

Assessment of natural and technogenic hazard at large hydraulic structures in the northern and arctic territories

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Abstract. Hydroelectric power plants are an important source of electricity in the world, but at the same time they can face various emergency situations that can lead to significant economic and environmental consequences. Recently, neural networks have become an increasingly popular tool for modeling and predicting emergency situations at hydroelectric power plants. This article discusses approaches to assessing the consequences of possible accidents at northern hydraulic structures. To develop scenarios and models, the Toxy + risk software and analytical complex and recurrent neural networks developed in the python programming language were used in the work. Various scenarios for the development of emergency situations have been developed and an assessment of the risk of their occurrence has been made.

1 Introduction

The emergencies that have occurred in recent years in Russia and abroad have significantly affected the state of the ecology of the northern and Arctic territories and affected the financial and economic stability of the city-forming enterprises. The need for special approaches to ensure the safety of the population and territories of the Krasnoyarsk Territory in modern conditions is due to a number of factors. Among them are both a wide range of sources of emergency situations of a natural, technogenic and biological and social nature, as well as the prevailing features of the socio-economic development of the region. Currently, there is a significant amount of scientific research and applied development to ensure the problems of industrial safety [1-7]. The issues of assessing the risk of the consequences of hypothetical accidents at large man-made objects are becoming increasingly important. Thus, as a result of the accident that occurred at the Sayano-Shushenskaya HPP in 2009, significant economic and environmental damage was caused. As sources of risk, hydraulic structures (HTS) can be divided into three groups - hydroelectric power plants (HPP), protective and bank protection dams, as well as dams of ponds and reservoirs.

In the Krasnoyarsk Territory, according to data for 2023, there are 5 operating HPPs and more than 1,000 small HPS. The risk of an accident at the hydroelectric power station is

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acceptable. At the facilities and in the authorities of the territories that fall into the zone of catastrophic flooding, there are Action Plans in the event of such an emergency.

The risk of an accident at small hydraulic structures is very high ~ 0.5 year⁻¹, since many of them have an emergency condition. An emergency state is a state of the hydrotechnical system, the failure to take measures in which will lead to the destruction of the dam, spillway and, as a result, to the complete or partial emptying of the reservoir, as well as the state in which the structure is not able to ensure the passage of the flood of the expected security. One of the effective ways to prevent the risk of emergencies at hydraulic structures is the organization of operational monitoring and modeling of processes and risk assessment. One of the effective modeling methods that have recently become widespread is big data analysis and neural network forecasting [8–11].

In general, modeling of emergency situations at a hydroelectric power plant using neural networks can be a useful tool to improve the safety and sustainability of a hydroelectric power plant. However, it must be taken into account that modeling should be carried out in combination with other methods and technologies in order to ensure maximum safety and efficiency of the hydroelectric power plant [12]. In addition, it should be noted that the modeling of emergency situations at a hydroelectric power plant using neural networks is a complex process that requires significant efforts and resources. It is necessary to continuously update the data and periodically check the health of the model to ensure its effectiveness and accuracy. It should be noted that modeling of emergency situations at a hydroelectric power plant cannot replace the expert opinion and decisions of the personnel working at a hydroelectric power plant. The model can serve as a decision support tool, but the final decision should be based on the expertise and experience of the staff.

One example of the use of neural networks for modeling emergency situations at hydroelectric power plants is the development of a monitoring and diagnostic system for hydroelectric units. This system can be used to monitor the condition of equipment and identify possible problems in real time. For example, if the system detects an anomaly in the operation of a hydraulic unit, it can alert operators to a possible failure and offer recommendations for correcting the problem.

Another example is the use of neural networks to determine the optimal operating mode of a hydroelectric power plant in real time. This may include optimizing the pressure and flow control processes in hydro turbines, which can reduce the risk of accidents and improve the efficiency of a hydro power plant.

The benefits of using neural networks to simulate accidents at a hydroelectric power plant include improved forecasting accuracy and efficiency, reduced risk of accidents, and increased safety at a hydroelectric power plant. One of the advantages of using neural networks to simulate accidents in hydroelectric power plants is the ability to create a control system that can learn from new data and improve its performance over time. This allows the system to adapt to changing conditions and improve its accuracy in predicting emergencies. In addition, neural networks can be trained on large amounts of data and can take into account complex relationships between various factors, which makes it possible to more accurately predict possible emergency situations.

Neural networks can also be used to predict other operating parameters of a hydroelectric power plant, such as water consumption, energy production, water level in a reservoir, etc. This can help hydropower plant operators make decisions to optimize system operation and improve system efficiency.

In this paper, we solved the problem of modeling scenarios and calculating the risk of their occurrence in emergencies at the Boguchanskaya hydroelectric power plant using neural network forecasting and building an analytical model.

2 Materials and methods

The scenarios for the development of accidents and the calculation of the risk of their occurrence were determined using the Toxy + risk analytical software package [13]. The risk assessment methodology embedded in the software product takes into account the consideration of the possibility of accidents directly at the facility under consideration, and takes into account the possible impact on people in case of accidents.

Damage zones determined by modeling tools are used in assessing the degree of environmental and individual risks.

According to the configuration of the destruction area, the zones of influence of damaging factors were determined and the boundaries of the zones of safe removal were established. The results were used to assess the degree of individual risk.

The methodological basis for predicting the consequences of emergency situations is based on a causal relationship of two processes: the impact of damaging factors on objects and the resistance of the objects themselves (risk elements) to this effect. Both of these processes have a pronounced random character. The probability of destruction of risk elements is affected by the spread in the strength of materials, the deviation of building elements from design dimensions, the difference in the conditions for manufacturing elements, and other factors.

The defeat of people depends both on these factors and on a number of other random events. In particular, on the probability of placing people in the risk zone, the density of distribution of personnel within the facility and the probability of being hit by debris when buildings are damaged to a certain degree of damage.

The impact of damaging factors during accidents is characterized by impact models and destruction laws. Impact models are dependencies that make it possible to determine the size of potential hazard (negative impact) fields, the intensity of damaging factors at each point of the field, and the frequency of the event. As damaging factors in the calculation of the consequences of emergencies, the impacts that cause the main destruction and damage were taken. Under the laws of destruction (damage) of risk elements is understood the relationship between the probability of their damage (damage) and the intensity of the manifestation of damaging factors.

At the forecasting stage, the models of impact and the laws of destruction (damage) were paired. The use of these methodological principles made it possible to obtain estimates of the consequences of the considered emergency scenarios.

To calculate risk indicators using the Toxy+risk software and analytical complex, the following initial data were used:

- information about hazardous substances;
- types of hazardous substances;
- the amount of hazardous substances circulating at the hazardous facility;
- weather conditions.

A scenario is understood as a complete and formalized description of the following events: phases of accident initiation, accident initiating event, emergency process and emergency, accident losses, including specific quantitative characteristics of accident events, their spatio-temporal parameters and causal relationships.

Events and destabilizing factors leading to an increase in the accident rate and the severity of their consequences on the equipment in operation:

- depressurization of pumps, valves, process pipelines, tanks and drain devices;
- malfunctions in the ground loop and lightning protection;
- violation of the rules for the operation of explosion-proof equipment;
- erroneous actions of production personnel when performing technological actions;
- use of overalls not prescribed by safety regulations;

- smoking, making open flames in unspecified places;
- reservoir overflow in case of failure of level sensors, emergency protection and erroneous actions of personnel;
- inconsistent actions of the supplier and recipient operators during tank filling operations;
- transfer of flame to the tank from the ignition of local gas contamination
- during evaporation of an emergency spillage from random sources of initiation;
- hurricane wind with a speed of more than 30 m/s, tornado, strong lightning discharges, low temperatures, solar radiation, flooding, meteorite fall;
- use of a tool that gives a spark, erroneous actions of personnel;
- transfer of flame to the tank from the ignition of an external emergency
- spills and formation of a fire zone;
- ignition of the product in case of damage to the tank from the excess pressure of the RF external emergency explosion of the fuel assembly.

Based on the analysis of statistical data and operating conditions for the development of scenarios and assessment of the consequences, the following main events and their probable frequency range of occurrence, which are presented in Table 1, are accepted.

Table 1. Statistical data on the frequency of occurrence of initiating accidents in petrochemical industries.

Trigger type	Event frequency, per year
Discharges of atmospheric electricity	$0.2 \cdot 10^{-4}$
Discharges of static electricity	$10^{-4} - 10^{-3}$
Fiction sparks	$5 \cdot 10^{-4} - 1 \cdot 10^{-3}$
Open flames and sparks	$5 \cdot 10^{-4} - 1 \cdot 10^{-3}$
Open fire at the fuel storage	$0.88 \cdot 10^{-4}$
Destruction of the fuel storage	$1 \cdot 10^{-4}$
Overflow of the tank when receiving products	0.18

With the development of an emergency according to the scenario, an explosion of oil products is predicted to cause material damage to process equipment and structures of other industrial sites.

With the development according to the scenario of an explosion of oil products or burning of oil products - a “fire-flash”, damage to the life and health of third-party organizations is possible.

The most dangerous scenario associated with a risk to human life and health is an accident with the release of oil products and the formation of a spill, and further formation and explosion, as well as the consequences associated with the overflow of the dam and flooding of settlements located in the downstream of the hydroelectric power station.

When determining the scenarios for the occurrence of accidents at the Boguchanskaya HPP and beyond, for each expected stage of the development of an accident, an analysis is made of the conditions for the occurrence, transition of the accident from the previous stage to the next one, its consequences are assessed, and optimal methods and means of prevention and localization are determined. An analysis of the possible causes of accidents at the Boguchanskaya HPP site made it possible to identify the following possible scenarios for the development of emergency situations.

Scenario group 1 related to accidents on process equipment (in case of depressurization of connecting hoses, pipelines, pumps, flange connections):

- Scenario 1.1. (most probable scenario): depressurization of the connection of hoses (pipelines, pumps, flange connections), release of oil products, ingress of oil products into the reservoir, evaporation of oil products.

- Scenario 1.2.: depressurization of the connection of hoses (pipelines, pumps, flange connections), release of oil products, evaporation of oil products, formation of a cloud of an explosive mixture of vapors of oil products and air under favorable meteorological conditions, explosion of a cloud of an air-fuel mixture from an ignition source
- Scenario 1.3.: depressurization of hose connections (pipelines, pumps, flange connections), release of oil products, formation of vapors (evaporation) of oil products, ignition of oil vapors from an ignition source, spill fire, thermal impact on surrounding objects.
- Scenario 1.4.: associated with accidents at the hydraulic unit from the explosion of a transformer and damage to a damaged water conduit, followed by flooding of the turbine hall and oil spills.

Scenario group 2 related to accidents on process equipment during the passage of flood waters:

- Scenario 2.1.: An emergency situation, which consists in reducing the throughput capacity of the HPP's spillways during the period of flood waters with a probability of 0.01%, leading to overflow of the reservoir above the established standard values and leading to water overflow through the crest of the dam, followed by flooding of the downstream area.
- Scenario 2.2.: Emergency discharge of water not provided for by the project from the HPP located upstream, water overflowing over the dam crest, formation of a breakthrough wave.
- Scenario 2.3.: Impossibility of timely lifting of gates or failure of lifting mechanisms when a flood is skipped, level rise in the reservoir, water overflow over the crest of a concrete and earth dam, formation of a breakthrough wave.
- Scenario 2.4.: Accident associated with the rockfill dam of the hydroelectric complex, associated with the descent of the landslide mass of soil, the descent of the landslide mass of soil into the reservoir with the formation of an unforeseen wave, overflowing over the crest of the rockfill dam and flooding of the tailwater.

With the use of neural network prediction, the consequences of the accident were calculated for scenario group 2, using the architecture of a recurrent neural network with a long short-term memory LSTM written in the python programming language [14], using 128 neurons.

The following parameters were taken as initial parameters:

- hydrological information (inflow to the site of the hydroelectric complex; data on the observed inflow to the site of the hydroelectric complex; cycle of regulation of river flow by the reservoir, data on precipitation, water level at gauging stations in the upstream and downstream of the Angara River).

The data array for forecasting was obtained from operational monitoring data and archival data on flooding of the territory over the past 10 years, obtained from the Yenisei Basin Water Administration of the Federal Agency for Water Resources and the Central Siberian UGMS. The input parameters were selected empirically. The root-mean-square error for assessing the consequences of the implementation of scenario group 2 of the developed model was 12%.

3 Results and discussion

In accordance with the methodology described above, we also solved for a group of scenarios 1 and 2 using the Toxy + risk software and analytical complex, we assessed the point of view of the development of explosive situations associated with environmental pollution, destruction of buildings, structures, as well as injury and the death of people.

The predicted accident probabilities at the hydroelectric power plant site in accordance with scenario group 1 are presented in Table 2.

Table 2. Probabilities of occurrence of accidents and the boundaries of the affected area in the implementation of scenario group 1 in the development of an emergency at a hydroelectric power plant.

Scenario	The damaging factor of the accident	Probability of an accident per year	Spill fire oil product per area, m	The radius of impact of high-temperature products of combustion of petroleum products in open space from a "fire-flash", m
1.1.	Emission of oil products as a result of the destruction of process equipment	$7.5 \cdot 10^{-1}$	639.1	207.8
1.2.	Explosion of a cloud of fuel assemblies during the destruction of technological equipment	$5 \cdot 10^{-2}$	315.4	114.2
1.3.	Strait fire during the destruction of technological equipment	$2 \cdot 10^{-2}$	392.1	143.2
1.4.	Accident at the hydraulic unit from the explosion of the transformer and damage to the damaged water conduit, followed by flooding of the machine room and spilling of oil products	$2 \cdot 10^{-4}$	74.2	38.9

Further, for the group of scenarios 2, the predicted probabilities of the occurrence of an accident and the probable consequences presented in Table 3 were also calculated.

Table 3. Probability of occurrence of accidents and the boundaries of the affected area in the implementation of scenario group 2 in the development of an emergency at a hydroelectric power plant.

Scenario	The damaging factor of the accident	Probability of an accident per year	Areas of the flood zone, km ²	The number of settlements falling into the flood zone
2.1.	An emergency situation, which consists in reducing the throughput capacity of the spillway structures of the HPP during the period of flood water passage with a security of 0.01%, leading to overflow of the reservoir above the established normative values and leading to water overflow through the crest of the dam,	$4,1 \cdot 10^{-5}$	1321	53

	followed by flooding of the downstream area.			
2.2.	An emergency discharge of water not provided for by the project from a hydroelectric power station located above, overflowing water over the crest of the dam, the formation of a breakthrough wave.	$4 \cdot 10^{-5}$	1310	53
2.3.	The impossibility of timely lifting of the gates or the failure of lifting mechanisms when a flood is missed, the rise in the level in the reservoir, the overflow of water over the crest of a concrete and earthen dam, the formation of a breakthrough wave.	$3,4 \cdot 10^{-5}$	1315	53
2.4.	Accident associated with the rock-fill dam of the hydroelectric complex, associated with the descent of the landslide mass of soil, the descent of the landslide mass of soil into the reservoir with the formation of a wave not foreseen by the project, overflowing over the crest of the rock-fill dam and flooding of the tailwater.	$3 \cdot 10^{-5}$	412	27

At the second stage of the study, in accordance with the methodology described in the Materials and Methods section, we developed and trained a neural network model to predict the flooding of settlements located in the downstream of the Boguchanskaya hydroelectric power station in the event of probable emergency scenarios. The assessment of the accuracy of the developed neural network and analytical models was carried out with the data of operational monitoring during the passage of flood waters in the downstream of the Boguchanskaya hydroelectric power station.

The consequences expected during the development of an accident in the GTS include:

- partial destruction of the rockfill dam;
- catastrophic flooding of territories located in the downstream. Given the extremely large volume of the reservoir of the Boguchanskaya HPP, the entire lower Angara region and the banks of the river will fall into the flood zone. Yenisei located below the settlement Strelka;
- destruction and partial damage of the constructed HPP structures;
- flooding of farmland and forests;
- damage and partial destruction of housing stock, industrial facilities, elements of transport and communications in the zone of passage of a breakthrough wave;
- emergency discharge of pollutants into surface waters;
- shutdown of power generation for the period of emergency recovery work.

The number of possible settlements in the flood zone as a result of an overflow wave or increased discharge was made taking into account:

- travel time of the wave as a result of overflow and discharge from the reservoir to the settlements located on its route;

- parameters of the breakthrough wave;
- height marks of flooded points;
- cartographic assessment of the area of flooding of each settlement.

The zone of catastrophic impacts closest to the accident site will be in the most dangerous position, namely, settlements, to which the time of reaching a discharge wave with a height of more than 4 m will be no more than an hour, there are 23 such settlements in the zone of influence of the Boguchanskaya hydroelectric power station.

Visualization of the model of flooding of the territory of the considered group of scenarios 2 presented in Figure 1.

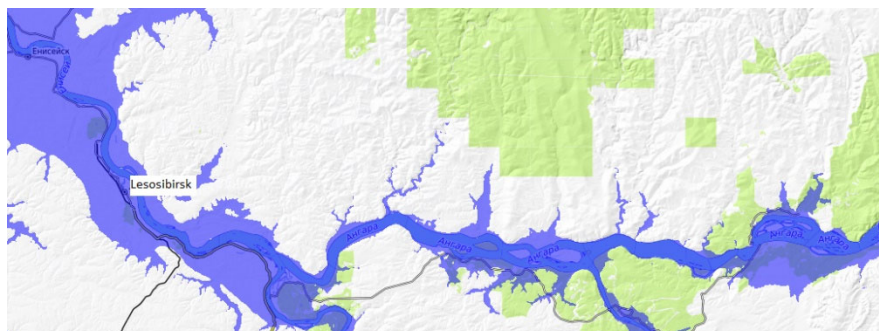


Fig. 1. Model of the flood zone as a result of the implementation of the group of dangerous scenarios 2 considered in this paper.

Analyzing the results obtained, we can conclude that if the scenarios considered in the work of group 2 under the worst scenario of the development of the situation are implemented, the total area of flooding of the territory will be more than 1300 km², more than 30,000 hectares of forest land, 53 settlements will be flooded.

In general, the approaches used in the work make it possible to assess the consequences of probable scenarios of emergency situations at hydraulic structures. However, the scenarios developed in this paper do not describe the entire variety of possible scenarios for the development of emergency situations and are the subject of further research in this area. An increase in the number of monitoring indicators and a sufficient amount of historical data can increase the accuracy of the model being developed and the quality of hydrological forecasts. In order to increase the security of settlements located in the downstream of hydroelectric power plants, it is necessary to increase the number of sensors for automatic control over the state of technological equipment with a system of neural network forecasting and evaluation of indicators, as well as to create at all hydroelectric power plants an integrated system of emergency warning of the population, consisting of automatic sensors for monitoring and transmitting alert signals. The approaches used in the work can be used in the development of action plans for the prevention and elimination of natural and man-made emergencies, as well as in organizing the safe passage of flood waters.

4 Conclusion

The approach to zoning the territory of a hydraulic structure according to risk levels, presented in this paper with associated fire and explosion hazardous facilities, shows that most of the personnel enter areas with high risk levels. The maximum level of risk for personnel located in the areas of action of damaging factors in case of accidents. estimated using the software-analytical complex Toxy+risk is $7.5 \cdot 10^{-1}$.

The use of neural networks for modeling emergency situations at hydroelectric power plants is a promising direction for improving the safety and efficiency of hydroelectric power plants. Neural networks can be used to predict accidents and create a monitoring and control system that will help hydroelectric operators make decisions to prevent accidents and improve system performance. However, it must be taken into account that the use of neural networks requires a large amount of data and high computing power.

Neural networks can help identify possible problems and prevent accidents, which can lead to economic benefits and reduce the negative impact on the environment. However, for the successful application of neural networks in this area, it is necessary to take into account various factors related to the availability of data, the quality of modeling, the regularity of training and model validation, as well as the use of other monitoring and control methods to ensure the safety of a hydroelectric power plant.

In addition, various machine learning algorithms, such as the support vector machine, random forest and feed-forward neural networks, as well as recurrent neural networks used in this work, are used to build models of emergency situations at HPPs. These algorithms make it possible to determine the dependencies between various variables and predict possible emergencies.

The results of the work represent a set of solutions that make it possible to increase the efficiency of the functioning of the safety system at hydraulic structures and to predict the situation in the zone of probable emergencies and to respond in a timely manner and prevent emergencies through the use of new methods for collecting and processing data from situation monitoring systems.

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