Socio-ecological consequences during the construction of a multistage system of flood control facilities on side tributaries

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Abstract. A method of protecting territories in a river basin during flash floods by creating a multi-stage system of intercepting flood control systems with temporarily filled reservoirs, with a phased construction of waterworks on side tributaries, including secondary ones. Using the computer programs developed by the authors, the operating modes of the hydroelectric system were simulated for a possible variant of placing their sections on the lateral tributary of the river: in the lower reaches - a traditional hydro system with an earth dam and a concrete spillway, including bottom holes and a surface spillway; upstream - an additional hydro system with a filtering dam made of gabion masonry, into which the missing accumulating volume is redistributed. The calculation of the social effect resulting from the considered method of protection by assessing the reduction of economic damage for settlements located in the downstream of the main flood control hydroelectric complex with participation in the cutoff of the flood peak of an additional temporarily filled reservoir located upstream of the river is performed.

1. Introduction
Deterioration of the ecological state of the environment leads to various changes in the climate [1-12]. An important factor in this process is the increase in agricultural areas, active construction, mining and other [11-21]. One of the negative factors is floods caused by rainstorms [16, 17, 20-26]. Almost all regions of Russia, which has a developed network of water bodies (about 3 million rivers, streams and temporary streams flow through the country), are subject to strong negative effects of floods. Modern radar and optical systems for determining the state of the weather [27-36] only predict a possible catastrophe. This gives you time to prepare for it.

The most common means of flood control is the regulation of the maximum river runoff by large reservoirs of complex hydroelectric complexes being built on main rivers with large forced volumes and areas of the water surface. The creation of such facilities leads to significant land acquisition and has a significant impact on the environment. Therefore, in recent decades, there has been a tendency towards the creation of predominantly low-pressure complex hydro systems with relatively small volumes of reservoirs and land acquisition areas. The consequence of a decrease in the volume of such hydroelectric complexes is the limitation of the guaranteed cutoff of the flood peak when regulating the maximum river flow.

Under the conditions of ongoing climatic changes, the capacity of the existing or projected flood control facilities may not be enough to transform the estimated maximum flow. A situation is possible...
when the passage of safe flows into the downstream pool will require an increase in the capacity of the reservoir, which is not always acceptable for socio-economic or environmental reasons. In this case, it is proposed to develop a system of protection of territories from flooding in stages, over time, constructing intercepting hydro systems with temporarily filled reservoirs on secondary lateral tributaries (3rd, 4th, ..., nth order) in the river network, creating a multi-stage system of flood control hydro systems and ensuring the protection of territories throughout the river basin. The development of small, minor watercourses in hard-to-reach places necessitates the use of relatively inexpensive, reliable options for dam structures. An economical variant of the hydro system, which allows to reduce or eliminate the use of expensive concrete elements and structures, is a filter dam made of gabion masonry, which can pass a given water flow rate into the tailwater through its body due to a porous filler (Fig. 1).

![Figure 1. Dam from gabions - height - 11 m.](image)

Excess water can also be discharged by overflowing the crest of the dam, which is unacceptable for most ground structures. For the assembly and filling of gabions, local available building materials are used; no complicated equipment or special equipment is required. Gabions require less repair and maintenance costs compared to traditional dam options.

2. Modeling the operating modes of the flood control system

Modeling of the operation modes of hydroelectric complexes is carried out for the system of hydroelectric complexes located on a lateral tributary of the river: in the lower reaches - a traditional hydro system with an earth dam and a concrete spillway, including bottom holes and a surface spillway; upstream - the proposed hydroelectric complex with a gabion masonry filtering dam. The schematic control diagram, including the designed hydroelectric system on the main tributary and the proposed additional hydroelectric system from gabions, is shown in Fig. 2.

![Figure 2. Calculation scheme for flood regulation by a multistage system of hydroelectric systems: 1 - main riverbed; 2 - lateral inflow; 3 - flooding zone; 4 - protected areas (settlements, agricultural land, nature protection facilities, etc.); 5 - main flood control waterworks; 6 - additional hydroelectric complex made of gabions.](image)
The assessment of the operating modes of the hydro systems is carried out based on the initial data: the hydrological characteristics of watercourses, the maximum permissible water discharge in the downstream of the i-th hydro system \( Q_{\text{max}} \). When performing the calculations, the extreme flows on the representative lateral inflow were increased by 10%, considering the increase in the water content of the rivers in the region under the scenario of a strong climate warming. The choice of the location for the placement of the gabion hydro system is based on GIS modeling. To do this, in the software package Global Mapper v21 created a digital terrain model of the river basin (Fig. 3).

![Figure 3. The investigated river basin on a digital elevation model: 1 - catchment of the selected inflow; 2 - section of the main hydroelectric complex; 3 - section of the additional waterworks.](image)

The location of the additional hydroelectric complex is chosen 30 km from the mouth and accumulates runoff from an area of more than 1000 km\(^2\). The location of the hydroelectric complex meets the following requirements: the lateral tributary is outside the protected areas, and a large settlement is located relatively close. Other tributaries either do not have the required water content, or fall into the territory of nature conservation objects, where the creation of a reservoir, even with temporary flooding, is unacceptable.

3. Results and Discussion

Modeling of the modes of the hydroelectric system was carried out in the developed simulation program [24-26]. As can be seen in the graphs (Fig. 4-5), the use of an additional intercepting hydroelectric complex on the side tributary reduces the water inflow into the reservoir of the main structure, ensuring the admission of admissible flow rates into the downstream. The water level in the reservoir of the main hydroelectric complex, when working together, decreases by 0.8 m.
Figure 4. Water discharge in the lower pool of the primary facility with an increase in flood discharge by 10% relative to the design: 1 - natural inflow of water 1% probability (huge flood); 2 - natural inflow of 10% probability (moderate flood); 3 - regulated water consumption in the lower pool when only the primary facility is in operation; 4 - regulated flow rate when working together with additional facilities.

Figure 5. Water discharge in the lower pool of the primary facility with an increase in flood discharge by 10% relative to the design: 1 - natural inflow of water 1% probability (huge flood); 2 - natural inflow of 10% probability (moderate flood); 3 - regulated water consumption in the lower pool when only the primary facility is in operation; 4 - regulated flow rate when working together with additional facilities.

The operating modes of the additional intercepting hydroelectric complex for a given flood scenario are presented in Figures 6 and 7.
When performing the calculations, the optimal parameters of the additional waterworks were determined: the width of the slotted spillway was 6 m, the length of the pressure front of the gabion dam was 300 m. Filtration through the structure was 46% of the total water consumption.

The zones of short-term flooding were determined, and the water standing time for the characteristic water levels was determined using GIS-modeling. The results obtained indicate a relatively small impact of the additional flood protection reservoir on forest ecosystems in the area of the proposed reservoir, which means that the construction of a hydroelectric complex at this place may be acceptable for environmental reasons.

4. Conclusion
The developed system allows minimizing the anthropogenic impact on the ecosystems of the catchment, since instead of a permanent large reservoir, a network of small reservoirs is created, having significantly smaller flood areas, filled only during the flood period, completely emptied during the rest of the year, ensuring the natural level regime of watercourses. A promising version of a multistage system of hydroelectric complexes located on a lateral tributary of the river has been selected, including: - a
traditional hydro system with an earth dam and a concrete spillway with bottom holes and a surface weir in the lower reaches.

With the use of GIS technologies, accessible, necessary information about the topography of the terrain was obtained, which made it possible to select the preferred sections of hydrosystems on the lateral tributary, to determine the marks of water levels, volumes and areas of reservoirs, zones of flooding of territories in the upper and lower bays, and others. Based on the calculation of the flood zones of settlements, it was revealed that the economic damage to settlements was reduced by about 6 times when implementing flood control measures.

References
[1] Nikolaev D, Chetiy V and Dudkin V, 2020 IOP Conference Series: Earth and Environmental Science 578(1) 012052
[2] Lukashev N 2019 Journal of Physics: Conference Series 1236(1) 012068
[3] Davydov R, Antonov V, Molodtsov D and Trebukhin A 2018 Advances in Intelligent Systems and Computing 692 915–920
[4] Davydov V, Cheremisikina A, Velichko E and Karseev A 2014 Journal of Physics: Conference Series 541(1) 012006
[5] Gryznova E, Grebenikova N, Ivanov D and Bykov V 2019 IOP Conference Series: Earth and Environmental Science 390(1) 012044
[6] Davydov V, Dudkin V, Myazin N and Rud’ V 2018 Instruments and Experimental Techniques 61(1) 140–147
[7] Davydov V, Velichko E, Myazin N and Rud’ V 2018 Instruments and Experimental Techniques 61(1) 116–122
[8] Davydov V, Velichko E, Dudkin V and Karseev A 2015 Instruments and Experimental Techniques 58(2) 234–238
[9] Baikin A, Kaplan M, Nasakina E, Kolmakov A, Sevostyanov M. 2019 Doklady Chemistry 489(1) 261–263
[10] Kalinichenko V, Glinushkin A, Sokolov M, Bakoyev S, Il’ina L 2019 Journal of Soils and Sediments 19(6) 2717–2728
[11] Glinushkin A, Motasova E, Aysuvakova T, Beloshapkina O, Dubenok N 2019 IOP Conference Series: Materials Science and Engineering 525(1) 012102
[12] Davydov V, Dudkin V and Karseev A 2015 Journal of Applied Spectroscopy 82(5) 794–800
[13] Davydov V 1999 Russian Physics Journal 42(9) 822–825
[14] Myazin N, Yushkova V, Taranda N and Rud V 2019 Journal of Physics: Conference Series 1410(1) 012130
[15] Petrichenko M, Vatin N, Nemova D, Kharkov N and Staritsyna A 2014 Applied Mechanics and Materials 633-634 1007–1012
[16] Murgul V, Vatin N and Zayats I 2015 Procedia Engineering 117(1) 819–824
[17] Vatin N, Petrichenko M and Nemova D 2014 Applied Mechanics and Materials 633-634 1007–1012
[18] Davydov V, Dudkin V and Karseev A 2015 Technical Physics 60(3) 456–460
[19] Smirnova S and Nikolaev D 2020 Journal of Physics: Conference Series 1695(1) 012136
[20] Davydov V, Nikolaev, D, Bukharov G and Pavlova Z 2020 Proceedings of the 2020 IEEE International Conference on Electrical Engineering and Photonics, EExPolytech 2020 9243948 p. 227–229
[21] Davydov V, Nikolaev D, Moroz A, Dmitrieva D and Pilipova V 2020 AIP Conference Proceedings 2308 060005
[22] Fadeenko V, Fadeenko I, Dudkin V and Nikolaev D 2019 IOP Conference Series: Earth and Environmental Science 390(1) 012022
[23] Davydov V, Fadeenko V, Fadeenko V, Popovskiy N and Rud V 2019 E3S Web of Conferences 140 07006
[24] Antonov V I, Davydov R V, Maslikov V I, Molodtsoy D V and Badenko V L 2019 Journal of Physics: Conference Series 1400(7) 077049
[25] Antonov V I, Davydov R V, Maslikov V I, Molodtsov D V, Chusov A N 2019 Journal of Physics: Conference Series 1368(4) 042076
[26] Macher C 2008 LWF altuell 66 26-29
[27] Moroz A, Malanin K, Krasnov A and Rud V 2019 Journal of Physics: Conference Series 1400(4) 044009
[28] Moroz A 2019 Journal of Physics: Conference Series 1368(2) 022024
[29] Moroz A 2019 Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11660 LNCS 710–718
[30] Moroz A, Malanin and Krasnov A 2019 Proceedings of the 2019 Antennas Design and Measurement International Conference ADMInC 2019 8969090 114–116
[31] Moroz A 2019 Journal of Physics: Conference Series 1410(1) 012212
[32] Podstrigaev, Smolyakov A and Grebenikova N 2019 Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11660 LNCS 525–533
[33] Smirnov K, Glagolev S and Tushavin G 2018 Journal Physics: Conference Series 1124(1) 022014
[34] Smirnov K, Medzakovskiy V, Vysoczky V and Glagolev S 2017 Journal of Physics: Conference Series 917(6) 062019
[35] Smirnov K, Glagolev S, Rodygina N and Ivanova N 2018 Journal of Physics: Conference Series 1038(1) 012102
[36] Smirnov K 2019 Journal of Physics: Conference Series 1368(2) 022073