Operational dependability of water intake facilities

Mariia Lavrova, Evgeny Orlov and Valeriya Zabalueva

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: mariia.lavrova12@mail.ru, viv-k@yandex.ru

Abstract. Operational dependability of water intake facilities means that all the elements provide execution of the specified functions for this intakes and water pre-treatment at operational level and in essential limits for any locality, town or industry. Questions about the reliability of water supply systems were taken and examined not only by Russian scientists (such as N. Abramov, L. Derushev, O. Primin, Y. Il’in, V. Makagonov, V. Malov) but foreign researchers too (Howe Charles W., Smith Mark Griffin, Qi Yang, Sanchez-Torres G., Paul Jeffrey). The water intake facility is the first element in a water supply system, as a result it has to be very reliable. It influences on the common quality of the system.

Some essential factors have been analyzed. Each of them could have affect on the water intake facility. So we should divide them into two main categories: natural and technical. The first one depends on the type of the water structure with using water intake facility, for example, rivers, water channels or reservoirs. Natural factors include presence or absence of biological deposits, sludges or something else. But technical factors have such properties as durability, storage characteristics and probability of survival.

It’s very important to say that dependability of water intake facilities could directly subject to probabilistic laws of happening any events, that could lead to element failure or breaking down of the whole system.

Based on the ranging natural and technical factors the special tables were compiled. Now we can determine the most and the least service or repair availability of the water intake facility failure at some specified parameters. By the way, if we sum up all the values of influence natural and technical factors, we will find out which one of the water intake facility has depleted operational conditions. Besides, it is important to say that such technical factors as durability, storage characteristics and probability of survival have been described by the specific mathematical dependencies and in sum with natural factors they let us understand the whole picture of considered problem.

Keywords: dependability, water intake facilities, water supply system, durability, factors, solve the problem

1. Introduction
Water intake facilities are hydraulic structures that provide water intake, its preliminary mechanical cleaning from suspended impurities and its supply to consumers.
In the urban water supply system, water intake facilities are the first ones in the technological scheme. So the operational dependability of their work fully depends on the water supply of the entire city or the settlement.

In this article, it is proposed to consider water intake facilities from surface sources that take water from water bodies and watercourses, as the most demanded in the systems of household, drinking and industrial water supply for obtaining large volumes of water in large cities and settlements, and to assess the degree of their operational dependability.

A large number of water intake structures from surface sources are affected by natural resources, that greatly complicate their operation and influence on the water intake. A lot of towns are built in difficult natural and climatic conditions, therefore the operational dependability of their water intake facilities must be at a high level to ensure the supply of the required volumes of water for domestic, drinking and industrial needs. Assessing the operational dependability of water intake facilities, natural and climatic conditions are often not taken into account.

Today there are certain difficulties in determining the operational dependability of water intake facilities. This is because the basic concepts of the reliability of water intake were formulated in the second half of the last century and now they require further refinement. They do not take a well-founded set of indicators into account, but they directly influence on the functioning of water intake facilities. The probability of their failure-free operation for a given operation period and the average time of failure-free operation are mentioned very often among the indicators characterizing the level of reliability in water supply systems. It is the operating time to the limiting state (failure), when the system is no longer able to supply the required volumes of water to the consumer. In addition, a non-fail-safe operation parameter is used, which in most cases was reduced to the mathematical probability of their fail-safe operation. This is an objective indicator, but it can not fully assess the operational reliability of a particular water intake unit without studying and applying other parameters.

Questions about the reliability of water supply systems were taken and examined not only by Russian scientists (such as N Abramov, L Derushev, O Primin, Y Il’in, V Makagonov, V Malov) but foreign researches too (Howe Charles W, Smith Mark Griffin, Qi Yang, Sanchez-Torres G, Paul Jeffrey). [5-7].

Some questions about operational dependability are considered in E.I. Saliev’s works. They are related to durability, which implies the property of reliability, consisting in the fitness of the technical system to conduct various maintenance and repair works to ensure, maintain or maintain operating parameters within the established tolerances during the required interval of operation time [8-9].

The mathematical foundations of reliability theory are considered in works of E.M. Galperin. This information is provided from the theory of random processes with certain concepts of probability theory that allow us to calculate the final probabilities of a state, if we know the parameters of the failure and recovery intensity flux or physically the average time of finding the system in these states [10-13].

In the works of E.A. Lebedeva reliability issues are considered in terms of the impact of various risks on water supply systems (individual, environmental, technical, social and economic) [14].

In addition, many authors have their own understanding of the notion of reliability [15-20], thus, it does not provide an opportunity to come to objectivity in these issues, which requires further research and development of a new approach to ensuring the reliability of water intake facilities.

2. Methods

It is proposed to study the basic concepts of reliability and create its own methodology for determining and classifying objects according to reliability theory, taking into account objective factors of the environment and the analysis behind the operation of water intake facilities.
The operational dependability of water intake facilities means that all the elements provide execution of the specified functions for this intakes and water pre-treatment at operational level and in essential limits for any locality, town or industry.

It is has such properties as durability, storage characteristics and probability of survival.

Durability is the property of structures and systems to remain operational during a certain time interval, by which we mean the service life of the structure before major repair or reconstruction.

Storage characteristics are the property of a water intake structure to maintain an operational state before the onset of the limiting state or before reaching the state of failure, in which the water intake facility will not be able to take the necessary volume of water.

Probability of survival is a property consisting in preventing and detecting the causes of failures, maintaining and restoring a working condition by performing maintenance and repair.

Thus, the above parameters are directly connected to each other.

It is also very important to say that the principle of operation of water intake facilities is described by probability laws by mathematical statistics of the onset or non-occurrence of certain critical parameters under which the operation of the system will be impossible or limited in any way.

As an evaluation of the above properties, the following indicators should be listed:

- the probability of failure-free operation (when the failure will not arise within a certain period of the cycle of water intake operation structure);
- the flow of failures (probability of the elements failure of the water intake structure);
- average life (average work product duration to the limit state or between capital repair or intermediate repairs);
- recovery time (the time required for the detection of a fault and its elimination).

3. Results
The operation dependability of the water intake facilities is fully affected by various parameters, which should be attributed to the technical and natural.

Technical parameters are the state of various elements of water intake structures, the failure of which can cause disruptions in the operation of the system to a greater or lesser extent. They are also leading to a complete outage of the structure or the onset of the failure parameter of the water intake facility.

Natural parameters are the parameters of the environment, which fully influence on the water intake structure, complicating its operation and leading to a complete failure of a water intake facility.

It is worth noting, that the natural parameters in contrast to the technical parameters are less predictable, and therefore require more thorough research and observation.

Technical and natural parameters are proposed to be ranked according to the degree of their negative impact on the water intake facilities, which will allow to present all data in a convenient tabular form.

Table 1 gives an example of the ranking of technical parameters.

**Table 1.** Example of the ranking of technical parameters by the degree of impact on the water intake structure

| Parameter                                                      | Ball |
|---------------------------------------------------------------|------|
| Water intake structure of channel type                        | 1    |
| Water intake facility of coastal type                         | 3    |
| Water intake facility of combined type                        | 2    |
| Number of sections of water intake facilities - 2             | 1    |
| Number of sections of water intake facilities - 3             | 2    |
| The presence of flat grids                                    | 1    |
| Presence of rotating grids                                    | 2    |
| Presence of grids with electric heating                       | 1    |
The presence of a water intake end of the socket type 1
The presence of a water intake filter-type head 2
The presence of a water intake head with a vortex chamber 3

To sum up:
Low level of reliability $\Sigma < 5$
Average level of reliability $\Sigma 6-9$
Maximum level of reliability $\Sigma > 10$

1: the minimum score (low level of reliability); 2 - average score (average level of reliability); 3 - the maximum score (high level of reliability). If some indicator from the table is absent in the water intake structure, then it is not considered and is not summarized.

Natural parameters for each water body (rivers, reservoirs, lakes, seas) should be presented in a separate table. They are different in their hydrological parameters. Table 2 shows the ranking options for the river.

**Table 2.** Example of the ranking of river parameters by the degree of impact on the water intake structure

| Parameter                                                             | Ball |
|----------------------------------------------------------------------|------|
| Presence of a small amount of sediment                               | 3    |
| The presence of an average amount of sediment                         | 2    |
| Presence of a large number of sediments                               | 1    |
| Having a lot of sludge                                               | 1    |
| The presence of a small amount of sludge                              | 1    |
| Formation of a stable freeze-up                                       | 2    |
| Formation of unstable freeze-up                                       | 3    |
| Contamination of the shore                                           | 2    |
| Contamination of the channel                                         | 1    |
| Small river speeds                                                    | 2    |
| High river speeds                                                     | 1    |
| Low quantity of dreisena, balanus and mussels                         | 3    |
| High quantity of dreisena, balanus and mussels                        | 2    |
| Presence of frosts and sherbs                                        | 1    |
| Absence of frostbites and schugzor                                    | 2    |
| Presence of polynia                                                   | 2    |
| Absence of polynia                                                   | 3    |
| Availability of shipping                                             | 1    |
| Lack of navigation                                                    | 2    |
| Presence of rafting by rafts                                          | 2    |
| Lack of logging                                                       | 3    |
| The presence of landslide phenomena                                   | 1    |
| Absence of landslide phenomena                                        | 2    |
| The presence of an unstable channel and the processing of shores      | 1    |
| Stable course, no coast processing                                    | 2    |
| Channel freezing                                                      | 1    |
| No freezing of the channel                                           | 3    |

To sum up:
Low level of reliability $\Sigma < 13$
Average level of reliability $\Sigma 14-25$
Maximum level of reliability $\Sigma > 26$

1: the minimum score (low level of reliability); 2 - average score (average level of reliability); 3 - the maximum score (high level of reliability). If some indicator from the table is absent in the water intake structure, then it is not considered and is not summarized.
Table 3 gives an example of the ranking of natural parameters for reservoirs. It should be said that this example of ranking is suitable for lakes as well (freshwater), as the reservoirs and lakes are similar in structure.

**Table 3.** Example of the ranking of the natural parameters of the reservoir (lake) in terms of the degree of impact on the water intake structure

| Parameter | Ball |
|-----------|------|
| The presence of low waves | 3 |
| The presence of medium waves | 2 |
| The presence of high waves | 1 |
| Low amount of sediment | 3 |
| High amount of sediment | 2 |
| Strong destruction of shores | 1 |
| Weak destruction of shores | 2 |
| Formation of a large number of hummocks | 1 |
| Formation of a small number of hummocks | 2 |
| Unstable freezing | 1 |
| Steady freeze | 2 |
| High chrominance | 2 |
| Low chrominance | 3 |
| Formation of shugozators and frostbites | 1 |
| Absence of shugozators and frostbites | 2 |
| Availability of shipping | 2 |
| Absence of shipping | 3 |

To sum up:
- Low level of reliability $\Sigma < 13$
- Average level of reliability $14-25$
- Maximum level of reliability $\Sigma > 26$

* $^a$: 1 - the minimum score (low level of reliability); 2 - average score (average level of reliability); 3 - the maximum score (high level of reliability). If some indicator from the table is absent in the water intake structure, then it is not considered and is not summarized.

Table 4 gives an example of the ranking of natural parameters for the seas and oceans. It should be noted that this example of ranking is also suitable for salt lakes (for example, the Caspian, Balkhash, etc.), which are remnants of the ancient ocean and are similar in composition to the seas.

**Table 4.** Example of the ranking of natural parameters of the seas (oceans) in terms of the degree of impact on the water intake structure

| Parameter | Ball |
|-----------|------|
| Strong destruction of the coast due to its subsoil | 1 |
| Weak destruction of the coast due to its subsoil | 2 |
| Strong sedimentation of sediments along the shoreline | 1 |
| Weak sedimentation of sediments along the shoreline | 2 |
| Strong reformation of the seabed | 1 |
| Average reformation of the seabed | 2 |
| Weak reformation of the seabed | 3 |
| Strong waves | 1 |
| Average wave availability | 2 |
| Weak waves | 3 |
| The presence of a tsunami | 1 |
| The absence of a tsunami | 3 |
| The presence of landslides | 1 |
| Absence of landslides | 3 |
| Strong salinity of water | 1 |
| Average salinity of water | 2 |
Weak water salinity 3
A large number of marine fouling 1
A small amount of marine fouling 3

To sum up:
Low level of reliability $\Sigma < 10$
Average level of reliability $11 - 19$
Maximum level of reliability $\Sigma > 20$

$^a$: 1 - the minimum score (low level of reliability); 2 - average score (average level of reliability);
3 - the maximum score (high level of reliability). If some indicator from the table is absent in the water intake structure, then it is not considered and is not summarized.

4. Discussion

After compiling the ranking tables (tables 1-4) of the technical and natural parameters that directly affect the water intake facilities, it is necessary to compile a final table on which the most reliable or unreliable object can be selected taking into account the above factors.

In addition, it is worth noting that each natural object is unique in its own way. In some cases, it will be necessary to conduct various additional investigations to obtain more objective information on the processes occurring in it.

Table 5 shows the results of the calculation of the choice of the most reliable object, taking into account the maximum number of points by indicators.

**Table 5. Ranking of technical and natural parameters for choosing the most reliable object of water intake facilities**

| Total number of points | Summary                                      |
|------------------------|----------------------------------------------|
| Less than 44 points    | Low level of reliability of water intake facilities |
| 45 to 71               | The average level of reliability of water intake facilities |
| More than 72           | High level of reliability of water intake facilities |

Thus, for the first time a ranking method was developed in order to determine the degree of reliability of the water intake structure, along with the previously proposed solutions and thanks to which it is possible to identify the most unreliable object and make decisions about its possible and early reconstruction. Natural factors in this matter should be of decisive importance, as the most difficult to predict in comparison with technical parameters.

5. Conclusions

Based on the scientific works of reliability, analysis of methods of operation and operation of water intake facilities, the following conclusions were drawn:

- the generalized concept of reliability of a water intake facility is given, it includes parameters of durability, storage characteristics and probability of survival;
- the work of the water intake structure is described by the probabilistic laws of mathematical statistics;
- technical and natural parameters were developed and described that affect the operation dependability of water intake facilities;
- based on the above parameters, ranking tables have been compiled on the basis of which it is possible to determine the lowest level of operation dependability of a water intake structure, which allows identifying the most complex objects in terms of technology and nature and attributing them to the most damaging objects, for which it is advisable to monitor and then reconstruct in first priority;
- the natural parameters for each water body are strictly individual and have their own distinctive features, which will require a possible adjustment in the specifically selected case.
References

[1] Primin O 2014 Water supply and sanitary engineering Analysis of factors affecting the reliability and environmental safety of water supply networks chapter 7 pp 16-22

[2] Primin O 2016 Ecology and Industry of Russia Ten AE Evaluation of reliability of pipes made of high-strength cast iron with nodular graphite and their use for laying in karstic territories chapter 9 pp 20-25

[3] Deryushev L and Pham H 2014 Rationing of the requirements of reliability of water supply systems in Vietnam (Moscow: Moscow State University Press) chapter 9 pp 7-21

[4] Deryushev L and Hai F 2015 Bulletin of the Russian University of Friendship of Peoples On the standardization of reliability of pipes and pipelines (Series: Ecology and life safety) chapter 3 pp 60-68

[5] Howe Ch and Smith M 1994 J. of Env. Ec. and Man. The value of water supply reliability in urban water systems 26 pp 19-30

[6] Matrosov E, Harou J, Huskova I, Kasprzyk J, Lambert C and Reed P 2015 J. Hydrology Many-objective optimization and visual analytics reveal key trade-offs for the London's water supply 531 pp 1040-53

[7] Odiyo J, Makungo R, Mwaka B, Ndiritu J and Ntuli C 2015 Water S A Yield-reliability analysis and operating rules for run-of-river abstractions for typical rural water supply 41 chapter 3 pp 375-382

[8] Saliev E, Nikolenko I and Gaffarova E 2012 The effect of maintainability on the reliability of water supply systems (Moscow: Uchenye zapiski Krymskogo Engineering-Pedagogical University) chapter 6 pp 43-49

[9] Saliev E 2014 Bul. and tech. sec. Reliability of the functioning of water supply and sanitation systems chapter 49 pp 179-184

[10] Galperin E 2011 Urban plan. and arch. On the demand for indicators of reliability of water supply and sanitation systems chapter 1 pp 57-61

[11] Galperin E, Poluyan V and Chuvilin V 2006 Water supply and sanitary engineering Reliability of water supply and sanitation systems chapter 9-2 pp 38-42

[12] Galperin E 2009 Modern problems of science and education Reliability of water supply and sanitation systems chapter 1 pp 26-27

[13] Galperin E and Strelkov A 2015 Water supply and sanitary engineering About the reliability of water supply and sanitation systems chapter 12 pp 39-46

[14] Lebedeva E 2014 Risk assessment as one of the mechanisms for managing the reliability of water supply and sanitation systems (St. Petersburg: Safety in emergency situations. Collection of scientific papers of the VI All-Russian Scientific and Pr. Conf. FGAOU VO "St. Petersburg Polytechnic University of Peter the Great") pp 109-114

[15] Pavlov Yu and Kuzminsky R 2017 Mod. Prob. of improving the work of railway transport Improving the reliability of outdoor water supply and sanitation networks of a modern city chapter 13 pp 99-104

[16] Kuzmenko V, Belov G, Bobkov O and Klyavlin M 2014 Water supply, water disposal and env. protection systems Engineering theory of reliability in the design of water supply and sanitation systems (Ufa: International scientific and technical conference of students, graduate students and young scientists: articles and abstracts.) pp 100-106

[17] Nikolenko I, Ryzhakov A and Umarov R 2016 Construction and technogenic security chapter 3 (55) pp 75-81

[18] Sautkina T and Fryagina D Technical regulation in transport construction chapter 5 (13) pp 78-80
[19] Adelinin A, Nurullin Zh, Busarev A, Sheshheva I and Khamidullina A 2013 Some Aspects of the Economic and Potable Water Supply in Kazan (Kazan: Kazan State Architectural and Construction University) chapter 1 (23) pp 168-173

[20] Kolesnikov E and Malkov S 2014 Development and testing of the water supply system without a water tower (Tula: Tula State University Technical science) chapter 2 pp 220-225