Scientific basis of proposals for optimizing the operating mode of the Upper-Svir Reservoir

I Yu Milyutina, A A Sapozhnikova, O V Gorelits and I V Zemlyanov

N. N. Zubov State Oceanographic Institute, Roshydromet, 6, Kropotkinskii Lane, 119034, Moscow, Russian Federation

lynx-inga@rambler.ru*, asapozhnikova@mail.ru, gorelits@mail.ru, ivz@geocentre.ru

Abstract. The study analyses long-term and seasonal changes in the water regime elements and water balance components of the Upper-Svir Reservoir, including inflow, runoff and fluctuations in water level of Lake Onego over the whole observation period. It is shown that currently there is an increase in the frequency and duration of high levels of Lake Onego. The impact of climate changes and HPP operation on lake level rise has been assessed. Science-based recommendations to optimize the operating mode of the Upper-Svir Reservoir, aimed to reduce the level of Lake Onego, have been developed.

1. Introduction

The Upper-Svir Reservoir was formed as a result of the backwater of the upper Svir River and Lake Onego after the construction of the Upper-Svir hydroelectric power plant (HPP) in 1951-1952 in order to ensure the navigation along the Volga-Baltic waterway. The Upper-Svir hydroelectric complex is the upper stage of the Ladoga HPP Cascade operated by Nevsky Branch of TGC-1.

The dam of the Upper-Svir hydroelectric complex is located near the town of Podporozhye, 97 km from the source of the Svir River – the only outflow from Lake Onego. The catchment area of the Upper-Svir Reservoir is 67 100 km².

The Upper-Svir Reservoir includes the river part and Lake Onego. The reservoir provides over-year flow regulation by resources of Lake Onego, weekly and daily - due to the resources of the river part. The normal water level of the Upper-Svir Reservoir is 33.3 m BS [1]. In recent decades, the levels of Lake Onego have regularly exceeded this mark, leading to intensification of the negative impact on the coastal area. In order to develop scientifically based proposals to optimize the operating mode of the Upper-Svir Reservoir and to reduce this impact an analysis of the inflow, runoff and water level regime of Lake Onego in relation to climatic factors over the whole observation period was carried out.

2. Materials and methods

The most detailed assessment of the parameters and particular features of hydrological regime, water balance structure, long-term variability in the Lake Onego level and its fluctuation spectra in relation to climatic characteristics, based on the results of many years complex researches, is presented in the publications of the Karelian Research Centre of the Russian Academy of Sciences [2-5]. The generalization of the Hydrometeorological Service observations of the studied basin is given in the scientific and applied reference book of the State Hydrological Institute, which includes the results of
analysis of long-term fluctuations in inflow to the Upper-Svir Reservoir and of calculating its probabilistic characteristics [6].

The presented study is supplemented by the analysis of HPP discharges in comparison with the natural runoff in the pre-regulation period, takes into account modern materials of climatic characteristics observations for the catchment area of the Upper-Svir Reservoir and assesses the combined influence of natural and anthropogenic factors on the regime of Lake Onego levels.

Long-term changes in the level of Lake Onego were analyzed for the period of 1881-2019 according to the data of the Voznesenye gauge station, which has the longest observation series, based on the annual publications of the Hydrometeorological Service [7-9] and the data of the Automated State Water Monitoring Information System [10].

Total and useful inflow to Lake Onego (1932-1951) and the Upper-Svir Reservoir (1952-2014) was adopted according to the data of the State Water Cadastre [9; 11]. Useful inflow takes into account the difference in precipitation and evaporation from the water surface and can serve as a comprehensive indicator of climate variability at the catchment area.

The outflow from Lake Onego during the natural period (1881-1951) was estimated by the discharges of the Svir River at the Myatusovo gauge station, located 16 km upstream of the dam of the Upper-Svir HPP [12]. The runoff of the Svir River during the regulated period (1953-2019) is characterized by the discharges of the Upper-Svir HPP according to the data published in the annual editions of the State Water Cadastre [8; 9] and provided by the directorate of Ladoga HPP Cascade.

Analysis of long-term and seasonal variability in the main climatic characteristics - air temperature and precipitation - was carried out for the entire catchment area of the Upper-Svir Reservoir on the basis of open interpolated grid data arrays CRU TS (Climatic Research Unit, University of East Anglia) over the period of instrumental observations 1901-2018 [13].

3. Results and discussion
To assess the influence of climatic characteristics on the water regime of the Upper-Svir Reservoir, combined difference-integral curves (DIC) of the average annual amount of precipitation, total inflow and the average annual levels of Lake Onego at the Voznesenye gauge station were constructed (figure 1). Periods of reduced, medium and increased water availability are distinguished on all three curves. Despite some delay in crossing the timeframe, long-term changes in the level of Lake Onego accord with changes in climatic factors.

The construction of the Upper-Svir HPP coincided with the transition from the long period of reduced water availability (1881-1951) to a period of medium water availability (1952-1980). The modern reservoir operation falls on the period of increased water availability (1981-2019).

Analysis of the data shows that the values of climatic characteristics during the start period of reservoir operation (1952-1980) are relatively stable and close to the 1961-1990 Climate Normals. Over the last 40 years, there has been a steady increase in the average annual air temperature (by 1°C) and annual amounts of precipitation (by 30 mm) [14]. The obtained results are consistent with climate studies for the territories of Karelia [15] and Finland [16].

These factors caused natural humidification at the catchment area and an increase in inflow to the Upper-Svir Reservoir, which resulted in rising levels of Lake Onego (figure 2).

Since the 1980s there has been an increase in the frequency and duration of daily levels of Lake Onego exceeding the normal water level (figure 3). A comparison of the modern situation with particular years of increased water availability that occurred during the natural low-water period suggests that the lake responded to increased inflow in a similar way under pre-regulation conditions.

Seasonal climate changes in recent decades have influenced the intra-annual variability in inflow to the reservoir. The growth of average monthly air temperatures relative to the 1961-1990 Climate Normals is observed in all months of the year, especially significant in December-February [14]. The increase in monthly precipitation is fixed in November-March and in May-July. It has resulted in frequent winter thaws, an earlier onset of the spring season and a later onset of the cold period.
Figure 1. Combined difference-integral curves (DIC).

Figure 2. Average annual water levels of Lake Onego according to the data of the Voznesenyegauge station from 1881 to 2019 and averaged over periods of water availability.
Figure 3. Exceedance of representative marks by daily levels of Lake Onego according to the data of the Voznesenye gauge station for the period 1881-2019.

The increase in inflow to the reservoir is noted in winter low-water (January-March), most significantly during the spring flood (in May and especially in April). More frequent rainfall flooding is observed from August to December.

Average annual HPP discharges, averaged for the periods of medium and high water availability (582 and 598 m³/s), are less than the natural runoff of the Svir River at the Myatusovo gauge station, averaged for the low-water period (607 m³/s). Excess of average annual useful inflow over HPP discharges was about 20 m³/s in average for the period of medium water availability, and has reached 50 m³/s during high-water period. The HPP discharges compensate the increased total inflow, but are insufficient to drawdown the useful inflow, resulting in the accumulation of additional water volumes in Lake Onego.

Despite the increase in winter low-water inflow, the HPP discharges in December-March exceed the natural runoff of the Svir River, which provides more intensive drawdown of Lake Onego. At the same time, the decrease in HPP discharges relative to the natural runoff in April-May is combined with the increase of flood inflow and results in additional rise of Lake Onego levels. The increase in HPP discharges in August-November relative to the natural runoff values is not enough to compensate the increased inflow during summer-autumn floods. In combination, this does not allow the lake level to be reduced with the previous intensity; as a result, the lake comes to winter low-water at higher marks of water level.

4. Conclusion
The Upper-Svir HPP is currently operating under the conditions of a prolonged high-water period caused by modern climate changes. Increased inflow during spring flood period, frequent and
prolonged summer-autumn floods combined with insufficient HPP discharges result in accumulation of additional water volumes in Lake Onego and increase in the frequency and duration of high levels.

The ability of Lake Onego to accumulate water resources during high-water periods is related to its storage capacity and is determined by the significant excess of flood inflows over the throughput capacity of the Svir River bed.

To reduce the levels of Lake Onego it is advisable to increase average values of HPP discharge (600-900 m³/s) during spring and summer-autumn floods. At the same time, it is recommended to maintain discharges within 400-600 m³/s during the low-water period and in particular low-water years in order to drawdown the water volumes accumulated in the previous high-water period.

Optimization of the operating mode of the Upper-Svir HPP will contribute to the safety of hydrotechnical constructions, reduce the load on the hydroelectric complex and the negative impact on the coastal area.

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