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MULTI-YEAR DYNAMICS OF THE CHANNEL PROCESSES IN THE DESNA RIVER NEAR CHERNIHIV CITY

Channel deformations of the Desna River near Chernihiv city were analyzed based on field studies and analysis of various temporal cartographic materials and space images. The hydrological regime of the river is characterized by intensive channel processes, which can be rather hazardous for the functioning of residential and economic infrastructure. Today, there is a rather worrying situation on the northeastern outskirts of Chernihiv city, where the channel meander is at the final stage of its development and in the period of the nearest high floods, the formation of a straightening duct and the transformation of the meander into a flood channel is possible. As a result, the river, which flows directly along the city outskirts and widely used for recreational purposes, will become several kilometers away from the city. Based on the study of the hydrological regime of the river, quantitative assessment of the morphological parameters of the river, and the nature and intensity of the transformation of the meander over a long period as well as the forecast of the development of the meander for the coming years were made. Measures to stabilize the conditions of the river channel were proposed.

Key words: river, channel deformations, channel processes, meander, morphological parameters, hydrological regime

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INTRODUCTION

The Desna River is the longest and second by the basin largest tributary of the Dnipro River. It flows into the Dnipro River in a distance of 920 km from its river mouth from the left bank. The total length of the river is 1130 km, of which 591 km is within the borders of Ukraine. The area of the basin is 88,900 km² (Surface water resources, 1971). The hydrological river regime is characterized by a high transport capacity of the stream and the presence of intensive channel processes along almost its entire length.

Channel processes (CP) are the result of the interaction of the hydrological regime of the flow, the bedding surface, and limiting factors, each of which, in turn, depends on several mutually influencing factors of the natural and artificial nature. The nature and intensity of channel deformations in certain river sections depend on the interaction of individual factors of CP (Kondratiev N.E. et al, 1982; Kozytskyi O.M., 2011). Variety of natural conditions and existence of a wide floodplain cause different channel deformations. The meso- and macroforms are formed in the process of transportation, which together with the limiting factors of the channel processes determine the morphological type of the channel and valley along its entire length. The dependence of sediment transport conditions and channel forms of sediments on the hydro-

lic regime of the river (which is determined by the changes in the slope of the river channel), as well as changes in the width of the channel floodplain, cause a great variety of forms of channel processes along the river. The change in the quantitative parameters of the main factors of RCP and the conditions of their interaction in different morphological sections of the river channel determines the formation of river channel types with different transportation conditions and the processes of river channel formation developing by their laws. Despite a large number of studies, starting from Thomson, 1877; Kümmel, 1895; Davis, 1903, Bowman, 1904 and up to the latest studies, the results of which were summarized in the works of Gao and Li, 2023; Kleinhans et al, 2023; Finotello et al, 2024, the processes of meander formation still remain insufficiently studied. Verification of existing conceptual and empirical models of meander formation processes requires both data on long-term field measurements on the rivers of various hydromorphological conditions, and the results of studies of long-term morphological dynamics of river channels based on new remote sensing techniques when using multi-temporal satellite images with very high temporal and spatial resolutions (Nicola Surian, 2012).

Almost all types of channel processes are found on the Desna River; the predominant ones are free and

incomplete meandering, characterized by full development of meanders on floodplains and incomplete cycles of forming straightening ducts. *Figure 1* shows a system of 7 meanders located on the 127–150 km section of the river. The two central meanders are developed by the classic scheme of free meandering. At the same time, the upper meander has already been broken long before the formation of the loop, and the 3 lower meanders are developing due to the erosion of the top of the meanders and the increase in the length of the channel. The width of the meander belt has increased from 1,685 m to 2,472 m since 1943, and the meander wave (the distance between adjacent knick points) remained constant. The erosion of the concave bank is more than 400 m, and the erosion intensity is more than 6 m/year. In the period of high floods, when the floodplain is inundated greatly, the formation of a straightening duct is possible in this area without forming a loop and breaching the land bridge.

In some areas of the river valley, the processes of deformation development are dominant in the form of floodplain multi-arms, with the typical presence of ducts straightening groups of meanders. Less often, mainly in the places where the floodplain narrows, there are processes of limited meandering, characterized by meander sliding down the river while preserving their size and shape.

In the meandering areas, channel deformations are manifested in the form of erosion of the concave

bank (especially meander tops), the increase in the width of the meandering belt, sediment accumulation near the convex bank, the sliding of river bars and reaches, which cause the change in the shape and size of the meanders, the erosion of land bridges and the formation of straightening ducts and river dead arms (Daus M. E., 2017). The average intensity of deformations (bank erosion) is about 3–4 m/year, and the maximum one exceeds 10 m/year (State of technogenic and natural safety of Chernihiv region in 2021). Straight sections of the river are characterized by relatively high stability and prevailing processes of reverse vertical deformations, the maxima of which are mainly timed to high floods. Exceptions are straight sections of the river channel with high sandy banks not fixed by vegetation, where spatial deformations are caused by bank caving with subsequent sand avalanches, wave processes, and water-saturated sand avalanches during periods of sharp fluctuations in water levels. The processes of sediment accumulation and the formation of channel shapes in the form of side heads, river bars, and low islands are typical for extending straight sections of the river channel. The transportation of bottom sediments occurs mainly in a structural form (movement of meso- and microforms) and an unstructured form in the deepest sections of the cross-section of the river channel.

In addition, in connection with recent climatic changes and a decrease in river water content, accu-



Fig. 1. Meandering section of the Desna River between the villages of Lebedivka and Nadynivka

Explanation to the figure: The red line is the contour of the meander as of 1943, the purple line is the contour of the meander as of 2021

mulative processes (sediment deposition) have intensified in the Desna River channel due to the absence of high floods, which provide the necessary hydraulic conditions for transporting sediments to the Dnieper River channel. All this led to significant shallowing of the river and deterioration of navigation conditions.

The purpose of the work is to assess the channel processes of the Desna River near the city of Chernihiv, to develop organizational and engineering measures to stabilize channel deformations, as well as to improve the ecological state of oxbow-type floodplain water bodies that have undergone significant degradation.

Research methodology. The study of the dynamics of channel deformations and determining the mechanism and directions of the development of channel forms of the Desna River were performed based on in-situ hydrometric measurements of the channel and channel forms along the entire length of the channel meander in the period 2019–2021, as well as a comparative analysis of topographic maps and space images. The quantitative assessment of vertical channel deformations is based on analyzing combined longitudinal and transverse channel profiles made in different years of research (Shevchuk S.A. et al, 2015). The evaluation of the scale and intensity of spatial channel deformations, in particular the erosion of the bank line and the development of meandering processes, was performed based on a comparative analysis of large-scale topographic maps of various times M 1 : 250,000 (1941–1953); M 1 : 100,000 (1951–1991), electronic landscape maps of Ukraine M 1 : 100,000 (2000–2021); Earth remote sensing data using the ArcMap 10 program in the WGS_1984/ UTM_Zone_36N coordinate system and the 2000 SRTM_90 digital relief model with an altitude accuracy for M 1 : 25,000 maps.

Static and kinematic methods of GPS observations were used when piloting water bodies to ERS digital materials and determining their coordinates. Piloting gauging sections was performed by determining their geographical coordinates using a GPS station. Determining the depths greater than 1 m was performed using an echo sounder. The river depth was determined with a leveling rail along the bank line to 1 m depth and in shallow areas. River depths within the water area were determined depending on the configuration of the river bottom by an echo sounder near the bank line and turning points of the channel profile in 1–2.5 m, and in the middle part in 2.5 m.

DYNAMICS OF A CHANNEL MEANDER

Channel meanders are at different stages of their development. Regular processes of meander development dynamics are often disturbed by anthropogenic factors that sometimes create problems for economic

activities and settlements, located on the floodplain. The development of spatial deformations can often be dangerous for the functioning of the established infrastructure, so implementing complex technical measures is necessary to prevent the negative consequences of deformation manifestation. Today, a similar situation has developed near the Bobrovytsia micro-district on the northeastern outskirts of Chernihiv city. The channel meander is at the final stage of its development there, and the formation of a straightening channel and the transformation of the meander into a floodplain inlet are possible during the nearest high floods. As a result, the river, which flows directly along the city outskirts and widely used for recreational purposes, will become several kilometers away from the city.

For the section of the Desna River near Chernihiv city, the prevailing type of channel process is incomplete meandering, but the meander in the study area is developing by the typical scheme of free meandering, which is characterized by all stages of meander development: from a relatively straight channel (formed as a result of breaching the previous meander loop) to the sinusoidal loop, its further deformation and elongation, with a gradual decrease in the width of the land bridge and breaching the loop with the formation of a river dead arm. The width of the floodplain here exceeds 10 km, and the slopes of the valley do not limit the spatial development of the meander. There are numerous canals, backwaters, and lakes of oxbow-type on the floodplain, which indicates the intensity of meandering processes in the past. Spatial channel deformations here are very uneven, which is largely due to different stages of meander development.

The meander in the area of the Bobrovytsia micro-district (*Fig. 2*) is at the final stage of its development. Its formation occurs due to the aggradation of the right bank at the meander mouth, erosion of the opposite left bank in the area of the land bridge, erosion of the left bank before the meander top, aggradation of the bank line water area near the opposite right bank (with the formation of an island), as well as the erosion of the meander top itself. That leads to its elongation and unfolding around a fixed point in the area of the knick point with the adjacent meander located downstream. Erosion occurs mainly during high floods, and aggradation occurs in low-water periods and during the flood decline. Similar but opposite processes are developing on adjacent meanders, the tops of which are oppositely directed. All this leads to constant erosion of the land bridge and will result in its inevitable breaching in the future.

At present, the length of the meander (the distance along the forewater between the knick points) is 3.2 km,



Fig. 2. Meander of the Desna River in the Bobrovytsia microdistrict of Chernihiv city

the width of the meandering belt is about 3 km, the width of the land bridge in the narrowest place is only 155 m, the width of the meander in the middle part is 140 m. Erosion of the left bank and aggradation on the right bank of the upper wing of the meander and aggradation of the left bank and erosion of the right bank on the lower wing of meander create the effect of the meander sliding downstream.

The dynamics of the meander development over the past century and a half can be traced based on a comparative analysis of topographic maps and space images. Fig. 3 shows combined maps of the meander section — a map of the second half of the 19th century and a modern topographic map. Fig. 4 shows a military topographic map of 1941, a map of the General Staff of 1989, and a modern space image. In the presented images, we can see the transformation of the meander shape from sinusoidal (almost symmetrical regular shape) with a wide land bridge to an elongated, extended, and loop-like one with a narrow land bridge.

To quantitatively assess the meander dynamics and changes in its morphological parameters, the combined profiles of the meander different years are shown by lines in different colors. Over more than a century and a half, the meander shifted downstream

by 690 m, the width of the meander (the distance between the same-name banks of the opposite wings of the meander) decreased from 1050 m to 635 m, the width of the meandering belt increased from 2200 m to 3050 m. The length of the meander (the distance between the knick points of the meander) grew from 2370 m to 3245 m. A rather significant decrease in the intensity of channel processes in recent years is primarily due to the absence of high floods and a long low-water period in the last decade. For this period, there was a minimum runoff for the historical period. The lowest river levels were recorded in the low-water period in 2015 and 2019. The main meander parameters for different years are given in Table 1.

Presented in Fig. 5, the combined contours of the meander for the period since 1868 demonstrate the intensity and nature of changes in the parameters of the meander top and its position. Intensive development of channel processes and the meander mainly occurs during high floods. Since 1970, high floods have not occurred on the Desna River, but despite this, the meander continues to develop even now. Fig. 7 and 8 show the dynamics of the development of the meander top for the period from 2007 to 2012 and 2018. Pictures taken only in the low-water period, where there



Fig. 3. Combined 19th-century and modern topographic maps of the studied area (modern contours of the meander are shown in blue)



Fig. 4. Topographic maps of 1941 (a), 1989 (b) and a modern space image (c)



Fig. 5. Combined meander contours since 1868 (blue line — contours of 1868; yellow — 1941; red — 1989; green — 2018)

Table 1. Morphological parameters of the meander and characteristics of its development compared to 2019

Year	1860	1941	1989	2019
Meander sliding distance, m	690 (1860–2019)	300 (1941–2019)	35 (1989–2019)	—
Meandering belt width	2200	2600	3000	3050
Meander width, m	1050	890	700	635
Meander length, m	2370	2650	2800	3245
Channel width, m	95–300	95–170	90–220	85–180
Land bridge width, m	670	560	240	155

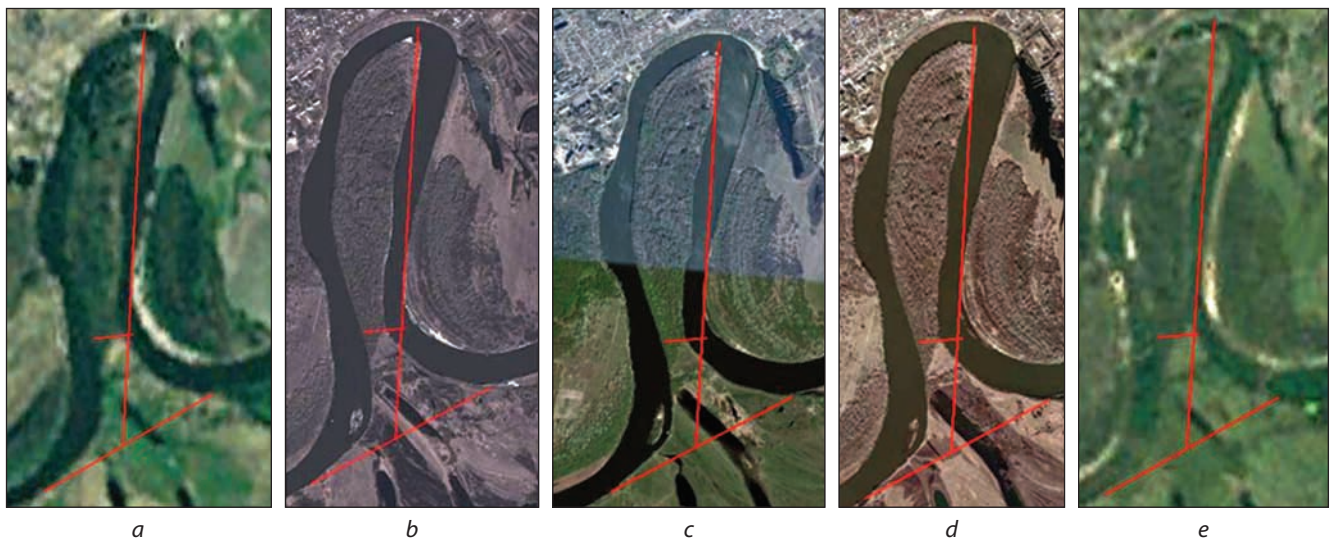


Fig. 6. Dynamics of meander development in recent years: *a* — 1984; *b* — 1998; *c* — 2011; *d* — 2015; *e* — 2017 (the position of the red lines is fixed on the map)



Fig. 7. Space image of the convex bank of the meander top as of July 24, 2018 ($H=103.98$ m BES)

Explanation to the figure: The red line is the contour of the meander top as of July 27, 2007 ($H=104.19$ m BES); the purple line is the contour of the meander top as of October 3, 2012 ($H=103.88$ m BES); yellow line is erosion width for 2007–2018.

were low water levels, were used to ensure the reliability of the assessment. In 2007, the level was 31 cm higher than in 2012 and 21 cm higher than in 2018. Analysis of the figures shows that the width of erosion of the left meander bank before its top for the first five years was 16 m, and in subsequent years, it increased to 26 m (yellow line in *Fig. 7*). The erosion area before the meander top is shown in *Fig. 9*.

Simultaneously with the erosion of the left bank before the meander top, the sand spit aggradation occurred behind it (*Fig. 9*) with a width of about 10 m. The specified erosion is primarily caused by relatively high flood flow rates during floods in 2010 ($843 \text{ m}^3/\text{s}$) and 2012 ($710 \text{ m}^3/\text{s}$). The slip of the meander top can be seen in *Fig. 10*, where a red line with fixed coord-

inates is drawn on space images of different times. The width of the channel before the meander top has increased from 195 to 221 m since 1994 (excluding the width of the newly formed island and the sandbank on the right bank). Because the island width is 87 m, the width of the channel at the low-water period has decreased by 61 m. The erosion width of the meander top on the right bank has increased by 15 m compared to 1985.

The total cycle of the meander development ends with breaching the land bridge and forming a straightening channel and a river dead arm at the place of the meander itself. The studied meander has passed all the formation cycles and is currently at its final development stage. Breaching the land bridge will have extremely negative consequences for Chernihiv city, as the river will move away from the city by a distance of more than 1.5 km. Over the past 150 years, the width of the land bridge has decreased from 670 m to 155 m (*Figs. 11 and 12*), and since 1984 — by 90 m. At the same time, the opposite right bank was aggraded to a width of about 13 m. Even in the absence of high floods since 2007, the width of the land bridge decreased by 28 m. The intensity of the land bridge erosion for the last 160 years is 3.3 m per year; for the period from 1941 to 1989 it was 6.7 m/year, and for the last 30 years, it was 2,8 m/year.

Explanation to the figure: The horizontal red line is the channel width in 2007; the purple line is erosion of the left bank before the meander top; the green line is left bank aggradation behind the meander top.

The left bank was strengthened with a stone facing at the beginning of the meander near its concave bank (in the section of the land bridge), and three



Fig. 8. Satellite images of the meander section in 2007 (a) and 2017 (b).

Explanation to the figure: The horizontal red line is the channel width in 2007; the purple line is erosion of the left bank before the meander top; the green line is left bank aggradation behind the meander top; (to compare the dynamics of the meander since 1985, a vertical red line was drawn from the right bank of the top of the meander in 1985)



Fig. 9. Erosion of the left bank before the meander top and aggradation behind the meander top



Fig. 10. Slipping the meander top: a — 1985; b — 2007; c — 2017

short bank protection spur dikes were also arranged to prevent the land bridge erosion (Fig. 13). That made it possible to stabilize the bank line and prevent the breaching of the land bridge. As the space images show, the bank protection structure was built in 2008 (in the 2007 image (Fig. 13 b), it was not yet there). By

2012, the spur dikes were partially destroyed (Fig. 13 c), but by that time they had already fulfilled their function, provided bank protection. Today, the spur dikes have been almost destroyed, and only the lower one is partially saved (Fig. 13d). The condition of the bank protection structure is satisfactory today, but its length

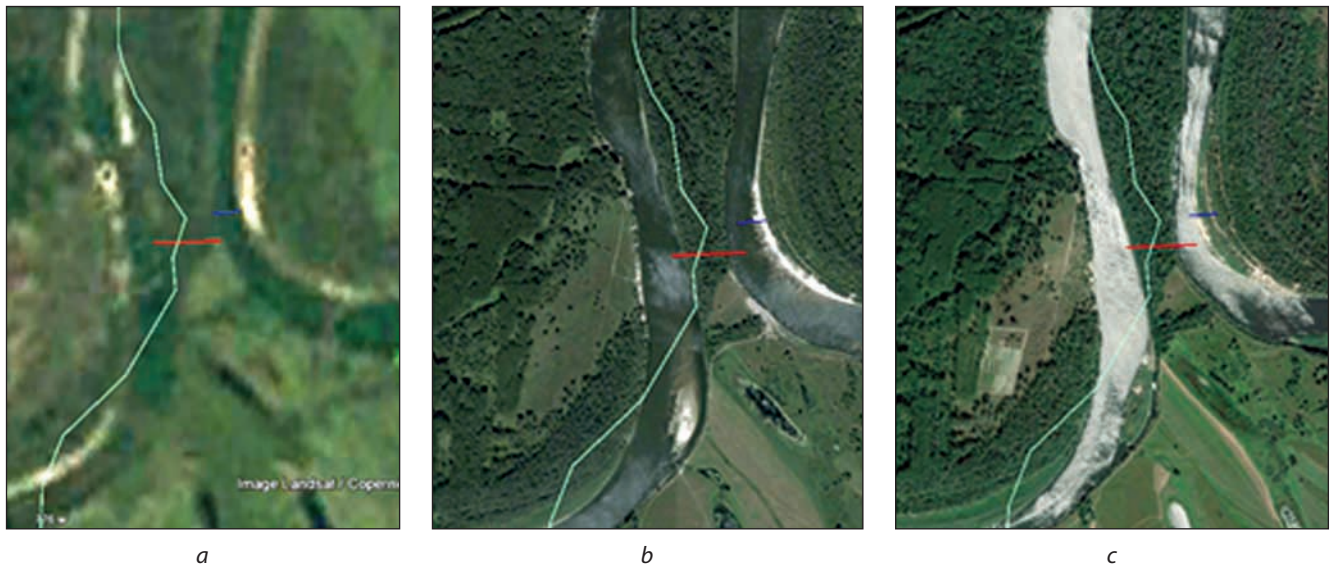


Fig. 11. Erosion of the meander land bridge from 1984 to 2017: *a* — 1984; *b* — 2007; *c* — 2017

Explanation to the figure: The red line is the width of the land bridge in 1984; the blue line is the aggradation of the opposite to the land bridge, right bank.



Fig. 12. Combined contours of the left bank of the meander in the section of the land bridge

Explanation to the figure: red line — 1985; green line — 2007; blue line — 2020. The thick brown line indicates the required length of the bank protection.

is not sufficient. After the bank protection structure (downstream), intense bank erosion continues.

The width of the bank erosion after the bank protection structure is 13 m (Fig. 14). After the section of stone facing, the bank was partially reinforced with concrete slabs, but they were destroyed and do not perform a protective function today (Fig. 15). Stabilization of the land bridge section as a result of the completed bank protection, as well as the bank erosion downstream of the bank protection structure, caused the displacement of the land bridge. Today, its narrowest point is not at the meander mouth but downstream, where the most intensive bank erosion

processes are observed. The bank here is sandy, steep, almost vertical, and strongly eroded, with a height of about 5 m. Intensive bank erosion is largely restrained by the well-developed root system of trees and shrubs (Fig. 16). To prevent further erosion of the bank and a possible breaching of the land bridge during intensive floods, it is necessary to extend the bank protection along the entire length of the left bank of the meander in the section of the land bridge, i.e. for a distance of about 200 m. The area of the necessary bank protection is shown in Fig. 12.

As a result of the intensive deposition of sediments just before the meander top near the right bank, a sandbank with an overwater part almost 90 m wide (in the low-water period) was formed, which, as a result of the formation of a shallow channel (Fig. 17), turned into a sandy island (Fig. 18), at present overgrown with shrubs more than 2 meters high.

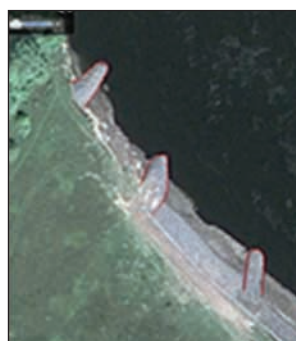
In Fig. 19, space images of the island are given in chronological order, on which the contours and parameters of the island in the low-water period of 2019 are drawn with red lines, which enables us to assess the intensity and mechanism of its formation. For analysis, only the pictures taken in the low-water period were selected. The maximum amplitude of the water level in the given pictures is 52 cm. The height of the island above the low-water level in September 2021 (103.37 m above sea level) was 2.08 m. The transverse profile of the left bank of the island in its middle part and the survey area are presented in Fig. 20. In 1985, the island did not exist yet, and the meander top (convex left bank) was only 26 m away from the current position of



a



b — 2007



c — 2009



d — 2012



e — 2020

Fig. 13. Bank protection on the land bridge of the meander (red lines show the initial contours of the spur dikes, as of 2009)



a



b

Fig. 14. Erosion of the bank beyond the bank protection zone



Fig. 15. Remains of bank protection with concrete slabs downstream the area of the stone facing



Fig. 16. Erosion of the land bridge downstream the bank protection area



Fig. 17. Channel between the island in the meander section: *a* — upstream; *b* — downstream



Fig. 18. Panorama of the island from the side of the boat station as of 2015 (a) and 2019 (b)

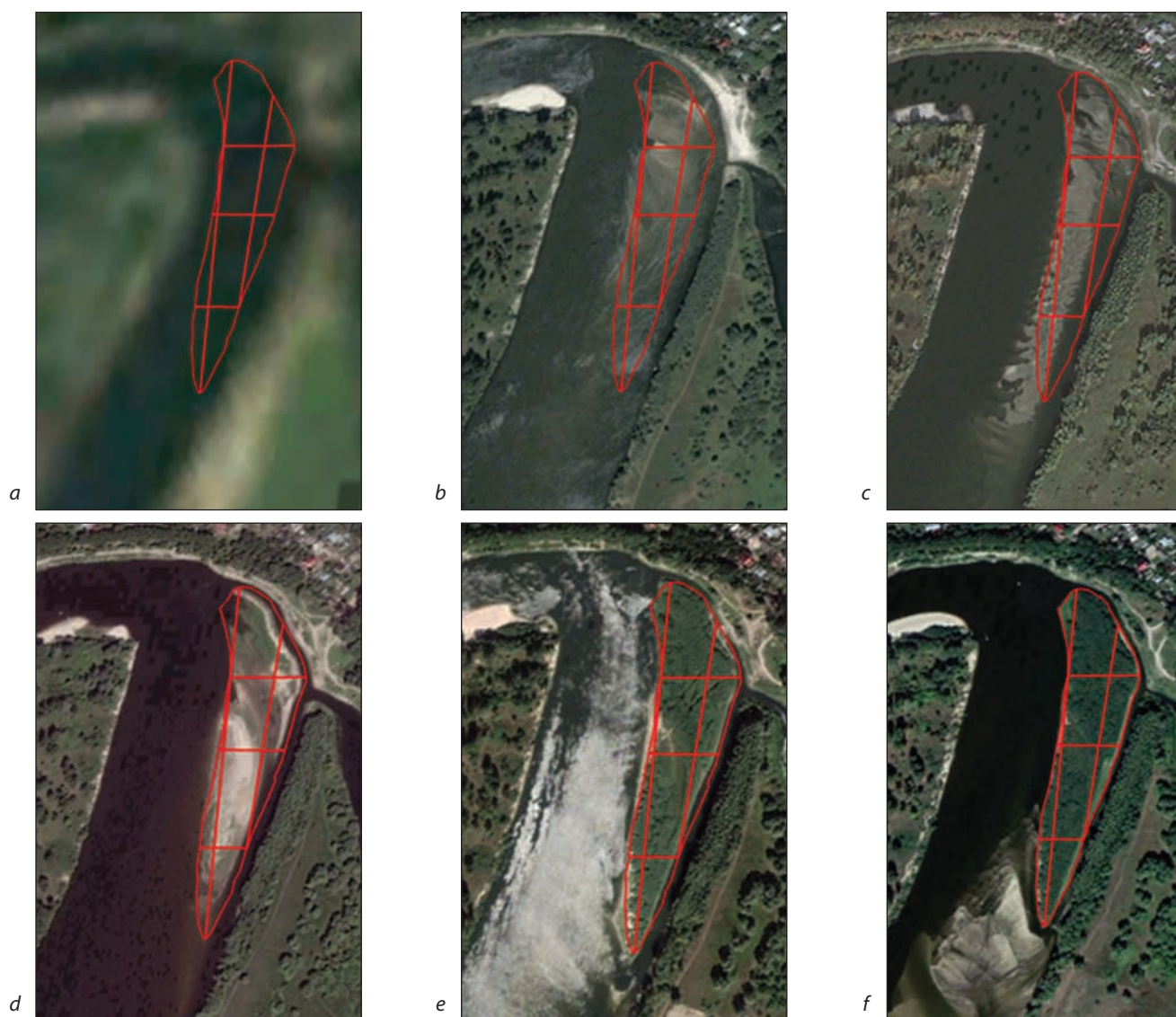


Fig. 19. Dynamics of island formation before the meander top: a — 31.12.1985; b — 27.07.2007, $H=104.19$ m BES; c — 03.10.2012, $H=103.84$ m BES; d — 08.06.2015, $H=104.22$ m BES; e — 20.08.2017, $H=103.70$ m BES; f — 19.08.2019

the island. In 2007, the formation of a sandbank near the right bank of the meander and a narrow channel along the bank was already visible.

In the low-water period of 2012, the contours of the sandbank became sharper, and the width of the channel increased. In the image of 2015, the island's contours became sharper, and its shape took on its current contours. In 2017, the island's contours became sharper, and its entire area was overgrown with shrubs. At the same time, the 2017 and 2019 images clearly show the formation of a wide sandbank before the island and along its upper part. There is also a shift of the fairway channel towards the left bank of the river.

The maximum amplitude of water level fluctuations in the studied area is 9.11 m, the average low-water level is 104.31 m above sea level, and the average annual water level fluctuation is 4.96 m. So, the island is inundated during floods almost every year. The height

of the island in September 2021 was 105.45 m above sea level, and the height of shrubs and trees on the island reached 3–5 m (Fig. 20). Fig. 21a–c show space images of the island during the floods of 2011, 2016, and 2013, when the water levels were 0.26 m, 1.4 m, and 3.39 m, respectively, and higher than today's levels of the island surface. The contours of the island cannot be traced not only during the high flood in 2013 (only the tops of tall trees on the right bank and in the area of the boat station are visible (Fig. 21c)) but also during the low floods in 2011 and 2016 (Fig. 21a, b), which indicates the absence of tree vegetation on the island in those years. That is also confirmed by a panoramic photo of the island taken in 2015 (Fig. 18a) at the canal outlet from the boat station. As can be seen from the picture, the island was not high; its height above the low-water level visually did not exceed 1 m. The absence of tree vegetation on the island in the photos indicates that the intensive increase in the

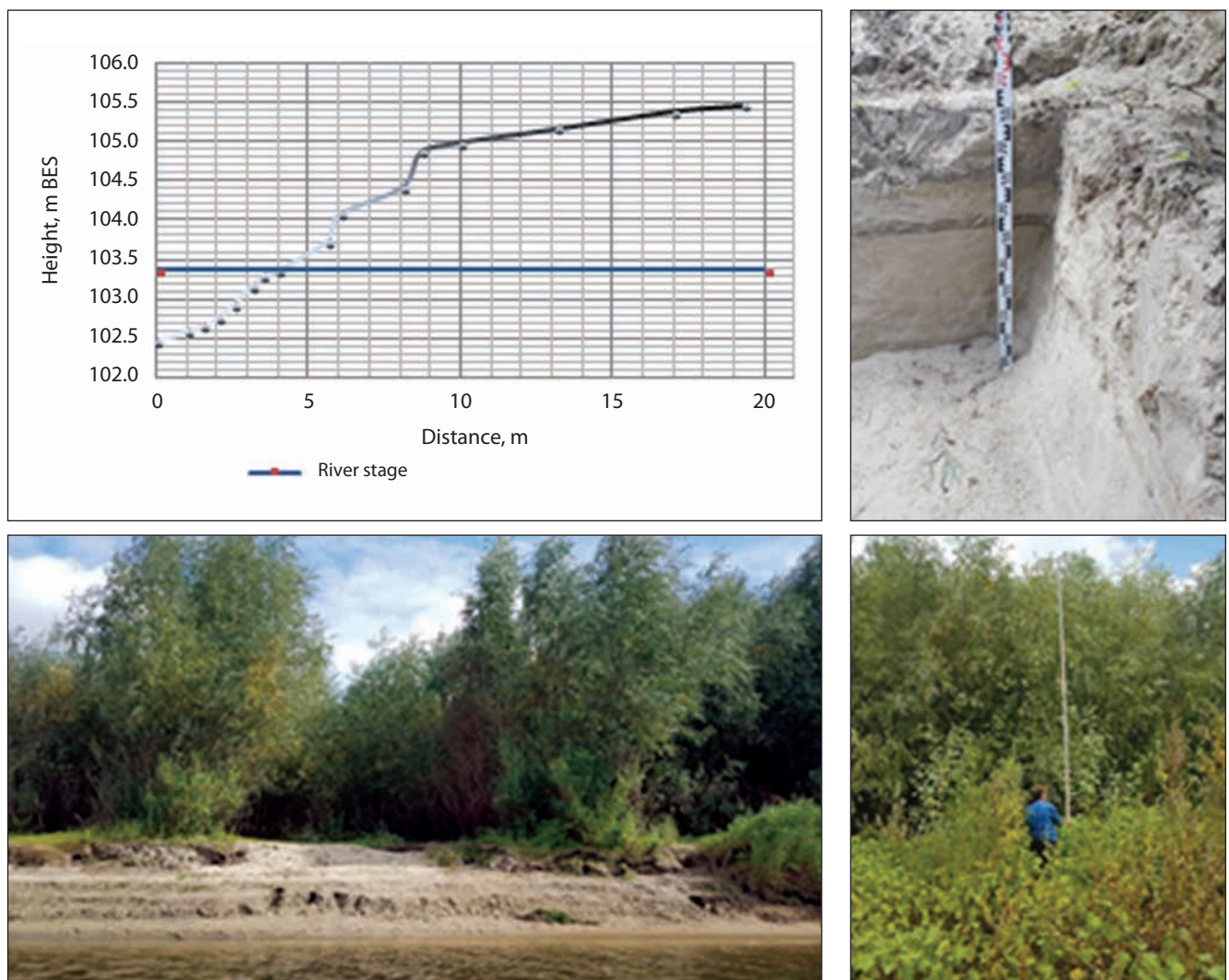


Fig. 20. Transverse profile of the island bank and cross section

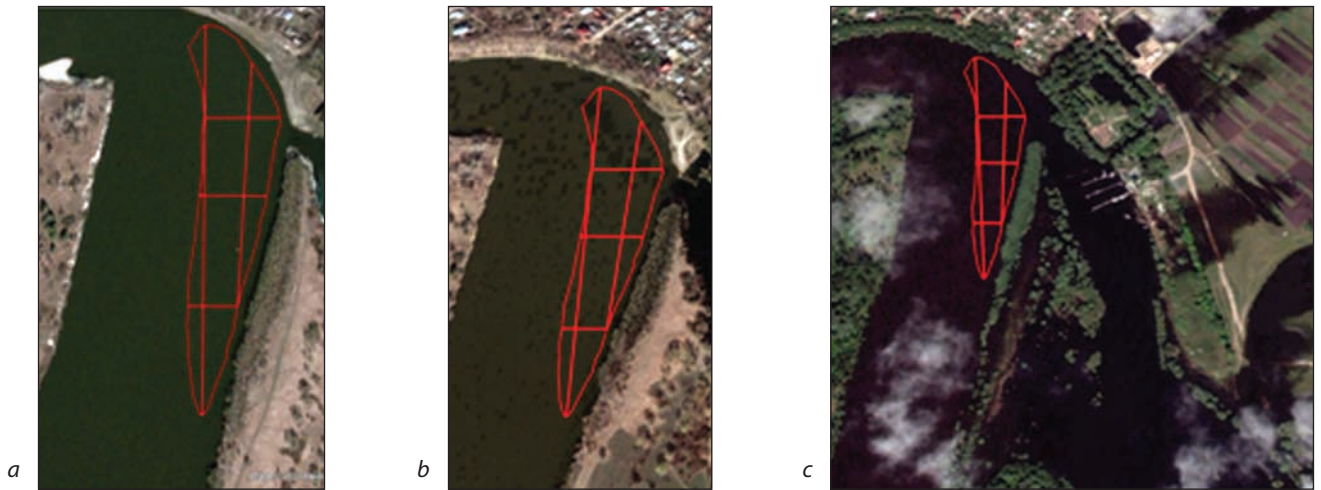


Fig. 21. Flooding of the island during floods: *a* — 03.04.2011, $H=105.71$ m BES; *b* — 05.04.2016, $H=106.85$ m BES; *c* — 15.05.2013, $H=108.84$ m BES

height of the island has been taking place since 2014 (Fig. 19d).

One of the main reasons for the intensive increase in the height of the island is dense vegetation, which sharply increases the roughness of the channel during floods and causes a sharp decrease in the speed of the flood flow at water levels exceeding the height of the island. Decreasing flow speed leads to intensive deposition of sediments not only on the island but also on its riverside water area.

The newly formed island, 450 m long, is only the visible above-water part of the accumulative sandbank, the length of which upstream from the island reaches about 300 m. Performed bathymorphic searches showed that the width of the sandbank reaches almost 150 m in the area of the upper wing, which is about 80% of the channel width. The width of the deep-water part of the channel with low-water depths greater than 1 m is only 35 m. In almost the entire studied area upstream the island in the central part of

the channel, the depths were 10–40 cm (Fig. 22). Along the upper wing of the meander, the flow is pressed against the left bank and the talweg is at a distance of 15–20 m from the low-water mark, which caused intensive erosion of the left bank (Fig. 23). In the section of the middle of the island, the fairway channel gradually moves to a distance of 70 m from the bank.

As a result of a sharp decrease in the channel cross-section there is a sharp increase in the speed of the stream flow, which, in turn, activates the erosion processes of the left bank and the accumulation of sediments in the middle part of the channel and along the right bank (Fig. 17b, Fig. 24), aggradation of the left bank near the meander top, as well as intensification of erosion of the right bank (from the city side) in the section of the meander top.

The surface velocity of the stream flow along the talweg was 1.3 m/s, which is more than twice as high as the maximum low-water velocity on straight sections. As mentioned above, the width of the erosion of



Fig. 22. Sandbanks on the Desna River within the boat station



Fig. 23. Erosion of the left bank of the Desna River to the top of the meander



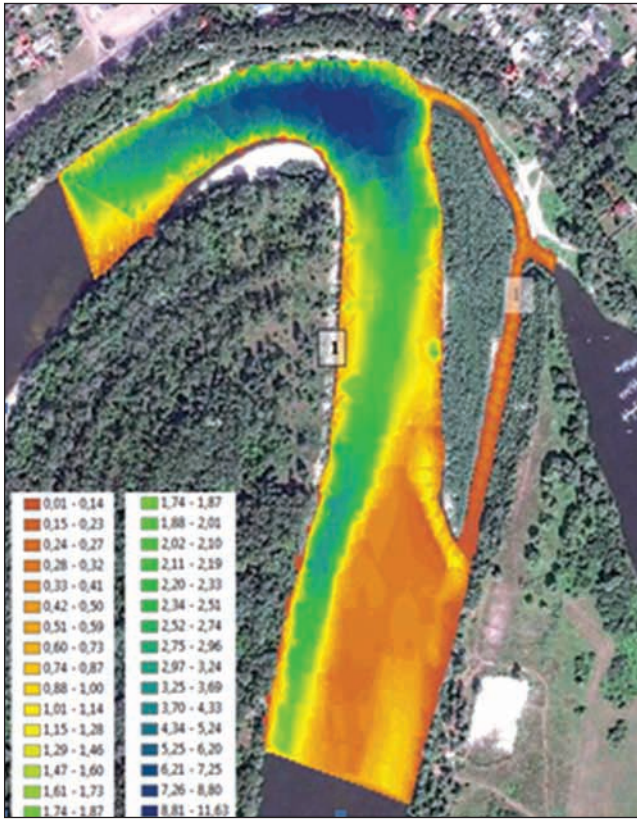
Fig. 24. Sand aggradation before the island

the left bank here is 26 m over the last 13 years. Active erosion processes along the bank are observed even now. A sharp increase in flow velocity due to decreasing the channel cross-section activates not only spatial deformations but also deep deformations. In the section of the meander top from the right bank side, the depth of the stream flow during the study period reached 11.6 m. Because the amplitude of river level fluctuations is almost 8 m, the depth of the stream flow during high floods here can reach 19 m.

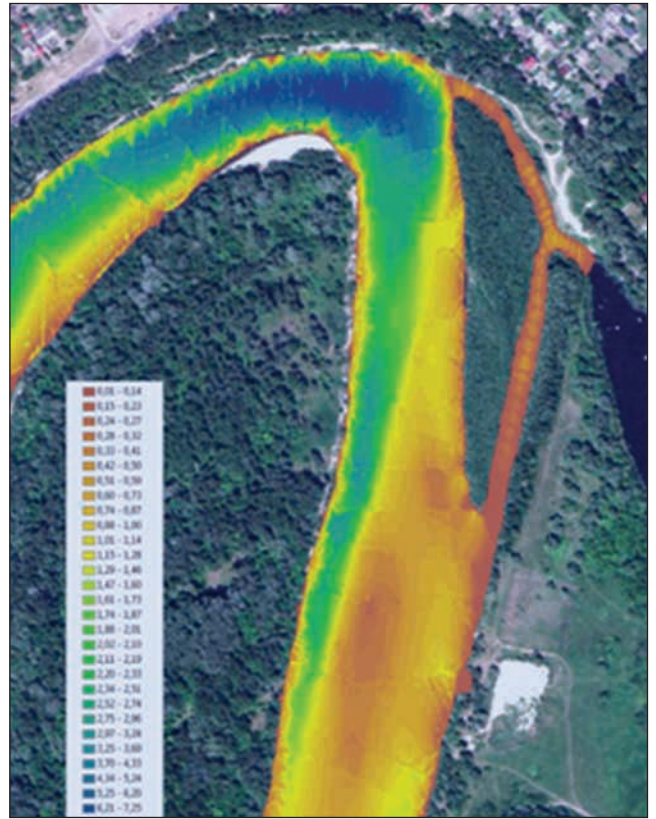
Determination of the bathymetric parameters of the meander and assessment of the channel dynamics in recent years were performed based on bathygraphic studies on July 11, 2019, and September 13–15, 2021. The water level during the study in 2021 was 103.37 m BES, which is only 2 cm higher than in 2019. That enabled us to perform a comparative assessment of depths and vertical channel deformations without making corrections for different water levels. The measurement results are given in *Fig. 25*, where stream flow depths are shown using the appropriate depth scale. The scheme of gauging sections is shown

in *Fig. 26*. It should be noted that the last two years were characterized by very low water content, low transport capacity of the river, and minimal channel deformations and sediment flow. Channel processes were mainly characterized by only slight transformation of bottom sediments and silt deposition.

The performed measurements showed that at the meander mouth, in the section of land bridge, the channel width changes from 180 m in the center of the meander to 140–100 m before its straight section. The analysis of the transverse profiles of the channel in the indicated area shows the shallowing of the channel near the right bank. Near the convex bank, a wide unflooded sand spit was observed, which gradually turned into shallow water (*Fig. 27*). The width of the shallow water zone, with a depth of up to 1 m, decreases along the section from 45 m in section 1 to 32 m in section 4. The shape of the channel here is gorge-like, with a gentle right and very steep left slope. The talweg of the channel, about 10–15 m wide in the section of the land bridge, is located at a distance of 10–15 m from the left bank (cross-section 1–3). The



a



b

Fig. 25. Maps of depth measurements (m) at the meander top on the Desna River: a — 11.07.2019; b — 13.09.2021

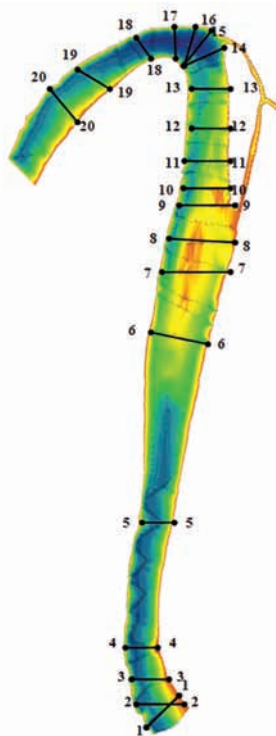


Fig. 26. Gauging sections of the upper wing of the meander on the Desna River



Fig. 27. Accumulative processes along the right bank at the beginning of the meander (section of the land bridge)

maximum depth of the channel is 5 m. Downstream the land bridge the talweg moves away from the bank by a distance of 25 m, and its depth increases to 6 m (Fig. 4). In general, the analysis of bathymorphic studies in the section of land bridge indicates intensive accumulative processes near the convex right bank and the shift of the river talweg towards the curved left bank in the section of land bridge. That, in turn, indicates a high probability of shifting the talweg directly to the left bank in case of intensive floods, which will inevi-



Fig. 28. Island in the middle part of the channel

tably lead to the bank collapse and possible erosion of the land bridge.

Further to the section of the land bridge, in the middle part of the upper wing of the meander, the channel acquires a trough-like shape with a steeper left slope. The width of the channel bottom increases to 65 m, the maximum depth decreases to 4.5 m, and

the sandbank near the right bank disappears (gauging cross-section 5). Further, downstream, 500 m away from gauging cross-section 5, the width of the channel increases by 60 m, the depth decreases sharply, and a sandy underwater island of 120 m wide and about 1 m high begins to form in the middle part of the channel. 2 talwegs with 1.4 and 1.6 m depth are formed in the channel (gauging cross-section 6).

Downstream, the width of the channel increased to 190 m in the distance of 350 m from the beginning of the island, and the main channel began to form near the left bank, with a depth of 2 m, as a result of that the height of the island increases. If in gauging cross-section 6 the depth in the central part of the channel was 0.6 m, then in gauging cross-section 7 it decreased to 0.2 m, i.e. it was aggraded by 40 cm. Downstream the underwater island appeared above the water surface (Fig. 28). Over the past 2 years, there was a significant accumulation of sediments near the right bank directly before the island. Aggraded sandbanks appear above the water's surface, blocking the canal near the island. If only an underwater side head was observed directly before the island and the canal in 2019 (Fig. 29a, b), then in 2021, accumulative depo-



a



b



a



b

Fig. 29. Sediment accumulation before the island: *a, b* — 2019; *c, d* — 2021

sits were visible above the water surface (Fig. 29c, d). The right-hand channel was filled with sand. The talweg of the channel shifts to a distance of 12 m from the left bank, and the maximum depth of the channel increases to 2.4 m (gauging cross-section 8).

In gauging cross-section 9, located near the island top, the main channel completely shifts to the left bank. Of the 200 m of the total width of the channel, 130 m is covered by a shallow zone with a depth of 0-0.4 m (excluding a narrow zone along the left bank of the island). The talweg of the channel shifts to the left bank for a distance of 8 m, and the depth increases to 3.4 m. The slope of the channel becomes almost vertical.

Near the island, the most intensive channel-forming processes were observed in the study area. Near the upper (downstream) section of the island, according to 2019 measurements, the talweg of the channel began to shift towards the middle of the channel (30 m away from the bank), the width of the deep-water part (more than 2.5 m) increased to 60 m, along the island left bank, a canal was formed with a depth of 1.5 m. Over the last two years, the maximum depth of the channel increased by 0.5 m, the talweg shifted to the left bank by 13 m, there were aggradation processes on the right slope, and the canal was almost choked up along the island. All this indicates intensive accumulative processes along the channel's right slope and erosion processes in the area of the talweg and the left slope of the channel. In gauging cross-section 11, approaching the meander top, the talweg continued to shift to the middle of the channel; the left slope of the channel became gentler. Accumulative processes have continued along the right slope in recent years, and the canal along the left bank of the island completely disappeared.

In the middle of the island in 2019, the talweg was located near the middle of the channel, but in the last 2 years, intensive erosion processes took place along the left slope of the channel. As a result, the width of the channel increased sharply, the left slope became steeper and shifted almost 25 m towards the bank. During the same period, accumulative processes took place along the right slope, which caused its partial decline.

In the area before the meander top (the lower part of the island) as of 2019 (gauging cross-sections 14, 15), the channel acquired an almost regular parabolic shape, with a talweg in the center. The maximum depth increased sharply to 8 m. In 2021, a partial shift of the talweg towards the right bank, the left slope decline, and the increase in the steepness of the right bank were recorded. In the center of the meander, the shape of the channel changed little, but the depth in-

creased to 12 m. In recent years, further erosion of the convex left slope has been observed (gauging cross-sections 16). Starting from the center of the meander top, the channel gradually became asymmetrical, the talweg shifted to the right bank, the left slope declined, and the right bank steepness increased. Over the past 2 years, at the meander mouth, the channel depth has increased by almost 1 m (gauging cross-sections 17). Further, after the meander top, the talweg of the channel shifted sharply to the right bank, the channel became sharply asymmetric, and the maximum depth decreased in gauging cross-sections 18 to 7.5 m and in gauging cross-sections 19 and 20 to 4 m.

In recent years large sediment accumulation before the island has significantly worsened the flow conditions and water exchange in the canal between the island and the right bank. That resulted in intensive siltation of the canal and the strait to the boat station, where the depth was about 0.2–0.5 m. That made it necessary to clear the lower section of the strait in 2021 to ensure the passage for boats from the boat station.

CONCLUSIONS

The regular natural processes of the meander development in the study area primarily manifest in the formation of a wide right-bank sand bank and channel narrowing, reduction of the channel capacity, shift of the river talweg, and the maximum flow speed towards the left bank and its intensive erosion before the meander top, retreat of the bank line, aggradation of the left bank near the meander top, as well as the erosion intensification of the right bank in the area of the meander top. In the future, this will inevitably lead to further erosion of the meander land bridge of the meander and the breakthrough of the loop. As a result, the channel will be straightened, the loop will die off, and it will turn into a river dead arm.

Taking into account that the width of the land bridge has been decreasing in recent decades with an average intensity of about 1 m per year and today is only 155 m (the length of the meander is 3250 m), its erosion and the formation of a new channel is possible during several high floods, or one flood of a low probability, similar to the floods occurred in 1917, 1931 or 1970. The meander top is located on the northeastern outskirts of Chernihiv city, and the river is a place of active recreation. In case of land bridge erosion, the river will move away from the city by more than 2 km. It is necessary to increase the river channel capacity by clearing it from accumulated sediments along the right bank of the upper wing of the meander, as well as by channel dredging and forming of a new chan-

nel fairway distant from the left bank at the meander mouth to reduce the intensity of channel processes in the area of the meander top, in particular, to prevent the erosion of the left bank before the meander top and the right concave bank near the meander top.

Cutting the island, clearing and deepening the right-bank sandbank, and forming a new fairway channel will ensure an increase in the channel area of the waterway and, accordingly, a decrease in the flow speed and its erosive capacity, as well as prevent a sharp fall of the flow to the left bank and reduce the intensity of its erosion. It should be noted that accu-

mulative sediments near the meander top and downstream the convex bank of the river should not be cleared, since these deposits are a source of sediment transportation to the opposite bank downstream and ensure its relative stabilization.

It is necessary to provide periodic monitoring of channel deformations (especially after high floods) to track the dynamics of channel forms and take timely measures to prevent negative processes of meander development in the future, in the case of dredging and bank protection works (Obodovsky A.G. et al, 2001; Kozytskyi O.M., 2011).

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БАГАТОРІЧНА ДИНАМІКА РУСЛОВИХ ПРОЦЕСІВ Р. ДЕСНА БІЛЯ М. ЧЕРНІГОВА

Річка Десна, на її українській ділянці, не зарегульована системою водосховищ та визначається значною транспортуною здатністю потоку і, відповідно, великими об'ємами твердого стоку. Для гідрологічного режиму річки є характерною висока інтенсивних руслових процесів, які часто розвиваються у напрямках, що небезпечні для функціонування усталеної житлової і господарської інфраструктури. На сьогодні склалася небезпечна ситуація на північно-східній околиці м. Чернігів, де руслова меандра знаходиться на завершальній стадії свого розвит-

ку і вже в період найближчих високих паводків можливе утворення спрямлюючого русла і перетворення меандри в заплавну протоку. В результаті річка, яка протікає безпосередньо вздовж околиці міста та широко використовується в рекреаційних цілях стане віддаленою від міста на декілька кілометрів. В результаті проведених натурних досліджень і аналізу різночасових картографічних матеріалів та космічних знімків виконано аналіз руслових деформацій р. Десна біля м. Чернігів. На основі дослідження гідрологічного режиму річки, кількісної оцінки морфологічних параметрів русла, характеру та інтенсивності трансформації меандри за багаторічний період, виконано прогноз її розвитку на найближчі роки, а також запропоновано заходи щодо забезпечення умов

стабілізації русла. Зокрема, для зменшення інтенсивності руслових процесів на ділянці вершини звивини запропоновано збільшити пропускну здатність меженного русла річки шляхом його розчистки від накопичених наносів вздовж правого берега верхнього крила меандри, а також проведення днопоглиблювальних робіт і формування нового фарватера русла, віддаленого від лівого берега на вході у звивину. Для недопущення подальшого розмиву перешийку і його можливого прориву у період наступних високих паводків запропоновано продовжити кріплення берега вниз за течією річки.

Ключові слова: річка, руслові деформації, руслові процеси, меандра, морфологічні параметри, гідрологічний режим

