11. Волчек, А. А. Оценка колебаний максимальных уровней воды рек бассейна Припяти на территории Беларуси / А. А. Волчек, И. Н. Шпока, Д. А. Шпока // Вестник Брестского государственного технического университета. Серия : Водохозяйственное строительство, теплоэнергетика и геоэкология. – 2020. – № 2. – С. 27–30.
12. Расчетные гидрологические характеристики. Порядок определения. Технический кодекс установившейся практики ТКП 45-3.04-168-2009(02250). – Минск : РУП «Стройтехнорм», 2010. – 55 с.
13. Статистические методы в природопользовании : учебное пособие для студентов высших учебных заведений / В. Е. Валуев, А. А. Волчек, П. С. Пойта, П. В. Шведовский. – Брест : Изд-во Брестского политехнического института, 1999. – 252 с.
14. Волчек, А. А. Гидрологические расчеты : учебное пособие / А. А. Волчек. – Москва : КНОРУС, 2021. – 418 с.

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ESTIMATION OF BREAKING RISKS OF ZHINVALI EARTH DAM TAKING INTO CONSIDERATION THE "CAPRA"

G. V. Gavardashvili, E. G. Kukhalashvili, T. G. Supatashvili, I. R. Iremashvili, I. A. Qufarashvili, K. G. Bziava, G. T. Natroshvili

Tsotne Mirtskhulava Water Management Institute of Georgian Technical University, Tbilisi, Georgia, givi_gava@yahoo.com

Abstract

Georgia is one of the most vulnerable countries to natural disasters within South Caucasus Region. In recent years, the disaster risk has increased due to faulty land-using. Outstanding building codes lead to inadequate building construction. There is a lack of real data on natural disasters and the impact of mudflows, floods, debris flows etc. on land-use planning and prompt actions after above mentioned catastrophes. Therefore, it is important task to carry out assessments of critical structures sensitive to natural threats such as dams and reservoirs. In order to be able to improve the resistance of hydraulic engineering structures it is necessary to utilize a formal risk analysis framework, such as the Critical Asset and Portfolio Risk Analysis (CAPRA) method. The scientific article examined the creation of a framework for the condition of the earth dam and risk management using the analysis of the critical state and the risk portfolio, which was developed by Professor Billal Ayyub who represents Maryland University in USA, to examine human-caused threats, such as terrorism events, and natural hazards, such as flooding due to dam failures, with focus on potential failure modes due to deterioration. For this purpose, based on the field and theoretical studies, the regulation of hydrological (floods, debris-flows, snow avalanches), geological (erosion, mudflows), and seismic (earthquake), as well as those natural disasters formed in the water area of Zhinvali Reservoir, which determines the stability and reliability of the Zhinvali Earth Dam, is estimated using existing statistical data and theory of reliability and risk. Special attention is paid to

the safety of the population living in the risk zone, as well as the development and evaluation of methods and principles of the impact of expected disasters.
Keywords: Zhinvali Earth Dam, risk, reliability, stability, safety, CAPRA.

ОЦЕНКА РИСКОВ ПРОРЫВА ЖИНВАЛИЙСКОЙ ПЛОТИНЫ С УЧЕТОМ МЕТОДА «CAPRA»

Г. В. Гавардашвили, Э. Г. Кухалашвили, Т. Г. Супаташвили, И. Р. Иремашвили, И. А. Купарашвили, К. Г. Бзиава, Г. Т. Натрошвили

Аннотация

Грузия является одной из наиболее уязвимых к стихийным бедствиям стран Южного Кавказа. В последние годы риск бедствий увеличился из-за неправильного землепользования. Устаревшие строительные нормы и правила приводят к ненадлежащему строительству. Отсутствуют реальные данные о влиянии стихийных бедствиях, таких как оползни, наводнения, селевые потоки и т.д. на планирование землепользования и оперативных действиях после вышеупомянутых катастроф. Следовательно, важной задачей является проведение оценки критических сооружений, чувствительных к природным угрозам, таких как плотины и водохранилища. В целях улучшения устойчивости гидротехнических сооружений, необходимо использовать такую формальную структуру анализа рисков, как метод анализа критических активов и портфеля рисков (CAPRA). В научной статье рассмотрено создание основы для оценки состояния земляной плотины и управления рисками с использованием анализа критического состояния и портфеля рисков для изучения антропогенных таких угроз, как террористические акты и стихийные бедствия, с акцентом на возможные режимы разрушения. Данный метод был разработан профессором Биллалом Айюбом, который представляет Мэрилендский университет в США. Для этой цели, на основе полевых и теоретических исследований, а также с помощью существующих статистических данных и теории надежности и риска, была дана оценка регулирования гидрологических (наводнения, сели, снежные лавины), геологических (эрозия, сели) и сейсмических (землетрясения), а также стихийных бедствий, образующихся в Жинвальском водохранилище. Особое внимание уделяется безопасности населения, проживающего в зоне риска, а также разработке и оценке методов и принципов воздействия ожидаемых бедствий.

Ключевые слова: Жинвальская земляная плотина, риск, надежность, устойчивость, безопасность, метод “CAPRA”.

Introduction. The geographical location of the Georgia complicated mountainous terrain, and other factors shape the wide diversity of the climate. Georgia has various climate zones starting with everlasting snow-caps and glaciers to warm humid subtropical forests and humid semi-desert steppes. Various hazardous meteorological and hydrological phenomena, such as mudflows, debris-flows, droughts, floods, avalanches, etc. are observed over the region. It is anticipated that the frequency of occurrence of extreme weather and climate events will increase due to the climate change. However, there are no systematic studies on the variability of climate over the country.

Georgia is one of the most vulnerable countries to natural disasters within South Caucasus Regions. In recent years, the disaster risk has increased due to faulty land-using. Outstanding building codes lead to inadequate building construction. There is a lack of real data on natural disasters and the impact of mudflows, floods, debris flows etc. on land-use planning and prompt actions after above mentioned catastrophes [1]. Therefore, it is important task to carry out assessments of critical structures sensitive to natural threats such as dams and reservoirs.

In order to be able to improve the resistance of hydraulic engineering structures it is necessary to utilize a formal risk analysis framework, such as the Critical Asset and Portfolio Risk Analysis (CAPRA) method, to examine human-caused threats, such as terrorism events, and natural hazards, such as flooding due to dam failures, with focus on potential failure modes due to deterioration. The use of such methods requires data on their response to natural disasters and human-caused events (such as terrorist attacks). Meeting the data need requires collection of recordings of local disasters that may be appeared at the dams and reservoirs. The results obtained from the analysis of the data will provide information crucial for developing tools to disaster response and management plans in the South Caucasus.

Materials and Methods. Modern evidences of the use of hydraulic engineering structures reveal that the present world requires protecting a population from the results caused by natural disasters, which provoke not only big ecological, but also economic, social and demographic problems. Damage to or destruction of the nation's water supply and water quality infrastructure by natural disaster could disrupt the delivery of vital human services in the country, treating public health and the environment, or possibly causing loss of life. Interest in such problems has increased greatly due to the disaster that took place in Tbilisi (capital of Georgia). In the course of implementation of scientific researches, the genetics of the origin of floods and mudflows carried out in Tbilisi on 13-14 June 2015 and its causes are linked to the objectives of our research. As a result of the disaster, the zoo's territory, urban infrastructure and, unfortunately, the victims of human and animal life took place.

Taking into account that it is generally impossible to implement accurate prediction of emergency situations that occur at hydraulic engineering structures (such as dams, reservoirs, etc.) under the influence of different factors and at different time periods, we have not any universal method to assess these processes. Therefore, it is necessary to take science-based preventive measures using innovatory means and modern technologies. Special attention should be paid to the development of rapid response mechanisms and operative warning of population about possible danger.

The majority of existing dams can be considered as difficult and combined systems, which include structures of different scopes and kinds. Though, a failure of any structure may cause especially difficult results, possibly, human life loss. In the majority of cases the cause of incidents for dams, wharf walls, reservoirs etc. may be their deterioration and influence of external dynamic (due to for example earthquake, landslide, inundation, intensive erosion processes etc.) as well as mechanical forces (due to for example terrorist attacks). Construct gaps occurred in design and construction phases cannot be omitted as well. On a world scale the majority of dam failures generally happened in earth dams, which in the majority of cases were induced by soil wash-out caused by seepage processes in the dam's core.

Safe operation of dams and reservoirs (both natural and artificial) existing in Georgia, and particularly Zhinvali Earth Dam is complicated by the condition that they entered the phase of deterioration and aging. The cadastre of reservoirs, carried out in Georgia in the 1960s-1980s, recorded 64 large and small reservoirs on the entire territory of the country. As is known, along with the basic economic purpose of reservoirs, special role is assigned to dams as one of the means of regulating natural disasters, including floods and freshets [2, 3, 4, 5]. The monitoring system for dams and reservoirs, which should give us opportunities to get information about existing and newly originated problems and to solve such gaps in time, does not exist. At present there are no warning systems, which in case of failure inform State Authorities and, appropriately, populations to reduce or control impact on the populations. Taking into account the above-mentioned situation, the mentioned structures can be easier destroyed by a terrorist attack, and as a result, the scale of failure will be immeasurable.

The survey object located on the territory of Georgia is a Zhinvali Reservoir. Selected area – Zhinvali Hydraulic Complex is located 35 km from Tbilisi entrance (Avchala district), 49 km from Tbilisi centre (Baratashvili Bridge). The Zhinvali Reservoir, which is fed by four water courses: Tetri (Mtiuleti), Shavi (Gudamaqari), Khevsureti and Pshavi Aragvi rivers, is of the capacity of 520 million m^3, while the area of the water surface is 733 million m^2 (see Figure 1) [6, 7, 8, 9].

The initial data on the Zhinvali Earth-Fill Dam are given in Table 1.

Table 1 – Initial Data for the Zhinvali Hydro-Scheme

№	Zhinvali Earth Dam (0.75)	Dimensions	Quantity
1	Reservoir capacity at normal filling level (nlf)	Million m^3	520
2	Depth of reservoir at dam (nlf)	m	96
3	Area of water surface at nlf	Million m^2	733
4	Width of dam at nlf	m	415
5	River depth at tail-race of dam	m	1
6	River width at tail-race of dam	m	25
7	Rate of river at tail-race	m/s	1
8	Depth of reservoir at the moment of dam accident	m	96
9	Degree of destruction of dam	-	0.5
10	Height of river bed bank breach	m	48
11	Mark of normal filling of reservoir	m	816
12	Quantity of calculation sections in river bed	unit	8

Covering multifunctional assignments in the fields of power, irrigation, water-supply, flood and inundation control Zhinvali Reservoir can be considered as a very important for Georgia from ecological and economic point of view. According to preliminary calculation, the following can be assumed in case of failure:

- Destruction of areas located nearby, including about tens of thousands hectares of agricultural lands;

- Destruction of populated areas, the ancient and the new capitals of Georgia (Mtskheta, Tbilisi) as well as a significant part of Rustavi;
- Failure of strategic objects (Natakhtari water-pumping station, which supplies drinking water to 40% of Tbilisi population and to a significant part of Dusheti, Mtskheta, Gardabani and Rustavi; Transcaucasia railway station, highways and bridges located on the territory of Georgia);
- Dam failure can cause a lot of human victims.

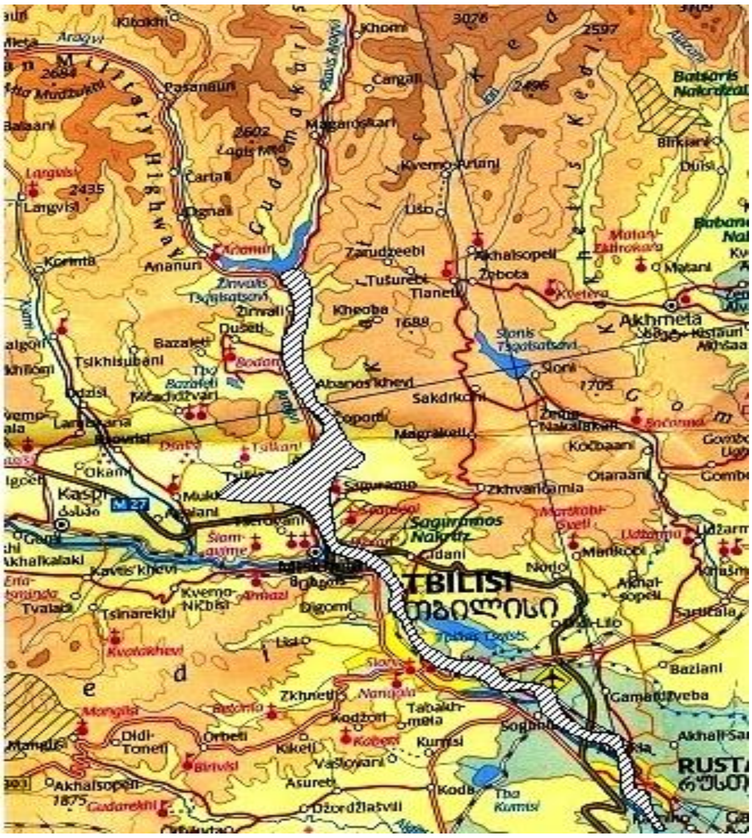

Figure 1 – Diagram of the territories flooded as a result of an accident at the Zhinvali Earth-Fill Dam

Implementation of the Critical Asset and Portfolio Risk Analysis (CAPRA). The CAPRA method is implemented for the purpose for analysing the Critical Assets and Portfolio Risks for Zhinvali Earth Dam. In general, the CAPRA provides a quantitative approach for all-hazards risk analysis. CAPRA is a five-phase process that identifies hazard scenarios that are relevant to the region or asset of interest, assesses the losses for each of these scenarios given they were to occur, allows for consequence-based screening, assesses the annual rate occurrence for each scenario, and provides results suitable for benefit-cost analysis [3, 10]. CAPRA produces risk assessments that can form the basis for identifying alternative risk mitigation strategies and evaluating them for their cost-effectiveness, affordability, and ability to meet risk reduction objectives. Figure 2 provides the CAPRA analysis tasks, the analysis techniques, and the output of each task.

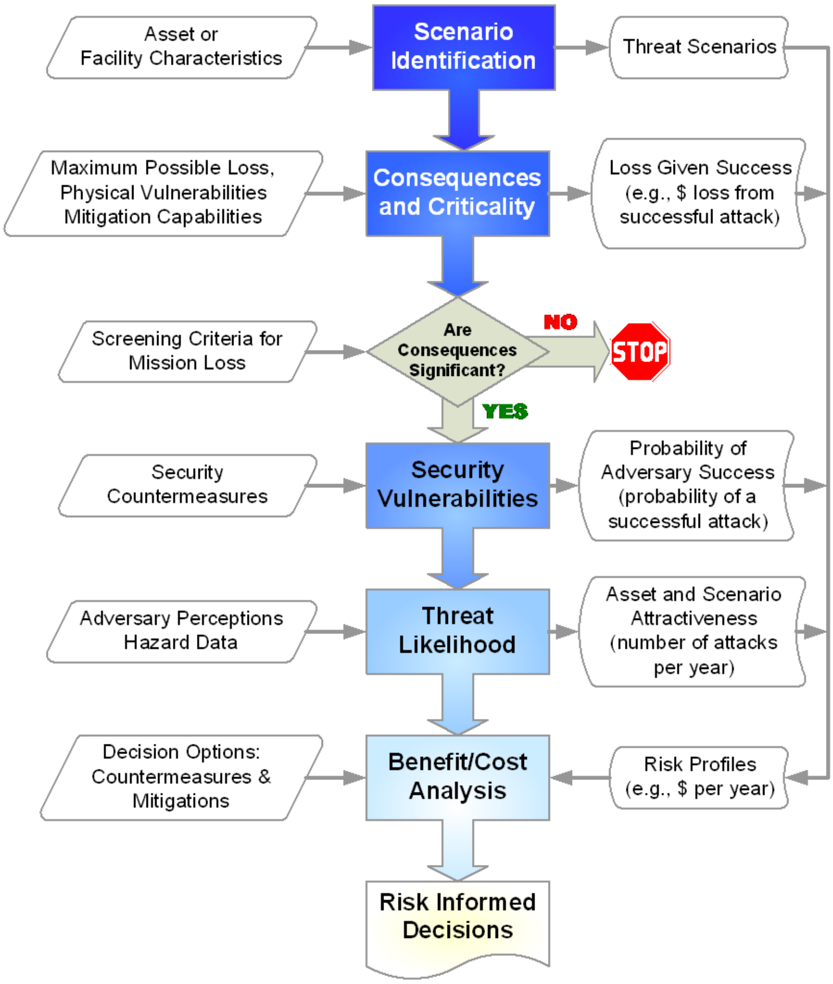

Figure 2 – Critical Asset and Portfolio Risk Analysis (CAPRA**)**

Bellow we have provided a general Risk Analysis in Engineering and Work Breakdown Structure for a Zhinvali Earth Dam.

Risk Analysis in Engineering. Performing risk analysis requires defining the problem at hand, which could span several disciplines or departments in an organization and encompass economic, environmental, technological, societal, and political dimensions [4, 11, 12].

Risk must be assessed, analysed, and managed within a systems framework toward the objective of optimum utilization of available resources and for the purpose of maximizing benefits and utility of stakeholders.

The discipline of systems engineering establishes the configuration and size of system hardware, software, facilities, and personnel through an interactive process of analysis and design in order to satisfy an operational mission for the system to perform in a cost-effective manner. A system engineering process identifies mission requirements and translates them into design requirements at succeeding lower levels to ensure operational and performance satisfaction. Systems engineers leverage their understanding of the system to determine the various interface requirements of the elements. Understanding the big picture is a key to identifying interfaces that affect the chosen elements and can change the structure of the system. Figure 3 shows how systems engineers identify needs from an environment, define engineering problems, and provide solutions that feed into the environment through a dynamic process.

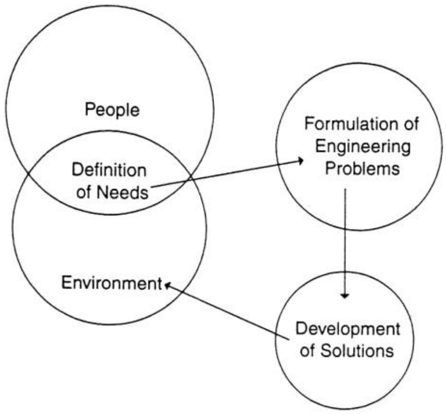

Figure 3 – Engineering and Systems

The definition of a system requires a specific goal, which can be determined from either needs identification or problem articulation. The goal statement should then be used to define a hierarchy of objectives that, in turn, can be used to develop a list of performance and functional requirements for the system. These requirements form the basis for system definition methods that are described here.

A system model can be developed through requirement and functional modelling. Dams can be modelled as systems with functional and performance requirements in an environment that has natural and human-made hazards.

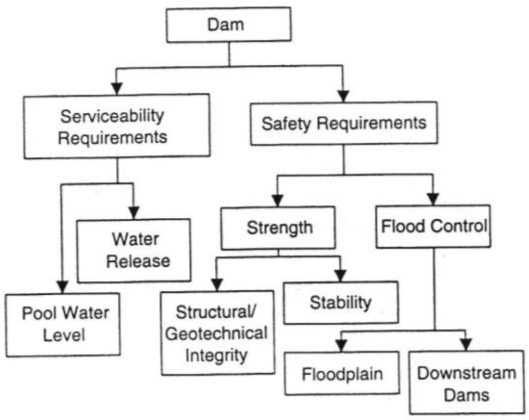

Figure 4 – Functional Requirements for a Dam

Limiting the model to only the physical system of a Zhinvali Earth Dam is shown in Figure 4.

The functional requirements of a dam are used to develop a system breakdown structure is the top-down hierarchical division of the dam into its subsystems and components including people, structure, foundation, floodplain, the river and its tributaries, procedures, and equipment. By dividing the dam environment into major subsystems, an organized physical defi8nition for the dam system can be created. The definition allows for a better evaluation of hazards and potential effects of these hazards. By evaluating risk hierarchically (top-down) rather than in a fragmented manner, rational, repeatable, and systematic outcomes can be achieved [13-16].

Work Breakdown Structure. The work breakdown structure as shown in Figure 5 for a Zhinvali Earth Dam is a hierarchy that defines the hardware, software, processes, and services of a system. The work breakdown structure is a physical-oriented family tree composed of hardware, software, services, processes, and data that result from engineering efforts during the design and development of a system. The breakdown of a Zhinvali Earth Dam into systems and subsystems in Figure 5 focuses on the physical subsystems, components, and human population at risk.

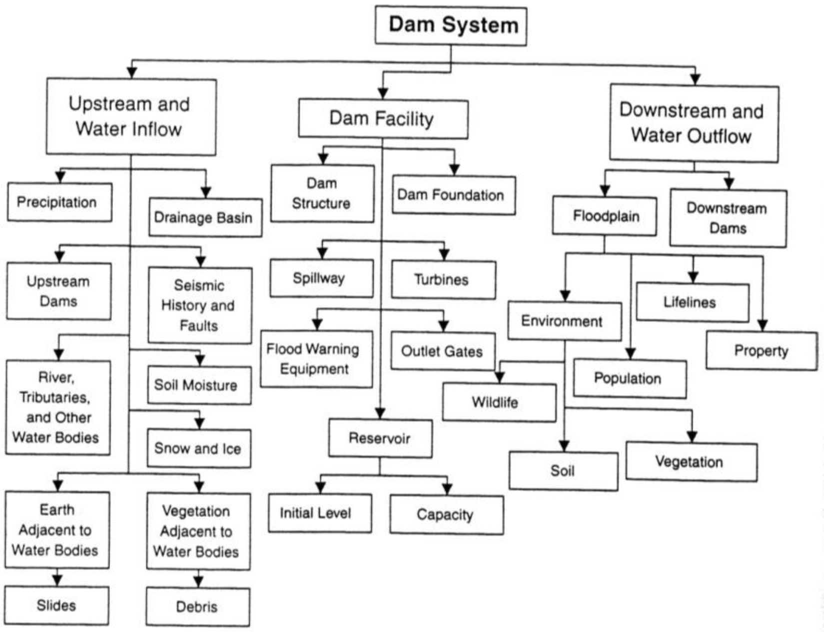

Figure 5 – Work Breakdown Structure for a Zhinvali Earth Dam

The system was divided into subsystems, such as the dam facility subsystems that include structural members, foundations, gates, turbines, spillway, alarms, and reservoir. The work breakdown structure was developed for the goal of performing risk analysis of dams. Each subsystem can be affected by and can be affected by and can affect other subsystems outside the hierarchy presented. While this breakdown is not complete, it does illustrate the hierarchy of the system and subsystem relations.

Prediction of Gully in the Downstream of the Zhinvali Earth Dam using the Theory of Reliability and Risk. According to the revised scheme of seismic zones of the territory of Georgia, the territory adjacent to the Zhinvali Reservoir belongs to the zone of 8-9 magnitude seismic activity, and in addition to the seismic risks, the Zhinvali Earth Dam is also located in the zone of active hazards including erosion-debris flows, landslide processes and floods [1, 17, 18].

An automatic monitoring system operates at the Zhinvali Hydro-Complex. The system includes: pressure and pressure-less piezometers that control the seepage mode; deformation monitoring system, high-altitude and planned geodetic network; automatic weather station, etc. Examination of the world statistics on earth dams showed that many accidents on earth dams are observed in those cases, when there is an overflow of water mass over the dam or in the case of enhanced seepage as a result of suffusion, damage of lower tail occurs firstly, so called occurring of gullies, which later outgrows into ravines, and at the last stage damage occurs to the lower slope of the dam and the complete destruction of the dam takes place [5, 19, 20].

Accidents under this scenario were recorded in the USA, Europe and Asia, unfortunately in Georgia as well, particularly in 1960 in the Tsageri Reservoir and in 1989 in the village Tskneti a 10-meter dam accident caused the death of three people. In this case, the cause of the accident was the overrun of loads obtained during the calculations of the earth dam, which is mainly associated with a decrease in the soil strength, the reason for which is an increase of the water discharge of seepage flows in the body of the dam.

Figure 6 – The general view of the Zhinvali Earth Dam

Figure 6 shows the general view of the Zhinvali Earth Dam from the axis of the dam in the direction of its upper and lower streams.

In a case of damage of reinforced concrete tiles in the upper part of the dam, the depth of the gully (*H*) arising from the action of seepage flows is calculated according to the following equation:

$$H = \left(\frac{\sigma_0 - 3{,}8}{1{,}04}\right)^{0{,}35} \alpha^{1{,}13} \text{ (cm)}, \qquad (1)$$

and the width (*B*) of the gully:

$$B = \frac{9{,}31 H^{0{,}94}}{\alpha^{0{,}6}} \text{ (cm)}, \qquad (2)$$

where $\sigma_0 > 3.8$ (mm/min) - is a maximum intensity of occurred precipitation (mm/s), the value of which is more than 3.8 (mm/s), and *a* is a slope angle, value of which is equal to $\alpha = 5^o - 27^o$.

The function of the relative magnitude of the depth and breadth of the gully arising in the downstream of the Zhinvali Dam, has a normal distribution pattern, taking into account the so-called norm of accuracy, and is expressed by the following mathematical equation:

$$f(H/B) = 0{,}564 \exp\left\{-6{,}2[(H/B) - 0{,}724]^2\right\}, \qquad (3)$$

and the reliability of the performed work is calculated using the following equation:

$$P(H/B) = \int_0^2 0{,}564 \exp\left\{-6{,}2[(H/B) - 0{,}724]^2 d(H/B)\right\} = 0{,}421, \qquad (4)$$

and the corresponding risk is calculated by the following formula:

$$R(H/B) = 1 - P(H/B) = 0{,}579. \qquad (5)$$

Consequently, using the obtained equation (5), we can calculate the stability conditions of the downstream of the Zhinvali Earth Dam using the theory of reliability and risk, when as a result of seepage on the soil surface of the dam's slope the system of gullies will be occurred.

Conclusions. Taking into account the results of theoretical and field studies, as well as considering the Critical Asset and Portfolio Risk Analysis (CAPRA) method, which provides for the quantitative assessment, testing and implementation of all expected risks, we can draw the following general conclusions:

- The positive and the sensitive aspects of the Critical Asset and Portfolio Risk Analysis (CAPRA) method are reviewed and evaluated;
- The essence of risks presented in the CAPRA method and the directions of their management are considered taking the main defining parameters of the Critical Asset and Portfolio Risk Analysis (CAPRA) model;
- The areas for identifying risks and their analysis, measures for risk management and response to them, as well as directions for quality assessment are presented;
- A general risk assessment of a Zhinvali Earth Dam was considered taking into account the likelihood of hazardous geological processes and hydrological disasters;
- The criteria for determining the likelihood of accidental situations and the expected negative consequences in case of breaking the Zhinvali Earth Dam are presented;
- Using the theory of reliability and risk, the law of distribution of the relative values function for the depth and width of gullies, created in the downstream of the Zhinvali Earth Dam is determined. This function is described by the so-called normal distribution function taking into account the norms of accuracy;
- The reliability and risks of the carried out theoretical scientific studies have been determined.

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References

1. Gavardashvili G. V., Kukhalashvili E., Supatashvili T., Kuparashvili I., Bziava K.G. and Natroshvili G. Field Survey and Assessment of Ecological Processes Occurring in the Water Area of Zhinvali Reservoir". 8th International Scientific and Technical Conference, Modern Problems of Water Management, Environmental Protection, Architecture and Construction". Tbilisi, Georgia, 2018, pp. 27–34.
2. Young G. O. Synthetic structure of industrial plastics. In *Plastics*, 2nd ed. vol. 3, J. Peters, Ed. New York: McGraw-Hill, 1964, pp.15–64.
3. Ayyub B. M. Rick Analysis in Engineering and Economics. Chapman&Hall/CRC. A CRC press Company, Boca Raton London, New York, Washington, D.C., 2009, 571p.

4. Ayyub B. M. and J. Klir George. Uncertainty Modelling and Analysis in Engineering and the Sciences. Chapman&Hall/CRC. A CRC press Company, Boca Raton London, New York, Washington, D.C., 2011, 378 p.
5. Gavardashvili G. V., Ayyub B. M., Bournaski J. E. and Arabidze V. Simulation of Flood and Mud Flow Scenarios in Case of Failure of the Zhinvali Earth Dam, International Symposium (With the support of UNESCO) on Floods and Modern Methods of Control Measures. Tbilisi, Georgia, 2009, pp.148–163.
6. Gavardashvili G. V. Forecasting of Erosion and Debris Flow Processes for the Energy Supply and Transport Corridors of Georgia Using the Theory of Reliability and Risk, 1st International Conference on Vulnerability and Risk Analysis and Management (ICVRAM), April 11–13, 2011, University of Maryland, USA, pp. 813–820 (*publishing ASCE*).
7. Gavardashvili G. V. and Ayyub B. M. The Field Investigation of Erosion and Debris Flow Processes in Catchment Basin of the Duruji River. 5th International Conference on Debris-Flow Hazards Mitigation, Mechanics, Prediction and Assessment. Padua, ITALY, 2011. pp. 63–71.
8. Mirtskhoulava Ts. E. Hazards and Risks (at some water and other systems. Types, Analysis, Assessment). 2 volumes, Tbilisi, "Metsniereba", 2003, 807p. (*in Russian*).
9. Risk-Based Security Analysis of the Hydraulic Systems in the River Network in the South Caucasus Region – Project Number: SfP 983833. NATO for Peace and Security Programme.
10. Kukhalashvilin E., Gavardashvili G., Kupreishvili Sh. Expected Risks of Cohesive Debris Flows and Fighting Against Them. LAMBERT Academic Publishing, Tbilisi, 2018, 87p.
11. Gvelesiani T., Jinjikhashvili G., Berdzenashvili G., Stepania T., Aronia G. On Prediction and Prevention of Debris Flow Catastrophic Impacts on Hydraulic Projects in Mountain Areas (Georgia, Israel). 5th International Scientific and Technical Conference. Modern Problems of Water Management, Environmental Protection, Architecture and Construction, Universal Publishing house, Tbilisi, 2015. pp.49–54.
12. Gvelesiani T., Jinjikhasvili G., Berzenashvili G. Modeling of wave generation processes in reservoirs due to seismic effects. Transactions Seismic Resistance and Rehabilitation of buildings Universal, Tbilisi, 2014.
13. Scheidl C. and Rickenmann D. Top Flow DF – A Simple GIS Based Model to Simulate Debris Flow Runout on The Fan. 5th International Conference on Debris-Flow Hazards (Mitigation, Mechanics, Prediction and Assessment). Padua, Italy, 14–17 June, 2011, pp.253–262.
14. Scheuner T., Schwab S. & McArdell B. Application of Two-Dimensional Numerical Model in Risk and Hazard Assessment in Switzerland. 5th International Conference on Debris-Flow Hazards (Mitigation, Mechanics, Prediction and Assessment). Padua, Italy, 14–17 June, 2011, pp.993–1001.
15. Minatti L. and Pasculli A. SPH Numerical Approach in Modelling 2D Muddy Debris Flow. 5th International Conference on Debris-Flow Hazards (Mitigation,

Mechanics, Prediction and Assessment). Padua, Italy, 14–17 June, 2011, pp.467–475.
16. Zhu X., Cui P. and Zhang J. Effects of Debris Flows on Cannel Morphology at Jiangjia Ravine Yunnan Province, China. 5th International Conference on Debris-Flow Hazards (Mitigation, Mechanics, Prediction and Assessment). Padua, Italy, 14–17 June, 2011.
17. Chernomorets S.S. Mudflow loci before and after catastrophes. Moscow: Nauchnyi Mir, 2005, p.200.
18. Mirtskhoulava Ts.E. Ecological breakdowns (prediction of risk of breakdown, measures for lowering the hazard), Tbilisi, 1993, 432p.
19. Urbanavicius V. Kaunas's Impact on Hydrodynamics of the Neman River. Alexander Stulginski University. Kaunas, Lithuania, 2013, 54p.
20. Mike 21 Flow Model. Hints and recommendations in applications with significant flooding and drying [interaktyvus] [žiureta 2012–12–10]. Prieiga per interneta: <http://www.dhigroup.com/upload/dhisoftwarearchive/papersanddocs/hydrodynamics/ MIKE21Significant Flodry Guidelines.

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ПЕРСПЕКТИВЫ РАЗВИТИЯ ЗЕЛЁНОЙ ЭНЕРГЕТИКИ В РЕСПУБЛИКЕ БЕЛАРУСЬ

А. П. Головач, С. В. Монтик

УО «Брестский государственный технический университет», Брест, Беларусь, golovach_anna@mail.ru

Аннотация

Одним из приоритетных направлений развития «зеленой» экономики в Республике Беларусь является повышение потенциала использования возобновляемых источников энергии, которые оказывают гораздо меньшее влияние на окружающую среду, чем ископаемое топливо. В статье представлен анализ развития использования нетрадиционных источников энергии в национальном топливно-энергетическом комплексе.

Ключевые слова: возобновляемые источники энергии, возобновляемая энергетика, энергоэффективность, топливно-энергетический комплекс.

PROSPECTS FOR DEVELOPMENT OF GREEN ENERGY IN THE REPUBLIC OF BELARUS

A. P. Golovach, S. V. Montik

Abstract

One of the priority directions of development of «green» economy in Republic of Belarus is increase in potential of use of renewable energy resources which have much less impact on the environment, than fossil fuel. In article the analysis of development of use of unconventional energy sources in national fuel and energy complex is provided.