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A.S. Zavadsky[1], V.V. Surkov[2], P.P. Golovlev, S.N. Ruleva, I.V. Krylenko, I.N. Krylenko, M.D. Goryachko, M.A. Samokhin

M.V. Lomonosov Moscow State University, the Makkaveev Research Laboratory of Soil Erosion and Fluvial Processes

[1] e-mail: az-mgu@mail.ru

[2] e-mail: vita.surkov@yandex.ru

Strategy of protection against hazardous channel and hydrological processes in rivers of developed territories and territories with focal development

Abstract: In 2012-2015, the Makkaveev Research Laboratory of Soil Erosion and Fluvial Processes of MSU, Department of Geography, carried out a research, including analysis of hydrological and channel regimes of the Tom river in the Kuznetsk basin (Kuzbass) and the Katun river up to Uimonsky (the Altai), intra-mountain drainage basins, the survey of floodplains and eroded banks, and modelling of floods occurring in floodplains. As a result, a concept has been developed to improve protection measures against hazardous hydrological and channel processes. More than 200 engineering and organisational events were suggested as part of the concept. Given the dense network of river banks and the high potential damage caused by floods in Kuzbass, the continuous protection of cities, large residential and commercial areas, as well as sections of roads and railways subject to erosion is a priority in the flood control concept. In the case of the Katun river basin, characterized by local development, low population density, and relatively small damage caused by floods, the emphasis is put on organisational measures: prevention, evacuation of people and property, insurance and compensation. Selective engineering structures should, as a matter of priority, reduce the dangerous erosion of river banks and ensure a high level of protection of the territory against floods.

Keywords: mountain rivers, floods, erosion of river banks, flood protection

The development of floodplains and river banks involves a certain level of risk. The economic use of floodplains requires taking into account the channel and hydrological regime of a given river, forecasting their changes, climate change, runoff, natural and industrial transformations of landscapes in river basins. In Russia, after devastating floods of the Lena (2001), the Amur (2013), the Northern Dvina (2013) rivers in Krasnodar (2002, 2012) and Stavropol regions (2017), various organisations and authorities operating in riverside areas have started to pay attention not only to the construction of flood control structures, but also to the development of flood control and flood relief strategies in river basins, administrative units and regions.

In 2014-2015, the Makkaveev Research Laboratory of Soil Erosion and Fluvial Processes, together with the Departments of Land Hydrology, Economic and Social Geography of Russia, and the Department of Geography of the Moscow State University, conducted research that included the analysis of hydrological and channel regimes of the Tom river in Kuznetsk (Kuzbass) and the Katun in the Umonsky (Altai) mountain basins, the survey of floodplains and eroded banks, and simulation of flooding in riverine areas. As a result, the concept has been developed to improve protection measures against dangerous hydrological and channel processes. More than 200 engineering and organisational events were suggested under its framework. The issue is relevant for Kuzbass, which has a centuries-old history of development of riverine areas, and for the Altai Mountains, where the population is concen-

trated in river valleys, and river floodplains are the only areas suitable for housing estates and transport routes. Individual approaches and solutions have been planned for each region, based on characteristics of natural factors and processes as well as regional development.

Seasonal and flash floods on mountain and semi-mountain rivers are devastating, because of the rapid flow of mountain streams, high water velocities, sudden and high water level rises. Floods of 1958 and 1977 on the Tom river were accompanied by great destruction and casualties. The river flooded one third of the territory of Novokuznetsk with a population of more than 100,000 and the Tom-Usinskaya GRES – the largest thermal power plant in Western Siberia. In the Altai area, severe floods occur every 3-7 years. In 2014, the Katun river washed away 500 km of roads, damaged 235 bridges and flooded more than 4,000 houses. The flood affected 27,000 people – 12% of the population living in the Altai Republic (Berdnikov, 2014). The losses amounted to 3.2 billion roubles, the cost of assistance provided to the population was more than 2 billion roubles. It is not only the floods that are dangerous in the case of mountain rivers. In 2002, the erosion of the left bank of the Katun river destroyed over 4 km^2 of the Ust-Koksa territory; 50 residential and other buildings on three streets were washed away.

The destructive nature of floods necessitates the construction of expensive protection structures. The cost of a 1,100 m long and 8 m high dam in Ust-Koksa amounted to 109 million roubles, or 20% of the total budget of the Ust-Koksa district. Since the 1960s, a whole network of dams and riverbank protection structures has been created in Kuzbass to protect cities and villages against flooding (55 structures have been built so far). High-performance non-overflow dams surround the city of Mezhdurechensk along the outskirts and central districts of Novokuznetsk. Lower-class dams protect peripheral areas of cities and major rural areas; reinforced roadbeds also serve as flood control structures. However, even an extensive network of protection structures does not guarantee the complete safety of residential areas and commercial infrastructures, as it was in the case of the 2004 flood. Water penetrates the diked areas under bridges through small tributaries. Climate change transforms the hydrological regime of rivers, and the dams built 50-70 years ago are not always in line with new conditions. Residential and commercial development of floodplains continues, even though the number of floods has increased over the past 15-20 years, and no reliable hydrological forecasts are possible in the changing climate. The old dams of Novokuznetsk and Mezhdurechensk need to be completely renovated and if they fail, the flood will become a disaster.

High-performance dams, erected with the support of the federal budget, protect only cities, water intake areas, factories, highways, i.e. areas where rivers may cause the greatest damage. Operational facilities (dams, barrages, cutoff walls and groynes constructed by local authorities and organisations) are created in response to current threats of flooding of housing estates, industrial and municipal facilities. They protect roads, villages and suburban districts, power lines, local industrial facilities, and access roads to bridges. The effectiveness of these facilities depends on the proper evaluation of channel evolution, the adequacy of solutions and the available resources. Often the constructions are carried out without feasibility studies or scientific research, according to the cheapest option chosen, by inefficient local authorities and with limited financial resources; they of the emergency nature and the quality of work is low. The material used is locally available and only occasionally the river banks are reinforced with concrete slabs or metal piles. In the case of the Katun river, the dams are usually reinforced with boulder rocks extracted from the river. Such temporary structures are sufficient to protect the river bank from erosion or to prevent flooding of the floodplain in years with average discharges. During 1% and 5% floods, these structures are insufficient to protect the riverine areas.

High-performance dams serve for 3-5 years, constantly requiring funds for restoration. In 2004, the Tom river broke through an earth dam in the village of Teleuty. The village was flooded and the population was evacuated. Although the 400 m dam on the Katun river near the village of Gagarki costs 5 million roubles, it is not fully reliable and there is still a risk of flooding in the village and erosion in the residential area. The structure has not been reinforced. It is

under unfavourable hydraulic conditions and is destroyed by the flow. However, the lightweight structure can prevent dangerous processes in the initial phase of a flood, provided that it is built at the right time and in the right place. In 2015, short spur dikes on the Koks river (the tributary of the Katun river) moved the midstream from the bank to the middle of the riverbed, thus preventing the erosion of the bridge supports in the village of Krasnoyarka.

In residential areas, the residents protect their houses from erosion by reinforcing riverbank slopes with rock rolls, concrete walls, metal sheets and piles. Construction of embankments, rock dumping at river sites and digging of drainage channels are carried out for the purpose of protection against flooding. Along the banks of the dangerously developing channel of the Katun river, the simplest flood barriers are installed, made of tree trunks tied with wire ropes, which disperse the stream by reducing its velocity, hence the impact on the river bank. These constructions are designed for dangerous processes occurring in normal hydrological conditions and cannot provide protection against severe floods when the channel evolution is intense. The effectiveness of flood protection is reduced by the lack of a common system designed for large sections of the valleys. Engineering structures, including the high-performance ones, are designed to protect specific objects, their function is often inconsistent, and sometimes their construction increases the bank erosion in the lower reaches of rivers.

The conditions of channel deformations, as well as hydrological and channel regimes of the Tom and Katun rivers are different. The water volume of the Tom river is three times higher (average long-term water discharges amount to 650 and 232 $m^3 \cdot s^{-1}$, the maximum – 11,200 and 4,600 $m^3 \cdot s^{-1}$). In both rivers, 3-4-month spring and summer seasonal floods occurred. The river outflow in this period amounts to about 70-80% of the total annual outflow. The downstream water-level amplitude in the Tom river increases from 3-5 to 7-8 m, in the upper Katun – it decreases from 4.5 to 3 m.

Upstream from the city of Novokuznetsk, the narrow bottom of the Tom river flowing along the southern edge of the Kuznetsk basin becomes wider, forming at 3.5-7th km lake-like forms. The gravel-sand riverbed is mostly of the mountainous type, with 1-3‰ slopes and the flow velocity of 1.5-3 $m^3 \cdot s^{-1}$, and is characterized by the presence of rapids. Straight sections of the river alternate with branching, forced and adapted bends. The rocky sides of the valley reduce the deformation of the channel. Straight sections are stable. Periodic increases in water discharges in braided sections of the river contribute to bank erosion, especially in channels previously characterized by low discharges. The rate of riverbank erosion amounts to some meters per year, but even this rate can be dangerous in case of further intense bank transformation. Downstream from the city of Novokuznetsk, the channel processes are unrestricted, the stability of the channel decreases, the length of the concave banks increases, and the width of the floodplain increases up to 11 km. The long-term dynamics of the river's water volume determines the cyclic flooding of the floodplain. In 1979-2003, the floods were small. At present, their levels are rising again, increasing the duration and depth of the floodplain flooding.

The Upper Katun is a powerful mountain river with a large amount of sediment load, high water velocity (up to 5 $m^3 \cdot s^{-1}$), moving point and braid bars, high rates of deformation of a semi-stable and unstable, mostly complex-braided channel. The Uimon basin is a region with freely developing channel deformations; local erosion of the river banks reaches 20-50 and even 90 m per year. Disastrous erosion occurs on concave banks of the main channel's bends, the development of which takes 25-45 years (from the formation of a bend till the final break-through of the neck, i.e. neck cutoff). The river has a wide (3.5 km) floodplain, with numerous channels. Secondary channels on the floodplain account for 10-30% of the river discharge, so changes in the main channel's discharges are correlated with the volume of water carried by secondary channels. The floodplain channels can develop and transform into high-water arms of the main channel, accompanied by a large-scale erosion of the river banks and the bottom, which threatens villages and farms located on the banks.

Residential areas of the towns of Mezhdurechensk (104,000 inhabitants), Novokuznetsk (550,000 inhabitants), Myskov (40,000 inhabi-

tants) with multi-storey buildings, 29 districts and villages, 25 gardens and suburban residential areas, the sites of Tom-Usinskaya GRES, Novokuznetsk and West-Siberian metallurgical industrial complexes, numerous industrial, commercial and municipal companies, ash disposal sites and waste landfills, oil handling terminals, recreational areas, and sports centres are located on the banks of the Tom river and its tributaries. Power lines, pipelines, local and federal routes run through the floodplain. There are about 15,000 different infrastructure objects in the area of periodic flooding or on concave banks. The floodplain of the upper Katun is a pasture land. The development of riverine areas is local: 12 villages with 7,500 inhabitants are scattered along the banks of the river in the upper part of the Uimon basin, along with small farms, a few agricultural enterprises, tourist facilities and hotels, roads of local significance; there are also several bridges across the river.

The development of flood control strategy consists of six stages. The first one includes the collection of cartographic material, information on the area and water bodies (scientific literature, inventory materials from survey and design offices); public opinion surveys on floods. At this stage, hydrological, geodesic and geomorphological studies of the riverbed and floodplain are carried out, populated areas and economic facilities are certificated, and protection structures are inspected. On the basis of collected data, hydrological and channel regimes of a river, as well as floods in the floodplain zone and bank destruction zones are analysed. The necessary point of this stage is mathematical simulation of the channel evolution and hydrological processes.

Computer simulation of the processes was carried out using a two-dimensional hydrodynamic model of the floodplain and channel complex – the "Flood" (Belikov and Militeev, 2002), which was successfully used to solve problems associated with flooding and flood control activities on the rivers of Russia. In the case of the Tom river, a simulation of flooding in areas located near the river banks was carried out for 1, 5 and 15% floods. For the Katun, this task was of minor importance; the main objective was to forecast a riverbed displacement in populated areas and in the vicinity of commercial facilities. At this stage, joint calculations using the "Flood" model and the one-dimensional *MIKE 11* model by the Danish Hydraulic Institute were carried out. To adapt hydrodynamic models to actual conditions, a wide range of initial data was used: a digital relief model based on field measurements and cartographic information, satellite images showing low and high waters, information obtained from residents and business entities, as well as calculated hydrological characteristics. The verification of the models showed good agreement between the measured and calculated water surface markers: they differed on average by 3-30 cm at the reference points. The models well reproduced the distribution of water flow through the arms and floodplain channels. The simulation enabled the identification of estimated levels of water, the depth and flow rate in the channel and in the floodplain of the Tom and Katun rivers. This allowed to correct the range of flooding zones, to create their maps (taking into account the existing dams) and to identify the eroded banks.

The second stage is to identify problem areas (sections of the channel and floodplain areas), where there is a risk of flooding in residential and commercial areas, and the possibility of their erosion. There are 121 areas of this type along the 140 km stretch of the Tom river valley (90 flooded areas, occupying 55% of the floodplain and 31 sites with 35 km erosion, accounting for about 8% of the total riverbank length). The simulation showed the possibility of water flowing over the low sections of Mezhdurechensk dams. In Novokuznetsk, the residential areas outside the protective dams are flooded: Lesnoy Abagur, Forshtadt, Sadovaya, Vodnik, etc. The water may enter the dam-protected city centre through passages under the railway embankment, as it happened in 2004. In addition, it is possible that when water reaches the floodplain by breaking through low dams located upstream of the Mras-Su river mouth, the villages of Novy Ulus, Kosoy Porog, Karchit, dozens of gardens and recreational areas, camps and tourist centres will be flooded. In the vicinity of the village of Borovkovo, where the bank is continuously reinforced, a 6 km stretch of the Mezhdurechensk-Novokuznetsk highway may be eroded. There is a risk of erosion of the Bezrukovsky water intake that supplies Novokuznetsk, and of the Novokuznetsk-

Abakan railway near the village of Kameshek. There are 21 high risk areas identified along a 50 km stretch of the Katun river, 13 of which are associated with erosion of banks on the main river bends. The risk of flooding in residential areas results from floodplain channels during the high water period.

At the third and fourth stages, the emergency situations (ES), caused by the channel evolution and hydrological processes, were ranked according to the periodicity and severity of consequences. It is necessary to prioritise the distribution of efforts and financial resources, the sequence of protection measures, especially in the case of a large number of facilities, like in Kuzbass.

The third stage includes an expert assessment of the possibility of crisis situation. It is rated as follows: 0 – no direct risk, 1 – low risk, 2 – medium risk, 3 – high risk. The duration and regularity of flooding in the area, the state of protection structures, the rate of bank erosion, and the frequency of hazardous events are taken into account. In the case of the Katun river, the most dangerous phenomena are related to horizontal deformations of the riverbed, in the case of the Tom river – to the flooding of territory and accidents on dams. There are four groups of floods: catastrophic, occurring once every hundred years and less often (1% or less probability of occurring in any given year); significant, recurring every 20 to 100 years (from 5% to 1%); high, recurring once every 10-20 years, and low, with more than 10% probability.

The severity of the impact of an emergency is determined at the four stage. The percentage of the flooded area (or eroded area) in the total residential area, the number of objects in the risk zone, their economic and social significance, the possible number of victims, the value of lost and damaged property are estimated. Due to the severity of consequences and the scale of destruction, the ES is classified as municipal or local, on-site and regional – within a large stretch of the valley. The assessment is carried out in compliance with legal standards in force in Russia (state standards, guidelines) and the available basic methods of damage calculation, which enables the determination of their cost characteristics.

In the Tom river valley, 13 out of the 121 risk areas are likely to be affected by regional emergency. Three of them are related to the risk of failure of the Mezhdurechensk dams and the water overflow. Residential areas and the industrial zone are most likely to be flooded, the infrastructure may be damaged, the operation of enterprises may be disrupted. The costs of evacuation of the population, the restoration and compensatory measures will be great. The breakdown of drainage systems is dangerous, leading to the flooding of embanked urban areas. The same situation is likely to occur in Novokuznetsk, where there are frequent cases of flooding of residential buildings through storm drains. Five sites have been identified where thousands of buildings are located and thousands of residents live in the 1% and 5% flood risk zone. The erosion of the Mezhdurechensk-Novokuznetsk highway near the village of Borovkovo, the Novokuznetsk-Abakan railway near the village of Kameshek – the only highway that directly connects Kuzbass and the south of the Krasnoyarsk Territory, is rated as an emergency situation on a regional scale. The overflow of water through the Mezhdurechensk-Novokuznetsk highway near the village of Karchit will also lead to a large-scale disaster – the residential area of 30 km^2, surrounded by flood embankments, has no culverts to drain water into the riverbed, and will be flooded for a long time. Flooding of settlements that have no flood control structures or have broken dams (40 sites) is rated as an on-site emergency. Housing and garden communities are transformed into cottage settlements with a permanent or long-term residence of people, and floods cost them much more than flooding of horticultural huts. These settlements also require protection, which is ignored by the authorities, because of their uncertain status. Local emergencies occur when the river erodes power-line supporting structures, flooding streets with private buildings and isolated farms.

The amount of damage (in terms of prices in 2014) caused by a 1% flood will be significant: 34.4 billion roubles, or 5% of the annual gross product of the Kemerovo region. Damage to residential areas is estimated at 27 billion roubles, including compensation for damages, expenses for restoration of houses, evacuation of people, medical assistance. During the flood, more than 2 million square meters of housing will be damaged – private households and the first floors

of multi-storey buildings. Damage to industrial facilities will be more than 5.5 billion roubles, of which more than 4.7 billion roubles will be spent on Novokuznetsk enterprises. Failure of the Novokuznetsk metallurgical plant lasting a few days is estimated at 42-45 million roubles. Therefore, the continuous flood protection of cities, large settlements and enterprises, eroded sections of federal motorways and railways in the Kuzbass area is an unconditional priority.

The situation on the Katun river is fundamentally different. With local development and low population density, flood damage is relatively small. Emergency situations will only occur regionally as a result of the highway erosion between the Ust-Koksa district centre and the residential areas located upstream: 5 villages and 1,800 inhabitants will be isolated. In the event of the bridge collapse in the village of Saksabay, large areas of hayfields and pastures will be temporarily inaccessible. The 1% flood can be rated as an on-site disaster due to a large number of flooded farms and the complexity of evacuation of more than 1,000 inhabitants. The erosion of residential areas is viewed as an on-site or municipal emergency, depending on the need to relocate the buildings.

Potential damage to 10 housing estates during a 1% flood is 23.4 million roubles, of which 13.4 million roubles are property losses of the residents and 3.5 million roubles is the cost of restoration of roads and communications. This amount does not include indirect losses that cannot be estimated. The temporary loss of the Ust-Koksa–Maralovodka motorway, the only transport line in the region, will create a great social tension: organising communication, supply, medical assistance, export of agricultural products, import of fuel, loss of transport and trade during the time of inactivity. The Upper Uimon is a historic village with unique buildings, the value of which is much higher than the actual cost. Direct damage caused by a 5% flood (12.1 million roubles) is much lower due to a significantly reduced range of flooding in the residential area; the number of victims will not exceed 400 people. The damage caused by a 15% flood is only 4.1 million roubles – the compensation for damage to the population and the cost of repairing the access roads to bridges.

Local development, dispersion of infrastructure located in flood risk areas and its low value mean that when resigning from construction of costly solid engineering protection against floods in areas with a small flood probability, emphasis is put on flood forecasting and relief measures: prevention, evacuation of population and property, insurance and compensation. Engineering facilities should first of all prevent dangerous erosion of the banks.

Flood protection measures are considered at the fifth stage: 1) dams; 2) bank-protection reinforced facilities, flood embankments, cutoff walls; 3) bottom dredging; 4) organisational and mobilisation activities.

In the Tom river valley, flooding of developed territories completely eliminates the runoff control. Hydroelectric multi-purpose complexes can be built at the riverhead. Such construction is still unfeasible, but feasibility studies can be carried out. At present, the focus is on building new dams and modernizing the existing ones: restoration of the damaged sections, repair of drainage systems, creation of adjustable gates in the mouths of tributaries. Narrowing the flood zone will increase the flood levels and may result in water overflow through existing dams that are not designed for new conditions. Therefore, it is suggested to protect only large areas of new residential development; for small settlements, partial protection and compensatory measures are foreseen.

Bottom dredging should be applied cautiously and selectively. During a flood on the Tom river, 70% of the annual outflow volume is discharged: the decrease in the maximum levels will be insignificant due to the lowering of the bottom, and during the low-level periods the water intakes and water supply channels will dry, riffles will become scarce and the water quality will deteriorate. However, there are river zones with backwater, where sediments are accumulated and dredging is required. The bottom dredging is most effective with simultaneous protection of banks: creation of new routes to guide the passage of river water in riffle areas and new secondary channels connecting the main channels as well as the construction of transverse dams and groynes.

The strategy for the Katun river includes a combination of organisational measures with the construction of occasional structures protecting residential and agricultural enclaves from erosion and flooding during 5% or higher

floods. In this case, dredging is an important and compulsory technique, e.g. guide banks in the main riverbed (accurately outlined taking into account the channel evolution), sediment control, reinforcement and embankment of floodplain streams in villages. The cutoff of bends is only possible at a ratio of $l/L > 1.4$; the cuts will be useless with smaller parameters. The erosion of the concave bank can only be prevented by building a dam along the entire erosion zone and the development of a straightening arm. Such a dam prevented the erosion of the Ust-Koksa village centre, where the straightening arm, diverting 42% of the river runoff, reduced the impact on the dam. Such projects are costly and in most cases certainly more expensive than the damage caused by the impact of the flow. The concave bank erosion area on developing bends must be defined and buildings in this area must be relocated (knowledge of the bend evolution cycle allows for early planning of the infrastructure location). Rapid intervention is also necessary in the event of secondary channels being activated and the flow in such channels can be blocked using light structures that divert the flow from populated areas.

The complex of organisational measures includes a variety of areas, relevant for both Altai and Kuzbass. Engineering works include the relocation of objects to a safe place, the reconstruction of roads for their use as dams and unsinkable entrances to settlements, the resettlement of small villages, the protection of which will cost more than their actual value; the implementation of construction projects of increased security (houses with deep basements, waterproof foundations, artificial embankments). The cadastral measures provide for the systematisation of information on the population, real estate, infrastructure in the floodplain, the development of land-use patterns taking into account the negative impacts of water, administrative restrictions on the development of riverine areas. Technical measures mean the creation of a single service for the operation of hydraulic structures, ensuring their proper operation and timely repair. Legal issues include the development of an insurance system against damage and risks. Purely institutional measures include prevention, planning and carrying out evacuations, rescue of the population, transportation of livestock and property, provision of resettlement by means of boats, equipment, supply of building materials, power generators, food, medicines; ensuring interaction between different agencies in emergency situations. It is necessary to increase the reliability of emergency forecasts by expanding the network of hydrometeorological facilities, setting up monitoring observations, including remote methods, monitoring of riverbed evolution. The latter is especially important for Altai, given the short-term and irregular nature of hazardous floods. The information should be sent in due time to the Emergencies Ministry and local authorities. Finally, it is necessary to conduct education and public outreach and train people how to act in case of emergency.

At the final, sixth stage, a detailed plan of specific flood control and bank protection measures for each region was developed, the operations of the first, second and third stages were defined. Without considering this detailed register, it should be noted that the economic efficiency of flood control measures was assessed and, with the use of the "Flood" model, 1% and 5% floods were simulated when implementing protective measures.

The simulation showed that the consistent implementation of the planned measures in Kuzbass will ensure the protection from flooding for almost all residential areas, reducing the flooded areas by a quarter. In some areas, the flood level will increase by 1.5 m due to the flow obstruction by the dams; the flow rate will increase by 15-30%, which will cause local erosion of the bottom and banks. The final design of the protection structures has been adjusted considering these effects. The cost of the suggested measures is 6 billion roubles or 0.8% of the annual gross product of the Kemerovo region. However, the comparison of costs with the estimated damage caused by 1% and 5% floods (34.4 billion roubles) shows the efficiency and justification of investments.

In the case of the remote Ust-Koksa district, the possibility of carrying out works at the expense of local resources was considered. The priority shall be given to the work without which the situation will deteriorate dramatically, or which will allow to resolve the problems at relatively low costs. The most important task is to protect transport routes, given the complexity of restoring the roads and bridges

on the mountain river. The long-term projects shall be implemented only with sufficient funding. Thus, the construction of a new dam in the village of Gagarka (14.3 million roubles) is much more expensive than the resettlement of several farms, which are at risk of bank erosion.

Computer simulation has confirmed the technical efficiency of the suggested engineering activities on the Katun river, but their cost (57 million roubles) is 2.5 times higher than the amount of possible damage caused by a 1% flood and almost 5 times higher than the amount of damage caused by a 5% flood. Even the cost of priority actions is greater than the possible damage caused by high season floods. However, in housing estates where the major damage is associated with flooding, the efficiency factor in the case of 1% flood is greater than one (1.7-4.1), i.e. the work is desirable. The indirect damage caused by road erosion should also be taken into account, which was not considered herein. Their protection is economically viable, since the restoration of eroded areas will still be required.

Flood prevention measures are costly, which indicates a high risk of development of riverside areas, especially in mountains and intra-mountain basins. The development of river valleys requires the development of flood prevention strategies. It is determined not only by the channel evolution and hydrological regime of the river, but also by the development of the area. In Kuzbass, where thousands of different facilities are located on the floodplain and in the bank zone of the Tom river, the priority is given to continuous engineering protection of bank zones with an active influence on the river channel; the construction of expensive high-performance dams and other engineering structures is economically viable. In the Uimon basin, with the dispersed distribution of housing estates and infrastructure, a combination of organisational measures and selective installation of passive protection structures is suggested. But even their cost often exceeds the possible damage caused by episodic floods.

However, in addition to economic efficiency, the social aspect of protection measures is important. Perception of a threat depends on the uniqueness of a given phenomenon and the prevailing stereotypes. People are very sensitive to rare, but destructive floods. Implementation of justified protection measures, even economically ineffective, has a positive effect on the subjective evaluation of people's safety as an element of the habitat comfort. This affects the psychological state, social behaviour, life plans, the level of credibility of the society and the management system (authorities), i.e. parameters that cannot be expressed in terms of money, but which affect the economic indicators and people's standard of living.

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References

Berdnikov A.V., 2014. Flooding in the Altai Republic: an objective assessment. Transport strategy - XXI century, 26: 29-34.

Belikov V.V., Militeev A.N., 2002. Complex of programs for the calculation of river currents (FLOOD). Russian Agency for Patent and Trademarks. Certificate of official registration of the computer program. No. 2002610941. Moscow.