ISSN 0097-8078, Water Resources, 2021, Vol. 48, No. 1, pp. 18–28. © Pleiades Publishing, Ltd., 2021.
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# The Distribution of Water and Suspended Sediment Flow during Spring Flood in the Forked Channel of the Lower Ob (Within Khanty-Mansi Autonomous Area)

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Received April 20, 2020; revised May 7, 2020; accepted June 9, 2020

**Abstract**—The forked channel is a rare and poorly known type of branching channel, the distribution of flow in which is of key importance for water transport, economic activities, and water resources development. The article is the first to analyze the distribution of the flow of water and suspended sediments between the major two branches of the forked channel of the Lower Ob, i.e., the Malaya Ob and the Gornaya Ob, numerous floodplain channels (branches), responsible for hydraulic interaction between them and the Severnaya Sos'va, a large tributary of the Lower Ob. It is shown that water discharges vary widely in both branches because of the secondary separation of branch channels, the distribution of flow among branches, deviation of sometimes considerable part of flow into floodplain channels (branches) and its return further downstream. General tendencies are revealed in water flow distribution in forked channes, and the mechanisms governing water flow distribution between the branches are described. A considerable effect on the Malaya Ob is due to its hydraulic interaction with the Severnaya Sos'va through floodplain channels, which withdraw an appreciable portion of water flow of the former. The development of the channel of the Gornaya Ob features a considerable limiting effect of the right main bank. During floods, both branches of the forked channel of the Lower Ob, at low turbidity, show a tendency toward decrease downstream. However, the downstream decrease in the solid discharge is more pronounced, reflecting the general trend in sediment accumulation in the Lower Ob.

*Keywords:* channel processes, bifurcated channel, the Ob, flow distribution, suspended sediment, water turbidity

**DOI:** 10.1134/S0097807821010127

## INTRODUCTION

The bifurcation of flow in branching river channels is of importance for revealing the role of branches in the channel operation of rivers, forecasting their transformations, assessing the unfavorable effects on the state of transport waterways, and substantiating the projects of ensuring safe navigation, the conditions for economic activities in riverine territories, and the development of water and other river-related resources [1, 8, 15, 17, 19]. Among the diverse branching river channels, forked channels are a rare and a peculiar phenomenon, which is still poorly known (especially, as compared with common and even complex channel bifurcations: conjugated, parallel-branching, etc.) [16]. These belong to the type of branching, in which rivers branch into two or more independent long channels (tens and even hundreds kilometers in length), separated by large floodplain massifs and running in the opposite parts or, in the case of more than two branches, in the middle of a very wide valley; they show hydraulic interaction through numerous floodplain channels [11–13] and form the highest structural level of branching [14]. Examples of such forked channels are the rivers of Volga and Akhtuba [6], Don and Aksai [7], Dniester and Turunchuk [3], and many others, which are often referred to in maps as rivers (the rivers of Akhtuba and Aksai) [11, 12]. However, the distribution of flow in rivers with forked channels has not been adequately studied (only their relative water abundance was evaluated), and the distribution of water discharges ($Q$, m$^3$/s) between the branches was limited to channel bifurkations [1, 4, 5, 15, 17]. The need to study these phenomenon increases in the context of the above-mentioned trend toward an increase in channel branching at an increase in the flow in large rivers [18] and the passage of extremely high floods [20].

In the Lower Ob, the forked channel shows especially high multibranching (up to four such branches in a section), which makes it unique among the Earth rivers in terms of branching (and, accordingly, the distribution of runoff), the length of the reach of occurrence, and the width of the channel system on valley bottom. It first appears in the Ob in its middle reaches upstream of Surgut and continues down to the confluence with the Irtysh, where three successive branches separate into the left part of the valley bottom; these branches run 15–25 km apart from the main channel and carry up to 30% of water flow; these are the Yuganskaya Ob, and the channels Bol'shaya Salymskaya and Neuleva, which discharges into the Irtysh through three branches [3]. In its lower reaches, the Ob separates into two major branches—the left Malaya Ob and the right Gornaya Ob, the latter being referred to as the Bol'shaya Ob downstream of the mouth of the Severnaya Sos'va.

Expedition studies in June 2019 were the first in this forked channel in the lower reaches of the Ob within the Khanty-Mansi Autonomous Area–Yugra (KhMAA-Yugra) to meausure water discharges and to take water samples for turbidity in all major branches and many floodplain channels and to reveal the main regularites in the distribution of water and sediment flow among the branches during spring flood at inundated floodplain and and active water outflow into floodplain streams.

## GENERAL CHARACTERISTIC OF THE FORKED CHANNEL

The forked channel in the Lower Ob (Fig. 1) begins downstream of Peregrebnoe V., where the river, flowing around the western margin of Siberian Spurs (Belogorskii Land), changes its direction from northwestern to northern, the width of the floodplain increases, first, to 20 km and next to 60 km, and the river separates into the Gornaya Ob (with a spring flood peak in 2019 of 8412 $m^3/s$) and the Malaya Ob (15044 $m^3/s$). From the Malaya Ob, before the threefold widening of its floodplain, a branch 64 km in length—the Togotskaya Ob—separates to the right into the central part of the floodplain; this branch forms a secondary channel bifurcation (the Nyulas branch 22 km in length separates from it, creating a third-order forking). Further downstream, large floodplain branches separate to the left along the normal to the Malaya Ob and flow into the Severnaya Sos'va; these are the Laporskaya Branch, which bounds Lyulinvor Highlands from the north (here, the floodplain abruptly extends up to 60 km), and the Pyrsym, and next, the Vaisova, which creates one more branching of the Malaya Ob channel. Essentially, the Severnaya Sos'va in its lower reaches is a joint flow of the river itself, two large Ob floodplain branches (the Berezovo gage measures the flow of the tributary and, partially, the main river) and the Vaisova branch. During spring flood, the flow of the Ob water from its inundated floodplain ads to this amount.

Secondary branching of the channel is typical of the Gornaya Ob as well; the Somutnel'skaya branch (26 km in length) separates to the right from the Gornaya Ob and receives the right tributary of the Ob—the Kazym river. The result is that the Ob is divided into a complex network of subparallel branches, leading to a unique distribution of runoff, which transforms the largest river into a complex network of branches, comparable with medium rivers in terms of water abundance and morphometric characteristics, and floodplain channels; this situation complicates, primarily, the use of the river for water transport.

Downstream of the confluence of the Malaya Ob with the Togotskaya Ob and next with the Severnaya Sos'va, the short branch Bol'shoi Nyurik, 24 km in length—an analog of another channel branching—crosses the Ob floodplain at a large angle and collects water from floodplain branches, flowing into it, and water flowing from the inundated floodplain (because of its nearly transverse direction). Merging with the Gornaya Ob, it considerably increases its flow and the Gornaya Ob becomes the Bol'shaya Ob.

## MATERIALS AND METHODS

The expedition studies were carried out since June 8 to 21, 2019. Water discharges were measured in the branches that form forked channels, in branches of channel bifurkations of the Malaya Ob and Gornaya Ob in the largest and some smaller floodplain branches, as well as at the mouths of tributaries, i.e., the Severnaya Sos'va and the Kazym. The gages were located such as to collect the fullest data on the distribution of water discharges, and they covered all branches across the valley bottom at the separation of the Malaya Ob and Gornaya Ob and at the bifurcations of both branches of the forked channel, at the separation of branches of 2nd-order bifurcations, and in the largest floodplain branches. In some cases, water discharges in individual branches of channel bifurcations were determined without measurements, i.e., by runoff balance calculations (that is, by data of water discharge measurements in nearby branches upstream and downstream of the bifurcation). At the approach and before the mouths of the branches in the largest and most compex bifurcations, as well as in the beginning and at the end of the working day, the Malaya Ob and Gornaya Ob were fully crossed by gages. This reduced the errors in the calculation of water discharges in the ungaged branches and enabled taking into account, at least as a first approximation,

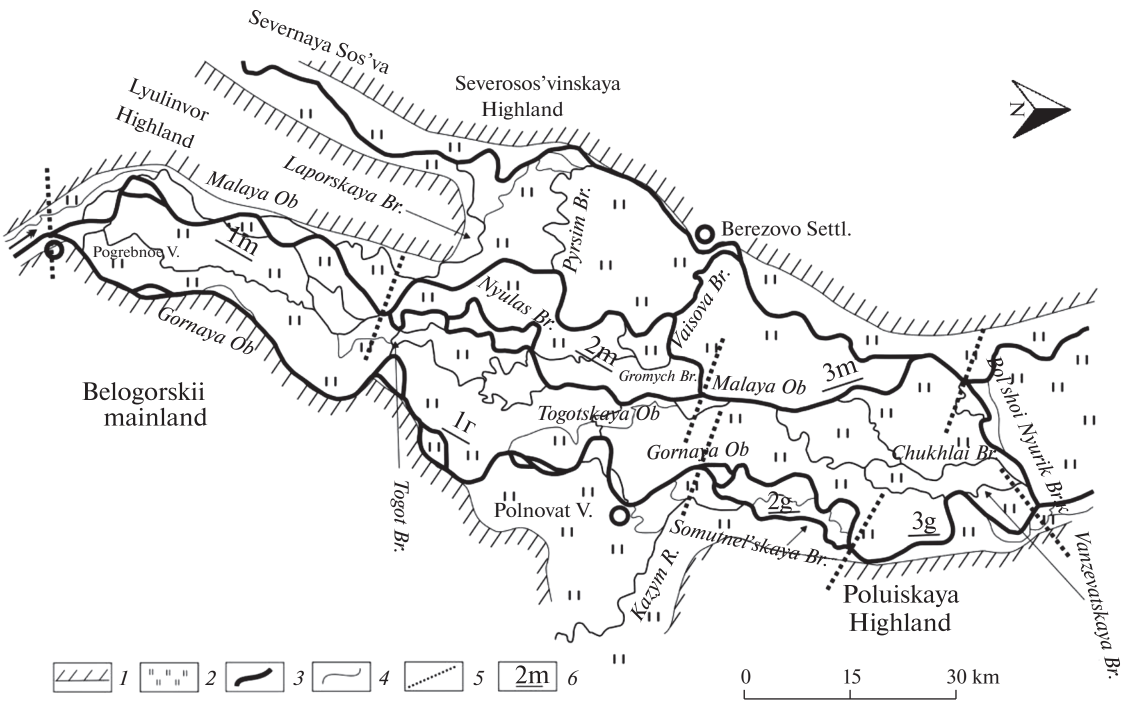


**Fig. 1.** The general scheme of the forked channel of the Lower Ob (within the Khanty-Mansi Autonomous Area–Yugra). (*1*) Main banks; (*2*) floodplain; (*3*) the channel of the Ob, branches of the forked channel, and the lower reaches of the Severnaya Sos'va; (*4*) the largest floodplain branches; (*5*) boundaries of the areas of the Malaya Ob and Gornaya Ob; (*6*) chosen measurement areas on (m) the Malaya Ob and (g) the Gornaya Ob, in which water discharge was measured. Here and in Figs. 3–5, br. means branch.

the proportion of water flow over the inundated floodplain and ungaged small floodplain watercourses.

The flow velocities and water discharges were measured by Acoustic Doppler Current Profiler (ADCP) (Sontek RiverSurveyor M9, the error in the estimation of water discharge ≤5%). The flow velocities and water discharges in the segments with depths below the ADCP applicability range can be evaluated with the use of numerical extrapolation methods available in the software of the device. The record and processing of ADCP measurement data were made with the use of RiverSurveyor Live data-processing software.

The studies were carried out during flood peak at the passage of maximal water discharges and at nearly invariable water level (according to the data of Belogor'e Settl. and Octyabr'skii Settl. in the Lower Ob), their variations over the entire period amounted to 5–7 cm. The total of 99 measurements of water discharges were made, including 30 covering the Malaya Ob and Gornaya Ob. Water discharges were calculated for 69 channel bifurcations. At the node of Ob separation into the Malaya Ob and Gornaya Ob, the measurements were carried out twice with an interval of 8 days, though the water discharge in the river remained the same.

Parallel to measurements of water discharge $Q$ ($m^3/s$), water samples were taken to determine water turbidity $s$ (mg/L) and the suspended sediment discharge. The mass determinations of $s$ were made using turbidimetric methods, i.e., methods of water sample analysis based on the measurement of the amount of light absorbed when it passes through a cuvette (test tube) filled with river water and placed into a turbidimeter. The obtained characteristics of optic turbidity in NTU (Nephelometric Turbidity Unit) were converted into the weight characteristics of water turbidity using the curve relating them to the measured actual turbidity ($g/m^3$) (Fig. 2). The total of 18 samples were taken for determining the turbidity by filtering, and 102 samples were analyzed for NTU. The range of optical turbidity for filtered samples was 28 NTU (the maximal and minimal values were 38.5 and 10.5 NTU, respectively), and the coefficient of correlation was 0.8. The range of weight turbidity is 64 $g/m^3$ (the maximal and minimal values were 82.7 and 18.7 $g/m^3$, respectively). The turbidity values were maximal in midstream zones and minimal in the floodplain branches with a considerable portion of clear floodplain water entering them.

## FLOW DISTRIBUTION

Table 1 gives measured water discharges in the major branches of the bifurcated channel of the lower Ob, in some largest floodplain channels, which show

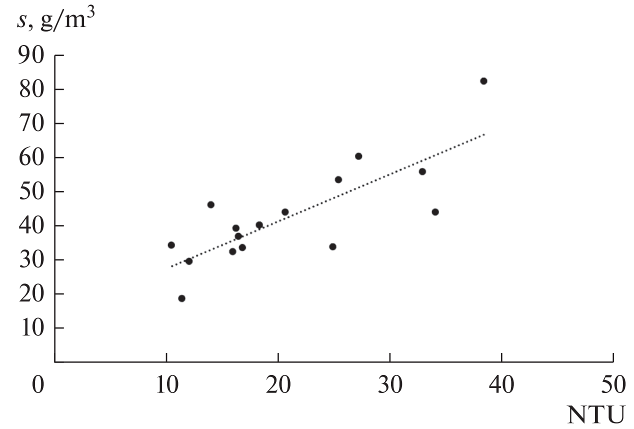


**Fig. 2.** A curve relating the optical NTU and the weight turbidity *S*.

flow redistribution over their length, as well as in Ob tributaries—the Severnaya Sosva and the Kazym.

### *The Malaya Ob*

The diversion of 38% of the total Ob flow into the right branch of the forked channel (the Gornaya Ob) and the distribution of water flow over floodplain channels (branches) and arms lead to a considerable changes in water flow in the Malaya Ob in the downstream direction. Ttherefore, it can be divided into three main segments: (1) the source of the Malaya Ob–the source of the Togotskaya Ob; (2) the source–the mouth of the Togotskaya Ob; (3) the mouth of the Togotskaya Ob–the source of the Bol'shoi Nyurik branch.

In the first segment 1m (Fig. 1), the width of the floodplain icreases from 14 to 25 km, and the channel, continuing the northwestern direction of the Ob in the upstream parts, shifts from the right main bank (Belogorskii mainland) at Peregrebnoe Vil. to the left side of the valley, represented by the slopes of the northern margins of Lyulinvor Highland, and continues running along or near them. Water discharge decreases toward the separation of the Togotskaya Ob from 15044 to 13902 m$^3$/s because of water outflow (1142 m$^3$/s) onto the inundated floodplain and, partially, into floodplain branches (flow measurements were not made in them because of the low flow; large floodplain branches in this area empty again into the Malaya Ob). At the beginning of the segment, the development of a steep bend led to the erosion of the floodplain dike in its near-head part, separating the channel of the Malaya Ob from a branch parallel to it. The flow in it increased (up to 31%) and, as a consequence, a floodplain-channel bifurcation formed. The spur of the bend of the Malaya Ob, the head of which contains the node of its separation from the Narykarskaya branch, consists of two islands—Mezh'yur and Bezymyannyi. This determines a complex system of runoff distribution (Fig. 3, Table 2), resulting in a drop in the flow in the main branch of the Malaya Ob (in the lower wing of the bend no. 5 in Fig. 3) by half (to 29% of the Ob flow as a whole); this, along with the transformation of the channel itself, creates considerable problems for navigation.

The segment 2m in the Malaya Ob (Fig. 1) features steady decrease in the flow downstream the branch. This is due to the separation of more than half of water flow (60%) into the Togotskaya Ob, an abrupt increase in the width of the floodplain up to 60 km, and the deviation of a considerable portion of flow into the floodplain branches on the left side the Laporskaya (1153 m$^3$/s or 19%) and the Pyrsim (435 m$^3$/s, 10%), flowing into the Severnaya Sos'va, the discharge of 512 m$^3$/s (according to tentative estimates) onto the inundated floodplain, and the bifurcation of the Malaya Ob because of separation of the Vaisova branch to the left from it, carrying 2490 m$^3$/s of water (67% of the runoff during 2019 spring flood). After this, the water discharge in the Malaya Ob decreases to 2323 m$^3$/s, creating unfavorable conditions for navigation in the reaches further downstream down to the confluence with the Togotskaya Ob because of the lack of water to ensure the necessary depths along the major waterway.

The analysis of water surface elevations in the Malaya Ob and the Severnaya Sos'va based on topographic maps showed no transverse gradient of dry-season levels. We can suppose that the formation of branches between the Malaya Ob and the Severnaya Sos'va is caused by a slope of water surface during spring flood because of the higher rise of water levels in the Ob than in the Severnaya Sos'va, and its higher flow: upstream of the inflow of the Laporskaya branch into the Severnaya Sos'va, the discharge in it, measured in June 2019, was 2574 m$^3$/s, while that in the Malaya Ob was more than twice as large and almost equal to water discharge in the Vaisova branch (2490 m$^3$/s). The total transverse flow of the Ob water through floodplain branches and the Vaisova branch was 1.6 times the water discharge in the Severnaya Sos'va (with the water inflow from the inundated floodplain not taken into account).

The high flow in the Vaisova branch is due to the favorable hydraulic conditions (relative to other branches) for the inflow into it in the bend, in which, near its head, it originates as a continuation of its upper wing.

The Malaya Ob contains several channel branchings. Near the source of the Laporskaya branch, this is the floodplain-channel bifurcation with morphology similar to the Mezh"yursko-Narykarskoe. Unlike the latter, the left branch is better developed here; this is a former floodplain branch, which has become navigable and takes 46% of water flow from the Malaya Ob.

**Table 1.** Water flow rates in the branches of the forked channel of the Lower Ob during spring flood (measured on June 2019)

| Branches, floodplain channels, tributaries | $Q$, m$^3$/s | $Q$, % | |
|---|---|---|---|
| | | of the Ob | of the Malaya or Gornaya Ob |
| Bifurcation node of the Malaya and Gornaya Ob | | | |
| Malaya Ob | 15044 | 64 | 100 |
| Gornaya Ob | 8412 | 36 | 100 |
| Malaya Ob | | | |
| The source of the Malaya Ob—the bifurcation of the Malaya and Togotskaya Ob | | | |
| Malaya Ob | 5595 | 24 | 40 |
| Togotskaya Ob | 8364 | 36 | 60 |
| The bifurcation of the Malaya Ob and Togotskaya Ob—the source of Pyrsim branch | | | |
| Laporskaya | 1153 | 5 | 19 |
| Pyrsim | 435 | 2 | 10 |
| The source of Pyrsim branch—the bifurcation of the Malaya Ob and the Vaisova Branch | | | |
| Vaisova | 2490 | 11 | 67 |
| Malaya Ob | 1213 | 5 | 33 |
| The bifurcation of the Malaya Ob and the Vaisova Branch—the confluence of the Malaya Ob and Togotskaya Ob | | | |
| Malaya Ob | 2029 | 9 | 23 |
| Togotskaya Ob | 6747 | 29 | 77 |
| The confluence of the Malaya Ob and the Togotskaya Ob—the confluence of the Malaya Ob and the Severnaya Sos'va | | | |
| Malaya Ob | 7224 | 31 | 52 |
| Severnaya Sos'va | 6652* | 28 | 48 |
| The confluence of the Malaya Ob and Severnaya Sos'va—the separation of the Malaya Ob and Bol'shoi Nyurik branch | | | |
| Malaya Ob | 8403 | 36 | 59 |
| Bol'shoi Nyurik | 5048 | 22 | 41 |
| Gornaya Ob | | | |
| The source of the Gornaya Ob—the separation of the Gornaya Ob and the Somutnel'skaya Branch | | | |
| Gornaya Ob | 3517 | 15 | 58 |
| Somutnel'skaya | 2568 | 11 | 42 |
| Kazum R. | 1651 | 7 | 20 |
| Between the separation and confluence of the Gornaya Ob and the Somutnel'skaya Branch | | | |
| Gornaya Ob | 3754 | 16 | 47 |
| Somutnel'skaya | 4219 | 18 | 53 |
| The confluence of the Bol'shoi Nyurik branch and the Gornaya Ob | | | |
| Bol'shoi Nyurik | 12566 | 54 | 71 |
| Gornaya Ob | 5205 | 22 | 29 |
| Great Ob | 17771 | 76 | 100 |

* The total discharge of the Severnaya Sos'va, the branches of Laporskaya, Pyrsim, and Vaisova, and the left tributary—the Vogulka R.

The same, nearly equal water distribution (in proportion 2/3) is typical of the singular bifurcations; at the general decrease in water flow in the Malaya Ob, it has a considerable effect on the conditions of the waterway. Other bifurcations, associated with islands on wings, either in the near-head parts of bends or in the single-sided bifurcations, are less significant (from 8 to 20% of water discharge during spring flood; some of them dry up in the low-water season).

In the segment 3m (Fig. 1), the width of the floodplain is ≤40 km, and only low-flow floodplain branches separate. The Togotskaya Ob, the flow of which has decreased by ~1500 m$^3$/s from its source to the mouth, ensures here almost three-fold increase in the runoff of the Malaya Ob. The confluence with the Severnaya Sos'va increases water flow in it by another 48% (from 8776 to 12451 m$^3$/s), and the maximal discharge of 13876 m$^3$/s was recorded immediately downstream from its mouth.

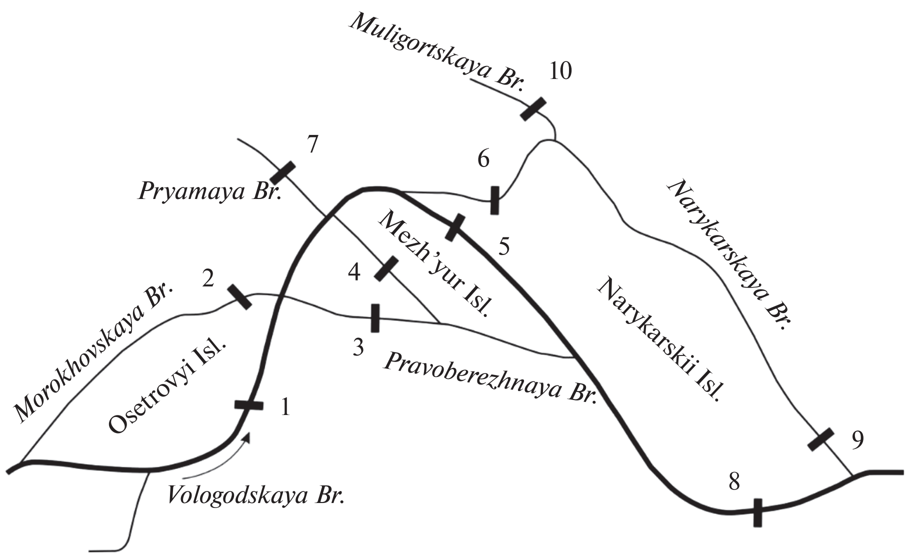


**Fig. 3.** Schematic Mezh'yurskoe-Narykarskoe floodplain–channel branching. The figures denote the gages of water discharge measurement (Table 2).

Downstream of the confluence of the Malaya Ob and the Severnaya Sos'va, a part of the flow (~400 $m^3/s$) inundates the floodplain; next the Bol'shoi Nyurik branch takes almost half of the flow (5041 $m^3/s$, 41%); this is the branch through which the navigation pass is shifting now from the Malaya Ob into the Great Ob. By the confluence with the Gornaya Ob, water discharge in it increases ~2.5 times (12566 $m^3/s$) due to the inflow of water from the floodplain, which it crosses nearly crosswise, and the inflow of several floodplain branches into the Bol'shoi Nyurik branch (Fig. 4, Table 3). Among them, the Chukhlai branch alone increases the runoff about twice, accumulating in itself the water of floodplain branches separating from the Malaya Ob and Gornaya Ob. Such increase in the flow is also typical of some other floodplain branches; however, they next discharge into the Malaya Ob. Thus, the flow of the Gromych branch, which withdraws 15% of water discharge from the Malaya Ob (673 $m^3/s$), at the confluence with it downstream of the inflow in the Vaisova branch, amounts to 43% (~1000 $m^3/s$), which is of great importance for the conditions of waterway here.

### *Gornaya Ob*

In the Gornaya Ob, water discharge during spring flood varies from 8412 $m^3/s$ at the bifurcation with the Malaya Ob to 5205 $m^3/s$ before the confluence with the Bol'shoi Nyurik Branch. In the first 90 km from its source in segment 1g (Fig. 1), where it runs along the right, leading main bank (Belogorskii Land) into the

**Table 2.** Water flow distribution in the Mezh'yurskii–Narykarskoe bifurkation

| Section no. | Branch, channel | Water discharge rate | |
|---|---|---|---|
| | | $m^3/s$ | the percent of the discharge of the Malaya Ob |
| 1 | Navigable at Osetrovyi Isl. | 11498 | 86 |
| 2 | Morokhovskaya | 1873 | 14 |
| 3 | Pravoberezhnaya | 1643 | 12 |
| 4 | Pravaya at Mezh'yur Island | 811 | 6 |
| 5 | Navigable—Mezh'yurskaya Branch | 6795 | 51 |
| 6 | Entrance into the Narykarskaya Branch | 4122 | 31 |
| 7 | Floodplain direct | 252 | 2 |
| 8 | Navigable in its lower part Bifurcations Narykarskii Isl. | 9249 | 65 |
| 9 | Outlet of the Narykarskaya Branch | 4945 | 35 |
| 10 | Muligortskaya | 823 | 6 |

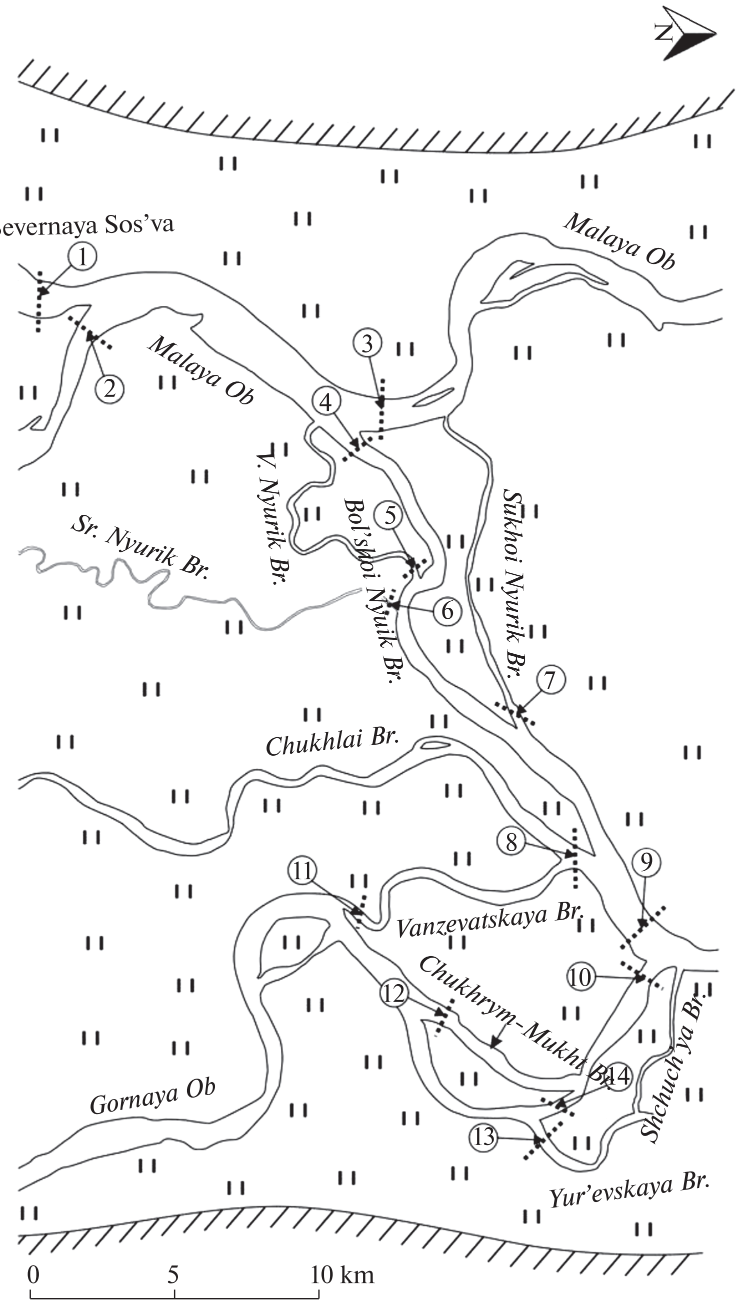


**Fig. 4.** Distribution of water flow rates during 2019 spring flood between the Malaya Ob, the Gornaya Ob, the Severnaya Sos'va, the Bol'shoi Nyurik Br., and floodplain channels. The figures denote measurement gages (Table 3).

left-side floodplain, the amount of flow passing from it into small floodplain branches is as little as 0.5% (439 $m^3/s$), and it is only in the end of the segment that 16% of water discharge (1342 $m^3/s$) run from it into the Togot branch, which crosses the floodplain along its diagonal and discharges into the Togotskaya Ob. The channel here is mostly linear and nonbranching, alternating with singular bifurcations, in which water discharge distributes almost equally (55 and 45%), or its major portion (up to 87%) passes left or right of the islands that form them, depending on the local conditions. At the end of this segment, downstream of a large cape, a sharp broken bend lies, in which 55% of flow is concentrated in the left curved branch (i.e., it runs along the bend), while the cutting branch takes 45% of water discharge. The Togot branch originates from the head of the bend; in the lower wing of this branch, the share of the flow in the Gornaya Ob decreases to 39%, creating some problems for navigation.

**Table 3.** Distribution of water discharge rates beween the Malaya Ob and Gornaya Ob, the Severnaya Sos'va R., the branch Bol'shoi Nyuric, and floodplain branches (measurements in June 2019)

| No. | Branch/channel | Water flow rate, $Q$, $m^3/s$ | The percentage of flow of | | |
|---|---|---|---|---|---|
| | | | Malaya Ob at sections 2 and 3 | Gornaya Ob at section 10 | Branch Bol'shoi Nyurik at sections 4 and 9 |
| 1 | Severnaya Sos'va | 6652 | 92.1 | 128 | – |
| 2 | Malaya Ob | 7224 | 100 | 139 | – |
| 3 | Malaya Ob | 8403 | 100 | 161 | 166 |
| 4 | Bol'shoi Nyurik | 5048 | 60.1 | 97.0 | 100 |
| 5 | Verkhnii Nyurik | 461 | 5.49 | – | 9.1 |
| 6 | Srednii Nyurik | 62 | 0.86 | – | 1.2 |
| 7 | Sukhoi Nyurik | 409 | 4.87 | – | 8.1 |
| 8 | Chukhlai branch | 4820 | 66.7 | – | 95.4 |
| 9 | Bol'shoi Nyurik | 12566 | 149 | 241 | 153 |
| 10 | Gornaya Ob | 5205 | 72.1, 61.9 | 100 | 103, 41.4 |
| 11 | Vanzevatskaya | 2582 | – | 49.6 | – |
| 12 | Chukhrym-Mukht | 2710 | – | 52.1 | – |
| 13 | Yur'evskaya | 766 | – | 14.7 | – |
| 14 | Gornaya Ob | 2389 | – | 45.9 | – |

Further than 90 km from the source (upstream of Polnovan V.), the effect of the main bank becomes weaker; the channel first shifts left from it, and next a wide floodplain of the Kazyma R. opens into the Ob valley (Kazyma water discharge, according to measurements in the spring flood of 2019, is 1651 $m^3/s$). Further downstream in segment 2d (Fig. 1), the water discharge in the Gornaya Ob decreases further to 3428 $m^3/s$ because of water withdrawal into the left-side branches, afer which, almost half (42%) of water discharge runs into the right branch of the bifurcated channel—the Somutnel'skaya branch, in which the mouth of the Kazyma R. lies. The result is that the Gornaya Ob before its confluence with the Somutnel'skaya branch carries less than half of water discharge, and in the main (navigable) branch, the discharge drops even further to 30%. The consequence is the almost complete cessation of navigation in this segment of the Gornaya Ob.

At the confluence with the Somutnel'skaya branch, the discharge in which, including the Kazyma R. flow, accounts for more than half (53%) of that in the Gornaya Ob, its discharge increases to 7973 $m^3/s$ in the segment 3d (Fig. 1). However, further downstream (Table 3) it decreases again because of, first, the deviation of one third of its flow into the left Vanzevatskaya floodplain branch, which increases the flow in the Bol'shoi Nyurik, and next, 13% more runs into the right Yur'evskaya floodplain branch, which empties into the Great Ob.

The confluence of the Gornaya Ob (its discharge at the mouth is 5205 $m^3/s$) and the Bol'shoi Nyurik branch (12566 $m^3/s$) forms the Bol'shaya Ob, in which the total water discharge is 17771 $m^3/s$, making it the largest branch in terms of water flow and the main navigable branch in the forked channel of the lower Ob within the Yamalo-Nenets Autonomous District.

## WATER TURBIDITY AND SUSPENDED SEDIMENT DISCHARGE

In the bifurcation node of the Gornaya and Malaya Ob (Fig. 5), the turbidity of the Malaya Ob (56 $g/m^3$), the flow of which is directed by the cape of the right main bank, is higher than that in the Gornaya Ob (34 $g/m^3$), separating from the Malaya Ob almost perpendicular to it. The suspended sediment discharge in the Malaya Ob (765.9 kg/s) is 2.5 times that in the Gornaya Ob (282.6 kg/s). This difference persists all along the bifurcated channel, a favorable condition for which is the location of the Gornaya Ob channel along the right main bank and the larger rate of channel deformations in the Malaya Ob, which manifests itself in the erosion of floodplain banks: on the average from 1.1 to 3.8 with a maximum of 6.2 m/year for the Malaya Ob; and on the average from 1.0 to 2.9 with a maximum of ≤4.0 m/year for the Gornaya Ob.

The Gornaya Ob shows relatively narrow turbidity variations (within 25–41 $g/m^3$). The turbidity in the Malaya Ob varies widely and is everywhere higher than that in the Gornaya Ob. The maximal value (70.5 $g/m^3$) was recorded in the right branch of the Tsigarskoe bifurcation, and the minimal value (38.1 $g/m^3$), immediately downstream of the source of

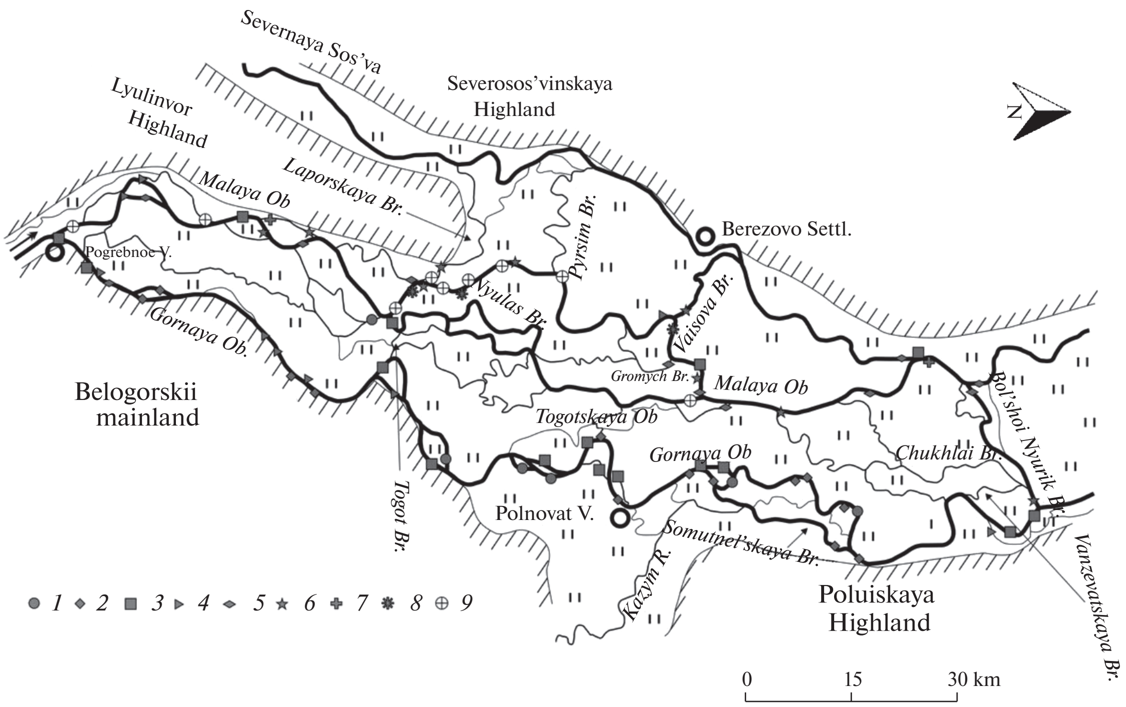


**Fig. 5.** Variation of turbidity along the formed channel of the lower Ob: (*1*) <30 g/m$^3$, (*2*) from 30 to 33, (*3*) from 33 to 36, (*4*) from 36 to 39, (*5*) from 39 to 42, (*6*) from 42 to 45, (*7*) from 45 to 48, (*8*) from 48 to 51, (*9*) >51 g/m$^3$.

the Vaisova branch. Downstream of the confluence with the Severnaya Sos'va, water turbidity in the Malaya Ob (46.4 кg/m$^3$) is larger than at the mouth of the Severnaya Sos'va (39.4 g/m$^3$); downstream of the confluence, the turbidity was found to vary in the cross-section of the flow: at the left bank, which contains the mouth of the Severnaya Sos'va, it is 34.4, and at the right bank, 46.4 g/m$^3$.

In the bifurcation node of the Malaya Ob and Torgotskaya Ob, both branches show a considerable difference in terms of water turbidity (53.9 and 36.0 g/m$^3$, respectively), although the water flow in the latter is 1.5 times greater: the Togotskaya Ob separates from the Malaya Ob at almost right angle, lying at the concave bank almost at the head of its bend. However, the suspended sediment discharge during spring flood is nearly the same in both branches (301.5 and 301.3 g/m$^3$, respectively), although water turbidity in the Togotskaya Ob is greater (51.7 compared with 39.3 g/m$^3$ in the Malaya Ob). It obviously reflects the higher activity of channel deformations in it.

In the bifurcation node of the Malaya Ob and the Bol'shoi Nyurik branch, water turbidity is nearly the same, 40.2 and 41.6 g/m$^3$, respectively. Along the Bol'shoi Nyurik branch (24 km), the increase in turbidity is minor (up to 44.7 g/m$^3$), while the water flow increases more than twice; this is due to the discharge of clarified water from the inundated floodplain and its branches.

The turbidity shows a general decrease along both branches of the bifurcated channel against the background of considerable variations determined by the local conditions (the presence of channel bifurcations, the separation and merging of floodplain branches, water discharge from the inundated floodplain, bank erosion, etc.) (Fig. 5). Indeed, the predominant values in the Malaya Ob are >70 in its uppstream part, up to 30–40 in its lower part, and from 40 to 30 g/m$^3$ in the Gornaya Ob. This correlates well with the longitudinal variation of the suspended sediment discharge along the main branches (Table 4), which differentiates over the identified areas. In the segment of the Malaya Ob from its source to the separation of the Vaisova Branch inclusive, the discharge of suspended sediments decreases by a factor of more than 20 (at a decrease in water discharge by a factor of ~7). Accordingly, the accumulation of sediments leads to an increase in the number of rifts, which limit the navigation in terms of water depth, especially, downstream of the separation of the Vaisova branch.

The water discharge in the Malaya Ob after its confluence with the Togotskaya Ob and next with the Severnaya Sos'va (the total water discharge with the Laporskaya, Pyrsim, and Vaisova branches) increases more four times, and the accompanying increase in the competence of stream causes an increase in suspended sediment discharge by a factor of almost 6 (up to 477.3 kg/s); however, it decreases to 140 kg/s toward the source of the Bol'shoi Nyurik branch.

**Table 4.** Variations of suspended sediment discharges during spring flood along the Malaya Ob and Gornaya Ob

| No. | Section (position) | Turbidity, g/m$^3$ | Suspended sediment discharge, kg/s |
|---|---|---|---|
| | Malaya Ob | | |
| 1 | Source (Peregrebnoe V.) | 56 | 765.9 |
| 2 | The source of the Togotskaya Ob | 53.9 | 301.5 |
| 3 | The source of the Vaisova branch | 38.1 | 34.4 |
| 4 | The confluence with the Togotskaya Ob | 39.3 | 79.7 |
| 5 | Upstream of the confluence with the Severnaya Sos'va | 46.4 | 262.1 |
| 6 | Downstream of the confluence with the Severnaya Sos'va | 34.4 | 477.3 |
| 7 | Upstream of the sources of the Bol'shoi Nyurik branch | 40.2 | 337.4 |
| | Gornaya Ob | | |
| 1 | Source (Peregrebnoe V.) | 34.0 | 282.0 |
| 2 | Polnovat V. | 31.9–34.4 | 198.8 |
| 3 | The left branch of the forked channel | 32.7 | 112.8 |
| 4 | Downstream of the confluence with the Somutnel'skaya Branch | 30.2–32.6 | 237.9 |
| 5 | Upstream of the confluence with the Bol'shoi Nyurik branch | 34.5 | 179.9 |

Similar changes, though with a smaller amplitude, are taking place along the Gornaya Ob. From its source, the discharge of suspended sediment shows a decrease, which is especially large after the separation of the Somutnel'skaya Branch. Downstream of the confluence with it and at an increase in water discharge more than twice, it increases by as little as 2.1 times; however, it decreases again toward the confluence with the Bol'shoi Nyurik branch. Thus, both branches in the forked channel of the lower Ob show longitudinal decrease in suspended sediment discharge during spring flood.

## CONCLUSIONS

The forked channel of the lower Ob (the Malaya and Gornaya Ob) within the boundaries of Khanty-Mansi Autonomous Area creates a unique distribution of the flow of the large river over numerous branches and channels during spring flood. Water discharge in the Malaya Ob, which accounts for 64% of the flow at its source, decreases more than 7.5 imes (down to 9%) near the confluence with the left tributary (the Severnaya Sos'va R.) because of deviation of a considerable portion of water in large tributaries, including the Togotskaya Ob and the Vaisova Branch, in which they are in excess of those in the Malaya Ob, and into numerous small floodplain branches, which separate the floodplain, extending to 60 km. In that case, the Vaisova Branch and two floodplain branches (the Laporskaya and the Pyrsim), merging with the Severnaya Sos'va, increase water discharge in it during spring flood up to the values far in excess of the discharge in the Malaya Ob. It is only at its confluence with the Togotskaya Ob, that the flow becomes comparable with the inflow in the mouth section. However, downstream of the separation of the Vaisova Branch, many branches return into the Malaya Ob and it gains almost all the flow it had, though, partly, due to the water of the Severnaya Sos'va. At the same time, the width of the floodplain decreases to 40 km. Part of the flow distributed over the floodplain branches between the Malaya Ob and Gornaya Ob and the water inundating the floodplain merge to form the Bol'shoi Nyurik branch, which crosses the Ob floodplain almost across and leads to an increase in its discharge by ~2.5 times. This results in that, downstream of the confluence of the Gornaya Ob with the Bol'shoi Nyurik branch, water flow redistributes in favor of the Gormaya Ob, which, starting from this place, is referred to as the Bol'shaya Ob. Such merging of the flow, distributed over branches and channels, into two major branches distinguish the lower Ob from the mouth areas of other rivers, where water flow shows only the distribution over an increasing number of branches.

In the Gornaya Ob, which mostly runs along the right main bank, the deviation of water flow into floodplain branches is lesser. However, at the confluence with the Kazym R., a right branch—the Somutnel'skaya Branch—deviates from it, carrying 42% of water flow, which receives a tributary, resulting in the water flow in this branch rising to exceed that of the Gornaya Ob.

Water turbidity in the Malaya Ob and Gornaya Ob, measured during spring flood is relatively low. Both major branches show a weak tendency to its decrease. The decrease in suspended sediment discharge is more pronounced against the background of considerable variations because of the deviation of a part of flow into branches of channel forks, floodplain branches, and branches of channel bifurcations, and generally reflects the trend in sediment accumulation in the Lower Ob.

The identified regularities in the distribution of water flow and suspended sediments should be taken into account in solving water management and water transport problems in the development of the natural resources of the Lower Ob region.

## FUNDING

This study was carried out under Governmental Order to the Chair of Land Hydrology and Makkaveev Laboratory of Soil Erosion and Channel Processes, the Faculty of Geography, Moscow State University (no. AAAA-A16-116032810084-0: Morphodynamic Typiphycation of Forked Channels); the study was supported by the Russian Science Foundation (project no. 18-17-00086: Field Studies, Water and Sediment Runoff in Bifurcations at Different Levels) and the Russian Foundation for Basic Research (project nos. 19-35-90101: Hydromorphology and Transformations of Wide-Floodplain Channels of Largest Lowland Rivers: Case Study of the Ob and Lena; 18-05-48: Spatial Manifestations of the Extreme Low Water in a Waterway); the study was technically supported by the Adminisration of the Ob–Irtyshvodput' and Khanty-Mansi District Department of Waterways.

## REFERENCES

1. Alekseevskii, N.I. and Chalov, S.R., *Gidrologicheskie funktsii razvetvlennogo rusla* (Hydrological Functions of a Forked Channel), Moscow: Geograf. Fak. Mosk. Gos. Univ., 2009.
2. Baidin, S.S., *Stok i urovni vody v del'te Volgi* (Water Flow and Levels in the Volga Delta), Moscow: Gidrometeoizdat, 1962.
3. Borik, S.A., Integrated experimental studies and estimation of the effect of channel quarries on the hydrological regime of a lowland river: a case study of the Lower Dnestr, *Extended Abstract of Cand. Sci. (Geogr.) Dissertation*, OGML, Odessa, 1987, 17 p.
4. Dugina, I.O. and Sal'nikov, V.I., The redistribution of Amur flow at Khabarovsk, in *Tez. dokl. Vseross. gidrol. S"ezda. Sektsiya 6. Problemy ruslovykh protsessov, erozii i nanosov* (Abstracts of Reports of the Russian Hydrological Congress. Section 6. Problems of Channel Processes, Erosion, and Sediments), St. Petersburg, 2004, pp. 68–70.
5. Ermakova, A.S. and Kirik, O.M., Channel morphology and transformations in the Ust'-Aldanskii segment of the Lena, *Geomorfologiya*, 2006, no. 2, pp. 62–83.
6. Zaitsev, A.A., Ivanov, V.V., Korotaev, V.N., Labutina, I.A., Luk'yanova, S.A., Li Tszunsyan', Rimskii-Korsakov N.A., Rychagov G.I., Svitoch A.A., Sidorchuk A.Yu., and Chernov A.V., *Nizhnyaya Volga: geomorfologiya, paleogeografiya, i ruslovaya morfodinamika* (Lower Volga: Geomorphology, Paleogeography, and Channel Morphodynamics), Moscow: GEOS, 2002.
7. Ivanov, V.V., Korotaev, V.N., Pronin, A.A., Rimskii-Korsakov, N.A., and Chernov, A.V., Floodplain geomorphology and channel dynamics of the Lower Don channel, *Vest. Mosk. Univ., Ser. 5, Geografiya*, 2013, no. 6, pp. 63–67.
8. Kamyshev, A.A., Ruleva, S.N., and Chalov, R.S., Water flow distribution in channel branching of the Middle Ob, *Geograf. Vestn.*, 2017, no. 3, vol. 42, pp. 48–53.
9. Mikhailov, V.N., Rogov, M.M., Makarova, T.A., and Polonskii, V.F., *Dinamika gidrograficheskoi seti neprilivnykh ust'ev rek* (Dynamics of the Hydrographic Network of Nontidal River Mouths), Moscow: Gidrometeoizdat, 1979.
10. Simonov, A.I., *Gidrologiya ust'evoi oblasti Kubani* (Hydrology of Kuban Mouth Area), Moscow: Gidrometeoizdat, 1958.
11. Chalov, R.S., *Geograficheskie issledovaniya ruslovykh protsessov* (Geographic Studies of Channel Processes), Moscow: Mosk. Gos. Univ., 1979.
12. Chalov, R.S., Morphological types of branching lowland river channels, *Vodn. Resur.*, 1998, vol. 25, no. 2, pp. 179–185.
13. Chalov, R.S., *Ruslovedenie: teoriya, geografiya, praktika* (Channel Studies: Theory, Geography, and Practice), vol. 1, *Ruslovye protsessy: factory, mekhanizmy, formy proyavleniya i usloviya formirovaniya rechnykh rusel* (Channel Processes: Factors, Mechanisms, Manifestation Forms, and Formation Conditions of River Beds), Moscow: Izd. LKI, 2008.
14. Chalov, R.S., Intricately braided river channels of lowland rivers: formation conditions, morphology, and deformation, *Water Resour.*, 2001, vol. 28, no. 2, pp. 145–150.
15. Chalov, S.R. and Fedorovskii, A.N., Branching of rivers in the Northern Dvina basin, *Vod. Khoz. Rossii*, 2009, no. 6, pp. 37–52.
16. Chalov, R.S., Chalov, S.R., and Alekseevskii, N.I., Structural formation levels and typiphication of river channel branching, *Vest. Mosk. Univ., Ser. 5, Geogr.*, 2011, no. 4, pp. 8–15.
17. Chernyshov, F.M., *Povyshenie effektivnosti putevykh rabot na mnogorukavnykh uchastkakh rek* (Improving the Efficiency of Channel Operations in Multibranch River Segments), Novosibirsk: Izd. NIIVT, 1973.
18. Egozi, R. and Ashmore, P., Experimental analysis of braided channel pattern response to increased discharge, *J. Geophys. Res. Earth. Surf.*, 2009, pp. 941–962.
19. Latrubesse, E.M., Patterns of anabranching channels: the ultimate end-member adjustment of mega rivers, *Geomorphology*, 2008, vol. 101, nos. 1–2, pp. 130–145.
20. Schuurman, F. and Kleinhans, M.G., Bar dynamics and bifurcation in a modelled braided sand-bed river, *Earth. Surf. Process Landforms*, 2015, vol. 40, no. 10, pp. 1318–1333.

*Translated by G. Krichevets*