Directions For Improving the Efficiency of Forest Clear Cutting on the Territories of Reservoirs and Waterworks Under Construction

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Abstract. The article deals with the issues of increasing the forest resources use extent on the forested areas of reservoirs’ flooded territories of hydroelectric power stations (HPPs) – both projected and under construction- in multi-forest areas of the Russian Federation. The necessity of forest clear cutting and forest clearing carrying out on flooded territories and the importance of these measures for ensuring favorable environmental conditions in the area of hydro construction and in the water area of reservoirs are substantiated. The estimation of the wood volume cut in the process of reservoirs creation is presented and the reasons for leaving wood to be flooded are considered. The factors and circumstances that affect the indicators of economic efficiency of forest clear cutting are described. A comparative assessment of the applied technologies of forest clear cutting is made, ways to increase its profitability are outlined, and the impact of profitability on decision making on leaving wood to be flooded in the process of reservoirs’ territory preparation is estimated.

1. Introduction

The relevance of the research consists in the improvement of work efficiency and quality when cutting down tree and shrub vegetation and the increase of forest resources use extent, as well as in the need to reduce the amount of wood left for flooding in the process of reservoirs’ territories preparation for planned and under construction hydroelectric power stations.

About one half of the reservoirs operated in the Russian Federation were created by hydroelectric power stations dams (HPP), including all the largest reservoirs, their total volume being 783 km³, and the total surface area of the face being 56525 km² [1]. Most of these reservoirs are located in multi-forest areas of the Eastern Siberia. Reservoirs that, in addition to priority energy purposes, are used for water supply to localities and industrial enterprises, water driving, fishing, recreation, as well as for floods’ height and frequency decreasing. At the same time, the creation of such reservoirs causes a number of undesirable consequences for the ecology of the hydro-construction area, such as flooding, washing out, banks modification and collapse, water pollution, and others [2]. In this regard, certain environmental and technological requirements are imposed on reservoirs.

The special feature of the created reservoirs, especially in the multi-forest areas of Siberia, is the presence of significant areas and volumes of commercial wood within their projected borders,
including forest plots with a high rate of stand productivity, the average reserves of which per 1 ha reach 200 m$^3$ or more, and are of commercial value.

The creation of reservoirs during the construction of hydroelectric power stations in multi-forest areas is associated with the need to design and then clean up the flooded area from tree and shrub vegetation (TSV), which is carried out in the order of two types of work – forest clear cutting and forest clearing.

Commercial wood in the process of a reservoir preparation is subject to deal within forest clear cutting. These measures are carried out in order to ensure the quality of water that meets the requirements of sanitary standards, the formation of recreational attractiveness of the reservoir and the possibility of conducting navigation, fishing and other economic activities in its water area.

In addition, carrying out forest clear cutting and clearing on forested areas in the flooded zone will allow to reduce the amount of resulting floating wood that threatens the safe operation of hydroelectric power plants and clogs the water area of the reservoir.

Until recently, the requirements for TSV cutting were regulated by the standards of sanitary rules for the design, construction and operation of reservoirs SanPiN (Sanitary rules and standards) 3907-85 [3], as well as instructions for the inventory of tree and shrub vegetation in the areas of reservoirs flooding [4]. At the same time, despite the requirements of these documents and the circumstances justifying the need for forest clear cutting, as well as environmental requirements and directives for more complete use of forest resources, almost at all created reservoirs tree and shrub vegetation was left to be flooded.

The purpose of this study is to develop recommendations aimed at improving the efficiency of forest clear cutting and reducing the amount of wood left to be flooded when preparing the territories of hydroelectric power stations reservoirs.

2. Methods and Materials
Research methods include a review of works on forest clear cutting and clearing design on the territories of reservoirs, identification of the reasons for reducing the volume of TSV, cutting, simulation of the functioning of timber cutting machines systems, comparative assessment of technological processes and modeling of economic efficiency indicators of logging, a systematic approach and abstract-logical techniques for developing recommendations on the volume of flooded wood reduction.

3. Results and Discussion
The results of the study are to substantiate the reasons for reducing the efficiency of forest clear cutting when preparing the territory of reservoirs for flooding.

According to the research [5], due to the reason determined at the design stage of the economic impracticability of forest clear cutting in the areas where the stock of coniferous species per 1 ha was less than 50 m$^3$, the actual volume of flooded wood in the beds of the Sayano-Shushenskoye, Krasnoyarsky, Kureysky, Ust-Ilimsky and Bratsky reservoirs was 22.69 mln. m$^3$. Currently, the practice of wood flooding at the created reservoirs continues. Table 1 provides approximate information on the characteristics of the areas and reserves of tree and shrub vegetation on the territory of flooded zones of reservoirs of some hydroelectric power stations built over the past 20 years.

**Table 1. Siberian HPSs reservoirs’ beds characteristics.**

| Indicators          | Hydroelectric Power Stations |
|---------------------|------------------------------|
|                     | Bureyskaya | NizhneBureyskaya | Ust-Srednekansky | Boguchanskaya |
| Flooded area, thousand ha | 64.1       | 11.7             | 19.5            | 153.1         |
| TSV stock, thousand m$^3$ | 3557       | 325.8            | 402.2           | 9549.9        |
including commercial wood volumes 3227 275.5 189.2 5309.8

Planned volume of forest clear cutting\textsuperscript{a}, thousand m\textsuperscript{3} 2003 13.5 34.0 1142.25

Forecasted volume of TSV flooding, thousand m\textsuperscript{3} 890.1\textsuperscript{b} 312 368.2 8407.6

\textsuperscript{a} Accepted for the project, taking into account the unavailability of certain areas for development; or accepted for the project due to the refusal of forest clear cutting

\textsuperscript{b} Taking into account the disposal of illiquid volume

As can be seen from the table, despite the presence of significant volumes of commercial wood within the borders of reservoirs and the development of projects for cutting down tree and shrub vegetation at the design stages of waterworks, large volumes of wood are subject to flooding.

The decision on the procedure of and conditions for carrying out forest clear cutting, as well as on the amount of forest flooded on the territory of the reservoir being created is made on the basis of feasibility study of wood harvesting which is carried out at the design stage of measures for preparing the reservoir, and takes into account the current economic conditions in the area of hydro construction. It is a wide spread assumption that almost always in the process of reservoirs creation, this work is unprofitable. Table 2 shows the results of project calculations of the estimated cost of work on forest clear cutting of some reservoirs, performed by specialized research organizations in the framework of the development of project documentation for forest clear cutting and forest clearing. In 2004, a similar calculation was made by the Khabarovsk design and research Institute "Dallespromproekt" for the Bureyskoye and Nizhne-Bureyskoe reservoirs, and in 2010 by the Siberian state technical University - for Boguchanskoye.

Table 2. Estimated cost of work on forest clear cutting.

| Indicator | Indicators on the reservoirs |
|-----------|-----------------------------|
|           | Bureyskoe (on the territory of the Khabarovsk region), IV\textsuperscript{th} quarter prices 2002 | Nizne-Bureiskoye, 3\textsuperscript{d} quarter prices 2007 | Boguchanskoye, IV\textsuperscript{th} quarter prices 2011 |
| Estimated cost of 1 m\textsuperscript{3} of harvested wood, RUB | 1770.41 | 3027.1 | 2885.8 |
| Cost of 1m\textsuperscript{3} of sold wood, RUB | 708.23 | 1009.1 | 854.2 |
| Loss per 1 m\textsuperscript{3} of harvested wood, RUB | 1062.17 | 2018 | 2031.6 |
| The loss ratio, \% | 60 | 67 | 70 |

Technical and economic calculations show that in the conditions of the modern market, commercial forest clear cutting on the territory of reservoir flooding zones is a loss-making activity with a negative profitability of logging. The cost of harvesting and selling this wood cannot be justified economically. At the same time, it should be noted that in many cases unprofitability is due to objective reasons, the main of which are: low commodity structure of forest plantations in the flooded zone and the lack of a market for fuel and low-grade wood in the region; the work area stretching along the main river and its tributaries; significant forest resources remoteness from main transportation routes and key areas of
wood consumption, lack of road-transport infrastructure for timber hauling to the territory of the projected reservoir, and the compressed schedule of works due to the waterworks schedule.

Thus, loss-making, negative economic efficiency of forest cutting is one of the main reasons for refusing to carry it out resulting in leaving wood to be flooded. In accordance with the requirements of the SanPiN (Sanitary rules and Standards) 3907-85, if forest cutting is not carried out, the work on cutting down tree and shrub vegetation is limited to complete forest clearing only on the areas of special-purpose plots, its clearing being necessary for sanitary requirements and requirements of the industry water users.

At the same time, if forest clear cutting is not carried out, a forecast of water quality is developed, the indicators of which depend on the amount of organic substances in the flooded zone and the ability of organic sources to be extracted. As a rule, such calculations are carried out for two different scenarios of forest clear cutting: it’s carrying out in full volume on the entire flooded area, or refusing to carry it out with the implementation of forest clearing only on the areas of special-purpose sites. Based on the results of research conducted in 2009 by the Institute of water and environmental problems of the Far East branch of the Russian Academy of Sciences for the Bureyskoye and Boguchanskoje reservoirs it was found that carrying out measures for forest clear cutting and forest clearing can reduce the intake of organic substances to the reservoir from 2.4 to 7.6%, depending on the chosen scenario [6]. Thus, the impact of wood left uncut over large areas on reservoirs use and water quality appeared to be not significant.

At the same time, in our opinion, when designing measures for cutting down TSV and developing a feasibility study for forest clear cutting on flooded areas allocated for reservoirs, a number of factors and features that can influence the results of economic efficiency of forest clear cutting are not taken into account, namely:

- Technological solutions for forest clear cutting carrying out do not involve the use of modern multi-operation machines and cable installations, but are based mainly on the use of mechanized wood harvesting using petrol-powered saws and choker skidding tractors. This technology is characterized by increased labor intensity, low labour productivity, which ultimately leads to an increase in the estimated cost of harvesting of 1 m$^3$ of wood;

- The individual rates of the Federal register of estimated standards [7], which is used to determine the estimated cost of logging operations, do not include rates for the use of modern logging machines and equipment, as well as cable installations. This circumstance is a deterrent to the introduction of modern technologies into the design practice of forest clear cutting;

- The results of calculating the economic efficiency indicators of forest clear cutting cover the entire forested area and volume of wood within the boundaries of the reservoir without allocating separate logging areas that tend to possible existing points of forest consumption or main roads;

- The projects do not fully take into account the possibility of using alternative types of forest transport and harvesting methods, for example, the combined use of water and land wood transport, the combination of selective logging with clear cutting, etc.;

- The absence of a legislative mechanism for the possible transfer of part of the forest Fund in the flooded area for harvesting to interested local loggers with the implementation of possible compensation payments in the form of subsidies from the budget in case of loss, or the transfer of part of the forest Fund for harvesting and use by the local population.

In addition, the method of calculating water quality takes into account only the presence of mineral and chemical impurities in the water, but does not take into account the degree of contamination of the reservoir with floating wood mass formed as a result of flooding and forest stands washing out.

To determine the impact of the applied equipment and technology on the efficiency of forest clear cutting, a comparative assessment of two variants of technological processes and systems of machines for logging operations was carried out. The calculation of economic efficiency indicators was made for the conditions of forest clear cutting on the territory of forested areas of reservoirs-basins of the Leningrad hydroaccumulating power plant (LenGAES), designed 250 km far from St. Petersburg. Commercial forest stands on flooded areas have the following characteristics: total volume of 435.1 t.
m³, including liquid one equal 403.1 t. m³, an area of 1717.6 ha, the average annual volume of wood harvesting and export of wood - 67.2 t. m³, the species composition of the stands 3S2P4B1A (30% - spruce; 20% - pine; 40% - birch; 10% - aspen), the average volume of tree length- 0.46 m³, the reserve of fresh standing timber per hectare - 229 m³, the yield of merchantable wood - 73%.

When carrying out a comparative assessment, the traditional mechanized assortment technology based on petrol-powered saws and skidding tractors was adopted as the basic one (variant 1). As an alternative, the most advanced and successfully used machine assortment technology in Russia based on multi-operation machines-harvesters and forwarders (variant 2) was adopted. In calculations, it is assumed that the “Harvester-forwarder” machine complexes include a feller for harvesting individual large-sized trees or for developing small local hard-to-reach areas. In addition, for the development of forest allotments located on slopes with a steepness of 20 degrees and more in the composition of variant 2, felling of trees by the feller manually using petrol-powered saws with subsequent skidding of wood by cable skidders is provided.

A brief description of the compared variants of technological processes and machine systems is presented in table 3.

| Table 3. Variants of technological processes and machine systems. | Variant 1 | Variant 2 |
|---------------------------------------------------------------|-----------|-----------|
| Tree felling – PMS³ Husqvarna 372XP, Limbing – PMS³ Husqvarna 372XP, Assortment loading and hauling – PMS³ Tree felling, limbing, Assortment skidding and piling – Forwarder³ John Deere 1410; Assortment loading and hauling – PMS³ Tree felling – PMS³ Husqvarna 372XP, Limbing – PMS³ Husqvarna 372XP, Assortment loading and hauling – PMS³ |
| PMS³ + PMS³ + SCDT³ + PMS³ + HB³ + HB³ (liquid volume logging 403.1 t. m³) | FLBM³ + Forwarder³ + HB³ (liquid volume of logging 380.6 t. m³) | PMS³ + CSI³ + PMS³ + HB³ (the liquid volume of logging is 22.5 t. m³) |

³ PMS - petrol-motor saw.
⁴ SCDT - dragging tractor with sliding choker equipment.
⁵ HB - hydraulic boom mounted on a log truck chassis.
⁶ FLBM - felling-limbing-bucking machine (wheelied harvester).
⁷ Forwarder – tractor for skidding round timber (skidding of assortments).
⁸ CSI – cable skidding installation.

The calculation of technical and economic indicators for the variants was made by modeling. All technical and economic indicators of the machines and equipment operation are based on the materials of location study of the cycle of the machines operation and simulation of the technological process. Comparability of the indicators of the compared variants is provided by the volume of production, the analogy of technological operations performed, the main operating conditions, methods for
determining cost and natural indicators. The calculations were made in accordance with industry recommendations [8].

Technical and economic indicators of the compared variants of forest clear cutting technological processes are summarized in Table 4.

**Table 4.** Estimated cost, profit and profitability of forest clear cutting carrying out and sales of round wood sales.

| Expenditures item                                      | Indicators for variants | 1          | 2          |
|-------------------------------------------------------|-------------------------|------------|------------|
| Estimated cost of 1m³ of harvested wood                | (RUB/m³, in the prices of the 1st quarter of 2012) | 1001.0     | 693.2      |
| The average formed selling price of 1m³                |                         | 835.6      | 835.6      |
| Profit (loss) from sales of products                   |                         | -165.4     | 142.4      |
| Profitability (loss) of products, %                    |                         | -16        | 21         |

The calculations made showed that forest clear cutting technological process being realized on the basis of multi-operation machines (variant 2) resulted in the decrease of wood harvesting estimated cost by 31% if compared with traditional mechanized logging technology, while the profitability of forest clear cutting significantly increased. The decrease is due to labour productivity increase as well as felling personnel reduction when working according to the second variant.

It should be noted, however, that based on these data, one should not judge the efficiency of forest clear cutting on the territory of Siberian reservoirs – both projected and being created, since there are significant differences in the natural -production and economic conditions of hydro – construction, which require a feasibility study for each specific reservoir.

At the same time, the research performed and the results presented show the dependence of indicators of economic efficiency and expediency of work on forest clear cutting on the applied technological process and systems of logging machines. At the same time those modern methods should be used which allow choosing the forest plot of the greatest commercial interest [9]. Comparative assessment of different logging technological processes helps to give more objective estimation of forest clear cutting expediency on certain forest plots and to avoid mistakes when making a decision on whether to leave the wood to be flooded partially or completely.

These circumstances will allow, in our opinion, a more objective approach to decision-making on the refusal of forest clear cutting on the territory of projected reservoirs and will allow to reduce the amount of wood left to be flooded during the preparation of reservoirs’ territories.

**4. Conclusion**

In order to increase the economic efficiency and expediency of forest cutting and to select the most competitive option for its implementation, a comparative assessment of various technological processes and logging machines system should be performed when designing measures for reservoirs’ territories preparation for flooding. At the same time, the area occupied by commercial plantations should be divided into several sections, taking into account the possibility of their development using the existing transport, technological and timber processing infrastructure. The economic efficiency of such sites should be evaluated separately.

In order to be able to carry out design calculations of the cost of forest clear cutting using the most efficient and competitive systems of machines, it is necessary to expand the Federal register of estimated standards by developing and including Federal unit prices for the production of timber cutting operations with modern multi-operation logging machines and cable installations.

Due to the fact that the Sanitary rules for the design, construction and operation of reservoirs SanPiN (Sanitary rules and standards) 3907-85, regulating the requirements for the nature, volume and
conditions of cutting TSV, are currently invalid, it is advisable to develop rules for the design of reservoirs that would take into account the features mentioned above.

When calculating the forecast of water quality, in addition to the content of mineral and chemical substances generated by the wood left under flooding, both the degree of contamination of the reservoir with floating wood and its mechanical and fractional composition should be also taken into account.

The proposals and conclusions listed in the article will allow, in our opinion, to make approach to decision-making on leaving wood for flooding in reservoirs of waterworks under construction more balanced and objective, to reduce the volume of such wood, and thus to ensure a more efficient and complete use of forest resources.

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