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The Danube River Delta

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The Danube River Delta

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ISSN 2730-6674 ISSN 2730-6682 (electronic)
Earth and Environmental Sciences Library
ISBN 978-3-031-03982-9 ISBN 978-3-031-03983-6 (eBook)
https://doi.org/10.1007/978-3-031-03983-6

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Preface

The Danube basin covers about 10% of Europe's surface area and has a wide variety of natural, socioeconomic and political conditions. Human pressures have increasingly affected the Danube River and its basin (e.g., water and land use, engineering works, water pollution, etc.). They have led to quantitative (water flows, allusions) and qualitative changes in the water, and thus to changes in the morphology of the whale and the delta. These pressures have also affected the functionality of water and flood ecosystems.

Danube River Delta (DRD) is the complex result of the Danube and the Black Sea interaction. The collection of natural and man-made phenomena taking place in the Danube basin and at the Black Sea level has generated what we are seeing today in the delta. The Danube Delta is individualized as a physical–geographical unit toward adjacent units (plateau, marine sector). The Danube Delta is included under the category of regional wet plain relief forms on highly fragmented river alluvial deposits. The Danube Delta is characterized by positive relief forms known as grindings and negative relief forms represented by lakes and channels. Today, the delta takes the form of a flat surface with a slope of 0,006 ‰, which is crossed by numerous Danube branches, channels, lakes and marshlands.

The particularities of this area have led to its ecosystem, social and economic development being different. Hence, the need to update the studies was carried out for the first time in 1960. The Danube Delta has undergone a period of transformation due to the centralized visions of territorial development of the socialist regime. Local interventions to regenerate ecosystems heavily affected by agricultural or industrial activities are then recorded.

The lack of funds to regenerate the deltaic area, experience in implementing projects financed from external sources, constantly changing legislation and with many gaps has led to situations that have eroded natural ecosystems, depopulation of the area and a decline in economic activities. The literature review indicates that there are some sources about the Danube River and its basin but to the best of the editor's knowledge no recently books exist about the Danube River Delta. Therefore, the idea of this book was born on in Bucharest in October 2019 in a meeting with Dr. Daniel Constantin Diaconu (the second editor).

This volume of the series brings together contributions of scientists, experts and researchers from Romania who are involved in research related to the Danube River Delta (DRD) and familiar with its characteristics. The book addresses variety of connected topics to cover the critical issues of the DRD. It includes 13 chapters grouped into 4 parts, including (I) DRD Environmental Change (Chapters The Danube Delta Environment Changes Generated by Human Activities"–"Water Flow Variability in the Danube Delta Under Climatic Changes Conditions"), (II) Water and Waste Management (Chapters "Water Management on the Territory of the Danube Delta Biosphere Reserve" and "Integrated Waste Management in the Danube Delta Biosphere Reserve"), (III) Societal Dimensions: Demographics, Health and Education and (IV) Integrated Sustainable Development. In the following paragraphs, we will provide an overview of each of the 14 chapters focusing on its unique objectives.

Part I covers the environmental changes in four chapters. The chapter titled "The Danube Delta Environment Changes Generated by Human Activities" presents the effects of human activity on the environmental state of the DRD and the fluvial response to these anthropogenic interventions. The chapter also presents information on the characteristics and dynamics of sediments transported by the river reflected in the riverbed morphology. It includes 94 references. While the chapter titled "Danube Delta Lakes as Sinks for Natural and Anthropogenic Environmental Changes" provides detailed study of bed-sediments of 36 lakes (larger or smaller) from the lagoon–deltaic edifice of the DD were studied in detail. It assesses how environmental and anthropogenic factors may affect spatial and temporal variations in sediment flux and recent sediment dynamics within the DD watersheds. This was done by assessing the main physical–chemical parameters of sediments (i.e., total organic matter, total carbonates and siliciclastic fraction) in 36 lakes of the deltaic–lagoonal edifice. These lakes are of fundamental scientific interest, considering their capacity to contain unique records of environmental depositional processes which have taken place over time. It contains 141 references.

Additionally, the chapter titled "Assessment of Climate Conditions and Changes Detected Over the Historical Period (1961–2013)" presents the spatial distribution and changes detected in the main climatic variables, air temperature and precipitation, in the Danube Delta. It also aims to investigate if there is any specific regional pattern and changes in 25 extreme temperature and precipitation indices in the Danube Delta over a historical period (1961–2013) calculated based on gridded data at a spatial resolution of 0.1 x 0.1 ° (latitude x longitude). To the authors' best knowledge, this study is the first developed research work at such detailed spatial resolution for extreme temperature and precipitation events in the focus region. The chapters contains 99 references.

The first part ends with a chapter that analyzes water flow variability in the Danube Delta under climatic changes conditions. The performed quantitative analysis on value ranges for a period of 34 years, indicates the current trends of water leakage in the context of global climate change. It contains numerous figures and a number of 18 references. On the other hand, Part II covered the water and waste management in two chapters. The first chapter is titled "Water Management on the Territory of the Danube Delta Biosphere Reserve" and focuses on only on two of the environmental aspects mentioned (elements related to the quality of water in the area and the pressures on water bodies). Particularly, the authors mention only those related to the environmental factor WATER (mentioned in the Integrated Strategy for Sustainable Development of the Danube Delta (2030) (ISSDDD) including the quality status of water bodies, pressures on water bodies, drinking water quality and wastewater, sewerage system and their treatment. It contains 20 references.

The second chapter of Part II is titled "Integrated Waste Management in the Danube Delta Biosphere Reserve" it is a documentary study on the generation and management of waste in the Danube Delta Biosphere Reserve. Waste, the end result of anthropic activities, is a growing problem for environmental protection. Several types of waste are generated in the Danube Delta Biosphere Reserve. These include household waste, floating waste, agricultural and food waste, medical waste, etc. It contains 27 references.

Part III covers societal dimensions in terms of demographics, health and education in three chapters. The author of the chapter titled "Specificity of the Demographic Dynamics in the Danube Delta" performs a detailed analysis of population dynamics in one of Romania's most isolated territorial systems, namely the Danube Delta. From a demographic point of view, this is a vast area that faces specific problems of isolation due mainly to the natural environment and its peripheral location both in Romania and in the EU. Knowing the specificity of demographic dynamics is extremely important in shaping the relationship between the demographic component and the local economy, being an important element that must be considered in designing effective sustainable management plans. It contains 40 references.

While the authors of the chapter titled "Medical Infrastructure Evolution and Spatial Dimension of the Population Health State from the Danube Delta" analyze the medical infrastructure evolution in the period 2000–2019, including the influencing factors. Additionally, they want to reveal the spatial disparities in the distribution of medical infrastructure, related to the territorial administrative units which are belonging to the Danube Delta. As study case, the malignant tumors situation is used for creating a comprehensive image upon spatial distribution of this affection, related to the Danube Delta natural and cultural conditions.

And the author of the chapter titled "The Danube Delta: Opportunities of Content Exploitation as Language Learning Experiences" explains the "Content and Language Integrated Learning (CLIL)" approach, which uses real information and a wide range of authentic materials to enhance language skills and students' exposure to new content. The method is used in language teaching and learning process in connection with an approach to learning philosophies which aims to bring education closer to the realities of our world, i.e., environmental education. She uses this combination of approaches to combine the scientific content of Danube Delta-related topics with language practice opportunities. This amazing combination of teaching and learning approaches could facilitate the exploitation of various resources with the double aim of raising awareness and increasing students' knowledge and, on the other hand, of creating opportunities for language acquisition.

In Part IV, the authors discuss the integrated sustainable development in five chapters. The chapter titled "The Societal Benefits as Results of Managing the Danube Delta Landscape and Changing the Stakeholders' Behaviours" provides the results of the analysis of the dynamics and interlinkages between the DRD governance and Danube Delta landscape, highlighting the influence on ecosystem services and the behavioral change of the key stakeholder in applying the nature-based solution to solve the Danube Delta's ecological and societal challenges. It contains 53 references. Additionally, the chapter titled "Climate Suitability for Sustainable Economic Growth Through Tourism in the Danube Delta" assesses the climate suitability for a possible extension of the season for outdoor tourism by using an enhanced version of the TCI (ETCI) to analyze if occupancy rates in the accommodation structures (and other related economic indicators) correspond to local weather conditions. Also, the authors propose two development scenarios for sustainable economic growth based on tourism in one of the most famous protected areas in Europe. It includes 64 references.

In addition to that, the chapter titled "The Structural Dynamics of the Local Economy in the Danube Delta" aims to conduct an analysis of the economy of the most spectacular isolated habitat in Europe, the Danube Delta. Therefore, the chapter includes an analysis of the economic subsystem of the Danube Delta, a geographically isolated territorial system, with an economic evolution resonant with the context of the national supersystem, but with many specificities determined by geographical particularities. It contains 59 references.

On the other hand, the chapter titled "The Role of Tourism Activities in the Integrated Economic Development of the Danube Delta" analyzes the main important indicators for the tourism activity in a very visited destination of Romania, a unique one, the Danube Delta. Among the indicators, the arrivals, overnight stays (as tourism traffic) and the number of companies, of employees (as jobs), the value of profit and the turnover have been analyzed. The chapters uses 54 references.

Additionally, the chapter titled "Danube Delta Integrated Sustainable Development Strategy." It focuses on analyzing the strategic documents developed by European, national, regional, county, and local authorities and highlightes the opportunities and constraints for the development of the Danube Delta. The analysis results in a set of very useful conclusions to help the concerning authority and stakeholders to strengthen the weakness in the analysed strategies.

The editors want to thank the contributing authors who made this high-quality volume a real source of information and knowledge on the interesting Danube River Delta by presenting the latest research findings related to DRD environmental, economic and social issues. Without the patience and efforts in writing and revising the different versions of the manuscripts to satisfy the high-quality standards of Springer, it would not possible to create this unique book and make it a reality. Great thanks are due to the reviewers of the chapters and the editors of the Earth and Environmental Sciences Series for the constructive comments, advices and the critical reviews. Additionally, acknowledgements should be extended to include all members of Springer team who have worked hard for a long time during the COVID-19 pandemic to produce this volume.

The volume editors will be pleased to receive constructive comments from their peers, stakeholders and decision-makers to improve future editions. Comments, feedback, suggestions for future improvement or new chapters on the DRD for the next editions are most welcome and should be sent directly to the volume editors via their email that are posted in the chapters.

Zagazig, Egypt
Bucharest, Romania
January 2022

Abdelazim M. Negm
Daniel Constantin Diaconu

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1 Introduction

The impacts of human activities on the fluvial systems have been investigated for a long time by numerous scientists [1–8, and many others]. Human interventions in a fluvial system (dams, dikes, dredging, groins, meander bends cut-offs, etc.)

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A. M. Negm and D. C. Diaconu (eds.), *The Danube River Delta*, Earth and Environmental Sciences Library, https://doi.org/10.1007/978-3-031-03983-6_1

modify the hydrological and sedimentary characteristics of rivers that control the environment and the geo-morpho-dynamics of the river courses [9–21].

The last two centuries have been marked by the construction of dams on numerous rivers, such as the Mississippi River, Yellow River, Nile River, Danube River, etc. [9, 22, 23]. At the same time, several studies have been carried out on the impact of the abovementioned structures on the riverine environment, on hydrology, sedimentology, and morphology [23–29]. Depending on its location, environment, substrate, and variables of control, each river responds differently to disturbances induced by dams [9] as they change the seasonal variability of liquid and solid discharges [30]. [31, 32] estimated that over 40% of the water flow of the world's rivers is currently intercepted and 25% of the solid discharge is trapped behind dams. Studies by [33] show that in the modified river courses of Central Europe, 50-year-frequency floods have decreased by 20% and ten-year floods can decrease up to 75%.

An example of the extreme impact of the construction of such reservoirs is that of the two Aswan dams on the Nile (the first dam, the old one, built-in 1902, and the second, new, dam, finished in 1970); the Nile suffered a reduction in total sediment load transported downstream from 100×10^6 $t{\cdot}y^{-1}$ to almost zero [30, 34]. Meade and Parker [35] studied a similar impact on Colorado (USA), which experienced a decrease in sediment load transported from 125–150 $\times 10^6$ $t{\cdot}y^{-1}$ in 1930, to 1.1 $\times 10^6$ $t{\cdot}y^{-1}$ now-a-day. The Mississippi River (at Baton Rouge) shows a similar decrease in sediment discharge between 1950 and 1975, following the construction of five dams, between 1953–1963, on Missouri [30]. Reservoirs built on the Yellow River (16 barrages, among them the Sanmenxia and Xiaolangdi dams) have induced reductions in sediment flow (up to 60%) [6] with an impact on the development of the delta and the coastline.

However, it should be mentioned that there are also rivers that have not changed their sediment regime as a result of anthropogenic interventions. Alford [36] refers to the case of Chao Phraya (Thailand), which shows no significant modification of the sediment flow following the development. Other similar cases are described by [30] on the Ob River (Siberia) and the upper Yangtze (in Yichang, China).

Besides the impact of hydropower dams and their reservoir lakes, a large number of engineering works can influence the river's hydro- and morpho-dynamical processes. The meander bends cut-offs for better navigation and for controlling the seasonal floods, stabilization of channels by embankments, etc. represents pressures on the river evolution pattern [37]. Numerous studies, theoretical, experimental, or *in situ* have shown that the modification of the sinuosity rates (in case of meandering rivers), the reduction in the variability of widths, or plan mobility could be the first response of a river to the construction of a dam [11, 27, 38–42]. Grams and Schmidt [43] demonstrated that the decrease of the channel width is not linearly correlated with the distance downstream from the dam, but is related to the degree of reduction of flood peaks induced by the dam, to the modification of sediment inputs, and local geomorphological characteristics.

In the case of meander belts cut-offs, the most important factor that influences the changes in water and sediment flows is the increase of the river free water slope.

The downstream area of the cut-off will be fed by a larger quantity of sediment resulting from the erosion of the cut-off canal and of the upstream area. Schumm [44] considers that the dynamic equilibrium of a cut-off canal will set in only after a few “local cycles” of erosion/deposition.

The best-known example of a large meander bends cut-offs program is the Mississippi River (USA) that have been performed in the 1930s to facilitate the evacuation of floodwaters and improve navigation. The river has been shortened by about 30% of its length (274 km). As the result of shortening, 15 meander bends were cut-off and isolated from the main channel. The river was shortened an additional 88 km between 1938 and 1855 by chute cut-offs. The period following the rectifications had a substantial impact on the morphology of the river by self-adjusting its course [25, 26, 45].

The Danube River (2875 km) is a major fluvial system with a drainage basin of 817 000 km^2 [46–48]. In addition, the river and its delta at the mouth in the Black Sea represent a very complex and large natural river-sea system in Europe [46]. A long history of navigation, industrial development, large-scale agriculture, more than 80 million inhabitants present across the basin, multiple hydro-energetic developments are some of the factors that influence the centuries-old evolution of the river. Its long-term evolution is marked by secular climate changes, transformations of the land use in the entire basin that have changed flow types and flood regimes, and reduced the volume of sediment inputs downstream [29, 47–56].

These impacts have been greatly amplified over the last 50 years by the watercourse regulations along the Danube River and its tributaries, including the construction of the two major hydropower dams Iron Gates I in 1971 and Iron Gates II in 1984 on the Romanian—Serbian border [29, 56, 57].

In the last two centuries, several hydro-technical works have been made within the Danube Delta territory, with significant impact on the delta environmental state, on the water and sediment flows, and on the morpho-dynamics of the distributaries, natural channels, man-made canals, interdistributary lakes and polders, the coastal zone of delta front, etc. [1, 54, 56, 58, 59].

2 Study Area

The chapter aims to present the effects of human activity on the environmental state of the Danube Delta, and the fluvial response to these anthropogenic interventions.

The Danube Delta (5600 km^2) displays three main distributaries: the Kilia at North, Sulina in the middle, and St. George at South. Unlike the northern branch, which also represents the Romanian - Ukrainian border and has remained almost natural, except its secondary delta, the other two distributaries have been modified for navigation through meander bends cut-offs (Fig. 1).

Since the middle of the nineteenth century, the natural hydrological regime of the Danube distributaries was influenced and modified by human activities. Important

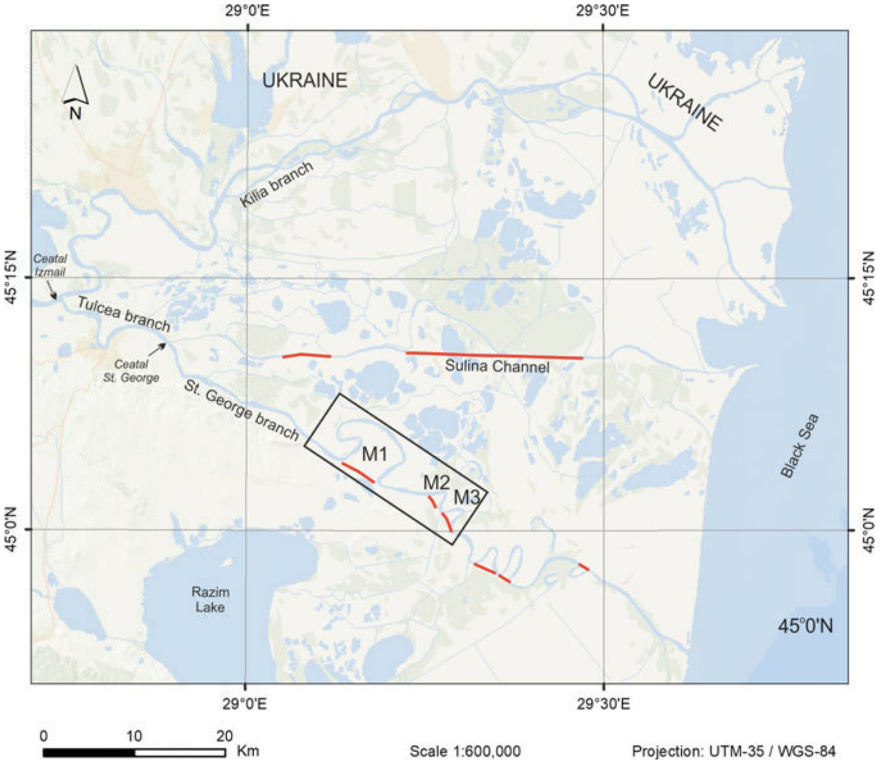

Fig. 1 The Danube Delta map (artificial canals of the rectified meanders of Sulina and St. George distributaries in red lines) and the location of the study area (Mahmudia-M1, the Upper Dunavăţ-M2, and the Lower Dunavăţ-M3 meanders) within the St. George branch

developments began after the establishment of the Danube Commission in 1856 in Galaţi, Romania [2, 54, 57, 60–64].

As a result of the extensive hydro-technical works for economic purposes, the total length of the man-made channels increased from 1743 to 3496 km [65] and the discharge of the Danube River to the delta inter-distributaries depressions increased from 167 m^3/s before 1900 to 309 m^3/s in 1921–1950 period, 358 m^3/s in 1971–1980 period and 620 m^3/s in 1980–1989 period [1, 50]. The effect was the perturbation of water circulation and sediment relocation within the delta [57].

In the deltaic depressions, during the ’60s and ’80s, a management plan was implemented for substituting the natural ecosystems with human-dominated ones (e.g., intensive fish and agricultural farms, poplar plantations). Intensive exploitation of reed and fish resources was put into action and large agricultural farms and tree plantations replaced large surfaces of wetlands from the delta [2].

The rectification of the Sulina distributary (Fig. 1) was carried out during the years 1868–1902 and shortened this branch by about 24%. The shortening and deepening of the river channel produced modifications on the hydrological regime inside the delta by increasing the water discharge of the Sulina distributary by about 10% (from 7–9% to about 20% of total Danube discharge) [54]. As a consequence, redistribution of water and sediment discharge among the delta distributaries have been recorded [53, 59, 66].

During the years 1981–1994, cut-offs of six free meanders of the St. George distributary were performed to improve navigation. The total length of the St. George branch was shortened by 32 km and consequently, the free-water surface became steeper and the flow velocity and energy (scouring and sediment load transport capacity) increased significantly. The St. George distributary water discharge increased by some 10% influencing the general water distribution among the delta distributaries [56]. The natural meander courses and the newly built cut-off canals evolved differently: clogging processes are very active within the natural courses of the rectified meander bends, while the cut-off canals are actively eroded becoming deeper and widener [54, 57, 67–70].

At almost the same period, the river and the delta systems have been deeply affected by the hydrological and sedimentary changes (reduction of the sediment discharge by some 40%) after the construction of Iron Gates I and Iron Gates II barrages. These changes are felt all along the downstream barrages river course (almost 700 km) and, especially, in the delta front coastal area [54].

3 Methods

Complex research and detailed investigation (using several modern methods and technics, such as ADCP, 3D bathymetry, diffractometry) have been performed in the Danube Delta on the St. George branch, which is considered deeply influenced by anthropic activities. Hydrological, morphological and sedimentological data are here presented. These data have been acquired along three meander loops located in the middle part of the St. George distributary: Mahmudia, Upper Dunavăţ, and Lower Dunavăţ (Perivolovca) meanders, named hereafter M1, M2, and M3, respectively. The measurements were made in two different hydrological regimes, at average to high-level waters in September 2016 and, at the end of a high peak of a flood period of spring waters, at the beginning of June 2017. The St. George branch carried out 1264 $m^3 \cdot s^{-1}$ and 2169 $m^3 \cdot s^{-1}$ during the measurements.

Hydrodynamics (ADCP). The data analysed in this chapter were acquired with two equipment, ADCP Workhorse Sentinel 600 kHz and ADCP RiverRay 600 kHz (manufactured by Teledyne RDI) mounted on a powerboat [69, 71]. During the two field campaigns, 25 transverse ADCP profiles were completed at relevant cross-sections of the three meanders: at the bifurcations (sectors A, I, and L), at the confluences (sectors G, K, and N), and along the cut-off meanders (profiles C, D, E, F, J, and M). The marks 1, 2, and 3 describe the position of each profile in the sector: location on the natural single upstream channel (1), on the former meander (2), and the cut-off canal (3) (Fig. 2).

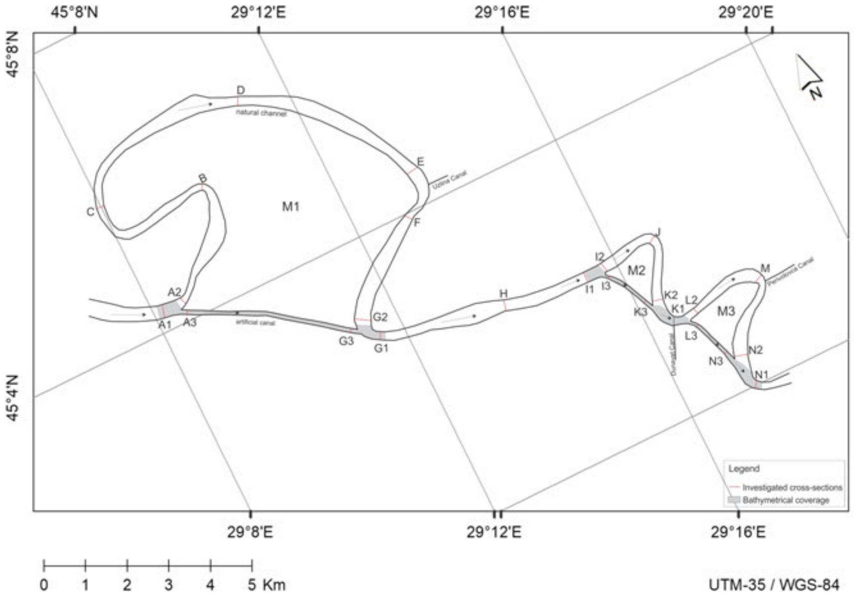

Fig. 2 Study area, the three meanders of the St. George Branch (Danube Delta). The investigated cross-sections (ADCP profiles and sediment samples) are marked with red lines and the 3D bathymetrical coverage in gray areas

Morphology 3D mapping. Multibeam sonar bathymetry data were collected during two field campaigns on NIRD GeoEcoMar's RV ISTROS, equipped with an ELAC Nautik SeaBeam 1050D multibeam bathymetric system (ELAC 1050D, 180-kHz). The depth data were processed using the software packages HDP Post/FLEDERMAUS [64, 72, 73].

Grain size analysis of bed sediments. Bottom samples were collected with a grab sediment sampler, on more than 40 sediment stations, distributed along the three meanders, on each investigated cross-section (Fig. 2). The sediment grain size analyses were done by diffractometry using the grain size laser analyzer „Mastersizer 2000E Ver.5.20 (Malvern Instruments Ltd.-Malvern UK). The equipment determines the percentages of particles in the various dimensional classes present in 0.10 μ–1 mm interval with an accuracy of 1% and a reproducibility of 99%. Particles larger than 1 mm were separated by sieving on fractions, weighed, and reported to the percentages obtained by diffractometry [74]. The texture categories (sand, silt, clays) were separated using the Udden-Wentworth logarithmic scale and for the classification of the sediments, the Shepard diagram was used [75–77].

Determination of the *suspended sediment concentrations* was made in the laboratory using the filtration method. In all the selected cross-sections, water samples (with a 5 L horizontal Niskin-type bottle) were acquired in three verticals (left balk, right bank, and center). The water samples were filtered with a Millipore filtration unit, using 4.7 cm acetate cellulose filter membranes of 0.45 μm porosity, according to STAS 6953-81.

4 Results and Discussions

4.1 Overview of Flow Processes

The water flux distribution between the natural course of meanders and cut-off canals is varying from one sector to another, depending on several factors such as the ratio between the former and the new canal length, the diversion angle, and the bed level difference between the natural channel and the cut-off canal. Representative measured velocity profiles from June 2017 are used to illustrate the 2D structure of flow at bifurcations (A1, A2, A3, I1, I3, L2, and L3), confluences (G1, G2, G3, K2, K3, N1, and N3) and on the natural course of meanders (J and M) (Figs. 4, 6, 7, 8 and 10).

4.1.1 First Cut-Off—Mahmudia Meander Belt (M1)

In September 2016, at the bifurcation (A1/A2/A3), the water flux balance is conservative (the liquid flow A2 + A3 ($1220 + 25 = 1245\ \text{m}^3 \cdot \text{s}^{-1}$) is equal to the water discharge through A1 ($1264\ \text{m}^3 \cdot \text{s}^{-1}$)). The cut-off channel of M1 receives 2% of the upstream flow [73]. In June 2017, at the same location, the cut-off channel of M1 receives 3.8% of the upstream flow. Upstream the cut-off canal entrance (profile A1), the core of high velocity is located on the right side and at the center of the channel. The channel bed is asymmetrical with the thalweg situated on the right side. The flow is directed toward the right bank, in the direction of the cut-off canal entrance, similar to that along the cut-off canal (profile A3). In June 2017, the cross-section through the entrance in the natural course of the meander (A2) shows a sediment deposition zone located on the left side, with low velocities values (0.4–0.6 $\text{m} \cdot \text{s}^{-1}$) (Figs. 3 and 4).

In September 2016, at lower discharge, access through this section of the natural course of the meander was not possible. The water discharge decreases progressively along the natural course of the meander, as well as the flow velocities (from 0.05 to 0.01 $\text{m} \cdot \text{s}^{-1}$ in September 2016 and from 0.44 to 0.05 $\text{m} \cdot \text{s}^{-1}$ in June 2017). The water flow velocity increased in the cut-off canal (from 0.48 $\text{m} \cdot \text{s}^{-1}$ upstream of the bifurcation, on A1, to 0.58 $\text{m} \cdot \text{s}^{-1}$ downstream, on A3) in September 2016, and respectively from 0.76 $\text{m} \cdot \text{s}^{-1}$ to 0.90 $\text{m} \cdot \text{s}^{-1}$ in June 2017) enhances incision processes within the canal.

At the confluence of cut-off canal and the natural course of the meander (profiles G1, G2, and G3) several nucleuses of higher velocities persist in the central areas of profiles G1 and G3, while the velocities of G2 (on the natural course) are very

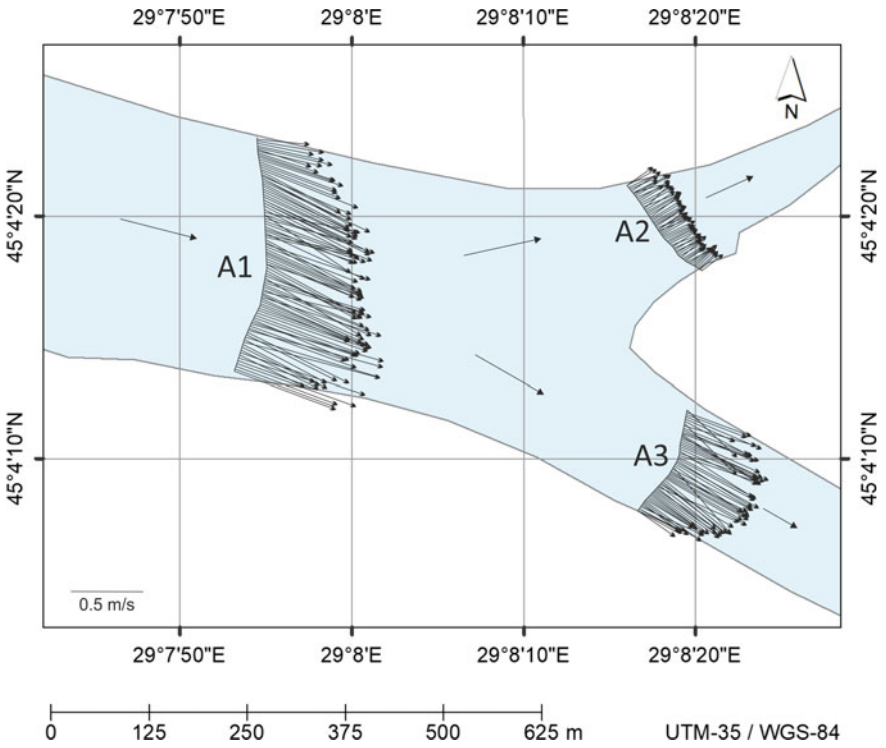

Fig. 3 Depth-averaged flow velocities (black arrows) at the bifurcation area of M1 cutoff in June 2017

low and homogeneous (0.01 m·s^{-1} in September 2016 and 0.05 m·s^{-1} in June 2017) (Figs. 5 and 6).

4.1.2 Second Cut-Off—Upper Dunavăţ Meander Belt (M2)

The percentage of upstream discharge captured by the meander natural course was over 87% of the water discharge in September 2016, and 77.7% respectively in June 2017. The water flow increase in the natural channel; incision processes are identified at the bifurcation sector (I1–I2) with high-velocity values located in the right bank of the profile I1 (Fig. 7).

The velocities are homogeneously distributed on the cross-sections, which demonstrates the active dynamics of the difluence/confluence zones of the system (Fig. 8). At the confluence (profiles K1, K2, and K3) several nucleuses of higher velocity have been observed in the central part of profiles K2 and K3 (Figs. 8 and 9).

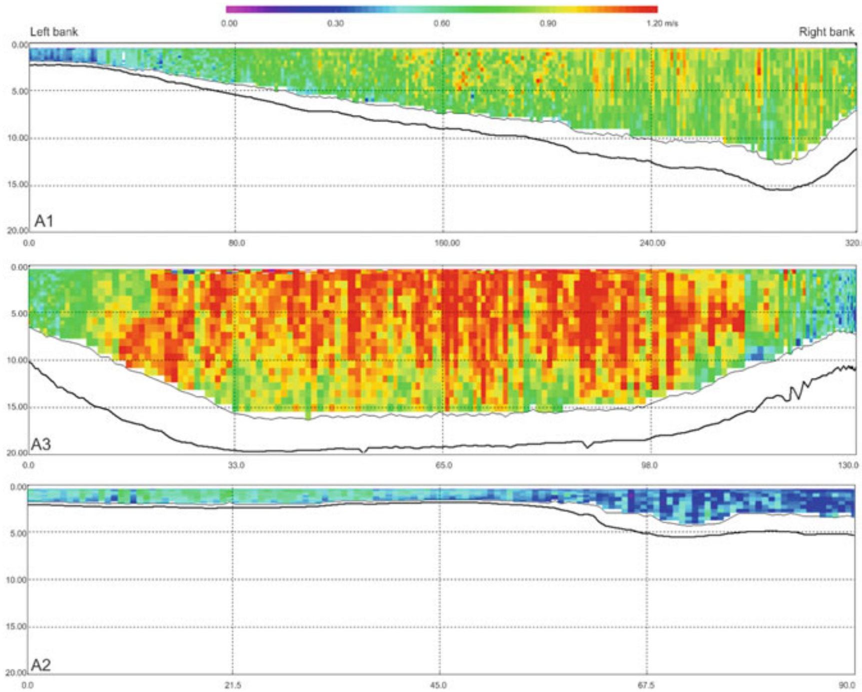

Fig. 4 Distribution of local velocities magnitude within cross-sections measured with the ADCP at the upstream bifurcation (profiles A1, A2, and A3) in June 2017

4.1.3 Third Cut-Off—Lower Dunavăţ (Perivolovca) Meander Belt (M3)

The water fluxes at the bifurcation are distributed unequally between the natural course of the meander (L2 = 25 $m^3 \cdot s^{-1}$ in September 2016, and 78 $m^3 \cdot s^{-1}$ in June 2017) and the cut-off canal (L3 = 1225 $m^3 \cdot s^{-1}$ in September 2016, and 2003 $m^3 \cdot s^{-1}$ in June 2017), with a very high flux in the cut-off canal (≈96–97% of total).

In terms of water velocities, in September 2016, the lowest average values (per cross-section) were situated between 0.16–0.50 $m \cdot s^{-1}$ on the natural channel and the highest mean velocities values were measured on the cut-off canal (around 0.70 $m \cdot s^{-1}$ in September 2016 and 1.13 $m \cdot s^{-1}$ in June 2017). The velocities are homogeneously distributed on the cross-sections (Fig. 10). At the apex zone (profile M), the asymmetric shape of the channel indicates obvious aggradation of the river bed in the central part of the channel.

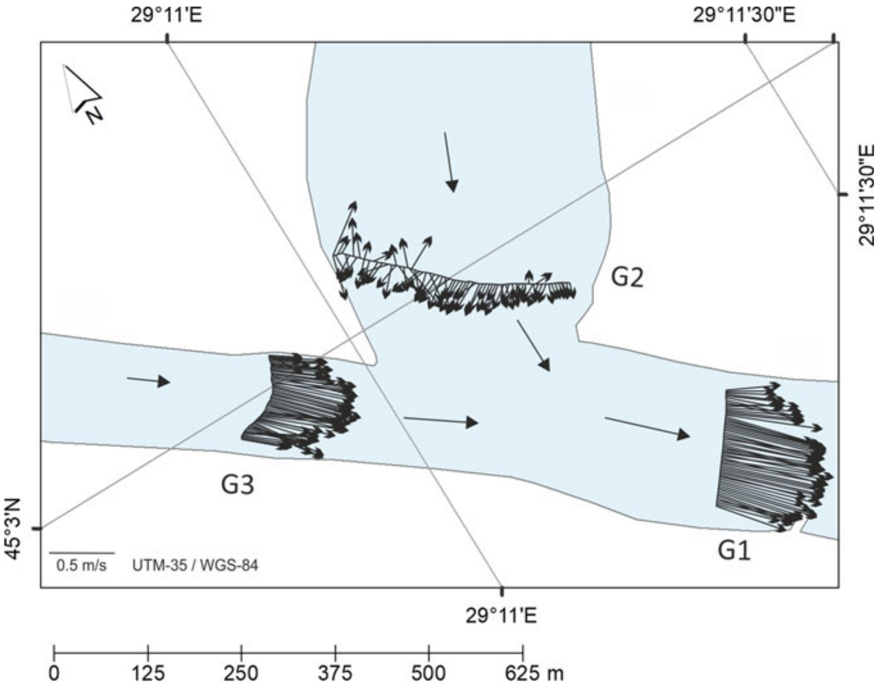

Fig. 5 Depth-averaged flow velocities (black arrows) at the confluence area on the M1 cut-off in June 2017

4.2 Bed Morphology and Bedforms Classification

The anthropic works influenced the local sedimentary transit of the St. George channel and their bed morphology differently. Figures 11 and 12 show the bathymetrical maps of the cut-off canals of the studied meanders. The canals were initially designed to be 7–8 m deep and 75–100 m wide (1984–1988) [67]. Their depth measured thirty years after (in September 2016 and June 2017) is much greater, with a maximum of 22 m and 27 m (relative water depths) for M1 and M3.

For meanders M1 and M3, the cut-off canals continue the direction of the main water flux in the natural course, and this determines the taking over of the main water discharge of the distributary by the cut-off canals, while the cut-off canal at the meander M2 which is oriented approximately at 75–80° to the direction of the main flux in the natural course, only a relatively small part of the flow of water and sediments from the natural course enter the cut-off canal. Consequently, the cut-off canals at the meanders M1 and M3, where the flow velocity is very high, are strongly eroded and their depth increased significantly while in the cut-off canal at the meander M2 no strong scouring processes are registered.

Bedforms are dynamic sediment accumulations occurring on a channel bottom, being scaled to the flow velocity and channel depth [78] and also depending on

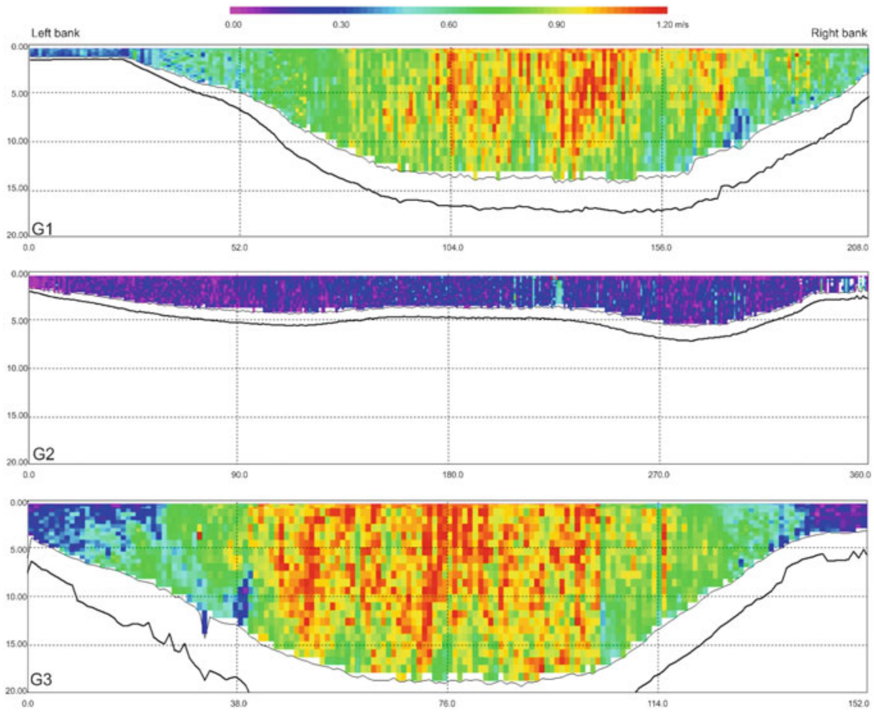

Fig. 6 Distribution of local velocities magnitude within cross-sections measured with the ADCP at the downstream confluence (profiles G1, G2, and G3) in June 2017

the texture and abundance of sediments. Various bed-form classification nomenclature for bottom sand beds are found in the literature [78–82]. Here, van Rijn's classification is applied (ripples, mega-ripples, and dunes).

The ripples, mega-ripples, small and large dunes are the most common bedforms identified along the canals. The most important factors which depend on their formation are the flow velocity, the depth of the channel, and the texture of sediments.

Ripples are primary bedforms with heights up to a few centimeters (length, $L < 0.6$ m, $H < 0.7$ m). Mega-ripples are bedforms with a length similar to water depth [80]. The water depth of the St. George branch ranges from 2 to 27 m. Consequently, mega-ripples are defined here by $L < 25$ m and $H < 1$ m. Mega-ripples have been identified all along the three cut-off canals, being the most common bedform in the study area. Mega-ripples have been measured as independent forms, or as superimposed bedforms on dunes. The measured mega-ripples dimension was between $1 < L > 25$ m and $0.5 < H > 1$ m [72].

Successions of small dunes with a height between $1 < H > 1.5$–2 m and lengths between 20–$30 < L > 400$ m are situated especially at the bifurcation (A1-A2-A3, K1-L2-L3) and confluence areas (G1-G2-G3, K1-K2-K3, N1-N2-N3). Mega-ripples were identified on the surface of all small dunes. Large dunes are quite rare, typically

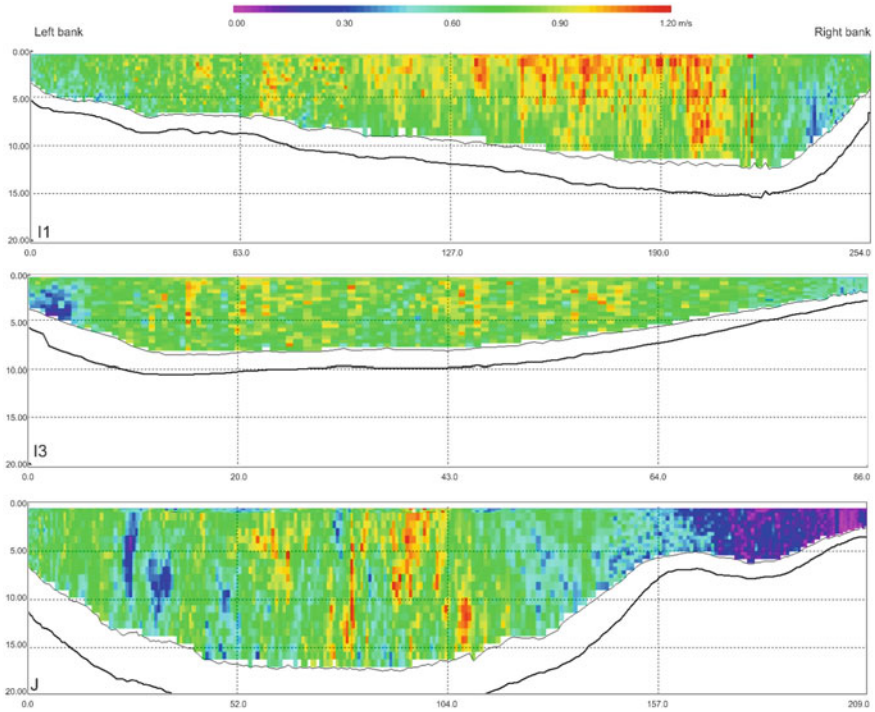

Fig. 7 Distribution of local velocities magnitude within cross-sections measured with the ADCP at the upstream bifurcation (profiles I1 and I3) and at the apex of the former meander M2 (profile J) in June 2017

greater than 400 m in length and higher than 2 m. A large dune was measured at the confluence of the M1 meander belt, measuring more than 7 m in height and more than 500 m in length (Fig. 13).

4.3 Suspended Sediment Concentrations and Sediment Fluxes

The suspended sediment load of a river varies in concentration over time and depends primarily on the precipitation regime in the river basin, the lithology of geological formations and soils within the basin but also, in the same time, on the anthropogenic factor. Most of the sediment load transported by rivers has as source the erosion of soils and geological formations. The anthropic activity (especially building, agriculture, industry) can also introduce significant amounts of sedimentary, but also dissolved fractions. In most cases, the distinction between the fraction due to the

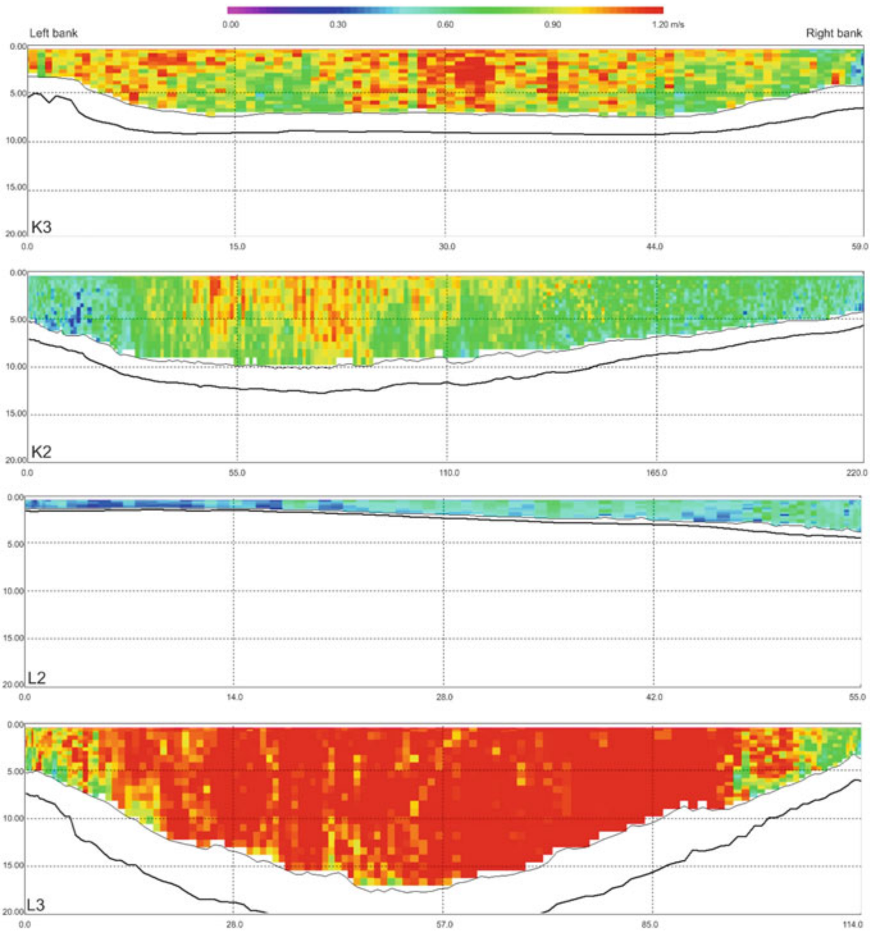

Fig. 8 Distribution of local velocities magnitude within cross-sections measured with the ADCP at the confluence of M2 and bifurcation of M3 (profiles K2, K3, L2, and L3) in June 2017

natural processes and an anthropogenic fraction is very difficult or even impossible to achieve.

Suspended sediment load represents over 80–85% of the total sediment load transported by rivers to the Sea [83]. Attention will be focused on the study of suspended sediments load concentration and suspended sediment discharge. The bedload transport is not included in the calculations of this chapter but is generally estimated as about 10% of the total sedimentary load for most of the rivers [84].

We estimated the discharge of suspended sediments by a common formula described in the literature [85, 86], which is based on correlating the concentration in suspensions with water velocity and section area (the water discharge):

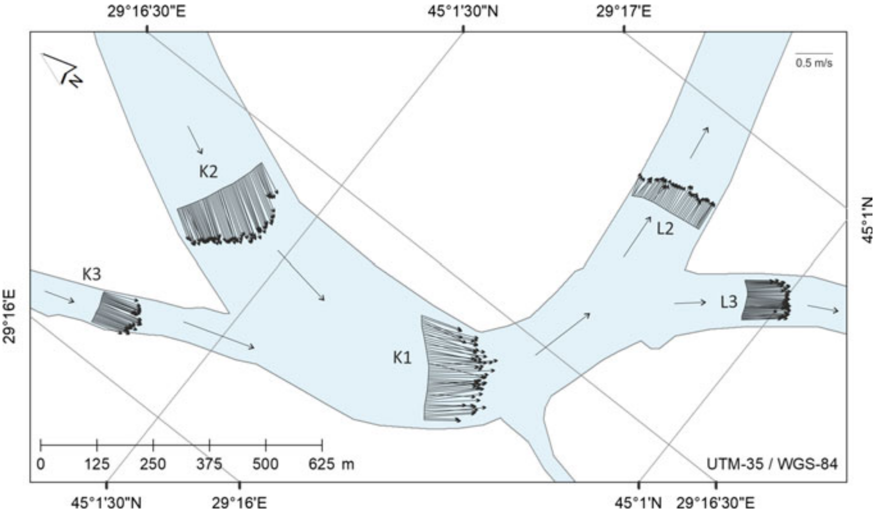

Fig. 9 Depth-averaged flow velocities (black arrows) at the bifurcation and confluence area of the M2 and M3 cutoffs in June 2017

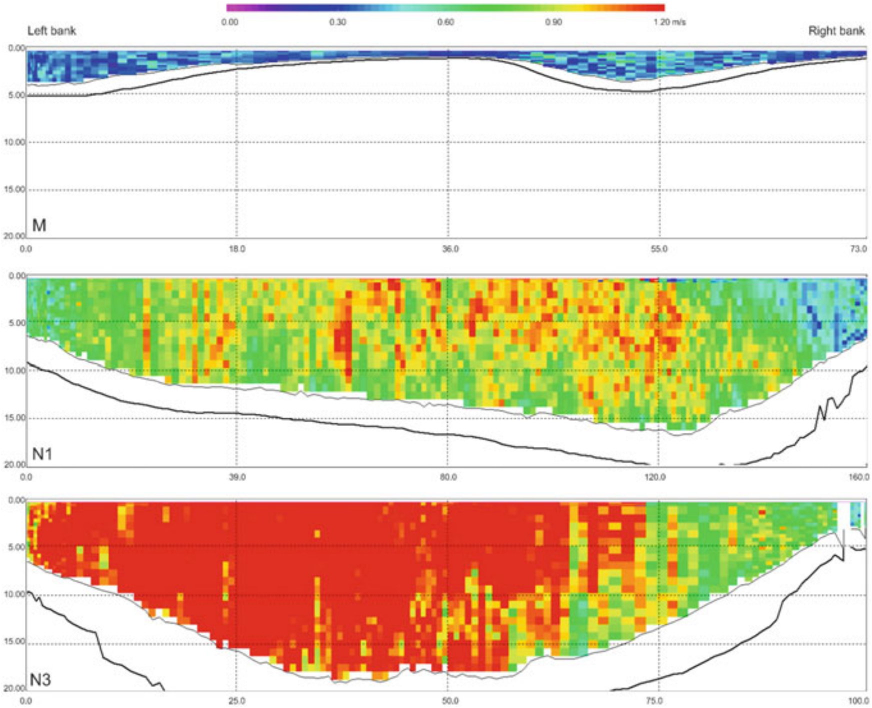

Fig. 10 Distribution of local velocities magnitude within cross-sections measured with the ADCP at the downstream confluence (profiles N1 and N3) and at the apex (profile M) of the former meander M3 in June 2017

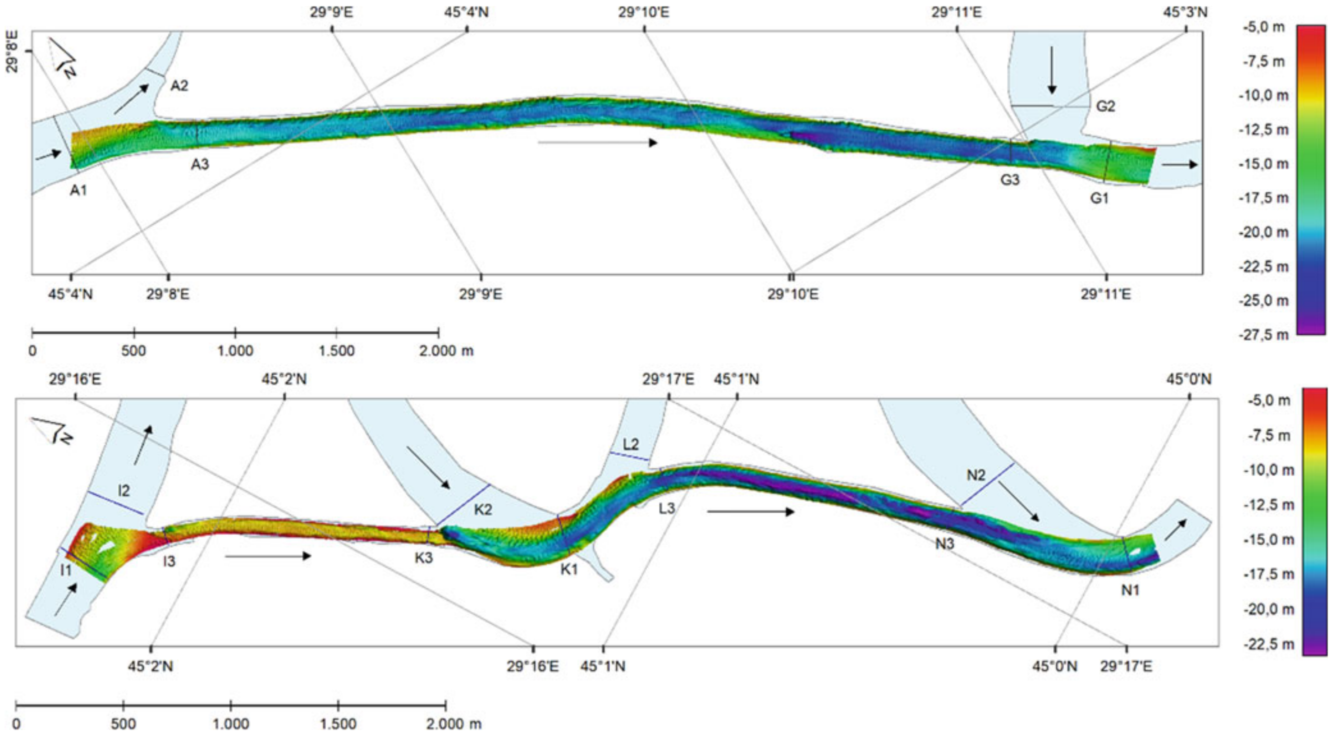

Fig. 11 Morphology of the artificial canals of the M1, M2, and M3 meanders in September 2016

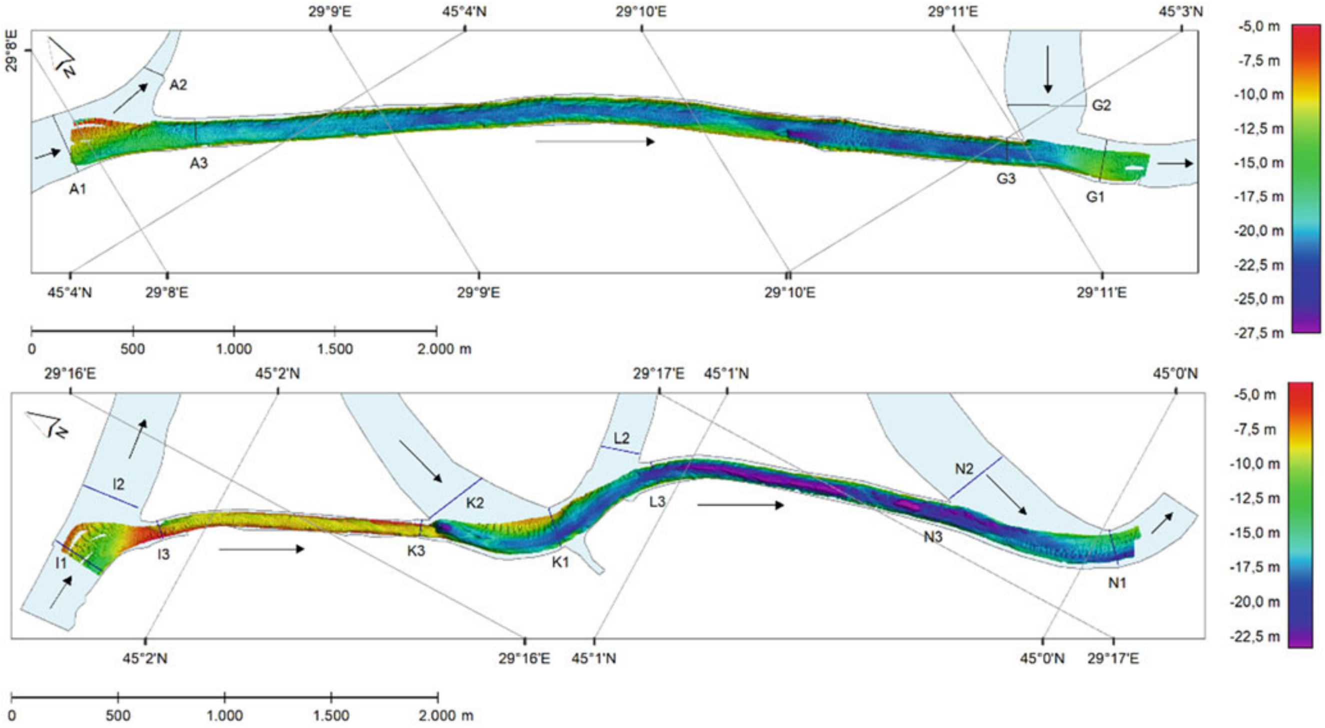

Fig. 12 Morphology of the artificial canals of the M1, M2, and M3 meanders in June 2017

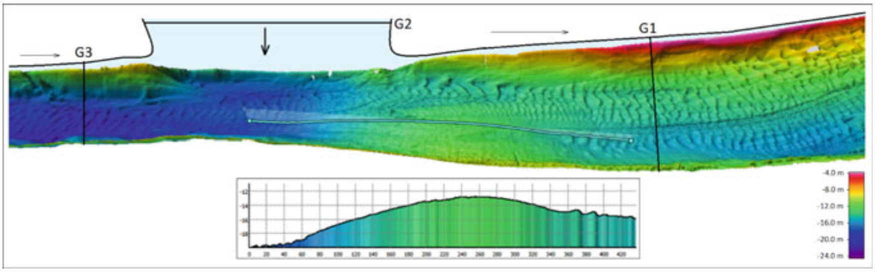

Fig. 13 Large dune situated at the confluence of M1 cut-off

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

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

The concentrations of suspended sediments (SSC) measured on the investigated sections range between 10.0 and 38.2 mg l^{-1}, in September 2016, and between 5.0 and 24.1 mg l^{-1}, in June 2017 (Fig. 14 and 15). These values are very low compared to values of the same type of other large rivers: for the Mekong (Thailand) average values of 962 mg l^{-1}, for Mississippi (USA) 849 mg l^{-1}, and even 8240 mg l^{-1} for Rio Grande (USA) [87].

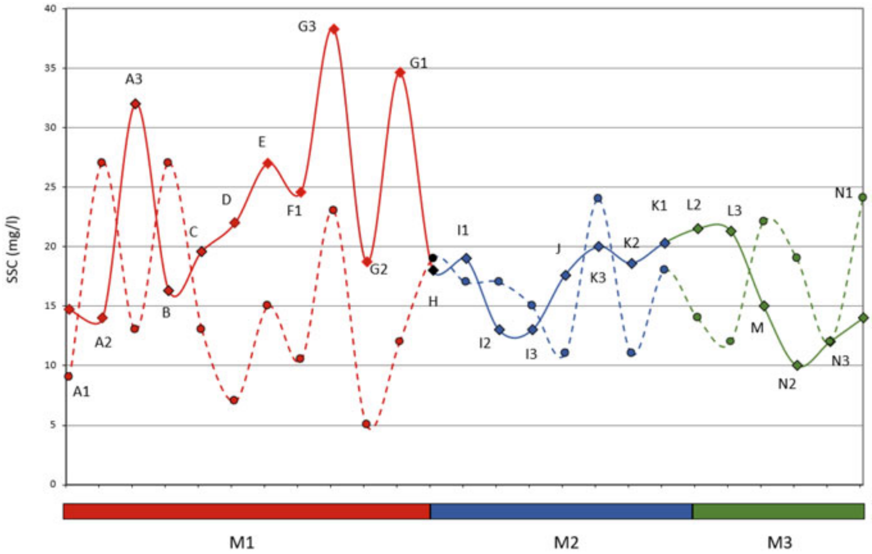

Fig. 14 SSC (mg/l) mean values within cross-sections of the meanders M1, M2, and M3 in September 2016 (continuous line) and June 2017 (dashed line)