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ENVIRONMENTAL CONSEQUENCES OF THE CONSTRUCTION OF THE BOGUCHANY DAM – PRESENT CHANGE AND PROJECTIONS

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ABSTRACT

The paper covers changes in the geographical landscape caused by the erection of the Boguchany dam, the fourth in the Angara river cascade. The reservoir, on which filling operations started in 2012, is intended to occupy the entire 357 km of valley that separate its dam and the Ust-Ilimsk dam. The full length will be reached when the normal water level (NWL) is achieved at 208 m a.s.l. At that level the reservoir will have an average depth of 25 m and the maximum of 75 m. The reservoir will have a surface area of 2326 km^2, a shoreline length of 2430 km and a width ranging from 1.2 to 15 km. The reservoir will flood areas of villages, also 1131 km^2 of forest and 296 km^2 of agricultural land, including arable land, meadows and pastures. The rising of the water level in the reservoir will generate subsequent changes to the environment according to a known pattern which involves changes to the landform (e.g. as a result of coastal processes and silting), water relationships (e.g. rising of the ground water table and change in the water quality), local climatic conditions, and types of ecosystems and habitats, etc.

Keywords: Angara River Dam Cascade, Boguchany Reservoir, environmental changes, land use, valley flooding

INTRODUCTION

The damming of a river valley and the consequent creation of a reservoir leads to very significant changes in the geographical environment [1]. These changes affect natural processes [2, 3] as well as conditions for human life and economic activity [4, 5]. In order to construct a reservoir impounded by a dam, people living in the areas designated for flooding have to be resettled, the area has to be deforested, agricultural use of land has to be discontinued and modifications of the transport and transmission infrastructure (roads, power lines, pipelines, etc.) have to be introduced. The construction of the dam and the filling of the reservoir affect the river environment, which used to be a natural water system from the river's sources down to its mouth. Changes to this system are hierarchical. Initially, abiotic effects emerge such as the change in the hydrological regime, thermal regime, water quality and the transported suspended load. These transformations result in changes in primary production and the structure of producers (plankton, periphyton, macrophytes). It is only in the next stage that higher levels of the food chain (invertebrates, fish, birds and mammals) are affected. During the filling of the reservoir and its subsequent operation, environmental (geomorphological and hydrogeological) changes take place as well. The new level at which the contact zone between water and land is established results in the development of shore processes

(initially mainly abrasive ones) as well as in an increase in the groundwater table. This significantly affects development possibilities in the vicinity of the reservoir. These wide-ranging environmental changes make reservoirs investment projects with a particularly high environmental impact, similarly to e.g. quarries.

The purpose of this article is to present some changes that are occurring in Eastern Siberia (Russia) in connection with the construction of the Boguchany Reservoir on the Angara River [6]. The Reservoir (impounded by the dam built in the vicinity of Kodinsk) will be the fourth water body in the cascade system of the Angara River, which flows from Lake Baikal (Fig. 1). Reservoirs on the Angara River are the outcome of investment plans made several decades ago, which envisaged damming up the waters of the river along its entire length by building nine dams [7]. Over time, the plans were modified, and only four dams have been constructed so far (Fig. 1).

The Boguchany Reservoir investment project has a huge impact on the environment, since it will be among the largest reservoirs impounded by dams in the world and this was the reason why it was selected as the object of the study.

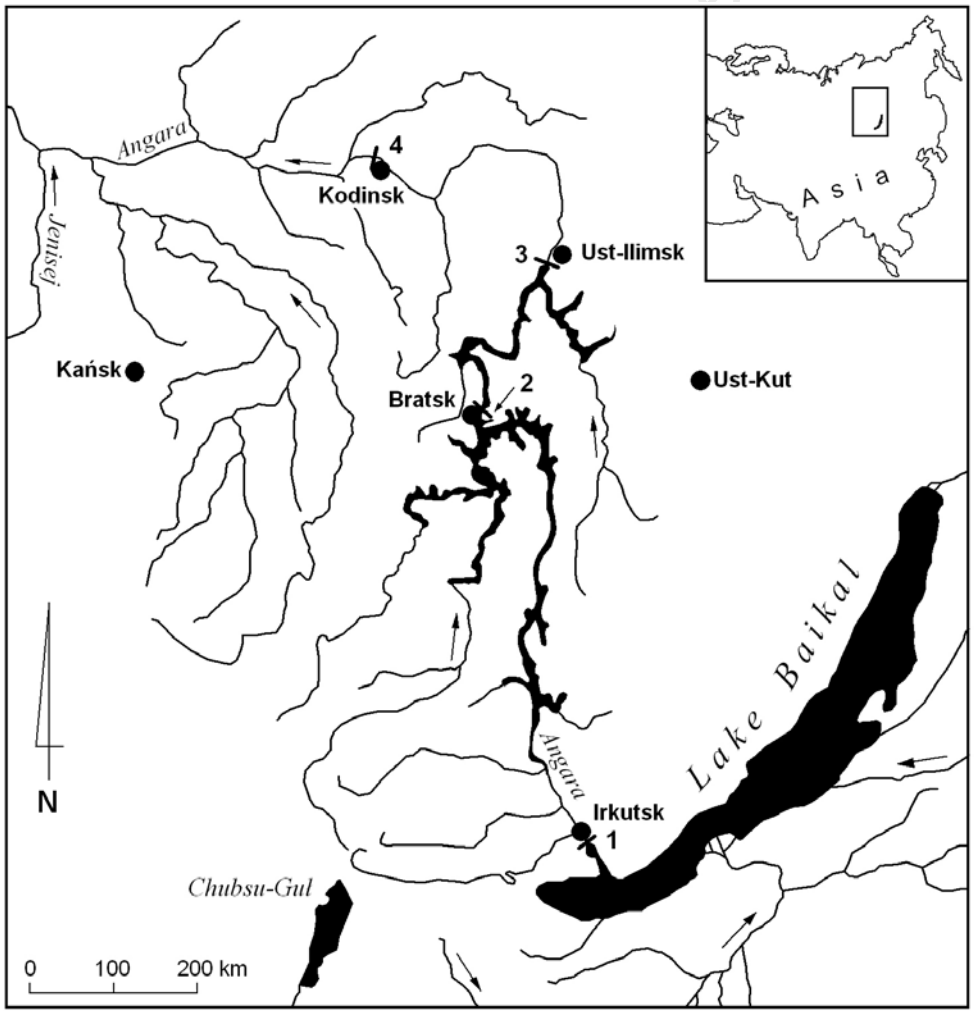

Figure 1. Angara River Dam Cascade: 1 – Irkutsk dam, 2 – Bratsk dam, 3 – Ust-Ilimsk dam, 4 – Boguchany dam.

RESEARCH METHODS AND RESERVOIR PARAMETERS

The research conducted consisted mostly of a detailed analysis of historical and contemporary maps of the Angara River valley within the reach that was to be flooded. The extent of the Reservoir shoreline after reaching the normal water level (NWL = 208 m a.s.l.) was marked on a topographic map. This enabled the cartometric analysis of the new reservoir basin. Thematic (hydrographic, hydrological and geological) maps were also analysed, enabling some environmental developments in the vicinity of the Reservoir to be predicted. A significant amount of useful information was obtained from regional literature and media reports published by the administrator of the Reservoir, which is the Russian RusHydro energy company.

The dam of Boguchany Reservoir is located near the town of Kodinsk, 1334 km from the Angara headwaters in Lake Baikal. The reservoir is intended to occupy the entire 357 km of valley that separate its dam and the Ust-Ilimsk dam (Fig. 2). The full length will be reached when the water level is achieved at 208 m a.s.l. (NWL). At that level the column of water will have a height of 67 m (the high difference of water level above and below the dam) and the Reservoir will have an average depth of 25 m. The Reservoir will have a surface area of 2326 km^2, a shoreline length of 2430 km and a width ranging from 1.2 to 15 km. The filling of the Reservoir commenced in May 2012. In September 2012, the water level reached 178 m a.s.l., and in November it was 185 m a.s.l. The latter level was maintained during the winter. In 2013, the filling of the Reservoir is to resume and it should be completed no later than 2014.

RESULTS

The search for a location for the Boguchany Reservoir dam began in 1965. Initially, a spot near the town of Boguchany was picked, but in 1971, after all options had been reviewed, it was decided to dam the valley near the village of Kodinskaya Zaimka. In 1977, a new town of Kodinsk was constructed for dam builders in its vicinity. The technical design of the dam and Reservoir was approved by Regulation No. 2699 of the Council of Ministers of 7 December 1979. The construction began on 18 June 1980.

The construction of the dam devastated the landscape of this reach of the valley. After several years, an impressive hydraulic structure (dam) together with a number of ancillary structures emerged. The Boguchany dam has a length of 2690 m and a maximum height of 96 m. It consists of two sections (concrete and earth). The concrete section is adjacent to the left river bank – it is 96 metres high and the top section, which is 828.7 m long, is situated 214 m a.s.l. The volume of the concrete dam section is approximately 2.5 million m^3. The earthen section of the dam is adjacent to the right river bank. It is an earth embankment with a clay core and rock fill, reinforced with layers of asphaltene and concrete. This part of the dam is 77 m high and has a volume of approx. 5 million m^3. It is 214.9 m wide at the base and the width of the top section is 20 m. The top section, which is 1861.3 m long, reaches 212 m a.s.l.

The preparation of the reservoir basin for flooding involved the liquidation of many localities (Fig. 2). On the right bank of the Angara River (downriver from the Ust-Ilimsk dam) the following settlements were liquidated, among others: Kata, Usoltseva, Panovo, Verkh Kezhma, Kezhma, Vydeleniy, Taezhniy, Koda. On the left bank of the river, the following settlements were among those liquidated: Edarma, Aksenovo,

Kutarey, Nedokura, Kosoy Byk, Bolturino, Dvorets, Rozhkova, Pashina, Prospikhino. Some islands on the river also used to be inhabited and settlements such as Selengino, Frolovo, Privalikhina, Savina, Zaimka or Aleshkino disappeared. In total, ca. 12,000 people were resettled. Some were given new flats in the town of Kodinsk, while others left for the southern parts of the Krasnoyarsky District and for the Republic of Khakassia. Around 1,700 people moved to Ust-Ilimsk, Bratsk or even to the vicinity of Irkutsk. In some localities, detached houses built for the displaced were grouped into settlements to preserve relationships between neighbours.

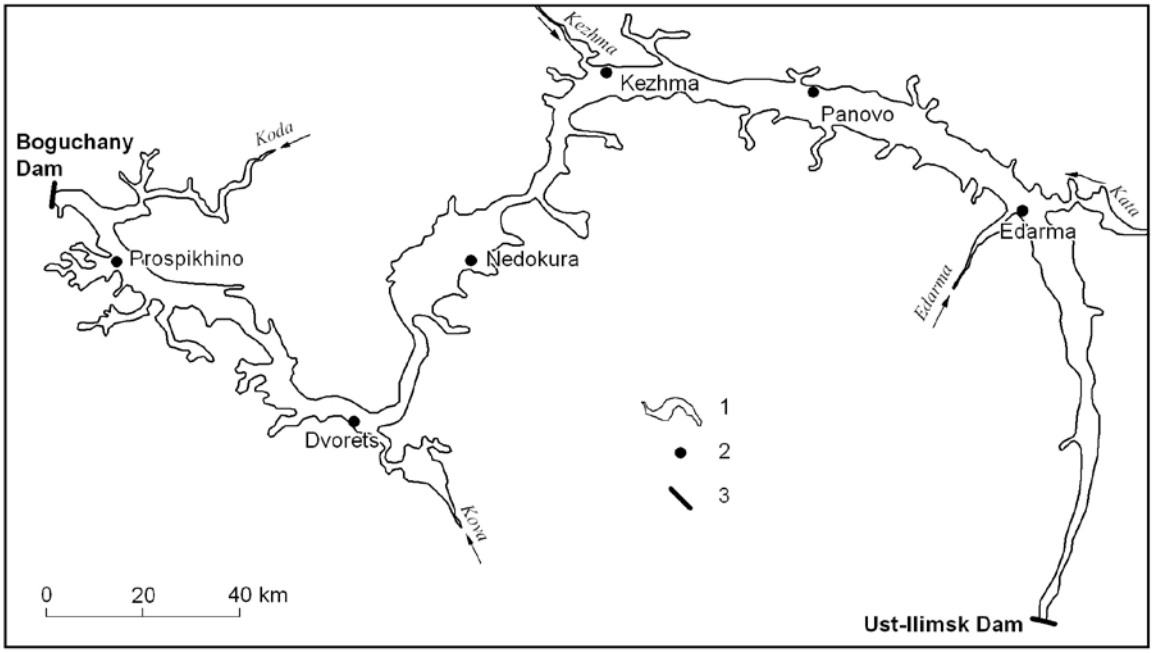

Figure 2. Boguchany Reservoir after filling: 1 – shoreline at the normal water level (208 m a.s.l.), 2 – liquidated villages, 3 – dams.

The liquidation of towns, villages and settlements was part of the process of preparing the bottom of the future Reservoir. As inhabitants left the areas that were to be flooded, the structure of land use changed. Agricultural land (arable fields, meadows and pastures) with a total area of 296 km^2 became wasteland. The extent of forest communities also changed. Within the framework of preparing the area, 1131 km^2 of forest were felled already in the 1980s. It is estimated that the volume of the removed biomass of trees and shrubs amounted to ca. 20 million m^3. The entire forest vegetation was not removed from the basin area, however – about 8 million m^3 of biomass (trees and shrubs) will be flooded. Opinions on its potential impact on the aquatic ecosystems of the Reservoir differ.

Investment plans related to the construction of the Reservoir assumed that its primary function would be the production of electricity in a hydroelectric power plant integrated with the dam, which would enable the development of infrastructure, and hence socio-economic development in the entire lower Angara River region. The first two turbines of the Boguchany hydroelectric power plant were commissioned on 15 October 2012, the third one on 25 October 2012, and the fourth one on 21 January 2013. This was made possible by the water in the Reservoir reaching the level of 185 m a.s.l. All nine

turbines will be capable of operating when the water reaches 208 m a.s.l. The turbines, with a total capacity of 3000 MW, will produce 17.6 TWh of energy per year. The electricity produced is already being fed into newly built grids. Currently, two grids are in operation: 1) Boguchany Dam – Priangarskaya – Razdolinskaya (with a length of 301 km); 2) Boguchany Dam – Angara – Kamala (with a length of over 500 km). At the end of 2013, the construction of the third (Boguchany Dam – Oziernaya) grid with a length of 330 km is to commence. The operation of the hydroelectric power plant is said to be a major factor from the point of view of environmental protection. It is estimated that with four turbines in operation, the hydroelectric power plant prevents the emission of 11.2 million tons of CO_2 into the atmosphere each year.

The Reservoir investment process not only resulted in the construction of energy infrastructure, but also affected the pattern of transport infrastructure in the Angara River valley. Apart from the construction of many roads, the most important achievement was the construction of the first bridge over the Angara River in the Krasnoyarsk District. The bridge is situated 130 km below the dam (measured along the river). It opened to traffic in November 2011. Its length is 1608 m and its width is 10 m.

The construction of the dam and the filling of the Reservoir have already caused and will yet cause numerous socio-economic changes, but they will also affect the natural environment. Hydrological changes are particularly pronounced in this respect. A water surface with an area of 2326 km^2 is being created (the maximum depth of this water body will be 75 m). The valley will hold 58.2 km^3 of water. Lower reaches of valleys of the tributaries of the Angara River such as the Kata, the Edarma, the Kezhma, the Kova, the Koda and others (Fig. 2) will also be flooded. All this will affect the hydrological regime hitherto prevailing downriver from the Ust-Ilimsk dam. It should, however, be noted that the regime of the entire Angara River has been subject to strong anthropogenic impact due to the cascade constructed. The natural regime was already modified at the beginning of the 1960s when the Irkutsk Reservoir started to operate in 1962. The filling of the Bratsk (1967) and Ust-Ilimsk (1977) Reservoirs amplified anthropogenic pressure [8]. In general, water levels in Angara cascade reservoirs are the lowest in winter. From the end of April / beginning of May the water level rises and reaches its maximum stage in September or October [9]. On average, 3005 m^3/s of water were discharged from the Ust-Ilimsk Reservoir from 1977 to 2008 (ranging from 2096 m^3/s in 1982 to 3784 m^3/s in 1995) [10]. The mean discharge of the Angara River in the vicinity of Kodinsk was 3450 $m^3/$ s. It should be added that currently, i.e. during the filling of the Reservoir, the discharge of the Angara River below the Boguchany dam is well below the average, which translates into a low water stage.

The damming up of water in the valley will lead to a change (increase) in the groundwater level. In the coastal zone of the new Reservoir, five areas can be identified where specific hydrogeological circumstances will emerge [11]. Area I lies in the vicinity of the flooded villages of Edarma, Keul, Kezhma and Dvorets. The groundwater there is related to alluvial deposits. The groundwater table will be less than 1 m below the ground level in some places and no deeper than 5 m overall. Area II is located in the central part of the Reservoir (on both banks) and is associated with Lower Triassic rocks. Changes in the water table will occur in an area of up to 5 km from the Reservoir (the fourth terrace will be partially flooded) and the thickness of the aquifer will reach up to 30 m. In area III (which is located downriver from the Ust-Ilimsk dam, near the town of Nedokura, on the left bank of the river below the mouth of the Kova

River), water-bearing sand and clay Carboniferous and Permian sediments are present. The water level will increase within the zone of up to 2-3 km from the shores of the Reservoir; locally the water level in the Reservoir will be higher than the groundwater level. Area IV is situated on the right bank of the Reservoir below the mouth of the Kova River and water is present in Cambrian and Ordovician rocks there. The impact of the Reservoir will be felt up to 2 km from the shore (locally up to 5 km) and the groundwater table will rise almost simultaneously with the filling of the Reservoir. Area V includes small patches of dolerite. Owing to the very low water-bearing capacity of these rocks, no increase in the water table is expected there.

The filling of the Reservoir to the NWL will be tantamount to establishing a new contact line between water and land. This line will be 1069 km long on the right bank, 1206 km long on the left bank and 155 km long around the islands that will form within the Reservoir. Along the line, natural processes will occur already during the filling of the Reservoir that will shape its coastal zone. The most spectacular will be the abrasion processes observed in all reservoirs of the Angara River Dam Cascade [12], i.e. the undercutting of banks inclined toward the Reservoir by the waves. These processes will result in the shoreline receding inland. It is estimated that sections of shoreline with a total length of 761 km [13] will recede. During 25 years of Reservoir operation, sections of shoreline with a length of 382 km will recede at least 50 m. The largest shoreline retreat (more than 150 m in 25 years) is expected in the area of the Kezhma River mouth where the banks consist of loose Quaternary sediments. Relatively stable shore sections that will not be washed away will be 1450 km long and heavily overgrown sections will be 211 km long. Accumulation is expected along 8 km of the shoreline [13].

The Boguchany Reservoir will undoubtedly become part of the Angara River sedimentary system, because from the very start of filling of nearly every reservoir, the bottom sediment cover begins to form as the water flow becomes slower. It is estimated that large-scale sedimentation processes in the Angara River occur below the Irkutsk Reservoir, beginning ca. 160 km downriver from the place where the river leaves Lake Baikal [14]. In the bottom sediment cover, various pollutants will accumulate depending on the intensity of anthropogenic impact [15]. Other geomorphological processes (linear and gully erosion, karst processes, aeolian processes) are also expected within the coastal zone of the Reservoir. These processes are observed in the vicinity of the reservoirs already in operation on the Angara River [16], and their reach is in some cases correlated with the extent of the zone in which the groundwater table fluctuates as a result of anthropogenic changes in the level of water dammed up in reservoirs.

The impounding of the Angara River by the Boguchany dam will cause changes in the composition of organisms living in the river. This will be the result of, *inter alia*, changes in water temperature and chemistry and the velocity of its flow. The current rapid filling of the reservoir poses a threat to, *inter alia*, the fish that swim up to spawn in the upper reaches of Angara River tributaries (whose valleys are being flooded). It is recommended that the water table be maintained as long as possible at the 185 m a.s.l. level, i.e. the level at which the Angara River flows freely within the reach 100 km downriver of the Ust-Ilimsk dam.

CONCLUSIONS

Due to the inclusion of reservoirs impounded by dams in its cascade, the Angara River is among the rivers whose environment has been comprehensively transformed as a result of anthropogenic pressure. The river geosystem has been transformed and divided into separate limnic geosystems.

The creation of the Boguchany Reservoir affects all elements of the natural environment of the lower Angara River valley. Significant changes are taking place with respect to, *inter alia*, the structure of land use (forestry, agriculture, etc.), water conditions in the area (hydrographic network and groundwater parameters) and the morphology of the valley.

As a result of the Boguchany Reservoir investment process, hydrotechnical, transport and transmission infrastructure has emerged in the Angara River valley. The settlement pattern has also changed. The hydroelectric function of the Reservoir has enabled the socio-economic development of the region.

The construction of the dam at Kodinsk and the filling of the Reservoir have caused the landscape to change. Within the flooded area, natural (e.g. riparian shrubs and forest communities) and cultural (rural and agricultural) landscapes have been replaced by that of a lake district. Devastated landscape was also temporarily present. In the next stage, the Reservoir will be assimilated in by the environment; this process will be affected by human activity in the coastal zone.

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