RISK ASSESSMENT AND THE PREDICTION OF BREAKTHROUGH WAVE DURING A DAM ACCIDENT

[a]ABDRAZAKOV K. FYARID, [b]ORLOVA S. SVETLANA, [c]PANKOVA A. TATIANA, [d]MIRKINA N. ELENA, [e]MIKHEEVA V. OLGA

[a] Federal State Budget Educational Institution of Higher Education «Saratov State Agrarian University named after N.I. Vavilov». Russia, Saratov, Teatralnaya sq., 1
[b] Federal State Budget Educational Institution of Higher Education «Saratov State Agrarian University named after N.I. Vavilov». Russia, Saratov, Teatralnaya sq., 1
[c] Federal State Budget Educational Institution of Higher Education «Saratov State Agrarian University named after N.I. Vavilov». Russia, Saratov, Teatralnaya sq., 1
[d] Federal State Budget Educational Institution of Higher Education «Saratov State Agrarian University named after N.I. Vavilov». Russia, Saratov, Teatralnaya sq., 1
[e] Federal State Budget Educational Institution of Higher Education «Saratov State Agrarian University named after N.I. Vavilov». Russia, Saratov, Teatralnaya sq., 1
Email: [a]mbc_@mail.ru, [b]ssv@ores.su, [c]editor@ores.su, [d]russia@prescopus.com, [e]info@ores.su

Abstract: With the use of modern methods of accumulated information analysis about the accidents on ground dams, it is possible to make the predictions concerning the probability of emergency occurrence and to calculate the possible consequences. The main reasons of subsoil dam destruction are the problems with ground bases or the lack of hydraulic structure capacity. The forecasting of a breakthrough wave expansion as the result of an accident was carried out using the example of the Nepokoevsky reservoir hydraulic structures in the Krasnopartizansky district of the Saratov region. In the event of a catchment structure destruction, the threat of the pressure front destruction is created, followed by the development of propane, through which the water front, spreading in the lower part of a hydraulic unit, forms a breakthrough wave and, thus, the territory flooding takes place. In order to predict a breakthrough wave and the flooding characteristics of the terrain during the break of hydraulic unit facilities, the "Volna" program (version 2.0) was used. In accordance with the classification of the Russian GTS Register, the level of dam safety is assessed as normal one, and the risk of a GTS accident occurrence probability is assessed as acceptable (permissible). According to the calculation results, the maximum flooding width will be 39.48 m on the right bank, the maximum depth of flooding will make 1.22 m at the distance of 0.95 km from the site of the hydraulic unit, the maximum speed of the wave will be 2.16 m/s at the distance of 11 km from the hydraulic unit site. At the distance of more than 23 km from the hydraulic unit site, the parameters of a breakthrough wave are within the permissible values, which do not cause destructive effect and any consequences of a negative nature.

Key words: forecast, dam, hydrotechnical structures, estimation, risk, breakthrough wave.

1 Introduction

According to statistics, the accidents and the damage of hydraulic structures on ground dams occur quite often. The causes of such accidents are various factors that could have arisen during design and construction stage or in the process of exploitation. The accurate causes of an accident, as a rule, are set after the emergence of an emergency. However, using the modern methods of different, already accumulated information analysis about the accidents that occurred, it is possible to make the forecasts concerning the probability of emergency occurrence and to calculate the possible consequences.

The main reasons of subsoil dam destruction are the problems with basement soils, or the lack of hydraulic structure capacity. The problems with basement soils are manifested when a reservoir is filled for the first time. An insufficient capacity is characteristic mainly for small-scale irrigation dams (Orlova S.S. 2016).

The lack of capacity is the result of a flood flow incorrect calculation, at which the water flow through a spillway and a drain is higher than the calculated values, and the structures can not cope with it; the malfunctioning condition of culverts during the passage of high water; dam accidents located upstream (O.V. Mikheeva, S.S. Orlova. 2014). Thus, water flows through the dam crest and its destruction takes place.

The most dangerous consequenced of a dam accident is the breakthrough of the pressure front and the emergence of a breakthrough wave, which can lead to huge economic losses, environmental disasters and social consequences spreading in the tail-water of a hydraulic unit (F.K. Abdrazakov, T.A. Pankova, S.S. Orlova, and Sirota V.T. 2017).

An assessment of risk and possible consequences as the result of an accident was carried out using the example of the Nepokoevsky reservoir hydraulic structures in the Krasnopartizansky district of the Saratov region.

Nepokoevskoe reservoir is built on the dry land (the Nepoevsky vale), located on the right bank, the first terrace above the floodplain, in the upper reaches of the Bolshoy Uzen river. The dam is located 2.2 km from the mouth of the Nepoevsky vale beam (the confluence point in the Bolshoy Uzen river) and 2.4 km to the southeast of the village Podshibalovka. The reservoir is intended for the accumulation of the Volga water during the inter-irrigation period, coming through the water outlet of the main canal central branch (VMK-2) of the Saratov irrigation-watering canal named after E.E. Alekseevsky (SIWC) to the beam Nepokoevsky vale, the feeding of the Bolshoy Uzen river in order to cover the water deficit during the summer vegetation period when water is collected for irrigation and water supply.

The facility has been operated for 33 years. There were no emergency situations during the operation. The solidity class of hydraulic structures is the IIIrd one. Dangerous stored wastes are absent. By the degree of danger, the GTS refers to the third class, the safety level is normal.

The structure of the hydraulic unit includes (at present):

- earth structure made of heavy loams with layer-by-layer compacting, the length along the crest of 2,074 m; the crest is suitable for traffic, its width makes 10 m and it has an asphalt surface; the mark of the crest makes 100.90 m, the maximum height makes 25.9 m, the maximum pressure on the structure makes 24.05 m;
- a spillway construction of a closed type - a bottom outlet, regulated by deep gates; an entrance threshold mark makes 78,80 m, an output mark makes 77,30 m; the maximum culvert capacity with FRL (98.05 m) is 81 m^3/s, with HWL (98.60 m) of 82.5 m^3/s.

The purpose of the study is to assess the risk of its occurrence on the basis of the forecasted scenarios for the development of a hydrodynamic accident and to predict the propagation of a breakthrough wave as the result of a hydrodynamic accident on a ground dam.

2 Methodology

2.1 The prediction of accident development scenarios

The forecasting of a breakthrough wave, and an accident risk assessment was carried out on the basis of possible scenarios for a hydrodynamic accident development.

The list and the probability of scenarios for the development of hydraulic structure accident on a dam are determined on the basis of possible causes and the nature of GTS dangerous damage analysis that can cause emergency situations and hydrodynamic accidents (Kuznetsov D.V. 2016).

2.2 Accident risk assessment

The assessment of an accident risk level at the hydraulic unit is carried out by the analysis of the factor cumulative influence which reflect the degree of danger and the degree of vulnerability for a GTS (Korenovsky A.M., Baklanova D.V. 2016). At the same time, the degree of danger determining the characterization of the processes occurring on GTS and in the zone of their influence, and representing the threat to life, or to the living conditions of people, facility and environment, is expressed by the hazard factor of an accident λ. The degree of vulnerability that determines the ability of GTS to lose its ability to perform specified operational functions as the result of negative impacts is expressed by the vulnerability coefficient v. The assessment of GTS accident risk also includes the comparison of the results obtained with the acceptable level of a GTS accident risk, regulated by existing regulatory documents (Methodical recommendations for the assessment of accident risk at hydrotechnical structures of the water facilities and industry (Text) // 2nd edition, revised and supplemented, M. "DAR/VODGEO", 2009.).

The complex characteristic of the object is the assessment of the total risk, which allows to perform a comparative assessment of a situation from the perspective of possible losses for existing or projected facilities. The risk assessment is based on the results of hazard factor monitoring and analysis, most significant for a given structure and its operating conditions (F.K. Abdrazakov, T.A. Pankova, V.A. Shcherbakov. 2016).

Hazard indicators are divided into 4 groups: 1) the excess of the natural loads and impacts taken by the design substantiation of GTS structure; 2) the substantiation and the compliance of design solutions with modern regulatory requirements; 3) the compliance with GTS structure project, the technologies of erection and operating conditions; 4) possible consequences and damage in the case of an accident on GTS.

At that, each group of indicators is analyzed for main vulnerabilities with an expert analysis. Vulnerability indicators are also subdivided into 4 main groups: 1) the state of a facility according to visual and instrumental observations, the compliance of the main parameters with the maximum permissible values (GTS safety criteria); 2) the state of environment in GTS influence zone (according to monitoring data); 3) the organization of GTS operation, the compliance with the norms and requirements for safe operation; 4) the readiness of a facility for the localization and the elimination of emergency situations.

The risk assessment of an accident is performed on the basis of an expert analysis of an accident hazard level and the level of GTS vulnerability. In order to assess an accident risk level, a risk factor is calculated based on the principle of these events intersection, i.e.:

$$r_a = \lambda \cdot v$$

where: λ - the hazard factor for GTS; *v* - the coefficient of GTS vulnerability.

The physical meaning of the coefficient r_a is that it represents a hazardous effect measure (dose) on a given GTS with an established degree of vulnerability. The level of GTS safety is assessed by the value of the risk factor r_a in accordance with the data given in Table 13 of the "Methodology" (Methodical recommendations for the assessment of accident risk at hydrotechnical structures of the water facilities and industry (Text) // 2nd edition, revised and supplemented, M. "DAR/VODGEO", 2009.).

The ranges of the coefficient r_a in Table 13 «Methods...» (Methodical recommendations for the assessment of accident risk at hydrotechnical structures of the water facilities and industry (Text) // 2nd edition, revised and supplemented, M. "DAR/VODGEO", 2009.) are assigned in such a way as to link practically the characteristics of an accident risk with the qualitative characteristics of safety level regulated by the "Administrative Regulations for the implementation of the state function by Rosvodresursy, Rostekhnadzor and Rostransnadzor concerning the state registration of hydrotechnical structures and the maintenance of the Russian Register of Hydraulic Engineering facilities», approved by the order No. 117/66 of the Ministry of Natural Resources and the Ministry of Transport of Russia on April 27, 2009.

The determination of the accident risk factor r_a makes it possible to estimate the probability (the frequency) of $P_a(GTS)$ accident occurrence in accordance with the following formula:

$$P_a(\text{ГТС}) = 0{,}5 erfc\left[\beta \cdot \frac{ln\left(r_a/r_k\right)}{ln\left(r_{доп}/r_k\right)}\right]$$

where $r_к$ is the catastrophic value of the risk factor ($r_k = 1$); $r_{доп}$ - the permissible value of the risk factor, above which the normal level of GTS safety is not ensured ($r_{доп} = 0{,}15$); β - the probability ratio, depending on GTS class (Table 14 "Techniques ...") (12); *erfc x* - probability function.

2.3 The prediction of a breakthrough wave in an accident

During the first phase of a hydrodynamic accident, a dam breakthrough takes place, which is the process of propane development, through which an uncontrolled flow of water from the upper water of the reservoir rushes to the tail water (F.K. Abdrazakov, T.A. Pankova, S.S. Orlova, V.T. Sirota. 2017). The flow of water, rushing into the passage, forms a breakthrough wave, which has a significant speed of movement and a great destructive power. Thus, a breakthrough wave in a hydrodynamic accident is associated with the emergence of an emergency situation associated with the flow of water at considerable speeds.

The main parameters of a breakthrough wave leading to catastrophic consequences include: the height and the depth of propane, the speed of the water flow, the temperature of water and the time of wave existence. The physical essence of a breakthrough wave is the unsteady movement of water flow, in which the main parameters change in time (Orlova S.S., Abdrazakov F.K., Pankova T.A. 2016;Orlova S.S., Abdrazakov F.K., Pankova T.A. 2018).

An unsteady motion is the most general form of motion, in relation to which the steady motion is a particular case of an unsteady motion. An unsteady motion actually goes to a steady one if there is a long section in the watercourse, close to the prismatic one, i.e. an unsteady motion on a part of this area practically turns into a steady one. A steady motion can be changed into an unsteady one if any cause causes the change of time consumption in one of reach sites, and consequently, the level and other parameters of the mode.

A dam destruction and the breakthrough of the pressure front lead to terrain flooding. The zone of flooding is formed gradually, as a wave passes along a river bed. Following the front of a breakthrough wave, its height begins to increase intensively, and after a certain period of time it reaches a maximum value exceeding the edges of the river banks, and thus a floodplain flooding begins (Ivashchenko I.N., Ivashchenko K.I. 2016). When the water level across the entire width of the flow ceases to rise, a more or less prolonged period of water movement takes place, close to the steady one. The final phase of the territory flood zone development is the decline of water levels. The result of a wave breakthrough, is the heavy deformation of a riverbed, and the floodplain remains excessively moistened for some time.

In order to predict a breakthrough wave and the flooding characteristics of the terrain during a hydraulic unit facility destruction, the "Volna" program (version 2.0) was used. The program allows you to assess the consequences of a hydrodynamic accident. The parameters of the terrain flooding are determined - the maximum depth of flooding, the width of flooding and the current speed; the arrival time of a front, a crest and a tail of a breakthrough wave, the maximum water flow in a site, a wave height (the exceed of water level above the level of a domestic flow) and the maximum mark of flooding.

Considering that during the entire period of hydraulic structure operation, the water levels in a reservoir were significantly lower than the design levels, and they have been declining steadily during the last years; the feeding of a reservoir from the water outlet of the second branch of the main canal (VMK-2) of the Saratov irrigation-watering canal named after E.E. Alekseevsky has not been carried out for a long time, and the maximum volume of spring flood of the Bolshoy Uzen river makes 2 million m^3 (based on long-term observations), the maximum volume of water recorded in the reservoir is taken for the entire period of operation (19.0 million m^3) to predict a breakthrough wave.

The initial data on a hydraulic unit are presented in Table 1.

Table 1 Initial data on a hydraulic unit

Hydraulic unit site characteristics	Parameter	Un. of meas.	Value
1. Reservoir volume	Wв	mln. m^3	19
2. Dam reservoir depth	Hв	m	16,45
3. Reservoir mirror area	Sв	mln. m^2	2,37
4. Reservoir width near a dam	Bв	m	2074
5. River depth in the downstream of a hydraulic unit	Hбо	m	0,5
6. The river width in the downstream of a hydraulic unit	Bбо	m	6
7. Flow velocity in the downstream of a hydraulic unit	Vбо	m/s	0,2
8. Reservoir depth at a dam at the time of HU destruction	Hp	m	8,6
9. The degree of hydraulic unit destruction	Ep		0,02
10. The breach threshold height	p	m	7
11. Reservoir water reduction mark	Zв	m	91,45

3 Results

3.1 Scenario prediction results concerning the development of a GTS accident

The works on the object survey were carried out in May 2017. For the last 5 years, the reservoir was not used for its intended purpose (water was not taken for irrigation and water supply, there are no fish farms). Since 2011, the reservoir has been shut off from the water outlet of the main canal (VMK-2) second branch of the Saratov irrigation and watering canal named after E.E. Alekseevsky.

Analyzing the current state of hydraulic structure parameters of the Nepokoevsky reservoir and the design data of the structural elements presented by the operational service of the hydraulic unit, the following conclusions can be drawn:

1. There were no emergencies during 33 years of operation of the Nepokoevsky reservoir, and no significant damage was observed in the elements of the structures. During the entire period of the reservoir operation, ongoing repair works were carried out, including the overhaul of the bridge crane, the manufacturing of the repair shutter, the elimination of partial damages on the upper and the lower slopes, etc.
2. During the entire period of the hydraulic structure operation, the water horizons in the reservoir were significantly lower than the design levels (according to the design, the NWL mark is 98.05 m, which corresponds to a total water volume of 48.8 million m3) in 2013-2017. The maximum volume of water was 7.5 million m3, which corresponds to the water level of 86.5 m, and for the whole period of the reservoir operation the maximum volume of water in it was 19.4 million m3 with the pressure of 16.45 m, which corresponds to the water level of 91.45 m.
3. The free capacity of the reservoir makes 29.8 million m3 and is capable of accumulating the floods with 0.5% of supply. Taking into account the foregoing and comparing the pressures acting on the dam in both cases (16.45 m and 23.6 m), it can be concluded that the values of the breakthrough wave parameters and, accordingly, the damages in the case of the dam possible destruction in the current operating conditions will be much lower, than at design parameters.
4. However, a partial or a complete destruction of the hydraulic unit will result in the loss of the reservoir capacity in the upper tail and, accordingly, the reservoir will not be able to perform its functions under current operating conditions.

The potential sources of danger for the GTS of the Nepoevsky reservoir may be the following ones:

- the manifestations of structural defects in hydraulic structures during long-term operation due to the aging of materials and the changes of their properties under the influence of external factors;
- the operation of the GTS does not comply with the requirements of the existing norms and rules for the provision of their reliability and safety;
- the lack of timely repairs of structures;
- the lack or an insufficient volume of measures to ensure the readiness of the facility to the localization and the elimination of emergency situations.

In accordance with the design features of the GTS of the Nepoevsky reservoir, several scenarios for the development of accidents can be predicted if it is operated in the project mode (Table 2).

Table 2 Scenarios for the development of possible reservoir accidents

Scenario №	Prerequisites and stages of an accident development on GTS
1	A spillway damage, creating the threat of waterfront destruction with propane and a flood zone development.
2	The damage of individual elements of the spillway structure, the failure of hydromechanical equipment, leading to the need for emergency reduction of pressure on the GTS and accompanied by the discharge of water.
3	An increased filtration through the body and the base of the dam with the dam body materials aging and the change of their properties under the influence of external factors, the appearance of local places on the bottom slope of concentrated water filtration, the slumping or the collapse of the dam lower slope, the development of a breakthrough and a breakthrough wave with further destruction of the dam.
4	A terrorist act, man-made and natural disasters creating the threat of the pressure front destruction with the formation of a closing gap and a flood zone.

The analysis of the list of 4 predicted scenarios for the development of GTS accident shows:

Taking into account the greatest depth (pressure) of water in the dam upper water dam during the development of a hydrodynamic accident under the scenario No. 1, this scenario may lead to the most severe consequences, due to the damage and the destruction of spillway structure elements in the case of the operation service unavailability to the elimination of the above-mentioned causes of a possible GTS accident.

The most likely scenario is the scenario №2, when the damage of individual elements of a spillway structure or the failure of hydromechanical equipment leads to the need of the GTS pressure emergency decrease, and the discharge of water into the downstream through the bottom outlet, which will lead to the river water level increase.

The scenario № 3, associated with the filtration of water through the dam body is unlikely in the interfaces of GTS elements and by the contact with the dam base. Many years of operation and visual observations confirm the absence of filtration and the removal of soil.

The likelihood of scenario # 4 implementation is difficult to assess. A terrorist act is unlikely due to the absence of any serious reasons for its commission and a high risk of an act performance. Technogenic and natural disasters are also unlikely because there are no sources in the immediate vicinity of the reservoir that can cause them.

3.2 Results of an accident risk assessment

The value of the coefficient β for class III facilities, corresponding to the permissible probability of an accident P_a (GTS), equal to $3\cdot10^{-3}$ 1/year, makes β=1,95 (SP 58.13330.2012).

Tables 3 and 4 present the results of an integrated expert assessment of an accident hazard and the vulnerability of the Nepokoevsky reservoir GTS for scenario 1 (with the most severe consequences).

Table 3 Integral assessment of an accident risk level

Item №	Hazard indicator	Hazard level	Code	Distinctive features on the basis of which the degree (the level) of hazard is determined according to the hazard indicator in question
1	The danger of natural load exceeding	No danger	0	The loads and impacts were reduced during the past period of operation, taken at the design basis of the dam construction at the Nepokaevsky Reservoir. The water level in the water storage did not exceed 91.45 m, which is much lower than the mark of NWL making 98,05 m.
2	Substantiation and the compliance of design solutions with modern regulatory requirements	Small danger	1	The project has no significant deviations from the current regulatory requirements (SP 58.13330.2012) for all estimated factors. However, it should be noted that there are no surface marks necessary for carrying out field observations at the dam, which does not meet the requirements of SP 39.13330.2012 for Class III facilities.
3	The compliance with structure design, the conditions of its operation, the properties of the construction and foundation materials	No danger	0	The structures of the dam correspond to the project taking into account the repair work carried out during the operation (the elimination of local damage to dam slopes, the bridge crane overhaul, the manufacturing and the installation of the repair shutter). The deviations from the project in USL markers and the volumes of the reservoir are caused by the changed operation regulations.
4	Possible consequences and the damage in the event of an accident	Small danger	1	In the case of the pressure front destruction at the GTS of the Nepokoevsky water reservoir with the existing marks of its filling, the damage from the hydrodynamic accident to the population and the enterprises in the area adjacent to the reservoir will be up to 100 thousand rubles. By the spread of a breakthrough wave (does not go beyond the limits of one district), the scale of the emergency situation in the case of an accident on the GTS (in accordance with the classification approved by RF Government Resolution No. 304 issued on May 21, 2007 (The resolution of RF Government No. 304 "On the Classification of Emergencies of Natural and Technogenic Character" issued on May 21, 2007)) is classified as a local emergency.

The integral code of hazard indicators in accordance with the data of Table 3 makes 0101.

The hazard ratio λ=0,125.

Table 4 Integral assessment of vulnerability

Item №	Vulnerability indicator	Vulnerability level	Code	Distinctive features on the basis of which the degree (the level) of hazard is determined according to the vulnerability index
1	The state of the dam according to visual and instrumental observations	Small	1	According to the observations and the surveys in general, the structures are in a working order, but there are chips in the concrete lining of the dam and the gates of the spillway are not closed tightly; there is no exceeding of the monitored PDZ indicators.
2	The state of the environment in the zone of hydraulic structure influence	Absent	0	The reservoir does not influence the state of environment and the living conditions of the population area where the hydraulic unit is located.
3	Organization of the dam operation (compliance with safe operation requirements)	Small	1	The organization of operation has minor deviations from the current regulatory requirements concerning GTS security: there is no KIA on the dam, which does not meet the requirements of SP 39.13330.2012 (14) for the construction of the IIIrd class structure. Round-the-clock duty is not provided.
4	An object readiness for the localization and the liquidation of emergencies	Small	1	There are minor deviations from the requirements for an object completion to the localization and the elimination of emergencies: the stock of building materials is stored not on a site but on the basis

Item №	Vulnerability indicator	Vulnerability level	Code	Distinctive features on the basis of which the degree (the level) of hazard is determined according to the vulnerability index
				of the operating organization, there is no local warning system (LWS) about an accident.

According to the data of the Table 4, the integrated vulnerability code of the dam is 1011, which determines the vulnerability factor v =0,2833.

In accordance with the received hazard factors λ and the vulnerability v the accident risk factor for the dam is

$$r_a = 0,125 \cdot 0,2833 = 0,0354$$

and an accident occurrence probability makes:

$$P_a(\text{ГТС}) = 0,5 \cdot erfc\left[1,95 \cdot \frac{ln\left(^{0,0354}/_{1}\right)}{ln\left(^{0,15}/_{1}\right)}\right] = 5,5 \cdot 10^{-4}$$

1/year

Similarly, the result of the integrated expert assessment calculation concerning the hazard and the vulnerability of GTS accident of the Nepoevsky reservoir is provided according to scenarios 2-4.

The integral hazard code is estimated as 1021, which corresponds to the hazard ratio λ = 0.125 For Scenario 2 (the most likely accident), where the maximum consequence may be an unscheduled operation of the reservoir with maximum project costs, which will not cause a significant hydrodynamic accident and territory flooding.

At that the vulnerability code for the dam makes 1021, which determines the vulnerability factor v = 0.3833. In accordance with the received hazard factors λ and the vulnerability v, the accident risk factor for the dam is

$$r_a = 0,125 \cdot 0,3833 = 0,0479$$

and an accident occurrence probability makes:

$$P_a(\text{ГТС}) = 0,5 \cdot erfc\left[1,95 \cdot \frac{ln\left(^{0,0479}/_{1}\right)}{ln\left(^{0,15}/_{1}\right)}\right] = 1,6 \cdot 10^{-3}$$

1/год

Given that scenario 3 and scenario 4 are unlikely, then the hazard factor λ and the vulnerability factor v will be equal. The integral hazard code is estimated as 0001 for them, which corresponds to the hazard ratio λ = 0.0625. At that, the vulnerability code of the dam is 0010, which determines the vulnerability factor v = 0.1. In accordance with the received hazard factors λ and the vulnerability v, the accident risk factor for the dam is

$$r_a = 0,0625 \cdot 0,1 = 0,00625$$

and an accident occurrence probability makes:

$$P_a(\text{ГТС}) = 0,5 \cdot erfc\left[1,95 \cdot \frac{ln\left(^{0,00625}/_{1}\right)}{ln\left(^{0,15}/_{1}\right)}\right] = 0,75 \cdot 10^{-6}$$

1/год

3.3 Breakthrough wave calculation results

The report on the work in the program "Wave" (version 2.0) is presented in Table 5 and in the form of calculated sites (Figures 1-7), by which it is possible to determine the parameters of a breakthrough wave and a territory flooding: wave height, flow depth, the movement velocity and the time of different peculiar wave point arrival (front, crest, tail) to the calculated sites located on the river below the hydraulic unit, as well as the duration of a wave passage through these sections and the time of its fall.

Table 5 Report on the work in the program "Wave", version 2.0

Breakthrough parameters	Site №									
			0 st.	1 st.	2 st.	3 st.	4 st.	5 st.	6 st.	7 st.
Site removal from a hydraulic unit	Lci	km	0	0,95	6,4	8,5	11	15,7	19,3	23
Maximum water flow in the site	Qi	t.m^3/s	0,01	0	0,01	0,01	0,01	0,01	0	0,01
Maximum flow velocity	Vi	m/s	2,27	1,83	2,36	1,81	2,16	1,35	1,97	1,18
Wave height	Hri	m	0,9	0,62	0,55	0,35	0,46	0,17	0,33	0,14
Maximum depth of flooding	Hi	m	1,4	1,12	1,05	0,85	0,96	0,87	0,63	0,64
Maximum mark of flooding	Zi	m	76,4	73,12	68,55	67,85	65,46	64,17	63,73	63,24
Time of wave front approach	Tфi	min	0	9,07	61,52	80,17	104,93	151,45	195,54	236,35
Time of wave crest approach	Tri	min	0	32,19	316,08	417,74	546,66	732,26	940,93	1089,5
Time of wave tail approach	Txi	min	12962,3	13041,4	13495,6	13670,6	13878,9	14270,6	14570,6	14878,9
Flooding time	Tзт	min	12962,3	13032,4	13434,1	13590,4	13774,0	14119,2	14375,1	14642,6
Maximum width of flooding along the left bank		m	16,81	22,42	27,58	35,92	28,1	25,25	38,59	30,42
Maximum width of flooding along the right bank		m	16,81	10,87	14,56	17,09	17,32	27	36,21	39,48

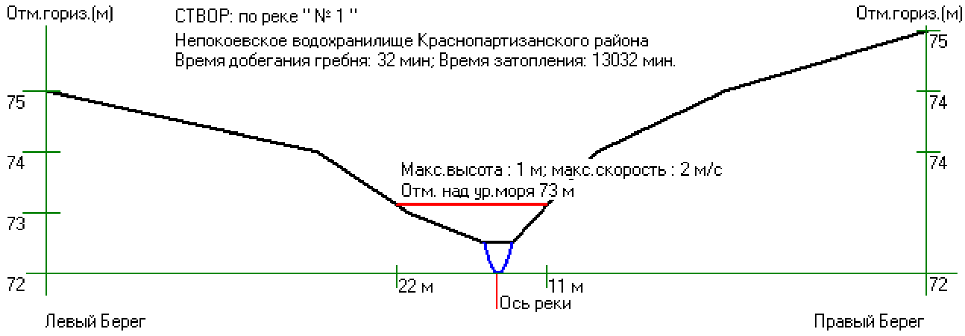

Figure 1: Site №1 – the removal from hydraulic unit makes 0,95 km.

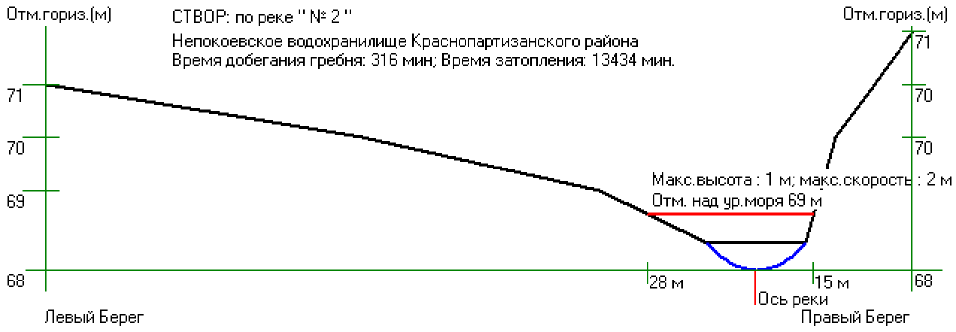

Figure 2: Site №2 – the removal from hydraulic unit makes 6,4 km.

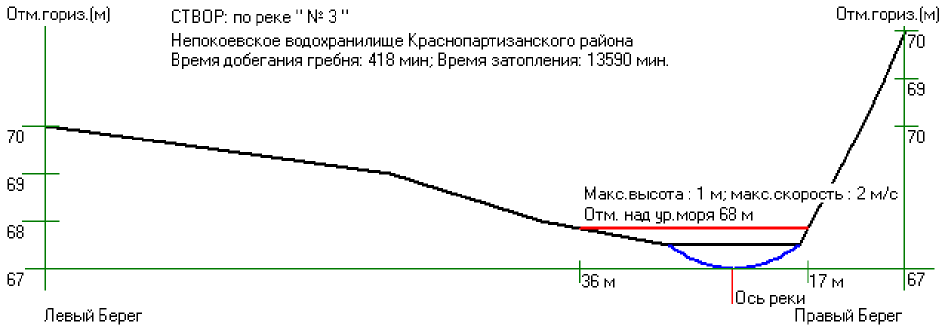

Figure 3: Site №3 – the removal from hydraulic unit makes 8,5 km.

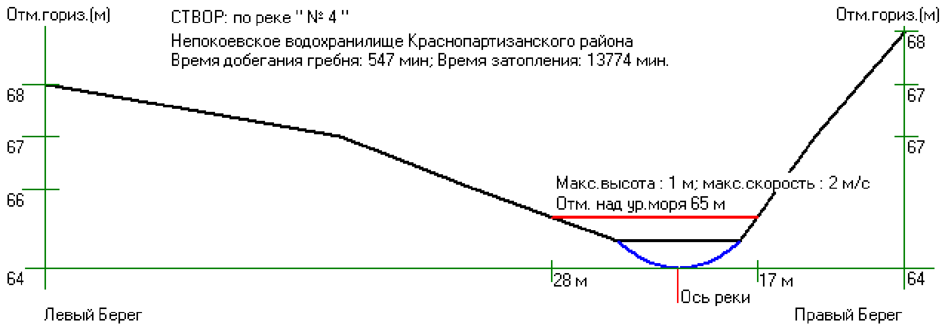

Figure 4: Site №4 – the removal from hydraulic unit makes 11 km.

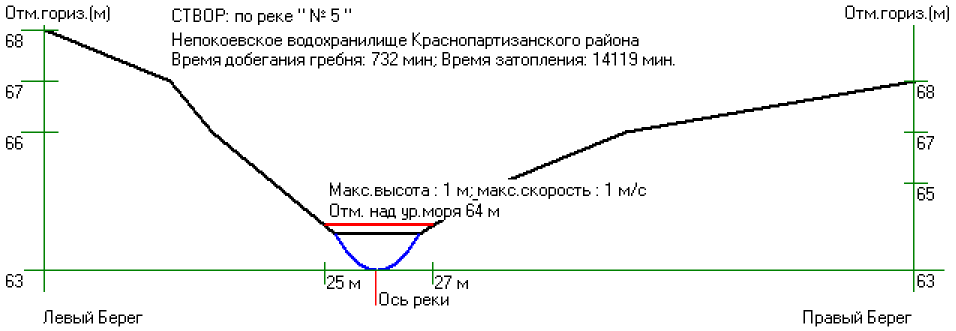

Figure 5: Site №5 – the removal from hydraulic unit makes 15,7 km.

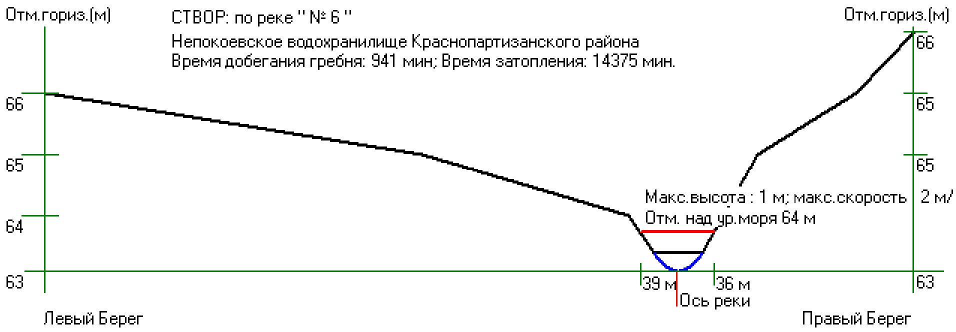

Figure 6: Site №6 – the removal from hydraulic unit makes 19,3 km.

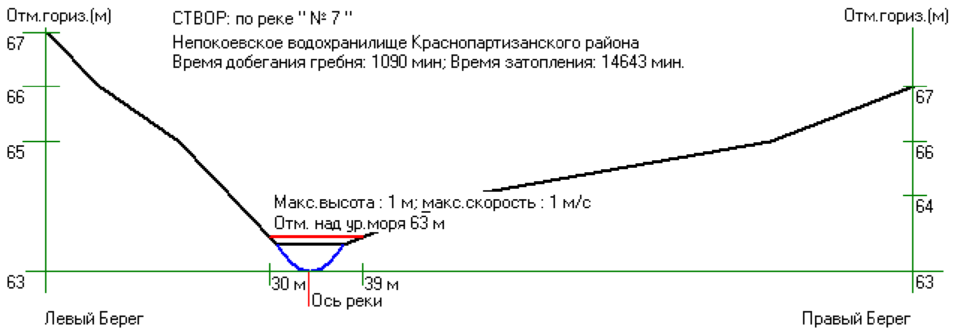

Figure 7: Site №7 – the removal from hydraulic unit makes 23 km.

Отметка горизонтальная (м) - Horizontal mark (m) / СТВОР: по реке "№7" - SITE: along the river "№ 7" / Непокоевское водохранилище Краснопартизанского района - Nepokoevskoe Reservoir of the Krasnopartizansky District / Время добегания гребня: 1090 мин.; Время затопления: 14643 мин. - Crest run time: 1090 minutes; Time of flooding: 14643 min. / Максимальная высота: 1 м.; максимальная скорость: 1 м/с - Maximum height: 1 m; maximum speed: 1 m/s / Ось реки - The river axis / Левый/правый берег - Left / right bank

4 Discussion

During the assessment of a dam hydrodynamic accident risk, it is necessary to predict the accident scenarios correctly taking into account all possible situations. Based on the results of risk assessment, the most likely scenario should be taken. The calculation of a breakthrough wave is carried out according to the scenario with the most severe consequences. When a breakthrough wave passes through the river floodplain, the water that leaves the banks sweeps away any obstacles and destroys the buildings and the structures that are on its way. Therefore, the parameters of a breakthrough wave dynamic interaction with structures are determined during calculation, and the parameters of its propagation in the floodplain regions are calculated (V.Ya. Zharnitsky, E.V. 2016).

Taking into account that the breakthrough wave is the main damaging factor at the hydrodynamic accident on the hydraulic structures, it is necessary to determine its parameters to assess the consequences in the zone of the area catastrophic flooding: the wave height, the depth of the stream, the speed of movement and the time of reaching the calculated sites, located on the river below the hydraulic unit, by various characteristic points of the wave (front, crest , tail) as well as the duration of the wave passage through these sections and the time of its decline.

5 Summary

In the event of spillway structure individual element damage, the failure of hydromechanical equipment, the maximum consequence may be an unscheduled drainage of the reservoir with maximum costs, which will not cause a significant hydrodynamic accident and territory flooding (the most likely scenario). In the case of the spillway destruction, the threat of the pressure front destruction is created, followed by the formation of a closing gap and the territory flooding, i.e. the most severe consequences (the most difficult scenario).

In accordance with the classification of GTS Russian Register, the level of dam safety is estimated as normal, corresponding to the accident risk factor within the established limits, namely, r_a<0,15; according to the classification of risk level (Table 16, "Methods ..." (12)), the risk of GTS accident occurrence probability is assessed as an acceptable (permissible) one, since the obtained probability values for the accidents on pressure GTS (Class III) are less than $3 \cdot 10^{-3}$ 1/year.

According to the calculation results, the maximum flooding width will be 39.48 m on the right bank, the maximum depth of flooding will be 1.22 m at the distance of 0.95 km from a hydraulic unit site, the maximum speed of the wave is 2.16 m/s at the distance of 11 km from the hydraulic unit site. At a distance of more than 23 km from the hydraulic unit site, the parameters of the breakthrough wave are within the permissible values, which do not cause a destructive effect and any consequences of a negative nature.

Literature:

1. F.K. Abdrazakov, T.A. Pankova, S.S. Orlova, V.T. Sirota. The estimation of reliability and the risk of a hydrodynamic accident on a dam (Text) // Agrarian Scientific Journal. - 2017. - № 12. - pp. 61 - 65.
2. F.K. Abdrazakov, T.A. Pankova, S.S. Orlova, and Sirota V.T. The forecast of a breakthrough wave parameters during a hydrodynamic accident on a dam (Text) // Agrarian Scientific Journal. - 2017. - №1. - pp. 35 - 39.
3. F.K. Abdrazakov, T.A. Pankova, V.A. Shcherbakov. The factors affecting the operational status of hydrotechnical structures (Text) // Agrarian Scientific Journal. - 2016. - №10. - pp. 56 - 61.
4. Ivashchenko I.N., Ivashchenko K.I. "Cost of living" and the safety of dams (Text) // Safety of power structures. 2016. - No. 1 (21). - pp. 3-29.
5. Korenovsky A.M., Baklanova D.V. The assessment of hydrotechnical structure accident risk of the Taigansky Reservoir in the Republic of Crimea (Text) // The ways of irrigated agriculture efficiency improvement. - 2016. - No. 2 (62). - pp. 113 - 119.
6. Kuznetsov D.V. Scenario of ground dam accident during water overflow through a dam crest by the analysis of the failure tree (Text) // MSSU bulletin. - 2016. - №4. - pp. 94-107.
7. Methodical recommendations for the assessment of accident risk at hydrotechnical structures of the water facilities and industry (Text) // 2nd edition, revised and supplemented, M. "DAR/VODGEO", 2009.
8. O.V. Mikheeva, S.S. Orlova. On the calculation of damage as the result of an accident at a hydrotechnical structure. (Text) // Agrarian Scientific Journal. - 2014. - №9. - pp. 38 - 42.
9. Orlova S.S. The analysis of accident and damage causes concerning water-retaining structures (Text) // The ways of irrigated agriculture efficiency improvement. - 2016. - No. 2 (62). - pp. 104 - 108.
10. Orlova S.S., Abdrazakov F.K., Pankova T.A. The assessment of agricultural object damage from an accident on a ground dam (Text) // Agrarian Scientific Journal. - 2016. - №6. - pp. 63 - 66.
11. Orlova S.S., Abdrazakov F.K., Pankova T.A. A breakthrough wave and the zone of flooding prediction in the event of an accident at a dam (Text) // Agrarian Scientific Journal. - 2018. - №3. - pp. 42 - 46.
12. SP 39.13330.2012. Dams from ground materials. (Text) Updated version of SNiP 2.06.05-84*.
13. SP 58.13330.2012 "Hydrotechnical structures. Basic provisions». (Text) Updated version of SNiP 33-01-2003.
14. The resolution of RF Government No. 304 "On the Classification of Emergencies of Natural and Technogenic Character" issued on May 21, 2007 (as amended and supplemented on May 17, 2011) (Access Mode: http://base.garant.ru/12153609/).
15. V.Ya. Zharnitsky, E.V. Andreev. Ground dams as an object of a dynamic system (Text) // Nature management. - 2016. - No. 1. - pp. 16-22.

Primary Paper Section: A

Secondary Paper Section: AQ