DOI: 10.23968/2500-0055-2021-6-4-24-33

STRUCTURAL FEATURES OF A WATER INTAKE FACILITY FOR MOUNTAIN AND SUBMOUNTAIN RIVERS

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Abstract

Introduction: The rate of urbanization is currently high. Therefore, it is important to use various elements and devices for water intake and water supply. **Purpose of the study**: We aimed to consider and analyze the structural features of a water intake facility for mountain and submountain rivers. **Methods**: In the course of the study, we used the synergistic research principle and statistical analysis. We analyzed the types of water supply networks at mountain rivers and identified the features of water intakes at water sources of this type. **Results**: A description of water intake features under flood conditions in the Amur Region, exemplified by the Bureya River, was obtained. The mountain rivers have an uneven runoff, which fluctuates not only throughout the year but also throughout the day. The water supply of the mountain and submountain areas shapes the idea of hydrological control over the regime of the mountain rivers. This paper will help to study changes in the average water inflow over the years and thus facilitate an accurate and detailed description of the water inflow characteristics in the Bureya reservoir when planning the water-energy modes of the hydroelectric power plant.

Keywords

Structural features, water intake, mountain area, submountain area, hydrological characteristics.

Introduction

The beginning of the 21st century is characterized by active industrial and agricultural development and urban growth, which has led to a sharp increase in water consumption from surface sources, including seas, rivers, reservoirs, and lakes. In Russia, especially in the Far East, the use of water and energy resources in the mountain and submountain areas is largely motivated by the nature of the terrain. Mountain ranges dominate the terrain of the Far East and northeastern Siberia. Due to the high indices of the economy, industrial production, agriculture, and construction in the Far East, the use of water resources in agriculture is highly relevant for the aforementioned territories. Water intake is carried out in the mountain and submountain areas; this has a major impact on the types of irrigation systems. This study presents a novel approach as it describes the specifics of water intake in the current emergency conditions at the Bureya hydroelectric power plant (Amur Region). Research on the construction of water intakes in such areas has been carried out for a long time. The energy supply capacity of the mountain and submountain watercourses is largely related to river morphology (Artamonov and Kroshkin, 1972; Kroshkin, 1980).

The problems of water intake in the mountain and submountain river basins have been studied by such prominent researchers as S. T. Altunin (1964), K. F. Artamonov and S. S. Satarkulov (1972), N. F. Daneliya (Daneliya, 1964; Daneliya et al. 1960), I. S. Rumyantsev and V. F. Matseya (1988), I. I. Levi (1967), K. V. Popov (1956), S. V. Semyonov (1950), Ya. V. Bochkaryov (Bochkaryov, 1969; Bochkaryov and Lugovoi, 1971), B. I. Melnikov (1989, 1994), A. I. Rokhman (1983), G. V. Sobolin and I. K. Rudakov (1964), A. V. Filonchikov (1990), A. Polad-Zade (1964), F. B. Bashirov (1986), A. I. Chavtorayev (1958), A. S. Babkin (2019), and Ya. I. Kaganov (1979).

During the construction of the first water intake structures in the USSR, the focus was mainly on increasing the use of water resources and reducing the number of negative factors affecting the structure of water intake facilities (Akhmedov and Mamedov, 1990). There were proposals for water intake structures for mountain rivers, including a catchment dam and a curvilinear water intake pocket equipped with a bottom sill at the entry point. The disadvantage of this structure is the roiling of bottom sediments, which contributes to the pollution of sedimentation tanks.

The available devices with a mechanical drive, including segment gates, do not ensure automatic regulation of the water level in the upper pool of hydraulic structures. The invention described by

S. T. Altunin (2015), V. N. Bukhartsev and N. P. Lavrov (2015), S. V. Sobol et al. (2016) aims to create such an automatic regulator. In addition, a variation of this invention has already been described in the scientific literature (Filonchikov, 1990; Surface water resources, 1973; Western Caspian Basin Water Management Board, 2020).

The proposed automatic regulator differs from the available ones in that the segment gates are mounted on one axis: one rigidly, and the other with the possibility of rotation. In other words, one of the gates has a rigid connection, and the other has a flexible connection with a floating drive placed in a shaft communicating with the lower pool.

When analyzing the history of the development, design, and construction of water intake facilities on the mountain rivers, it is necessary to pay attention to the features of the water intake facilities described in the works of Y. Ma et al. (2020), A. Wałęga et al. (2019), M. J. Brandt et al. (2016), O. K. Mawardi (1981), L. E. Armstrong and E. C. Johnson (2018), C. A. Morrissey et al. (2018), V. M. Silverthorn et al. (2018a, 2018b), Ya. I. Kaganov (1970, 1981), and P. Chattopadhyay (2006).

The features of water intake facilities on the mountain rivers include the following:

1) the presence of wide floodplains with pebble deposits and shallow unstable (walker) branches and arms;

2) strong fluctuations in costs; water discharges during floods can exceed those during low-water periods by 1000 times or more, and floods (from melting snow and from showers) usually come suddenly;

3) a significant amount of sediment, especially during flood periods; in addition, the sediment pieces in the mountain rivers are generally much larger than in the lowland rivers, and some rivers even periodically carry a significant amount of mud and rocks, including very large ones (the so-called mudflows);

4) in order to purify water from rocks and other components, the design must include special sedimentation tanks and filtering plants;

5) protection against possible structural damage and destruction during mudflows must also be taken into consideration;

6) a large number of various pump equipment units is installed to supply water, requiring reliable fixation.

Most of the water intake facilities are in unusable technical condition and need an upgrade. Technical and economic efficiency and environmental safety are important aspects as well. Some studies do consider the means of improving the structures for the intake of the underflow in the mountain and submountain rivers. Researchers propose a water intake facility of a combined type, which has the advantage of solving all environmentally and technically important issues (Babkin et al., 2018; Loginov, 2014).

Another option for increasing the life of water intake facilities is taking technical measures and ensuring their efficiency. Naumova et al. (2019) consider the methods of increasing the efficiency of operational measures to reduce sediment transportation in the intakes of irrigation systems. The efficiency of operational measures within a specific field was studied in detail in relation to the MASSCOTE approach modernizing irrigation management (Garcez-Restrepo et al., 2007; Hobbs et al., 1989; Kadiresan and Khanal, 2018; Luo et al., 2017; Renault et al., 2007).

A typical aspect of foreign studies is the predominance of the ecological aspect over economic considerations; most Russian studies, in the meanwhile, are aimed at eliminating technical flaws to achieve better economic benefits, as evidenced by the works of A. V. Klovsky and D. V. Kozlov (2016) as well as A. R. Paz et al. (2007).

This study aims to determine if it is possible to improve the efficiency of short-term planning for the water-energy modes of operation at the Bureya hydroelectric power plant and develop a method for short-term forecasting of water inflow into the Bureya reservoir, based on the hydrological data of model and meteorological forecasts.

Methods

The study is based on the synergistic principle of studying the structure of water intake facilities and includes statistical analysis.

Results and Discussion

The mountain rivers have certain qualities that distinguish them from the rivers in other regions of the country. They are characterized by large slopes in the upper sections, which leads to high flow rates and shallow depths. With the passage of rainstorms, the risk of flooding increases rapidly. The rivers transport a large amount of sediments, both bottom and suspended. Slush and bottom ice appear in winter. Mudflows are a common occurrence on the mountain rivers. In the submountain areas, changes in river channels are often observed. All of the factors above make water intake extremely complicated (Khapkova, 2013; Verbitskaya and Romansky, 2016). Therefore, water intake in the submountain areas is carried out from underground sources whenever possible.

Typology of Water Intake Facilities

For supplying water to small settlements and industrial enterprises on small rivers with an unstable open water flow, in the presence of an underflow, a combined water intake can be used. This type of water intake uses both open-flow and underflow intake (Arykova and Zholayev, 1961; Kaganov, 1981). Due to the structural complexity of water intake facilities, as well as the fact that water supply usually requires large volumes of water, the most expedient solution is the integrated use of the mountain rivers, which simultaneously satisfies the needs of water supply, hydraulic power engineering, and irrigation. With sufficient depths and water flow rates in the river, and in cases when no more than 25–30% of water is withdrawn, shore water intakes are arranged with bottom water intake, combined with first-stage pumps, with the introduction of sedimentation tanks into the structures for preliminary clarification (Figure 1). In the slush-bearing foothill areas, it is possible to use bucket water intakes and water intakes with the side discharge of water from the river by open canals.

The use of shore water intake facilities with bottom water intake, combined with first-stage pumps and the introduction of sedimentation tanks into the structure for preliminary clarification, is widespread in Western Siberia. The Tom River is one such example (Figure 2). The source of the Tom River is located in Khakassia, on the western slopes of the Abakan ridge. The water supply network on the Tom River was originally represented by the excavation of gravel-pebble deposits along the shore and a shore-type water intake. Later on, it was modernized via transition to bucket water intake. Its construction and operation served as the basis for substantiating the project of an infiltration gallery (Polad-Zade, 1964).

In the submountain areas, it is common for infiltration water intake facilities to use the underflow and groundwater (Gartsman et al., 2009; Vehvilainen, 1994). These facilities allow the river water to be pre-filtered through the soil of the river bank or the river bottom, as opposed to flowing directly from the river (Figure 3).

Infiltration water intake facilities (vertical wells, horizontal coastal and underflow drains and galleries) are quite widespread. Krasnoyarsk, Abakan, Kyzyl, Ulan-Ude, Bolshekamensk, Bikin, Suchan, and many other Siberian and Far Eastern towns and cities are supplied with drinking water exclusively from the underground runoff of channel sediments (Abilov, 2008; Akhmedov et al., Patent).

The use of water intake is expedient when the thickness of the aquifer is low. This excludes the possibility of using the groundwater reserves for covering seasonal water shortages.

The technical and economic efficiency of this invention is determined by an increase in the reliability of water intake, without reducing productivity, even if the gallery's entire section is flooded with groundwater, and if the water level in the well drops to a level that does not ensure the normal operation of the pump.

For insufficient river depths and insufficient water supply during certain periods, as well as when more than 25–30% of water is withdrawn, water intake facilities use diversion weirs. They have weir sills, undersluices, undersluice pockets, sand traps, gravel traps, and slush ice chutes installed in their water intake segments (Figure 4).

In the mountain areas with high and medium elevation, bottom lattice water intakes with sediment-intercepting and water intake galleries, which are also placed on the weir sills, are the most common. They allow for collecting water at shallow depths.

River intakes are used in the foothill areas of large rivers, and sometimes in the upland areas, provided that there is a stable channel with water depths, which, under minimal conditions and with slush ice run, are sufficient for water intake (Figure 5).

Water intake follows two main schemes: bottom water intake (using submerged water inlets) and surface water intake (using water intake buckets or side water discharge with an open canal).

On large rivers with bottom water intake, shore-type water intakes are used, combined with first-stage pumping stations. They are similar to water intakes used on the lowland rivers but include sedimentation tanks. There are river intake structures in the form of open canals that extend from the river at an angle to its axis, without any regulating structures or devices to wash off sedimentation.

The disadvantages of these structures include the following: a discrepancy between the amounts of water entering the canal, on the one hand, and con-

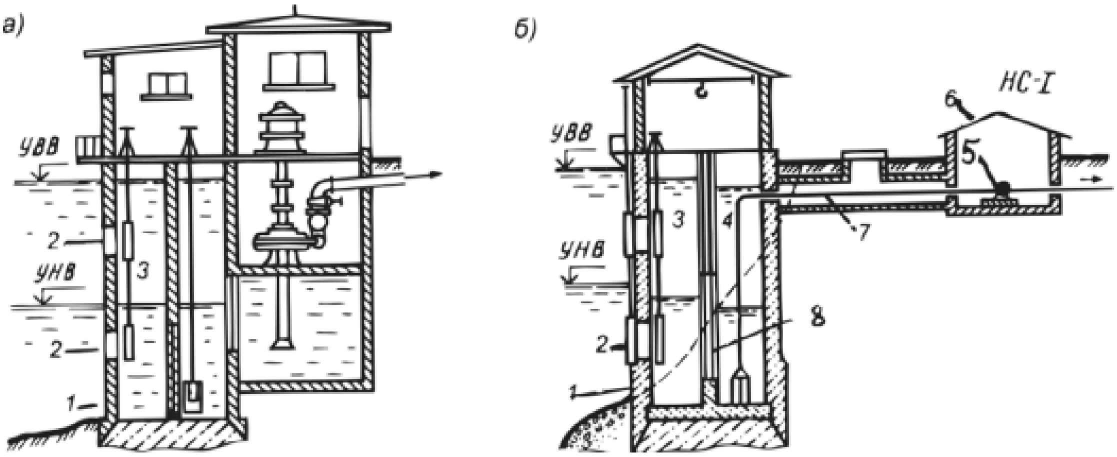

Figure 1. Water intake facilities with bottom water intake (a – combined with a pumping station; b – of a separate type; 1 – water intake well; 2 – entrance windows; 3, 4 – receiving and suction chambers, respectively; 5 – grids; 6 – suction lift pipelines; 7 – pumps; 8 – pumping station)

Figure 2. Water intake facility on the Tom River

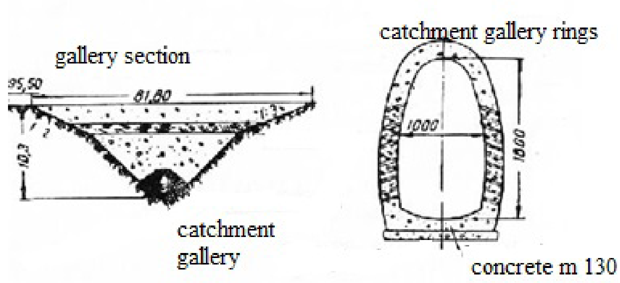

Figure 3. Infiltration water intake facility

Figure 4. Water intake with diversion weirs at the Bureya hydroelectric power plant (https://fishki.net/2603030-sejchas-stroitsja-v-rossii-post-nomer-19-nizhne-burejskaja-gjes.html)

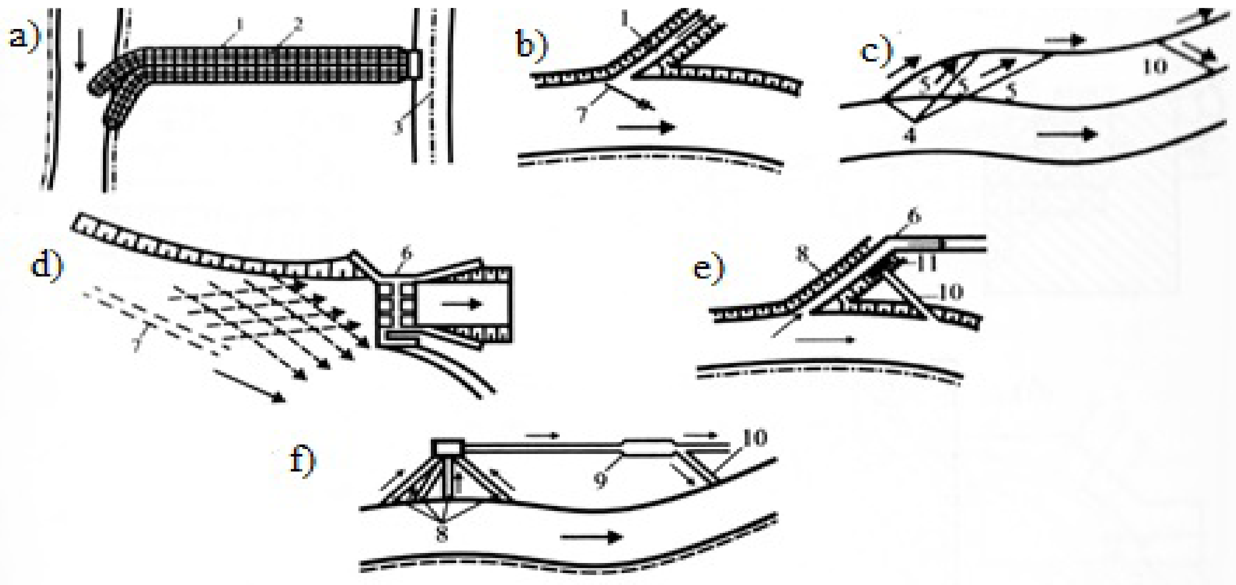

Figure 5. Main types of river intakes (a, b – water intakes with open canals without regulator sluices; c – multi-head water intake; d – water intake with a regulator sluice in the canal head; e – water intake with ditches and a regulator sluice, operating remotely from the river bed; f – multi-head water intake with ditches, regulator sluices, and sedimentation tanks: 1 – canal; 2 – weirs; 3 – water intake with a first-stage pumping station; 4 – canal heads; 5 – cofferdams; 6 – regulator sluices; 7 – stream-directing systems, designed by M. V. Potapov; 8 – ditches; 9 – sedimentation tanks; 10 – discharge canals; 11 – discharge canal sluices)

sumption rates, on the other hand; canal flooding; the ingress of a large amount of bottom sediments both into the water intake and further into the main canals, which leads to forced water supply disruptions; and the high operating costs of cleaning and repairing water intake facilities.

On rivers with shallow depths and a large quantity of slush, it is common to set up shore water intakes with a developed water intake front line (low, but with wide openings). They are often combined with a longitudinal gallery or transverse drain to capture underflow waters.

In the foothill areas of rivers with high slush content, abundant sediments, and depth levels that are insufficient for water intake, the use of buckets is widespread. The buckets may be completely buried in the bank or partially extended into the channel, with an upstream or downstream water inlet.

Water Intakes on the Mountain and Submountain Rivers: Their Features, Advantages, and Disadvantages

Bottom lattice water intakes are the most widespread type of water intakes on the mountain and high-mountain river reaches carrying large amounts of sediments of coarse fractions. It is a sill that blocks the channel and rises above the bottom of the river. A water intake gallery is cut into it and covered from above by the lattice. Water passes through the lattice and enters the inclined water intake gallery, through which it flows into a chamber with a washing device. Then, it is discharged through a canal, tunnel, or pipeline to a sedimentation tank or directly to the consumer. It is recommended to use bottom lattice water intake facilities on rivers with a slope of 0.02 and sandy bottom sediments in the flow of up to 6 mm in size, in the amount below 25% of the total volume of sediments. The length of the lattice is set to be approximately equal to the width of the river bed during the low-water period. The specific consumption of the withdrawn water is 0.08–0.5 m^3/s per 1 meter of the lattice.

Water intakes on the mountain rivers are represented by a variety of structures, all with their own advantages and disadvantages. The results of reviewing those are summarized in Table 1.

Table 1. Types of water intakes, their advantages and disadvantages

Type of water intake facility	Features	Advantages	Disadvantages
Water intake facility with bottom water intake	Integrated use of the mountain rivers, which simultaneously meets the needs of water supply, hydraulic power engineering, and irrigation	Used for supplying water with low rates, withdrawn from rivers that have high banks, making it difficult or even impossible to make an open canal in earth cuts	Depth of location, characterized by the formation of large amounts of sediments
Infiltration water intake facility	River water does not come directly from the river and is instead pre-filtered through the soil of the river bank or bottom	Under favorable hydrogeological conditions and provided that water quality is sufficiently good, the water can be used without additional purification	The expediency of water intake depends on the width of the floodplain and the capacity of the filtering soils
Water intake facilities with diversion weirs	The water intake segments feature sills, undersluices, undersluice pockets, sand traps, gravel traps, and slush ice chutes	They can be used in the case of insufficient river depths and insufficient water supply during certain periods, as well as when more than 25–30% of water is withdrawn	Rapid sediment clogging, possible breakdown of multiple structures
Bottom lattice water intake facilities with sediment-intercepting and water intake galleries	Water intake occurs from a certain depth, through a lattice at the water intake inlet	Used for both one-side and two-side water supply. The water intake section can occupy the spillway front entirely or in part	Such systems carry a large amount of stream and suspended sediments, which are discharged into sedimentation tanks. Sediment accumulation
River intake systems	The water comes from the river at the natural water level	The systems usually take up to 20% of the river discharge and are constructed on stable concave river banks to reduce the flow of sediment into the canals. This is the most environmentally friendly type	Discrepancy between the amounts of water entering the canal, on the one hand, and consumption rates, on the other hand; canal flooding; the ingress of a large amount of bottom sediments both into the water intake and further into the main canals, which leads to forced water supply disruptions; and the high operating costs of cleaning and repairing water intake facilities

The water intake facilities considered in this paper are typical of the Russian Far East.

In summer, cyclones come to the territory of the Amur River basin, bringing heavy rains. As a result, floods occur on rivers. During the emergency situation in August 2020, water consumption increased due to the high level of water filling the reservoir at the Bureya hydroelectric power plant. On August 17, 2020, the upstream level at the Bureya hydroelectric power plant reached 254.00 m (whereas the normal headwater level at the plant is 256 m). At 08:00 a.m., the inflow to the dam site was 4010 m^3/s. Today, up-to-date observation data on the Roshydromet network and forecast meteorological data come from the Internet resources of the Far Eastern Regional Research Hydrometeorological Institute and SKM Market Predictor. The former provides observation and forecast data obtained using the WRF mesoscale atmospheric model (Babkin, 2019), the latter provides forecast data from the ECMWF (European Centre for Medium-Range Weather Forecasts, 2016), adapted for the Russian Federation, as part of the Nonlinear Automatic Forecast Calibration (NAFC) project. Data from both sources are received by the 41st meteorological station located near the catchments of the Zeya and Bureya reservoirs and within their territory. After data collection and their initial check for gross errors, the data are placed in the corresponding database tables and formatted as files to be loaded into the flow formation model (Motovilov et al., 2017).

The system works in automatic mode, requesting data from the relevant sources every day according to a certain schedule. A key feature of the system used is that all incoming data, including forecast data, for all days get stored, allowing for verifications and quality checks of the forecasts received.

Hydrological forecasts are checked with the use of data on the actual daily water inflow to the Bureya reservoir, posted on the website of PJSC RusHydro.

The observation results are presented in Table 2.

Table 2. Bureya HPP data for August 2020 under flood conditions

Date of measurement	**Average water inflow, m^3/s**	**Water level in the reservoir, m**	**Flow through the dam, m^3/s**
August 17, 2020	4,010	254.00	2,300 ± 300
August 20, 2020	8,955	254.66	5,870
August 25, 2020	7,300	237.39	6,100
September 9, 2020	3,195	256.04	3,200 ± 300
September 11, 2020	3,075	256.03	2,300 ± 300

For comparison, Table 3 presents the Bureya HPP data for August 2016 (at that time the plant was operating in normal mode).

Table 3. Bureya HPP data for August 2016

Date of measurement	**Average water inflow, m^3/s**	**Water level in the reservoir, m**	**Flow through the dam, m^3/s**
August 14, 2016	2,620	252.43	2,250 ± 300
August 19, 2016	3,860	252.66	5,000 ± 400
August 29, 2016	3,295	252.02	3,200 ± 300
September 10, 2016	3,078	252.00	2,850 ± 300
September 15, 2016	2,890	252.00	-

The Bureya hydroelectric power plant has a dam-type water intake system. According to the observation results, under flood conditions on the Bureya River, a sharp increase in the average water inflow was observed between August 17, 2020, and August 25, 2020. The river regime changed due to heavy rainfall. The river runoff increased for a number of reasons: more abundant precipitation on the windward mountain slopes; less intense evaporation due to the lower temperature; precipitation reaches the river faster and along a shorter path due to the large surface slopes. This explains the sharp increase/decrease in the average inflow over such a short time (Borsch et al., 2016; Gartsman and Gubareva, 2007; Silverthorn et al., 2018a).

Observations of the hydroelectric power plants' average water inflow for the same periods in 2018 and 2020 are presented in the diagram in Figure 6.

The diagram shows a two-fold increase in the average water inflow at the end of August in 2020 as

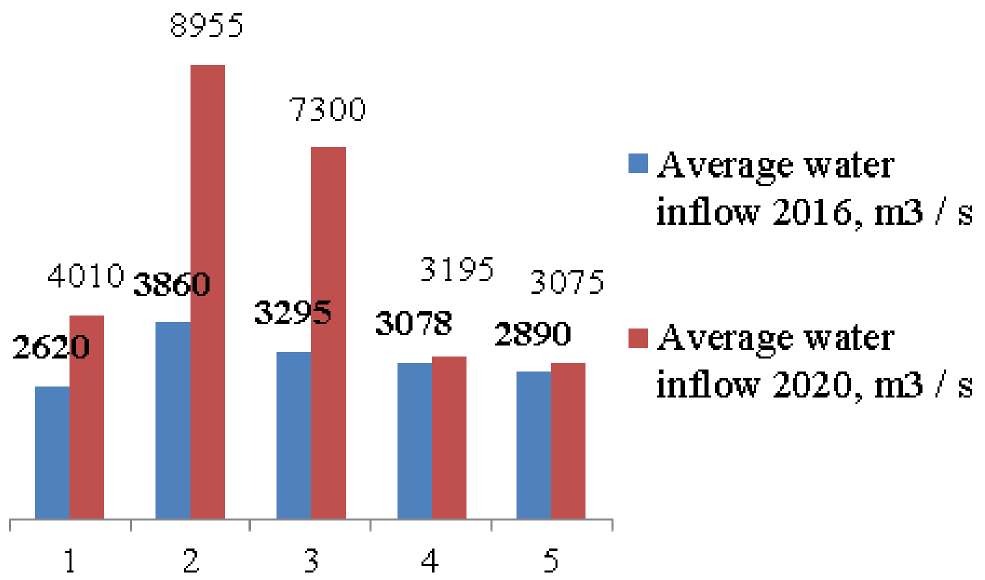

Figure 6. Diagram of hydroelectric power plants' average water inflow, by years (where 1–5 is the number of measurements)

compared to 2018. Further study of flood situations in the catchment area of the mountain rivers of this type will help to prevent emergencies in the Russian Far Eastern climate.

A study was performed to examine the water intake of the Bureya River in conditions when the reservoir was filled with large quantities of water. Research shows that the mountain rivers are characterized by fluctuating runoff not only throughout the year but also throughout the day. Sterile spills at the Bureya hydroelectric power plant began on August 17. For three days, an average of 7,900 cubic meters per second arrived in the reservoir every day. The maximum inflow was 9,010, while 5,870 cubic meters passed through the hydroelectric power plant. During the flood period, the plant's reservoir retained more than 600 million tons of water. On August 20, the upstream level rose to 254.66 m (whereas the normal headwater level is 256 m).

The catchments of the mountain and submountain areas shape the idea of hydrological control over the mountain rivers. This study identifies the main types of water intake facilities that are used in the Russian Far East, along with their features, advantages, and disadvantages.

As part of the study, we considered the water intake structure at the Bureya hydroelectric power plant.

Our insights will allow for predicting the inflow of water into the Bureya reservoir and drawing attention to the long-term dependence between emergencies and the capacity of the reservoir. This paper will help to study changes in the average water inflow over the years, which, in turn, will facilitate an accurate and detailed description of the water inflow characteristics in the Bureya reservoir when planning the water-energy modes of the hydroelectric power plant.

Conclusion

The paper discussed the main types of water intake structures on the mountain and submountain rivers, identified their disadvantages and the specifics of taking water from sources of this type. The catchments in the mountain and submountain areas shape the idea of hydrological control over the mountain rivers. In this study, we identified the main types of water supply networks structures that are used in the Russian Far East. This paper is the initial stage of assessing the accuracy and detail level of the water inflow descriptions in the Bureya reservoir when planning the water-energy operation modes of the hydroelectric power plant.

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