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Channel processes and its management on navigable rivers

Abstract: Inland waterways are the sector of the economy that is most dependent on channel processes and their management to ensure safety and favourable conditions for navigation. The main goals of the river channel management are to improve the waterways in terms of navigation and, at the same time, to preserve the rivers as natural sites. The presented study defines the criteria for classification of rivers and river sections according to the complexity of channel processes, their forecasting and management. The classification of rivers as waterways has been provided based on the complexity of channel process management and designing of dredging works and investments aimed at improving the navigation conditions. Examples of this approach are given based on specific rivers of Russia.

Keywords: channel processes, management, dredging, stability of channels, waterways

Inland waterways are the only sector of economy that requires knowledge of river channel processes along the entire length of rivers used for navigation. Other industries related to rivers (installation of communication networks across rivers, construction of engineering, public and domestic infrastructure on river banks etc.) have linear or spot contact with rivers. Therefore, local forecasts of river channel deformations or, in the most complicated cases, development directions of several co-existing river channels must be prepared and determined. Forecasting and comprehensive analysis of river channel processes are required along urbanized stretches of rivers or rivers of urban industrial areas, where various facilities are built and where complex, often multidirectional impact on riverbeds is observed.

In the case of rivers used for water transport, on the other hand, problems related to channel deformations must be solved along the entire length of navigable rivers. Furthermore, all forms of channel deformations are considered along the entire navigable sections of rivers: simple deformations associated with the movement of sediment particles by water flow; formation of ripple marks and dunes; long-term and seasonal changes of riffles; development and formation of channels, including changes in bends, branches and morphologically homogeneous sections; the directional and periodic nature of channel processes, horizontal and vertical channel deformations and deformations induced by dune movement; local deformations caused by the impact on rivers by communication routes, water intakes and other river bank structures; general riverbed transformations of rivers whose flow is regulated by hydroengineering complexes; forecasting of river channel processes according to seasonal, annual, long-term, cyclical and directional changes in the water flow and sediment runoff.

Navigation in Russia is currently carried out along the largest rivers as well as rivers belonging to the Unified Deep Water System of European Russia (the Neva River, the Svir River, the Volga-Baltic Waterway, the Volga River, the Moscow Canal, the Kama, the Volga-Don Canal, the Lower Don). To a very small extent, it still operates on the Middle Don, the Vychegda, the Sukhona, the Oka and other rivers, which were very intensively used in the past. Many navigable rivers, although still on the list of waterways, have almost ceased to be used as such. Rivers that remain important waterways require continuous improvement of navigation routes in order to increase their stability and reliability through the principles and methods based on the analysis of river channel processes. These include the Amur and the Lena rivers with the main tributaries – the Vilyuy and the Aldan, the Yenisey, the Ob, the Irtysh, and some of their tributaries, the Lower Volga and the Volga between the Nizhny Novgorod hydroelectric complex and the Cheboksary reservoir, the Pechora, the Northern Dvina (without their tributaries). However, the navigation on these rivers has become less intensive compared to the 1970s and the 1980s. In many cases, the survival of water transport on these rivers is determined by the fact that rivers are transformed into mining facilities, i.e. quarries – sand and gravel mixture are extracted as a construction material and water transport is used for both extraction and transportation of the extracted material. This situation has developed in Russia in recent decades, even though the country has a huge river network that could serve (and served in the past) as the most important means of communication.

Management of channel processes, aimed at improving the navigation conditions, is one of the oldest types of the economic exploitation of rivers. Waterways with straight or slightly curved course were created in Western Europe, and in order to maintain and increase their depth at low water levels, special structures were built, which limit and constrict channels up to two or three times. As a result of this approach, many rivers have been transformed into channels for water and sediment transport. In pre-revolutionary Russia, the Dniester, the Neman and some other rivers in the west of the country underwent a similar transformation (these rivers are now outside the borders of Russia). In Russia, and later in the Soviet Union and again in Russia, another method of improving the navigation conditions was adopted – dredging through riffles, including the creation of permanent trenches, which ensures the most comprehensive management of channel processes, using the excavated material dumps as alluvial guiding facilities. In fact, engineering structures improving the navigation were used on Russian rivers only in combination with dredging to enhance the positive effect of dredged trenches, to prevent sediment accumulation, to stimulate the processes of riverbed erosion in shallow river reaches, and to partially block the non-navigable river branches. Only in some cases (the Oka, the Moscow river, the Lower Don and the upper Sukhona), low dams equipped with floodgates were built to improve the navigation conditions and to raise the water levels in low-water seasons.

The management of channel processes consists in the artificial impact on river channels to reduce or prevent adverse effects of river channel processes, the use of natural positive trends in the development of riverbeds in the way desirable for life and activity of people. The objective of such river management is to satisfy the needs of water users in the most complete way, while preserving rivers as natural sites, minimizing possible negative effects related to their use and transformation by man. This method of management represents a system of organisational, technical, and regulatory actions aimed at stabilising the riverbeds. The stability and safety of riverbeds are improved by hydrobiological methods, which take into account the resources of rivers, including water, soil and minerals, as well as the exploitation of rivers as waterways, the location of communication routes across the rivers and of any infrastructures related to the development of riverine areas. Hydrotechnical activities related to water transport should be designed in such a way as to take into account the development trends in channel deformations, long-term and seasonal regimes, the impact of transformations of adjacent channels, planned river channel changes within morphologically homogeneous areas and the relationship between them (Chalov, 2017).

The management of channel processes consists of: 1) artificial impact on the riverbed, resulting in the processes of a given trend; 2) allowing for the main regularities in the river channel processes, which includes, on the one hand, the maximum protection of riverbeds as natural sites and, on the other, the achievement of planned objectives with the least damage to the environment; 3) consolidation of the riverbed shape in the optimal position for the maximum efficiency of operation; 4) carrying out compensatory measures to prevent undesirable consequences of river regulation, which require forecasting of the riverbed development under human impact conditions; 5) management of impacts on the riverbed exerted by other water users and operating agencies. Exploitation of rivers as communication routes, consolidation or improvement of waterways should take into account constant changes in the conditions under which riverbeds are formed, due to which some river sections are almost safe for navigation, while others require riverbed regulation to ensure the reliability of a waterway, dredging and other engineering works, sometimes on a large scale. Methodological guidelines and guidelines for the inclusion of river channel processes have been developed as a tool for maintaining the navigation capacity of waterways. However, in the case of long-term planning of water management, dredging and other engineering works, it is equally important to classify river sections according to the complexity of channel deformations, their intensity and threat to the economic infrastructure on river banks. To complete the required information, sections of rivers can be classified based on the complexity of river channel processes, their characteristics, and the channel reorganisation regimes. This in turn facilitates the planning of activities that support the management of channel processes. Classification of river sections according to navigation conditions, determined by river channel processes and their manifestations, and possibilities of their improvement defines the criteria by which it is possible to assess the complexity and threat of river channel processes, their complexity in river development, and the structure of measures ensuring the reliability of engineering infrastructures and activities i.e. the complexity of channel process management. The classification of river sections according to the complexity of channel process management is based on a system of indicators characterising: 1) the stability of the channel and the intensity of channel deformations; 2) morphodynamic riverbed types; 3) morphometric characteristics of the channel; 4) conditions for the channel-forming discharges; 5) distribution and behaviour of riffles, the nature of the channel favouring the formation of riffles or pools; 6) distribution and morphology of the floodplain, together with flood characteristics; 7) riverbank erosion rates and the erosion-line length; 8) prevalence of certain forms of bends, branches, meander bars and other forms of the riverbed; 9) direction and intensity of vertical channel deformations; 10) the rate of slope processes on rocky banks (landslides, talus); 11) fragmentation of river valley slopes by the network of ravines and the presence of debris cones covering the main riverbed, while in mountain rivers – the impact of mudflows along tributaries of the main rivers; 12) technogenic impact; 13) the extent of human-induced channel changes; 14) assessment of predicted channel deformations.

Each criterion or attribute has certain quantitative (numerical) values or qualitative characteristics (Chalov, 2017), which justify the typological classification of river sections, the amount of work necessary to ensure the safety of investments carried out on a river and the economic feasibility of their implementation. When combined together, they provide a database and a methodical approach to classify river sections according to the conditions of river channel process management, long-term water management, water transport and other types of exploitation of rivers, river basins and mineral resources of rivers. The use of this technique enables the division of rivers into sections based on the complexity of management of channel deformations (Chalov et al., 2016, 2017), the development of an effective system to regulate rivers throughout their length to ensure good navigation conditions and, in the case of urbanised and economically developed areas, also taking into account the needs of other water users. Consequently, a classification of rivers has been developed, which provides for the assessment of the impact exerted by economic activity carried out on rivers and in their basins on the river channel processes (Chalov, 2016).

With regard to the objectives of improving the waterways (maintaining and increasing the guaranteed dimensions) and long-term planning of dredging, the following criteria would suffice: 1) channel stability, intensity and types of channel deformations; 2) the morphodynamic channel type; 3) river runoff; 4) conditions for channel-forming water discharges; 5) location and changes of riffles, assessment of pool or riffle types in the channel. Obviously, the criteria listed above can be applied to other types of economic use of rivers.

According to these criteria, six categories of rivers can be distinguished based on the complexity of the management of channel deformation conditions to ensure normal navigation conditions and to improve the quality of waterways (Table 1). Category I – very high complexity – includes rivers with a totally unstable riverbed. In Russia, this includes the upper Ob downstream from the confluence of the Biya and the Katun, the middle reaches of the Lena, from Pokrovsk to the mouth of the Aldan river and the lower Lena from the mouth of the Vitim river to the village of Zhigansk, the Northern Dvina between the confluence with the Vychegda and the Vaga, and the lower reaches of the Mezen. These rivers consist of continuous riffles, constantly changing both during each individual trip and from year to year. The management of channel processes is associated with the implementation of capital dredging works, the construction of longitudinal dams, dam dikes and other engineering structures that help to secure the optimal fairway position and the possibility of straightening it. This category of channels is usually branched and is characterized by the presence of riffles along a long section of a river, exceeding hundreds of kilometres. In this section, all types of channels and riffles develop in connection with each other. Therefore, systematic and repeated dredging carried out during the navigation season is necessary.

Rivers of the second category of complexity (high) differ in their typical location and are characterised by a simpler morphology of both the channel and the riffles, as well as greater deformations of the channel. Therefore, despite all the difficulties in channel regulation, this category of rivers gives the opportunity to find the optimal location of the navigable route and the possibility of securing it. Riffles occur regularly, but usually in strictly defined areas. The main morphodynamic type of the channel are adjacent branches, which are characterized by a fairly regular reorganisation.

Leaving aside the assessment of other categories, category VI does not involve any difficulties in managing the channel processes. However, this does not mean that there are no other complications in navigation. Such complications include current movements near rocky banks, rock ridges in riverbeds and headlands along the banks, pebble and gravel sediments and deposits of incised channels.

An important part of the management of channel processes is the prediction of channel deformations. Current, seasonal, long-term and strategic forecasts are prepared, each with a specific time frame and hence the forms and methods regarding the management of channel process. Forecasts are prepared: 1) for river sections of a considerable length (for the purpose of water transport development, assessment of changes in the channel regime upstream and downstream of reservoirs, the development of riverbed quarries in rivers of urban areas); 2) for different types of river channels – bends, branches or their series (when locations and routes are selected for dredging works aimed at improving navigation conditions); 3) for individual forms of channel relief or elements of riverbed forms – riffles, arms, and specific parts of bends (Chalov, 2015).

Forecasting of channel changes should include: 1) determination of the direction and the rate of changes in the channel; 2) determination of the duration of individual stages and the nature of local deformations; 3) identification of connections between channel deformations and channel forms with the main factors – channel-forming water discharges, channel stability, floodplain structure, flood conditions, the shape and structure of rocky banks, seasonal and long-term fluctuations in water and sediment runoff; 4) identification of periodic, long-term, annual and seasonal deformations, relationships between them and the determinants. Forecasts are prepared for different time intervals: 1) the rate of changes in the channel, its erosion or shallowing, the probability of straightening the bends, development or shallowing of the arms; 2) the directional and long-term (determined by constant factors) or periodic nature of the process; 3) the stage of development of channels and forms of channel relief; 4) consequences of channel deformations for waterway conditions; 5) effectiveness of the recommended engineering works; 6) probability of complications that reduce the effectiveness of channel regulation.

Forecasts and predictive estimates are based on: 1) hydromorphological analysis of channels; 2) construction of *QI* diagrams that allow to estimate the conditions of channel formation depending on changes in the river runoff (*Q* – discharge and I – slope); 3) comparison of various cartographic materials, recording the location of channels at specific time intervals in connection with changes in hydrological characteristics and anthropogenic impacts on rivers (the method of trends); 4) hydromorphometric relationships; 5) calculations according to

Table 1. Characteristics of channels with different categories of complexity in the management of channel processes

Category of complexity		Stability of channel	Rate of channel deformations	Morphological types of channels	Riffles and riffle sections	
Index	Name				Frequency	Difficulty for navigation
I	Very high	Totally unstable, unstable	Very high	Branched (parallel arms and alternating branches with a large number of islands, arms and secondary channels), straight channel and one-sided branching, located along easily eroded high bank with landslides	continuous riffle section with prevailing riffles	Very high, complex seasonal and multiple channel changes, rapid accumulation of sediments in secondary channels; annual and repeated development of secondary channels throughout the year
II	High	Semistable	High	Branched (adjacent, single channel with secondary arms); straight channel with numerous meander bars arranged in a chequered pattern	riffles associated with channel forms, occurring in repetitive sequence	High; regular dredging
III	Increased	Semistable, relatively stable	Increased	Bends with local widenings; straight in floodplains, with local channel widenings or chequered pattern of meander bars	Riffles and riffle sections, alternate with pool sections and elongated pools	Average
IV	Moderate	Relatively stable	Weak	Bends; straight channel and single branches along a stable (rocky) bank; forced bends	Rare riffles in places of branching or confluence of arms, at bends of meanders and irregular rocky bank	Average
V	Low	Stable	Minor	Meandering, i.a. in the branches of floodplain-channel, branching and bifurcate channel, straight sections in the branching channel arms	Single riffles	Low
VI	None	Completely stable	No deformations	Incised, in erosion-resistant banks	None	Difficulties can be associated with bedrock outcrops, currents flowing close to the banks

empirical formulas; 6) analysis of paleochannels that allows to estimate the former discharges of a river at different stages of channel processes and to extrapolate to a remote perspective depending on the adopted scenario of changes in the natural environment and climate; 7) sediment balance, curves of relationships between discharges and water levels $Q = f(H)$ or specific levels, other calculation methods. The limits of applicability of these methods are determined under different conditions of management of channel processes. A retrospective analysis of channel changes in the Northern Dvina, the Mezen, the Pechora, the Vychegda, the Lena, and the Ob rivers allowed to establish patterns of their changes in the past in relation to the development of channels, fluctuations in the river runoff, and human impact. It has been found that global changes in the natural environment and climate as well as human impact lead to the transformation of channels and changes in their morphodynamic types. The frequency of these fluctuations should be determined in connection with the corresponding fluctuations in hydrological conditions of rivers. Temporal changes of channel forms determine spatial and temporal variability of methods used in the management of channel processes, and thus depend on the stage of development of channel forms (bends, branches) and major forms of channel relief (riffles), as well as on periodic fluctuations in water and sediment runoff and trends in their changes. In the case of directional changes in the river runoff, these transformations become irreversible. The consideration of such changes in the channel morphodynamic conditions results in different approaches to the design of infrastructure along waterways and the choice of methods used for channel regulation.

Forecasts of changes in channels and riffles, classification of the river according to the intensity and types of channel deformations and defining the principles of management for the purposes of river water transport were carried out for the Ob river (Chalov et al., 2016). The scope of dredging and channel straightening works has been specified for each of the specified sections of the river.

The maximum number of facilitates to ensure the guaranteed depths and their increase was planned for the sections of the Ob river flowing between the selected sites: the Biya and the Katun confluence, the Charysh river mouth, the Aley river mouth (complexity category I), the Novosibirsk hydroelectric complex, and the Tom river mouth (complexity category II). These works include the implementation of a large number of dredged channel sections and the construction of infrastructures improving the conditions of navigation. Dredged sections dominate in the river reaches of category I. Taking into account the forecasts, a radical change in the course of the navigation route is planned in the long term. A large number of dredged sections should be developed from the mouth of the Tom river up to the village of Sosnino (category III) and from Barnaul to Kamen-na-Obi (category IV). In the mouth section of the Aley river – Barnaul (category V), the prevalence of the meandering channel type allows only small-scale dredging within individual riffles. Also, dredging on a small scale is expected in the river sections flowing between the village of Sosnino, the Irtysh river mouth, and the Ob river mouth (category VI). Implementation of the planned water-transport activities will have a positive impact on the use of water intakes, will reduce the risk of accidents on the bridge and pipelines buried in the riverbed, etc.

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References

Chalov R.S., 2017. Upravlenie ruslovymi protsessami kak ksnova sovershenstvovania vodnykh putei. Vestnik Mosk. un-ta., Seria 5, Geografia 3, 3-13 [In Russian].

Chalov R.S. 2017. Parametrizatsia ruslovaykh protsessov dlia ruslovykh protsessov dlia ikh prognoznykh otsenok i diagnostiki opasnykh proyavlenii. Vodnye resursy 44(5), 551-562 [In Russian].

Chalov R.S., Rulyeva S.N., Mikhaylova N.M., 2016. Otsenka slozhnosti rusla bolshoy reki pri planirovanii vodokhozyaystvennykh veropriatiy. Geografia i prirodnye resursy 1, 29-37 [In Russian].

Chalov R.S., Rulyeva S.N., Mikhaylova N.M., Berkovich K.M., 2017. Parametrizatsii usloviy I form proyavlenia ruslovykh protsessov kak osnova planirovania dnougublenia (na primere r. Ob). Rechnoy transport (XXI vek) 1, 35-44 [In Russian].

Chalov R.S., 2016. Issues of channel processes research for the waterways maintenance at unconfined river channel of Russia. Geography and Tourism 4(2), 23-25.

Chalov R.S., 2015. O prognozakh Ruslovykh defomatsyi. Geomorfologia 4, 20-30 [In Russian].