

Svetlana N. Ruleva, Roman S. Chalov

Lomonosov Moscow State University, Moscow, Russia, email: rschalov@mail.ru

Restoration of the Katun River navigable waterways

Abstract: The paper presents an assessment of the effectiveness of the lower Katun River channel training works carried out for the navigable waterway creation and consequences of cessation of regular dredging operations over the last 25 years. Analyses of the channel morphodynamics and its modern characteristics allow authors to recommend the channel management strategy and operations required for restoration of the previously existing navigable waterway.

Keywords: channel processes, dredging operations, channel training, riffles, riffle reaches

1. Introduction

Regular navigation on the Katun River has been maintained since mid-1970s along its 30-km long section between its confluence with the Biya River and the Biyskiy gravel-sand quarry (BGSQ). Main purpose of navigation has been transportation of the extracted material from that quarry as well as direct extraction of gravel and sand from the river channel (Figure 1). In the end of 20th century suction dredge operation was conducted further upstream, up to the Verhnee Katunskoe settlement, in order to shift the main flow from the eroded bank on which that settlement is situated. Only lower 7 km of the present navigable waterway existed longer, linking the oil base and Verhnee Obskoe settle-

ment with the major navigation route along the Biya and Ob Rivers.

Organization and maintenance of the lower Katun River navigable waterway requires specific approaches as most of this river sections (upstream from the 9th km from its confluence with the Biya River) can be classified as semi-mountainous channel. It is characterized by high channel gradient (0.8-2.44‰), dominance of gravel-cobble fractions in bed sediment and high flow velocities on riffles (surface – up to $3.5 \text{ m}\cdot\text{s}^{-1}$, bed – up to $2.5 \text{ m}\cdot\text{s}^{-1}$). Under natural conditions (prior to dredging and construction of river training structures) the channel had low depth on riffles (about 0.5 m during

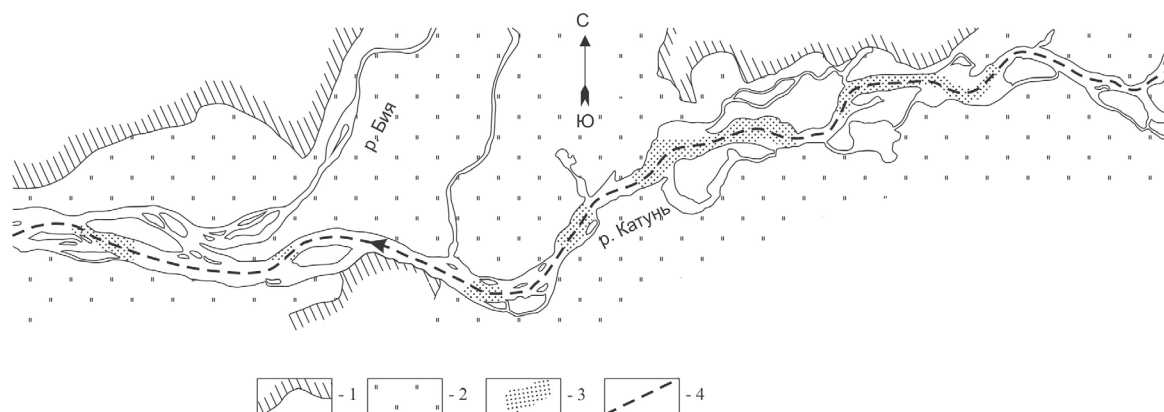


Figure 1. General scheme of the lower Katun River navigation organization. 1 – valley slopes; 2 – floodplain; 3 – dams; 4 – riffles and riffle reaches; 5 – navigable fairway

the low-water period) and morphologically complex chaotic braiding pattern with individual meanders. From the 7-9 km from the Katun River confluence with the Biya River its channel can be classified as lowland with gravel-sandy

or sandy bed sediment, relatively straight with alternating bars and individual islands. At the confluence the channel forms the deltaic type anabranching pattern.

2. Dredging of the Katun river and its consequences

Special channel survey was carried out on the lower Katun in 1974. Recommendations for channel dredging were developed basing on the survey results. Such works had been carried out in 1976-1980 and practically involved artificial channel adjustment along the entire navigable reach. Additional dredging and river training construction works continued until 1990. There were 12 river training constructions installed and up to $680 \cdot 10^3 \text{ m}^3 \cdot \text{year}^{-1}$ of dredging volume extracted. As a result of that maximum possible flow concentration in the main branch was achieved, channel planform stabilized and guaranteed navigation depth increased to 1.35 m (Pronin *et al.*, 1996; Berkovich *et al.*, 2000).

In 1990s dredging operations on the lower Katun River decreased and later ceased completely. Dump trucks became the main means of the BGSQ production transportation. Many river training constructions without appropriate maintenance were subsequently destroyed by ice and floods. As a result, the channel started to return to its natural conditions. Depths decreased (presently stated guaranteed navigation depth 1.1 m cannot be maintained during the low-water period when navigation stops),

navigation became infrequent with main purpose of direct gravel extraction from the channel. However some of the river training constructions are still functioning. Integral effect of the artificial channel adjustment is still evident. It is manifested by changed morphodynamic type of the channel, concentration of navigation problems at the two riffle zones, preservation of satisfactory waterway conditions between those and along the lowland reach including the Katun-Biya confluence zone. Such prolonged effect unambiguously proves that the general channel management strategy based on the known channel regime and natural deformation conditions was correct.

Gravel and sand extraction from channel for construction purposes also exerts substantial influence on the lower Katun River channel processes, in addition to the channel management for navigation. Its official volumes are in a range of $500-700 \cdot 10^3 \text{ m}^3 \cdot \text{year}^{-1}$. However, additional uncontrolled extraction of alluvial material from the channel bars for local purposes is approximately evaluated as other $250 \cdot 10^3 \text{ m}^3 \cdot \text{year}^{-1}$.

Nowadays (middle of the second decade of 21st century) there seem to be an emer-

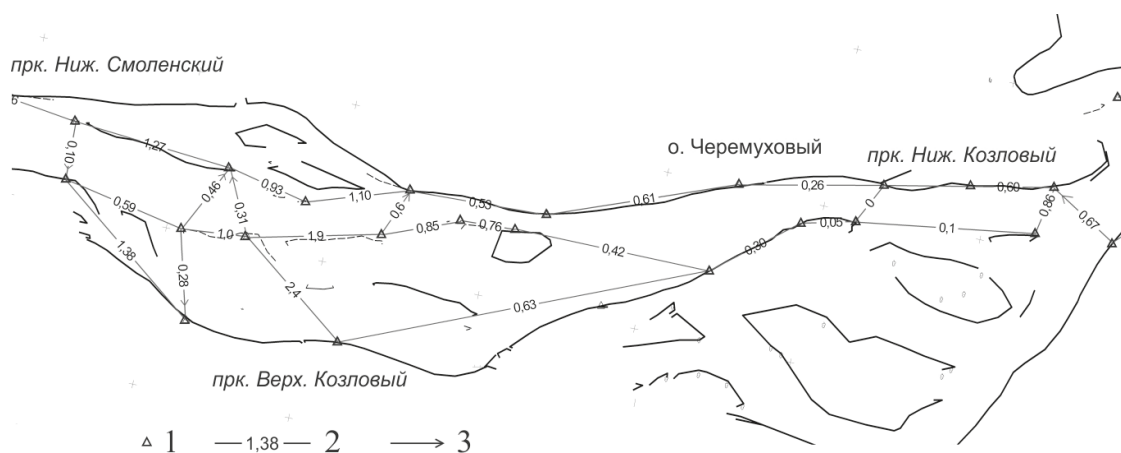


Figure 2. Water surface gradient distribution obtained by a single-day level survey (September 2015). 1 – survey posts; 2 – gradients (‰) between survey posts; 3 – transversal gradient directions

gent interest to restoration of the lower Katun River navigable waterway to the BGSQ and shift (return) from truck to barge transportation of the extracted material. To evaluate this option there were several surveys of the Katun River lower reach carried out in 2015. The Barnaul waterways Administration research party conducted channel bathymetry survey and daily water levels correlation for the most complex and problematic riffle zone (Nizhniy Smolenskiy – Kozlovye – Verhniy Chayachiy riffles). The Lomonosov Moscow State University (MSU) expedition measured discharge distribution between braids and branches, flow velocity fields, carried out channel analyses and from the data listed developed recommendations for restoration of the lower Katun navigable waterway. The proposed activities included resumption of capital dredging operations, repair of the existing and installation of the new river training constructions.

According to its hydrological regime the Katun River can be classified to the Altay-type characterized by high and prolonged (2-3 months) spring-summer flood period and autumn-winter low-water period. Typical annual hydrological cycle include two distinctive flood waves. The first in late April – early May associated with snowmelt in lowland and piedmont parts of the basin. The second in the mid-June related to snow and ice melt in mountainous part of the basin. The latter often exceeds the former. Mean annual discharge (the Srostki gauging stations) is $626 \text{ m}^3 \cdot \text{s}^{-1}$, maximum measured discharge (1958) – $5520 \text{ m}^3 \cdot \text{s}^{-1}$, maximum discharge in 2014 – $4100 \text{ m}^3 \cdot \text{s}^{-1}$. Water level range for the average hydrological year is 425 cm, mean maximum – 550 cm. There is a single interval of the effective channel-forming discharge for the lower Katun. It is equal to $1720 \text{ m}^3 \cdot \text{s}^{-1}$ with 15% excess probability and is observed before the main floodplain inundation almost every year. Ice jams can form within the studied river reach if the ice thickness exceeds 80 cm.

The lowermost reach of the Katun River often experiences flow backing from the Biya River during flood periods. Its maximum upstream extent can reach 18 km from the confluence. Upstream from the BGSQ the channel is largely in natural conditions. Downstream from there it was profoundly impacted

by gravel and sand extractions, dredging operations and training works.

The channel section between 30-15 km from the confluence is characterized by dominance of coarse (50-25 mm, 33-76%) and medium (25-10 mm, 17-43%) pebbles, while mean bedload particles diameter decreases downstream from 24-28 to 12-15 mm. Downstream from the Verhniy Chayachiy riffle (15 km) sandy particles appear in bedload composition together with gravels. Mean sand particle diameter at the channel section near the Katun-Biya confluence was 0.42 mm in 1974, while by 1984 it increased up to 0.57 mm as a result of intensive dredging operations. Channel bed areas covered by gravels increased twice over the 15-20 years period.

Transition from the semi-mountainous to lowland channel type is evident from sharp break of the water surface curve presently located between the Nizhniy Smolenskiy to Nizhniy Kozlovoy riffle (Figure 2). According to the geodetic levelling carried out in 1981, the break point was located in 9 km downstream from that channel section, near the Katunskiy and Ikonnikovskiy riffles. The observed regressive shift of the break point since 1981 can be related to both dredging operations for navigation purposes and sediment extraction as a construction material. These two activities together caused water level degradation up to 1.2 m (average – 0.6 m) along the Katun River lower reach and 0.16-0.23 m at its confluence with Biya. Present location of the channel long profile break is located at the Nizhniy Smolenskiy and Verhniy Kozlovoy riffles. This channel section exerts the most serious navigation problems with high range of water surface gradient variability during high-water periods. For water levels exceeding 1 m above the mean low-water, water surface gradients are in a range of 1.10-1.27‰ along the left bank, 1.0-1.9‰ along the flow axis and up to 1.38‰ along the right bank. Such variability results in high transversal water surface gradients, up to 2.4‰ above the submerged gravel braid bars in central part of the channel. For comparison, gradients in a pool upstream of the Nizhniy Smolenskiy riffle do not exceed 0.26‰, upstream the Nizhniy Kozlovoy riffle – 0.42-0.63‰. During the low-water period dramatic increase of channel gradient is also observed at the Verhniy Chay-

achiy riffle where it reaches 2.46‰. These are locations where flow velocities reach maximum values. Both Nizhniy Smolenskiy – Verhniy Kozlovoy and Verhniy Chayachiy riffles are characterized by highest flow velocities for the entire lower Katun River reach. For the former two flow velocity increase is also associated with the channel widening more than twice and flow deconcentrating between two main arms separated by a series of braid bars (highest discharge percentage for each of the braids during the flood recession does not exceed 35%).

Trend of flow concentration in a single-thread relatively straight channel (except for secondary braiding) and meander straight-

ening was already evident in mid-20th Century, before serious human impact on channel processes commenced. It resulted in shallowing of the right- and left-side secondary meandering branches. By the end of 20th Century after the large-scale channel dredging and training operations in 1970-80s, the main arm concentrated up to 95% of the total river discharge. As a result, it began to form several low-sinuosity meanders by gradual accretion of braid bars and islands to point bars at their apexes. By the beginning of 21st Century this system of meanders started exposing some evidences of the ongoing transformation.

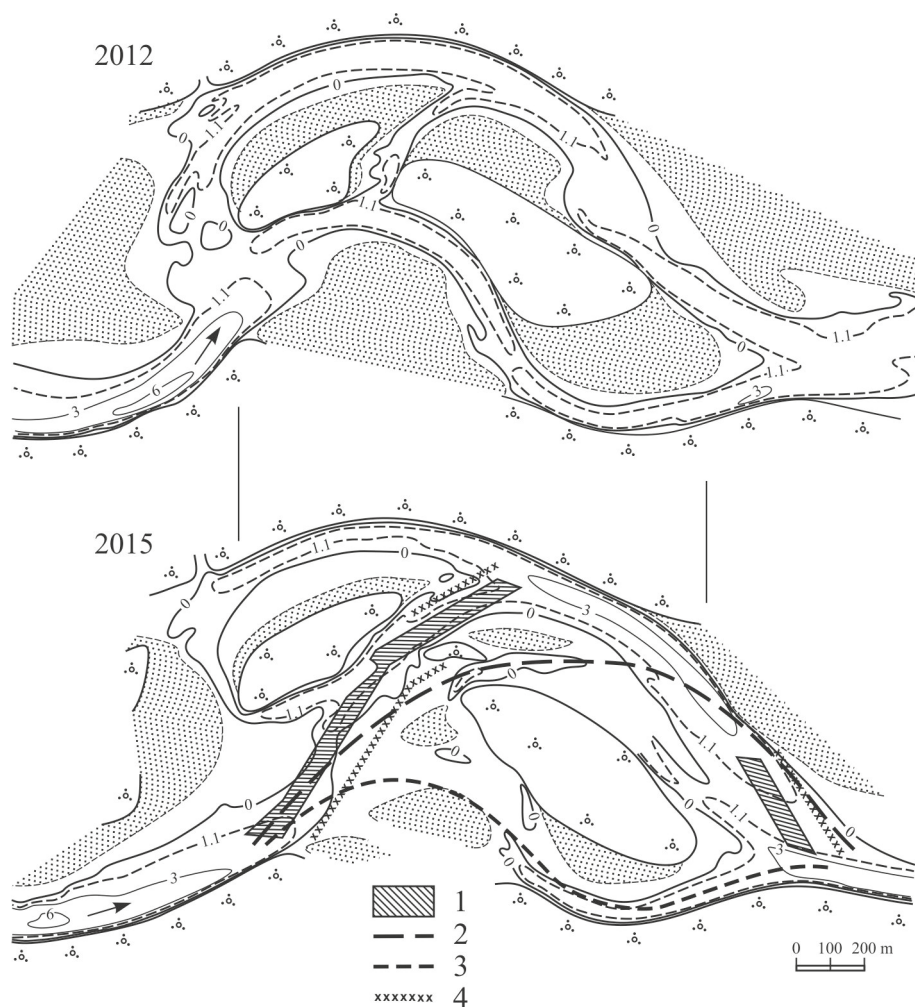


Figure 3. Channel deformations at the Sovhoznye riffles during the 2012-2015 period and scheme of the recommended channel training operations (on the year 2015 scheme). 1 – capital dredging cuts; 2 – navigable fairway for the next several years; 3 – perspective tracing of the navigable fairway; 4 – dumping of the material extracted from the channel dredging

At 15-4 km distance from the confluence with Biya, the channel type changes to low-land, evident by gradient decrease to 0.2‰. The channel width increases while its planform becomes practically straight, with two adjacent

low-sinuosity meanders with secondary braids in lower part of the reach. Further downstream near the Katun-Biya confluence the channel forms the deltaic type anabranching pattern. It splits onto three main arms, of which

the right one was navigable before 1980s. The central arm presently concentrates up to 65% of the total discharge due to the flow diversion by the dam connected to the bank-protecting embankments. First outflow from the Katun into Biya occurs through the Staraya Katun branch (only several % of the total discharge) that cuts through the Biya-Katun floodplain few kilometers upstream from their confluence.

There are at present two riffle sequences the most problematic in terms of navigation along the lower Katun River – Sovhoznye riffles and Nizhniy Smolenskiy – Kozlovye – Chayachi riffles. Complete restoration of the waterway largely depends on possibility of appropriate artificial channel adjustment at those locations. As described above, the Nizhniy Smolenskiy – Kozlovye – Chayachi riffles coincide with the channel long profile break. In contrast, the Sovhoznye riffles are located at the complex braiding zone at the convex side of the high-sinuosity meander apex (pathlength to wavelength ratio $l/L=1.7$, Figure 3) with four main channel arms. As recent as in 2012 the navigation fairway was located in the marginal left arm, bending almost transversally towards the left bank. At the same time the right arm also was deepening, with pool up to 2 m deep at its entrance, while the central arm between the islands was rather shallow with depths <0.5 m. The situation has changed dramatically as the large point bar gradually migrated downstream blocking the navigable left arm entrance. The central arm depth began to increase and eventually the navigation fairway has been moved there. At the same time both left and right arms have been infilled by sediment. Upstream end of the lower island was cut by the newly formed branch as the main central arm, in turn, split into two branches. All those channel deformations were mainly associated with the high 2014 flood. As a result, 63% of the total flow discharge concentrated in the main central arm between the upper island and the newly formed (cutoff) lower island. The former navigable left branch transferred only 18% of the total flow discharge, right – 7%, newly formed branch cutting the new island – 12%. Flow dissipation over wide bars during floods and deconcentration between several arms and branches generally cause decrease of its depth. At the Sovhozniy riffle crest it can be as low as 0.5 m

above the projected level for 2.2 m difference between working and projected levels. Dominance of coarse bed sediment determines riffle crest stability during flood recession stages. Hence, this riffle is among the navigation-limiting reaches of the lower Katun River.

The upper point bar continues its gradual downstream shift (up to 100 m per average-level flood). Within a next few years that may cause more active development of the newly formed branch and subsequent shift of the navigation fairway into it. In a longer perspective deepening and widening of the right arm with shift of large percentage of the total discharge into it can be expected.

Securing normal navigation conditions for the Sovhozniye riffles reach requires capital dredging operations along the central arm between the upper and lower islands. Upstream end of the dredged cut should be made funnel-shaped. It can be recommended to organize dumping of the bed sediment extracted by dredging to form the new flow-diversion structure blocking the right arm and partly as a spit at downstream end of the lower island. It should be born in mind, however, that downstream migration of the upper point bar can rapidly lead to infill of the dredging cut and further development of the new branch between the islands. In such a case an alternative decision would be to shift dredging operation and navigable fairway into that new branch. Further perspective will require dredging of the right arm and shift of the fairway into it in the future. Such location of the navigation fairway would be optimal for the Sovhozniye riffle planform. Therefore it will be desirable to fix such channel pattern by artificial training structures. Exact locations of such structures and dredging cuts will be determined basing on the existing channel deformations monitoring data and prediction for its future development.

The second problematic reach from Nizhniy Smolenskiy to Kozlovye riffles is the most difficult in terms of channel management. It is associated with local increase of the channel width downstream from the deep (up to 6-8 m) pool. The channel width between floodplain banks within the pool reach is about 250 m, downstream it increases more than twice. At the end of the riffle reach it decreases back to about 300 m. Deposition of coarse sediment washed out

from the upper pool causes formation of a large pebble-cobble dune crossing the channel diagonally from right to left bank. This large bedform is stretched almost along the entire riffle reach and creates significant break of the channel long profile. Depth above the dune crest decreases to 0.5-1.0 m over the projected level (for 2.0-2.5 m difference between working and projected levels). The dune crest is crossed by several riffle troughs (Figure 4). There is

another pool stretched along the right channel bank at central and lower parts of the riffle reach. Depths within it reach 3-4 m. That pool is bounded by the 0.0-0.5 m isobaths upstream from the lower channel narrowing. However, bend of the right bank deflects the main flow towards the third pool formed within the channel narrowing downstream from the riffles along the left bank.

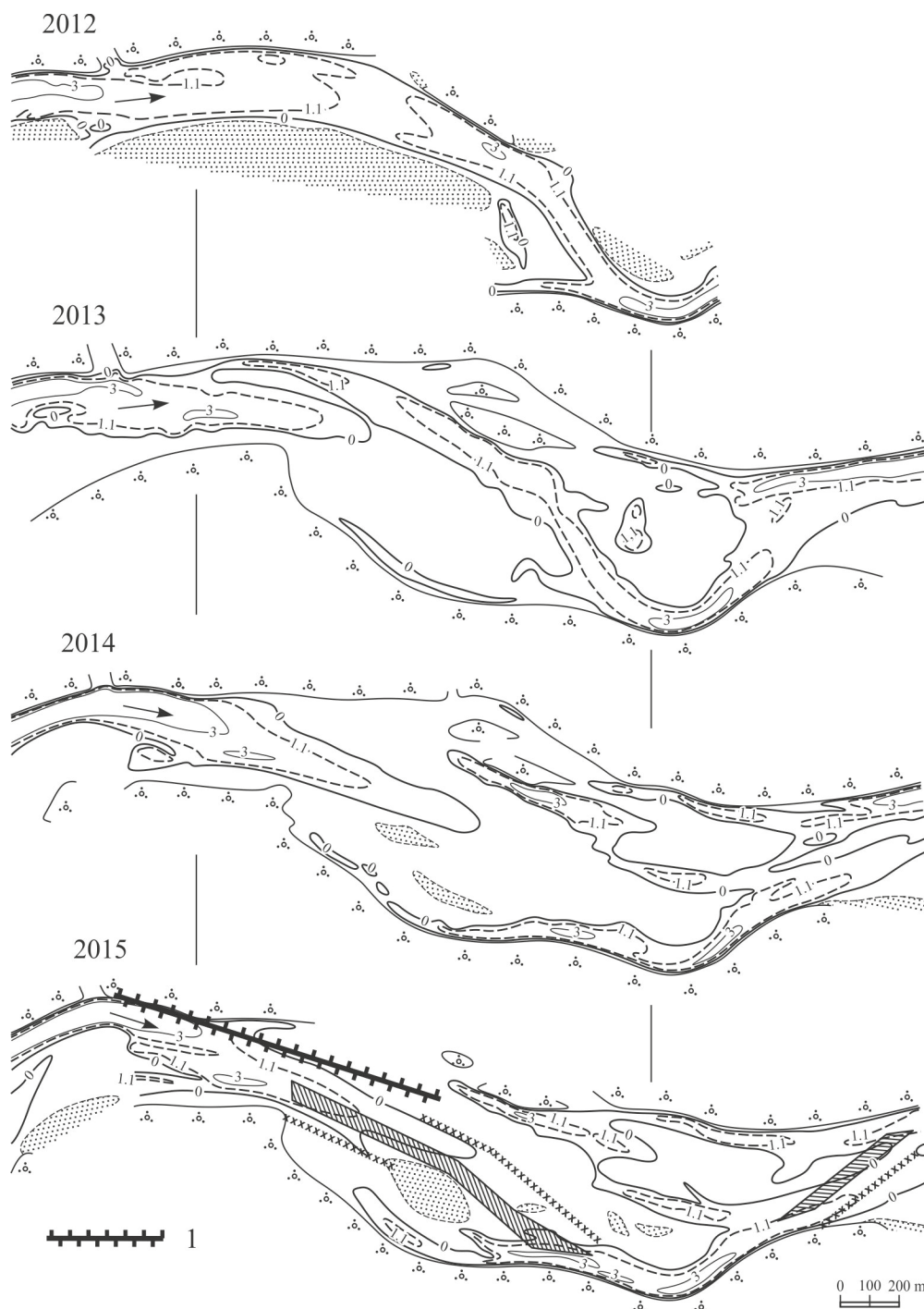


Figure 4. Channel deformations at the Nizhniy Smolenskiy and Kozlovye riffles during the 2012-2015 period and scheme of the recommended channel training operations (on the year 2015 scheme). 1 – proposed dam location. Other designations – see Figure 3

In 2012 left bank of the upper pool of Nizhniy Smolenskiy riffle had a planform concavity that diverted the flow axis to the right. By 2014 the left bank was eroded by 100-150 m and its flow-diverting influence ceased. These channel deformations caused bending of the main flow axis of the Verhniy Kozlovoy riffle around gravel bars. Ration of pathlength to wavelength of the main flow axis l/L reached 1.6 equal to its critical value.

High flood of 2014 resulted in cutoff of the Verhniy Kozlovskiy riffle lower point bar from the left bank and formation of the new branch along its distal edge. At the same time the entire gravel dune crest between upper and lower point bars of the Verhniy Kozlovskiy riffle was cut by four transversal troughs, while the upper point bar itself shifted 400 m downstream. The resulting situation at the Verhniy Kozlovskiy riffle became the most unfavorable for navigation in terms of bathymetry and fairway routing.

3. Conclusions

The only option for creation of stable navigable fairway at that channel reach is to carry out capital channel training works including dredging with over deepening to allow channel gradient decrease at riffles. In order to fix the navigable fairway at the optimal location it is necessary to stabilize the left bank and prevent further bank retreat along the upper pool of the Nizhniy Smolenskiy riffle. General recommendations for the Nizhniy Smolenskiy – Verhniy Kozlovoy riffles reach are as follows:

- 1) Construction of the dam about 1 km long along the left bank at the upper part of the reach (Figure 4) for preventing the bank retreat, blocking flow diversion into secondary floodplain branches, partly closing the entrance into the left arm along the point bar distal edge and to direct the main flow towards the projected capital dredging cut;
- 2) Dredging a capital cut (with over deepening up to 2.0-2.5 m) connecting the upper pool of the Verhniy Kozlovoy riffle with the lower pool under the right bank. One of its purposes is to decrease the water levels gradient in that direction (presently reaching 2.4‰). Dumpings of the extracted allu-

At present (in 2015) left branch along the left bank point bar distal edge at the Verhniy Kozlovskiy riffle intercepts about 51% of the total flow discharge (for 2.0 m difference between working and projected levels). However further downstream, between the Verhniy and Nizhniy Kozlovskiy riffles, about 34% of the total discharge is dissipated above gravel bars, while 37% is concentrated near the right bank promontory at the lower part of the right bank pool.

Hence it can be concluded that the present conditions of the Nizhniy Smolenskiy – Verhniy Kozlovoy riffles has been determined by channel deformations during the year 2014 high flood, downstream migration of gravel bars, increasing sinuosity of the fairway up to the critical value, intensive erosion of the left bank along the upstream pool and related accumulation of large volume of sediment produced by that bank erosion immediately downstream.

vium can be used to fill the transversal troughs cutting the gravel bars in order to prevent flow dissipation over bars and secondary branches;

- 3) Dredging another smaller cut connecting the right and left bank pools at the downstream end of the reach.

All other riffles located further downstream have also experienced certain channel deformations over the recent years. However, those have not caused serious worsening of the navigation conditions since the cessation of the regular dredging operations. That is reasonable to say that effects of the 1970-80s channel training works still exert pronounced positive effect on that reaches. Hence, the navigation restoration there will require only limited regular dredging and repair on dams which continue to effectively influence the flow adjustment.

Possible restoration of the navigable waterway on the lower Katun River can become the first positive sign of a new trend for reactivation of the waterways functioning for the entire Russia. It is believed that returning the attention to water transport can bring the new development to this branch of the transportation system.

4. Acknowledges

Investigations were carried out according to the research plans of the Lomonosov Moscow State University Faculty of Geography Hydrology department (channel analyses) and Makkaveev Laboratory of soil erosion and fluvial processes (channel deformations assessment under dif-

ferent anthropogenic impacts), under financial support of the RFBR (project 14-17-00155 – validation of approaches to channel processes management) and contract with the “Obvodput” Administration (field surveys, recommendations on artificial channel adjustment).

The article was presented at the International Scientific Conference
„Human Impact on the Fluvial Processes of Eurasian Rivers”
on September 7th-9th, 2016 in Bydgoszcz (Poland).

References

- Berkovich K.M., Garrison L.M., Ruleva S.N., Surkov V.V., Chalov R.S. 2000. Channel processes and anthropogenic impact on the lower Katun River channel and their effects on the floodplain landscapes. In: Soil erosion and fluvial processes. Vol. 12. Moscow, MSU publ., 130-157.
- Pronin V.I., Berkovich K.M., Ruleva S.N., Chalov R.S. 1996. Experience of organization of the navigable waterway on the semi-mountainous Katun River. Water Transport 4, 25-27.