & Novakowski, K. (2002). A field investigation of groundwater/surface water interaction in a fractured bedrock environment. *J. Hydrol. 269* (3-4), 169–193.

Pacioglu, O., Duţu, F., Pavel, A.B., & Tiron Duţu, L. (2022a). The influence of hydrology and sediment grain-size on the spatial distribution of macroinvertebrate communities in two submerged dunes from the Danube Delta (Romania), *Limnetica, 41*(1), 85–100.

Pacioglu, O., Duţu, L., Duţu, F., & Pavel, A.B. (2022b). Habitat preferences and trophic interactions of the benthic invertebrate communities inhabiting depositional and erosional banks of a meander from Danube Delta (Romania). *Global Ecology and Conservation, 38*, e02213.

Pojar I., Tiron Duţu L., Pop C.I., & Duţu F. (2021). Hydrodynamic observations on microplastic abundances and morphologies in the Danube delta, Romania. *Agrolife Scientific Journal, 10*(2), 142–149.

Popa, A., (1997). Environment changes in the Danube Delta caused by the hydrotechnical works on the St. George branch. *Geo-Eco-Marina, 2*, 135–147.

Pringle, CM. (2001). Hydrologic connectivity and the management of biological reserves: a global perspective. *Ecol Appl., 11*(4), 981–998.

Pringle, C. (2003). What is hydrologic connectivity and why is it ecologically important?. *Hydrological processes, 17*. 2685-2689.

Ren, J.H. & Packman, A.I. (2005). Coupled stream-subsurface exchange of colloidal hematite and dissolved zinc, copper, and phosphate. *Environ. Sci. Technol. 39*(17), 6387–6394.

Stanford, J.A. & Ward, J.V. (1988). The hyporheic habitat of river ecosystems. *Nature 335*(6185), 64–66.

Tiron Duţu, L., Panin, N., Duţu, F., Popa, A., Iordache, G., Pojar, I., & Catianis, I. (2022). The Danube Delta Environment Changes Generated by Human Activities. *Chapter 1 in The Danube River Delta, Springer - Earth and Environmental Sciences Library,* 3-32. ISBN 978-3-031-03982-9. doi: https://doi-org.am.e-nformation.ro/10.1007/978-3-031-03983-6_1.

Trifanov, C., Dumitriu, D., Mihu-Pintilie, A., Stoleriu, C. & Mierlă, M. (2022). Some morphodynamic aspects concerning the meandred river section of the Sf. Gheorghe's arm from the Danube Delta Biosphere Reserve. *Scientific Annals of the Danube Delta Institute, 27*, 129–138.

Vasiliu, D., Tiron Duţu, L., Bucşe, A., Lupaşcu, N., & Duţu, F. (2021). Geochemical characteristics of riverbed sediments in the Danube delta, Romania. *Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, X*, 258–264.

Vădineanu, A. (2001). Lower Danube Wetlands System (LDWS). *Observatorio Medioambiental, 4*, 373-402.

Wagner, F.H. & Beisser, C. (2005). Does carbon enrichment affect hyporheic invertebrates in a gravel stream? *Hydrobiologia, 544*, 189–200.

Zaharia, L., Grecu, F., Toroimac, I.G. & Neculau, G., (2011). Sediment Transport and River Channel Dynamics in Romania - Variability and Control Factors. In: Manning, A. J., editor. *Sediment Transport in Aquatic Environments*. London: IntechOpen. doi: 10.5772/21416.

Zhang, Y., Huang, C., Zhang, W., Chen, J., & Wang, L. (2021). The concept, approach, and future research of hydrological connectivity and its assessment at multiscales. *Environmental Science and Pollution Research, 28*, 52724–52743.