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Influence of the Vilyui hydropower plant on the regime of the Vilyui river

D D Nogovitsyn, Z M Sheina and L P Sergeeva

Department of Energy, Yakutsk Scientific Center of the Siberian Branch of the Russian Academy of Sciences Institute of Physical and Technical Problems of the North named after V.P. Larionova, Yakutsk, Russia

E-mail: administration@iptpn.ysn.ru

Abstract. Based on the analysis and comparison of the Vilyui river regime in the natural and regulated state, the article reveals the features of changes in the annual distribution of runoff, level and ice regimes and the regime of solid runoff. To assess the consequences of the impact of large hydroelectric power stations in the Far North, comprehensive studies of the Vilyui river basin were conducted. Vilyui hydroelectric station is the first hydroelectric power station in the permafrost zone. The reservoir is completely located within the Republic of Sakha (Yakutia). Despite the low level of development of water resources in the Far East, the prospects for the construction of traditional hydropower plants remain. The hydropower potential of the republic is estimated at 283 billion kWh, which is 66 % of the total hydropower potential of the Far East region. The construction and operation of hydropower plants on rivers leads to fundamental changes in the natural conditions of the river. The results of the study show that flow regulation by large reservoirs is the main factor of anthropogenic disturbances in the flow volume and water regime of the Arctic rivers. To date, the diverse effects of river regime changes after the construction of a hydroelectric power station on the territory of permafrost are not fully considered in either design or prospective planned developments. The importance of accounting and studying the consequences of flow regulation can be judged by the complex economic problems that arose after the construction of hydropower facilities in the European part of Russia. In this regard, a comprehensive study of changes in environmental conditions in the territory of permafrost distribution after regulation of river flow by large reservoirs is one of the most important tasks.

1. Introduction

The Republic of Sakha (Yakutia) is one of the regions of Russia with significant, unique natural resource potential. At present, and in the future, the large-scale development of fuel and energy resources, as well as the development of mineral deposits, is becoming relevant. However, Yakutia has significant hydropower potential. Only in the territory of Yakutia, the total installed capacity of possible hydropower plants is 78.145 thousand kW, and energy production is about 401.272 million kW/h [4]. Hydrostations already play an important role in the development of industry in the Republic of Sakha (Yakutia). To satisfy the needs of diamond mining enterprises for energy supply, the Vilyui hydropower plants 1 and 2 were built, as a result of which the largest artificial Vilyui reservoir was formed in the north-east of the country, which has no analogues in the zone of widespread permafrost. The construction of Vilyui hydropower plants completely covers the shortage of electricity in the West Energy Region of the Republic [5].



Regulation of river runoff by large waterworks leads to fundamental changes in environmental conditions both above and below the waterworks. The movement of water masses, thermal regime, chemical composition, and solid runoff depend on the operation of large hydropower plants [6]. The diverse consequences of changing river regimes in the North-East of the country after the construction of hydropower units are currently not fully considered in design or prospective planned developments.

The importance of accounting and studying the consequences of flow regulation for the downstream industries can be judged by the complex economic problems that arose after the construction of hydropower facilities on the Volga, Don, Irtysh, Yenisei, Angara and other rivers. At large reservoirs, there is a big problem associated with reduction of the negative environmental consequences of their creation, as well as resolving conflicts between hydropower and other water users [7]. The dam forming the reservoir, providing constant water for the time being, changes the natural state of the river flow and is a key factor determining their negative impact on the underlying ecosystems [8]. Thus, the discharge of large volumes of highly mineralized water from quarries led to a sharp deterioration in water quality throughout the Vilyui River.

The extent of violations of the everyday life of the rivers after their regulation for different geographical zones is far from the same and closely dependent on the position, size and type of reservoir. In this regard, questions of changing the hydrological regime of the regulated rivers of the Far North are of practical and scientific interest. At present, the Vilyui reservoir is the first in the cascade of hydroelectric power stations and can to some extent serve as an analogue for predicting possible hydrological changes in the future for other artificial reservoirs in permafrost.

2. Methods and materials

Work on the study of the features of changes in the hydrological regime of the Vilyui river after regulating runoff was obtained during field route and expedition studies. To analyze the data on the flow regime of the Vilyui River in its natural state, stock materials and literary sources were used.

3. Results

The Vilyui River is the largest left-bank tributary of the Lena. Taking into account the natural conditions, four sections are distinguished in Vilyui: the upper (from the sources to the confluence of the Chirkuo river), the Vilyui reservoir section, the middle (from the Chernyshevsky settlement to the Markha river), the lower (from the Markha river to the mouth) [9].

In the Vilyuy river food, snow nutrition is of primary importance, its share in the annual runoff is more than 60 %, rain nutrition accounts for up to 30 % and groundwater accounts for about 10 %. The upper course of the river is characterized by a high, single-peak spring flood, which is smoothed in the middle and lower reaches due to regulation of the river flow by the Vilyui reservoir. The creation of the Vilyui reservoir led to significant changes in the water regime of the river.

Vilyui hydroelectric station on the river Vilyui is the first large hydroelectric power station in the zone of continuous development of permafrost. Vilyui reservoir located in the upper reaches of the Vilyui river. The reservoir is completely located within the Republic of Sakha (Yakutia). The backwater from the hydro-system forming the reservoir extends along the Vilyui River to the mouth of the Chirkuo River.

The Vilyui reservoir, according to the technical design, is used for energy, water transport, water supply of settlements and industrial enterprises, fisheries.

The construction of the Vilyui Hydroelectric Power Station – 1, 2 was started in 1960, and ended in 1978. The power plant was built in 2 stages. The construction of the first stage (Hydroelectric Power Station – 1) was completed in 1967, the second stage (Hydroelectric Power Station – 2) in 1976. one.

The Stvor hydroelectric station is located 1315 km from the estuary, in a dense uninhabited taiga. The reservoir created by the backwater of the Vilyui hydroelectric dam is designed for many years of regulation. The volume of water in it is 35.9 km³, and the area of the mirror is 21702 [10]. The length of the reservoir along the former Vilyuya channel is 410 km along the Chone River – 274 km. The average width of the reservoir is 4.6 km, the largest – 15 km, the smallest – about 1 km. The average

Change in annual flow. Reservoirs constructed in the zone of insufficient moisture decrease water resources in the lower parts of the river basin due to increased evaporation from the water surface, compared with evaporation from land.

Losses on additional evaporation from a water mirror reach 0.5 km³. In percentage terms, this value is 3 % at Chernyshevsky, and 1.1 % at the mouth of Vilyui.

In spring, the natural runoff of Vilyuya in the average water year decreases by 6 times in the section of the Vilyui hydroelectric station, in the village of Suntar (575 km below the gauge of the hydroelectric power station) – by 2.5 times, in the village of Khatryk-Khomo (1193 km below the gauge of the hydroelectric power station) – 1.5 times [11]. The hydrograph of the Vilyuya flood at the site from the site of the hydroelectric station to the confluence of the Markha tributary is characterized by a single peak, and below the mouth of the Markha river it is characterized by a multi-peak.

In autumn, the value of Vilyuya runoff did not undergo significant changes, but the amplitude of fluctuations in water flow rates decreased significantly.

3

Level mode. The level regime is formed mainly due to water releases in the site of the hydroelectric station and lateral inflow. The beginning of the rise in water level during the passage of the spring flood began to depend mainly on melting snow on the catchment of the river Vilyui below the hydroelectric station.

Observation data above the water level of the river Vilyuy during the hydropower plant operation showed that at an elevation level in the hydropower station alignment (Chernyshevsky village) equal to 580 cm, the average increase was 450 cm near the village of Svldyukar (166 km from the target of the hydropower station) and 37 km from the village of Vilyuchan section of the hydroelectric power station) – 320 cm, near the village of Krestyakh (432 km from the target of the hydroelectric power station) – 320 cm, near the village of Suntar (575 km from the site of the hydroelectric power station) – 340 cm. During the day, the water level in regulated conditions can rise by 438 cm near the village of Chernyshevsky, by 327 cm near the village of Suldyakar, by 245 cm near the village of Vilyuchan, and by 188 cm near the village of Krestyakh, and 201 cm near the village of Suntar. The duration of standing high levels as a result of pops almost everywhere the same. She made up during the navigation launches in 1967 at the village Chernyshevsky 43 days and 41 days in all other posts. In 1968, high water levels stood at the village of Chernyshevsky for 70 days, at the remaining posts 67–69 days. A drop-in water level is slower than a rise. The average intensity of the decline during the observation period (1967–1971) amounted to 250 cm per day in the village of Chernyshevsky, 78 cm per day in the village of Suldyukar, 39 cm in the village of Vilyuchan, and 30 cm in the village of Krestyakh. Downstream depends mainly on the value of waste costs. With an initial value of discharge water flow equal to 2400–2700 m³/s, the release wave, the distance 575 km from the station of the hydroelectric station to the village of Suntar takes 6 days, with discharge costs 1400–1500 m³/s – in 9 days.

The level mode in the winter is distinguished by some features. The first feature is the very slow advancement of the trigger wave, the speed of which in the area under consideration is an average of 15 km per day. The second feature should include the incomparability of the magnitude of the rise in water level near the village of Chernyshevsky with that of other posts. This is explained by the presence of an ice-free area at the dam, which captures a water-measuring post near the village of Chernyshevsky. As a result of the drawdown of the reservoir in December 1967, the level in the village of Chernyshevsky increased by 156 cm, and in the underlying villages the level had the following values: in the village of Vilyucha, the level increased by 188 cm, in the village of Krestyakh – 151 cm, in the village Suntar – 132 cm. Near the village of Vilyuchan, the amount of rise turned out to be greater than that of the village of Chernyshevsky as a result of backing the ice level.

On the lower section of Vilyui, the level regime is mainly influenced by the flow regime of two large left tributaries of the Markha (catchment area 898002) and Thung (49800 km²). As a result of the influence of melt water from these tributaries, the multi-peak nature of spring levels is preserved on the site. The highest peak of the flood occurs slightly earlier than the peak of the waves of discharge flows. The first peak of the flood in the considered area is also formed, as in natural conditions, due to the melt water of the right tributaries: Ulakhan-Botuobuy, Ochchuguy-Botuobuy, Kheimpendyai and others. The second peak is formed mainly due to early melting of snow on the catchments of the left tributaries. This peak follows the first. The third peak is formed due to waste costs in the site of the hydroelectric station. The second and third peaks may coincide in time. Discharge costs increase the duration of the recession. The decline in water level under regulated conditions lasts from 90 to 100 days, and the summer low-water level is set in mid-August. The duration of the level rise is negligible – an average of about 20 days.

In the autumn-winter period, the level regime entirely depends on the magnitude and duration of the release waves. In September 1967 as a result of water discharge, the level in the downstream near the village of Chernyshevsky was raised by 710 cm. In the points Verkhnevilyuysk, Vilyuisk and Khatyryk-Khomo, the water level increased by 306 cm, 306 cm and 380 cm, respectively. The duration of the rise was the same and amounted to 6 days. In general, the flood from this release on the lower section lasted 94 days, and near the village of Chernyshevsky, water discharge lasted only 42 days. The level mode in winter during a sharp increase in flow in the site of a hydroelectric station

depends on local factors. For example, the same discharge water flow caused a level rise in Verkhnevilyuysk by 202 cm, in Vilyuisk by 61 cm, in Khatyryk-Khomo by 78 cm. The rate of movement of the release wave is very small: the distance is 313 km from the village of Verkhnevilyuysk to the village of Khatyryk –Homo wave passed in 17 days, i.e. the average speed was 18 km per day.

Change in solid runoff mode. A study of channel processes in the downstream is currently not carried out, apart from measurements of solid runoff at the village of Suntar and the village of Khatyryk-Khomo. The data show that the creation of a reservoir reduced solid runoff by an average of 3–4 times. So, the average solid runoff over two years under the conditions of operation of a hydroelectric power station was 4.5 kg/s, and over nine years under domestic conditions – 14.3 kg/s per year.

In 1968, three floods took place during the warm ice-free period in the village of Suntar. The first of them was formed by meltwater from the Vilyui catchment from the hydroelectric station to Suntar, the other two by discharge costs. The turbidity of the first flood water was on average 32 g/m³, and the water release waves from the reservoir were about 3 g/m.

Features of the ice regime in conditions of runoff regulation. In winter, in the lower pool near the dam an ice-free wormwood is formed. At the water gauging station, located 3 km below the hydroelectric station, the duration of freeze-up on average over two winters from 1967/68, 1968/69) was two weeks. Under the conditions of operation of the hydroelectric power station at full load, the size of the ice-free wormwood will be equal, according to the calculations of the Lenhydroprom, in the average winter weather of 30–40 km. In a period of very severe frosts, the wormwood will decrease to 25 km, and during thaws it will increase to 50 km. In ice-hole near the dam, no ice phenomena were observed. As one moves away from the hydroelectric station on the river, barriers form, their width reaching 35–50 m in the winter of 1968/69. Behind the wormwood there is a site with an unstable ice cover 10–12 km long. The opening of the river and the passage of the ice drift in the section from the village of Syuldyukar to the mouth do not differ from household ones. However, in the process of passing the ice drift there are features: firstly, it is an abundance of congestion on the river, and secondly, there is a large amount of ice on the banks. Their reason lies in the formation of winter ice along the entire length of Vilyui below the hydroelectric power station as a result of ice flooding and freezing of the volumes of water generated by the hydroelectric power station. Autumn ice formations are different from everyday ones. Under regulated conditions, the date of occurrence of primary ice formations and ice formation mainly depend on the amount of discharge costs. In 1967, on average weather conditions, autumn ice freezing occurred 8–10 days later than the average for many years under natural conditions.

In 1968, the beginning of freezing on the river was also subject to a discharge schedule and occurred on October 20–24. The pre-delivery period was reduced several times. For example, in the fall of 1967, on the section from Skldyukar to Verkhnevilyuysk, the duration of the pre-delivery period averaged 2–3 days. In domestic conditions, this period, as a rule, was kept within 9–15 days.

The thickness of the ice in the downstream basin has increased significantly compared with domestic conditions. In the winter of 1968/69, under the conditions of operation of the four units of the hydroelectric power station, the value of discharge costs averaged 140 m³/s. In the domestic environment, the costs in the HPP site in winter ranged from 48 m³/s in November to 4.5 m³/s in April. Increased discharge costs in winter contribute to an increase in the thickness of the ice cover by the formation of ice. The thickness of the ice increased by 1.5–2 times. Its increase along the length of the downstream is uneven and depends not only on the discharge of water, but also on the local characteristics of the riverbed. Compared to the maximum thickness of ice in an average weather year, the thickness of ice in the winter of 1968/69. Increased in the village of Syuldakar by 30, in the village of Velyuchane – by 103, in the village of Krestyakha – by 55, Suntara – by 50, Nyurba – by 72, the village of Verkhnevilyuysk – by 98, and in the city of Vilyuisk – by 49 cm. The largest ice thickness in winter 1968/69 was installed near the village of Vilyuchan (223 cm). The increase in ice thickness during the winter occurs spasmodically. For example, in Vilyuisk in January the ice thickness increased by 32 cm, in February by 10 cm, in March by 23 cm. At the village of Verkhnevilyuysk, on

the contrary, in January the ice thickness increased by only 14 cm, and in February and March, respectively, by 39 to 15 cm.

4. Conclusion

In conclusion, it should be noted that the Republic of Sakha Yakutia is one of the regions of the Russian Federation with a unique natural resource potential. In the long term, new grandiose plans for the industrial development of the territory will be essential for the republic. This will require new sources of energy supply for local and remote areas of new industrial development. One of the solutions is the construction of new hydropower plants.

The need to mitigate the negative impact of reservoirs on the environment requires a large-scale comprehensive assessment of the effectiveness of the construction and operation of cogeneration plants in the territory of the continuous development of permafrost. The revealed changes in the regime of rivers in permafrost are not sufficiently considered in the development of project documentation, and also are not taken into account in the integrated use of water resources in practice. This situation makes it imperative to expand research on the impact of the changed hydrological regime on the natural conditions of the Far North and the national economy. The object of study, as an analogue, can be the Vilyui River.

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