An assessment of environmental flow for modelling the operating conditions of Mongolian hydropower plants in the transboundary basin of the Selenga River

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Abstract. The decision of Mongolia’s Government to implement the projects for the construction of hydropower plants (HPPs) in the transboundary basin of the Selenga River caused the need to study their possible impact on the Russian part of the basin and Lake Baikal. To assess the impact of planned in Mongolia HPPs on the territory of the Russian Federation (water resources and ecosystem), we have studied the expected changes in the yearly hydrological regimes due to flow regulation. A methodology developed at the Melentiev Energy Systems Institute (MESI) allows integrating various models (hydrological, energy, environmental, etc.) into a single system. We have employed this system to model the parameters of the planned HPPs reservoirs and their regulation modes, as well as the deviations of hydrological regimes of Selenga River due to the HPPs construction from those under natural conditions. The concept of “environmental flow” is used to assess changes in the intra-annual hydrological regime of a river. We determine the boundaries of the environmental flow for each month based on an analysis of a variety of biotic and abiotic restrictions for the entire river bed from the border of the Russian Federation to the Selenga River delta.

1. Introduction

Currently, the government of Mongolia is considering three projects for construction of hydropower plants and hydraulic structures in the Mongolian part of the transboundary Selenga River basin. These are the Shuren HPP, the Egiin-Gol HPP and the Orkhon-Gobi water diversion system (figure 1) [1, 2].

In the event that these projects are implemented, the regulation of the Selenga River flow will inevitably change its annual hydrological regime. The change in the hydrological regime, in turn, will affect the ecosystems of the river and Lake Baikal basins. In this regard, it is appropriate to assess in advance the future operating conditions of the planned hydropower plants and the use of water resources of their reservoirs.

For the Russian part of the transboundary basin of the Selenga River, it is primarily important to determine potential changes in the intra-annual runoff at the border of the Russian Federation (the Naushki station) to be caused by the construction of the hydropower facilities in Mongolia. Regardless of technical characteristics of these facilities and operating conditions of the planned HPPs, it is necessary to develop a system of restrictions on the flow of the Selenga River in the village of Naushki, considering the potential environmental, water management and other risks to occur in the Russian Federation.
The data on the current state and prospects for the development of water management system in the Russian part of the transboundary Selenga River basin show that in the basin, the total volume of freshwater withdrawal from all water sources during a year with an average water content does not exceed 2% [3]. This gives ground to talk about the adequacy of water resources to meet various water management requirements now and in the future. The main restriction on the use of water resources at present and in the near future is environmental requirements. Therefore, special attention should be paid to this issue when considering the effects of flow regulation.

2. Models and methods
Assessing the impact of individual hydropower plants on the ecosystem, as well as their cumulative (cascade) impact, it is necessary to model the operating conditions of hydropower plants for different water conditions, including those during the periods of construction, initial filling of reservoirs, their seasonal filling, and drawdown during operation.

A methodology of consistent models [4, 5] was developed by a research team of the Melentiev Energy Systems Institute SB RAS to model (simulate) the operation of existing hydropower plants and those under design. The methodology allows integrating heterogeneous water management, environmental and energy models into a single system (figure 2).

The simulation system includes various models implemented as stand-alone software components. The models perform a specific set of functions that receive input data and parameters and transfer the results to other components.

The main models (blocks) of the system are:

- an energy model, representing a set of models designed to control the operating conditions of hydropower plants (optimization, simulation control by dispatch schedules) and estimate the parameters of reservoirs for various scenarios of their use;
- a hydrological model, including a set of models, developed to form deviations of abiotic indicators depending on changes in the flow rate of hydropower plants;
• a water management model, allowing for the restrictions on water withdrawal and the amount of permissible consumptive use, water consumption and water use for the studied areas in different periods;
• an environmental model, including a set of models intended for an analysis of biotic indicators, the state of aquatic and riverine ecosystems, modeling the impact (reaction) of ecosystems, formation of environmental restrictions, determination of an environmental flow at a given cross-section and reservoir releases for potential hydropower plants that take into account the environmental flow requirements.

![Diagram of the system of models](image)

**Figure 2.** The system of models "Flow-Ecology" of the Selenga River.

The basis for all the blocks is *an information database* on the most important hydrological, water management, energy and environmental indicators of various temporal (day, ten-day periods, months) and spatial (cross-sections of the four studied areas) resolution, as well as supporting data (meteorological indicators in the studied basin; GIS-data on the status of the river bed for different time periods, considering its changes, satellite images of various scales, the satellite sounding data on relief: SRTM, ASTER GDEM and others).

The energy block is designed to model the planned reservoirs and operating conditions of the hydropower plants. The reservoir modeling includes:
• assigning a projected site for hydropower plant according to the design characteristics of the hydro systems and the possibility of considering alternative prospective sites;
- setting a range of reservoir regulation with characteristic pre-design marks of its levels, including the dead storage level, normal water surface, the maximum water surface, and the level of pre-flood drawdown;
- outlining the geometry of a reservoir for its various levels with the possibility of presenting the results in the format of geospatial data (for example, KML);
- calculating the storage capacity for different water levels;

This approach was used to model the configuration of reservoirs of the designed hydropower plants in Mongolia (figure 3), the dependence of reservoir volume on water level (figure 4), conditions and duration of the initial filling. The main factors affecting the duration of the reservoir filling are the total inflow to the reservoir (water content), the amount of sanitary discharge into the lower reach, and the storage capacity.

![Figure 3. Simulated contours of Shuren reservoir.](image)

![Figure 4. Dependence of Shuren reservoir volume on the water level.](image)

Calculations showed that in the case of normal water content (50% flow availability), it would take 3-6 months to fill the Shuren HPP reservoir, 38-40 months to fill the Egiin-Gol HPP reservoir, and 2-4 months – the Orkhon-Gobi water diversion system. In the event of an extremely low water content (95% flow availability or more), the filling time may increase significantly: for the Shuren HPP – up to 25-27 months, for Egiin-Gol HPP – up to 66-76 months or approximately 5-6 years, and for the Orkhon-Gobi water diversion system – up to 15-25 months.

Modeling the HPP operating conditions includes:
- setting the criterion of the HPP operation (supply of firm average power in winter or summer, the maximum annual output of the HPP, minimization of idle discharges, etc.);
- assigning the minimum and maximum permissible HPP flow rates by month;
- setting constraints on the technical characteristics of hydro systems (efficiency, head, available power, etc.), as well as other energy, water management, environmental and social requirements;
- developing a dispatch schedule to control the HPP operating conditions.

3. Results and discussion

3.1. Determination of the environmental flow
The water flow in the Selenga River basin is highly erratic: long low-water periods, extremely high floods and the minimum winter flow rates. The ecosystem of the Selenga River basin is adapted to these natural conditions; however, the construction of hydropower plants can both smooth out the
extreme fluctuations and create other conditions for changes in the natural flow, including negative ones.

The previous studies conducted for various hydropower facilities in different countries within the framework of the "flow-ecology" approach indicated that the changes in the hydrological regime of a river during the year caused by the construction of hydropower plants are the primary factor of impact on ecosystems that inevitably lead to their changes [6-8]. At the same time, the risk of negative impact on the ecosystem increases with a rise in the amplitude of hydrological changes (deviations) relative to natural conditions. The risks of the hydropower plants impact are the probability that the values of abiotic (hydrological, morphometric, physicochemical, etc.) and biotic (microbiota, phytoplankton, zooplankton, fish, etc.) characteristics of ecosystems go beyond the limits of natural variability.

Following this approach, the environmental flow of the Russian part of the Selenga River can be assumed as a range of flow fluctuations under natural conditions at the border of the Russian Federation (the village of Naushki). Based on an analysis of a set of biotic and abiotic restrictions for the entire Selenga River bed [9-11], we have determined the boundaries of the environmental flow for each month (table 1).

Table 1. The environmental flow of Selenga River in Naushki.

| Month       | Average monthly flow (m$^3$/s) |
|-------------|---------------------------------|
|             | min    | max    |
| April       | 170    | 360    |
| May         | 300    | 740    |
| June        | 350    | 790    |
| July        | 350    | 1360   |
| August      | 350    | 1690   |
| September   | 300    | 1290   |
| October     | 200    | 610    |
| November    | 100    | 220    |
| December    | 80     | 125    |
| January     | 60     | 100    |
| February    | 60     | 75     |
| March       | 60     | 90     |

3.2. Impact of Mongolia’s HPPs operation on the flow in the Russian part of the Selenga River basin

Research (modeling) of the operating conditions of the planned hydropower plants in Mongolia in the transboundary Selenga River basin indicates that their construction can cause a considerable redistribution of the flow, i.e. a decrease in the summer flow and an increase in the winter flow. The Shuren hydropower plant will have the greatest impact on the change in the intra-annual Selenga flow regulation. During the winter period, the drawdown of the water accumulated in the reservoir over the summer may result in a three-fivefold increase in the flow compared to the average multi-year values. Accordingly, the period of the reservoir filling (summer) will be accompanied by a significant decrease in the flow with a possible two-threefold decline in the minimum monthly indicators on the border with Russia relative to the corresponding indicators under natural conditions. With a cascade of several hydropower plants in operation, the situation can be even more exacerbated during the low-water period.

Regulated flow can have a significant impact on the flow rates throughout the Russian part of the Selenga River bed. For example, with the cumulative impact and average water content, the reduction in flow rates in April-October for the natural one can reach 53% in Naushki, 22% – in Novoselenginsk, and 16% – in Mostovoi. The major impact on the level of Lake Baikal can be observed with medium and low water content. There can be a 10-cm decrease (10% of the useful regulation range) in the level of the lake by October compared to the natural flow.
These changes may affect the characteristics of ecosystems. The typical changes in abiotic indicators are:

- an increase in the levels and speeds in the winter period exceeds those observed under natural conditions, and in the summer period they differ slightly;
- a decrease in the temperatures in the spring-summer period by several degrees and an increase in the autumn period with a shift in the timing of ice formation;
- a reduction in turbidity (except for the situations where the flow of the Orkhon River at the confluence is much higher than the flow of the Selenga);
- a reduction in suspended sediment due to the construction of dams;
- changes in the duration and magnitude of floods and low-water periods (reduction in the duration of high water stand during high-water periods and an increase in the duration of low flow period in dry periods).

The changes in abiotic indicators, in turn, act as a stressor for biotic indicators. The most significant and critical problem for biotic indicators, representing aquatic ecosystems, is elevated flow rates (consumption) during the winter period. In winter, the increased water consumption will disturb the maturation conditions of the Baikal sturgeon, omul, whitefish and other valuable species of fish, which will inevitably result in a decrease in the number of populations and a change in the nature of hydrobiont communities (phytoplankton).

Violation of natural flooding regimes in coastal areas during the vegetation period will also lead to degradation of floodplain soils and vegetation, which will not only decrease their productivity but also destruct the aquatic ecosystems through a feedback system. The conditions for reproduction of amphibians, birds and mammals living in the riverine ecosystems will worsen.

In the context of global climate changes, long and deep low-water periods are also dangerous, when a long decrease in runoff during the period of reservoir filling may lead to irreversible consequences for the ecosystems in the Selenga River and Lake Baikal basins.

To take into account the requirements of the environmental flow of the Selenga River basin, the regulation of the Mongolian hydropower plants must meet special environmental requirements for permissible intra-annual maximum and minimum flow rates through the hydropower plants. Such flows (regimes) correspond to reservoir releases. Meeting the permissible flow rate restrictions should be checked based on the regulated flow at the site of the Shuren HPP (it is located in the Selenga River bed, 150 km from the Russian Federation border and regulates the Egin-Gol HPP flow) and the regulated flow at the site of the Orkhon-Gobi water diversion system (it is located in the Orkhon River bed, a right-hand tributary of the Selenga, which flows into the mainstream below the Shuren HPP near the border of the Russian Federation), considering the consumptive water use. The sum of the regulated flow of the Selenga and the flow of the Orkhon must fall within a permissible range of fluctuations in the environmental flow.

The specific feature of the Selenga flow with its large seasonal variability points to the conclusion that the greatest deviation of the regulated flow from the natural one can be achieved through the classic “energy” option of the HPP regulation with the accumulation of water reserves in the summer and their use in the winter. With an increase in the effective storage capacity, there can be an increase in the generation of hydropower in the winter, depending on the requirements of the Mongolian power system. However, this will lead to an increase in the winter flow, substantially exceeding the one previously observed under natural conditions.

4. Conclusion

The construction of hydropower plants in Mongolia will inevitably lead to negative changes in ecosystems. Under certain water conditions and flow regulation, the abiotic and biotic characteristics of ecosystems very likely go beyond the limits of natural variability (environmental flow).

The main risks for ecosystems are changes in the intra-annual hydrological regime, including elevated flows in the winter period.
Among the considered hydropower plants projects planned in the Mongolian part of the transboundary basin of the Selenga River, the Shuren hydropower plant will have the greatest negative impact on the territory of the Russian Federation. The impact of the Egiin-Gol HPP will be relatively smaller in magnitude, whereas the risks of negative impacts on ecosystems similar to those of the Shuren HPP remain. The Orkhon-Gobi water diversion system has a minimum impact.

In regulating the operating conditions of the Shuren HPP and Egiin-Gol HPP, the greatest (3-5 fold) deviations from natural runoff are observed in the winter period throughout the Russian section of the Selenga River. The greatest deviations from the natural runoff in the summer period occur when the water content is extremely low, in particular, the lower limit of the natural runoff fluctuation range is violated, having the flow availability of 98% or more.

Territorially, the upper border area of Naushki-Dzhida is subject to the greatest impact. The closer the Selenga mouth, the higher the impact of the Mongolian hydropower plants. In the lower reaches of the river (the Mostovoi and Kabansk stations), the deviations from the natural regimes will be observed only in the winter period.

In the event that the projects for the construction of Mongolian hydropower plants are implemented, the environmental requirements should be developed to identify the permissible average monthly values of the environmental flow at the border of the Russian Federation and Mongolia, including the minimum permissible values in the summer period and the maximum permissible values in the winter period. Violation of these restrictions would have the greatest negative impact on ecosystems.

Consideration of the environmental requirements and adoption of reservoir releases will reduce the negative impact but cannot guarantee the preservation of ecosystems in a state close to the natural. The implementation of these measures is an extremely challenging task, which is difficult to achieve in practice.

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