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RELIABILITY ASSESSMENT OF WATER SUPPLY SYSTEMS

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Abstract: *This article discusses the issues of assessing the reliability of a water supply system, taking into account the separation of water supply and distribution systems into external and home-based. Also, the availability coefficient of the water supply system and the methods for managing the quality of its operation were studied. At the same time, this method takes into account violations of the water supply system, environmental risks and energy costs, the repair strategy, and the optimization of the control system. In addition, recommendations are given to improve the quality of water supply management.*

Key Words: *water infrastructure, external water supply and distribution systems, home-based systems, availability factor, degree of violation of water supply.*

1. INTRODUCTION:

Water infrastructure has a great impact on both the environment and the social sphere, since it is associated with the massive and prolonged use of water, which is a natural resource, in favor of society. In Uzbekistan, in the highlands, occurs comparatively much rainfall, and in these areas there are relatively many sources of water. However, in the flat terrain located in the central part of the country, there is a shortage of water sources due to the small amount of precipitation. These areas receive water from rivers flowing from the upper reaches, with large rainfall. However, river flow is constantly decreasing due to the large consumption of water for irrigation of cotton, which is grown over a vast territory.

As described above, water resources in Uzbekistan are unevenly distributed, and in general regions where there is a shortage of water prevail. There are problems not only in amount of water resources, but also in their quality. Water supply facilities in Uzbekistan are burdened with problems of the quality and quantity of water resources, in particular drinking water.

Currently, in order to carry out deep reforms in agriculture and water management, specialists in the field of construction, design and operation are tasked with resolving the most pressing issues. In particular, the rational use of hydraulic structures, the repair of structures and building elements, the elimination of defects, and the cleaning of sediments in reservoirs [4-5, 8-9].

In order to effectively use the water resources of rivers in the republic, 55 reservoirs have been built. The volume of water to be collected in the reservoir is 20 km3. These reservoirs were built in the second half of the last century, mainly for irrigation, i.e. designed and built to provide agriculture with water, and not the population with drinking water. In this connection, the capabilities of reservoirs to provide drinking water are not docked with the housing and communal services of the country [10-12].

Successful reform of housing and communal services is possible only if the degree of achievement of the main goal of the reform - improving the quality of services provided - will have a concrete quantitative assessment. For example, when concluding agreements between consumers (residents) and a management company operating an internal water supply system, quantitative indicators (scale) should be determined by which it is possible to determine the level of water supply quality, the degree to which obligations are fulfilled and the reasonableness of the costs to ensure the quality of water supply.

Despite the outward simplicity of such an approach, its practical implementation is very difficult. This is primarily due to the fact that in the existing system of operation of water supply systems, managing operating organizations , which interact with the water consumer (population, tenants, etc.), are not producers of drinking water, the quality of which is quantified by standards (Sanitary Rules and Norms - SanPIN, state standard-GOST, Building Norms and Rules-SNiP) and can be measured and checked in one way or another. These organizations do not create water supply networks and equipment, do not engage in water intake and water treatment. Their functions are reduced to ensuring the smooth functioning of already created systems, minimizing unproductive (useless) water losses, rational use of energy resources and possible reduction of environmental risk caused by accidents in systems.

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Therefore, it is advisable to divide the water supply system into two parts: head structures (HS), which extract and process natural water using complex physical, chemical and bio-technologies into a vital food product - drinking water (producing goods), and a water supply and distribution system (WSDS), which provides services for the delivery of drinking water.

2. MATERIALS:

WSDS operation is divided into the operation of external water supply and distribution systems (EWSDS), which provides bulk water supplies, and the operation of home-based systems (IWSDS), which maintains internal water supply systems in working condition and sells drinking water at retail to numerous consumers - to the population.

There are no quantitative criteria for the quality of the operation of the IWSDS, collected in a separate document for evaluation by the consumer and regulatory organizations operation of IWSDS.

It can be tried to develop these criteria by summarizing and systematizing the available regulatory data on the individual links and elements of the water supply system, but even a quick overview of the various, often not verifiable (for example, the number of shutoff valve operation cycles) requirements of SNiPs, SanPINs, GOSTs and other regulatory documents, suggests that the practical use of these documents will be extremely difficult. In addition, each water supply system is unique in its own way, operates in external conditions and hydraulic modes that are unique to it, so using the average regulatory requirements for the operation of a particular system will not allow understanding between consumers and managing operating organizations.

Therefore, the criteria for the quality of the operation of IWSDS should be based on theoretical studies of the modes of their operation, maintenance, impact on natural water sources and the environment, which will link disparate indicators of modern standards into a single system.

3. METHOD AND DISCUSSION:

In many sectors of scientific and industrial activity, a reliable theory of reliability has been successfully used by all interested parties to fundamentally understand the degree of "usefulness" of the functioning of complex systems [1-3]. By definition, reliability is the feature of an object to perform its functions for a given period of time while maintaining specified performance indicators. For the operation of water supply systems, this can be formulated as a feature:

- to provide consumers with water in the required volume and with the required quality for given water losses, energy and labor costs for its supply;
- to influence, within acceptable limits, on environmental components (for example, when relocating sections of external networks) during the term of the contract between consumers and the managing organization. Moreover, of course, the duration of the contract should be commensurate with the average life of the systems.

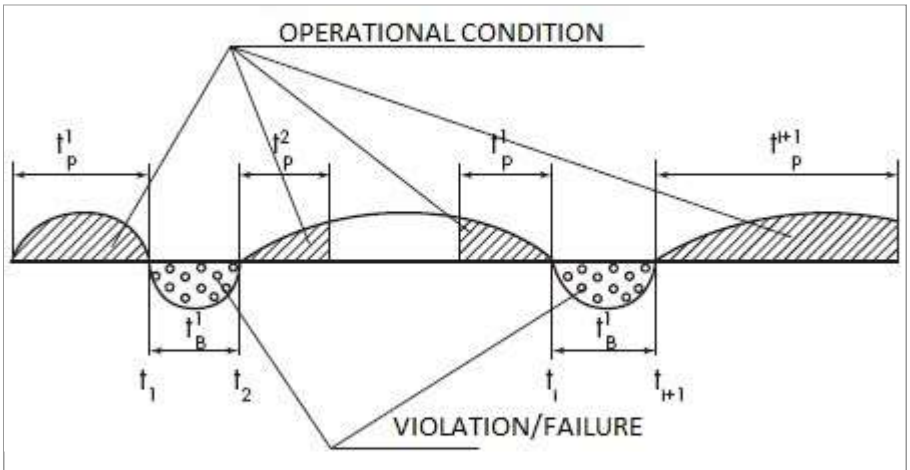

Figure 1. Timing diagram of the functioning of the water supply system

In time, the functioning of the system consists of intervals of operation and failures, determined by a violation of water supply or operating requirements for the system (Figure 1). Therefore, it is easier to quantify the

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operational reliability of water supply systems through the availability factor, which determines the fraction of the time of "normal" functioning of the system for the control period of the contract:

$$K_r = \frac{\sum T_p^i}{\sum \left(T_p^i + T_B^i\right)},$$

where T_p – system normal functioning time;

T_B – duration of violations in the system.

Using the availability factor (as well as other well-known reliability indicators, for example, the probability of failure-free operation, failure rate, etc.) to assess the operational reliability of water supply systems can give a positive result only at the first stage of the formation of relations between consumers and the managing operational organization (IWSDS), when only the possibility of assessing the quality of operation is important, without taking into account many features. For example, a water supply disturbance may be complete or minor. This may relate to one consumer or a group of them, etc. In addition, the economic justification of operational measures based on the availability factor is possible only in a general way.

A more differentiated assessment of the quality of operation of water supply systems can be obtained using the converted availability factor:

$$K_r = \frac{T \cdot N - \sum_{i=1}^{j} t_{0,i} \cdot n_i}{T \cdot N},$$

where T – estimated time (contract validity period);

N – total number of consumers in the system;
n_i – the number of consumers with a water supply disturbance over time $t_{0,i}$;
j – the total number of violations in the water supply.

An argument in favor of the converted availability factor is the fact that a similar indicator is used to assess the reliability of energy systems in the United States. However, in this form, the availability coefficient (and, accordingly, its derivative - operating costs) do not answer the following questions: how successfully and rationally the system is being operated, what are the reserves to improve the quality of water supply and reduce the costs associated with it. And most importantly, how to develop and optimize a system operation strategy, starting from its current state.

4. ANALYSIS:

A new approach to the operation of the system based on the management of potential failures and environmental risks of the water supply system by organizational methods (optimization of repair strategies, monitoring systems, etc.) can answer to above indicated questions [6-7].

In general terms, the operation quality management technique consists of the following steps.

- The degree of violation of water supply, environmental risk and energy costs in the event of a failure in the system is determined by the following parameters (Figure 2):

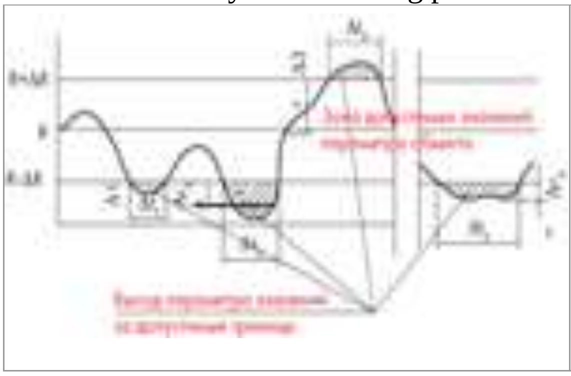

Figure 2.

Assessment of the operational reliability of water supply systems by indicators of magnitude, duration and frequency of malfunction

- the magnitude of the violation (deviation of parameters, disturbing effect, etc.);

- duration of failure;

- the frequency of repetition of such failures for a given period of time.

Between these parameters, a functional relationship is established, both direct and indirect. For example, an increase in the frequency of failures in the system entails an increase in the production load on operational units performing emergency repairs. This in turn leads to an increase in the waiting time for the start of restoration work and, accordingly, to an increase in the duration of failure. Environmental and economic indicators, for example, water losses caused by leaks, are put into functional correspondence with each failure parameter. At the same time, alternatives to organizational failure management are being considered. In particular, increasing the capacity of the emergency unit will lead to a reduction in water losses, but will require additional costs for the maintenance of personnel.

The results obtained make it possible to differentially evaluate the quality of operation of the system based on the converted availability factor, as well as calculate the material costs associated with the failures that have arisen.

- At this stage, possible strategies for the implementation of operational measures are developed, their adjustable parameters are determined, and a variant calculation of the impact of operational measures in certain conditions on the quality of water supply are developed, environmental risk during the operation of the system and all socially significant material costs associated with the operation of the system under consideration strategies are determined. For example, the well-known system of scheduled preventive repairs (SPR) provides for repairs that eliminate the physical deterioration of system equipment, performed at regular intervals, and unforeseen repairs that restore the equipment and parts of the system without changing their physical deterioration in case of accidents.

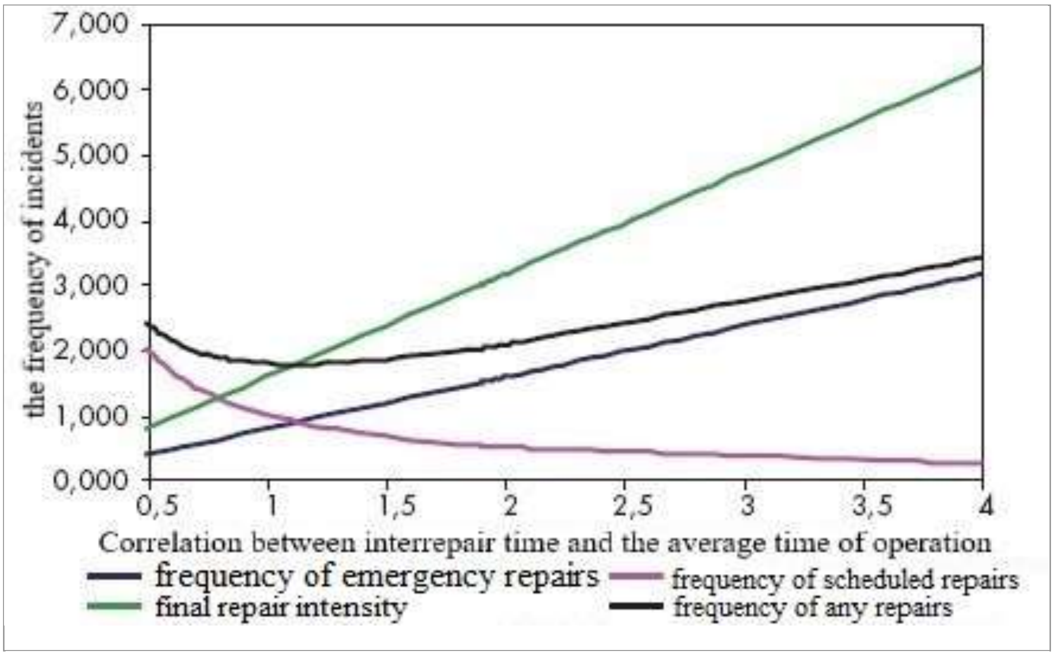

Figure 3. A graphical representation of the dependence of the failure rate on the ratio of the overhaul period and the average service life for strictly periodic scheduled repairs and minimal emergency

For such a repair strategy, the failure parameter — the frequency, as well as the general economic indicator — the intensity of operating costs (the entire set of costs associated with the operation, per unit time) depends on the designated overhaul period (Figure 3). Similar dependencies developed for the majority of practically used strategies for operating water supply systems allow, firstly, to assess the quality of operation and material costs associated with its provision, with the existing operational strategy and, secondly, to outline ways to optimize the ratio of quality and associated costs (Figure 4).

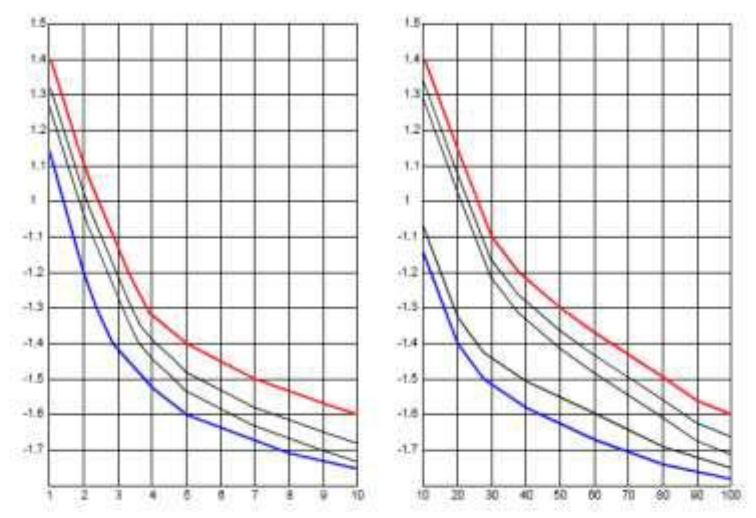

Figure 4. An economically optimal overhaul period with various cost ratios associated with planned and emergency operational situations and the relative cost of scheduled repairs

- The final stage of operating quality management involves step-by-step optimization of the control system.

Having assessed the failure parameters, as well as the magnitude of environmental risk and unproductive losses in the current conditions, it is possible to determine under which strategies of operating the water supply system the best indicators will be achieved. But their implementation may require fundamental changes in the structure of operating enterprises, financial activities. In modern conditions, most of the equipment malfunctions are eliminated in an emergency. At the same time, studies have shown that the best indicators of quality of operation and economic efficiency in most cases provide strategies with various options for scheduled repairs. To make the transition to them, additional material resources will be required, at least at the initial stage.

5. FINDINGS:

Despite the significant material costs of modern operational activities, it is impossible to withdraw part of the funds from them for the implementation of planned measures, since the effect of implementing optimal strategies will not be obtained immediately, but after a certain time. A decrease in investments in emergency services at this stage will definitely lead to a deterioration in the quality of operation and environmental safety. Only when as a result of the application of optimal operating strategies will a real reduction in unproductive expenditure of resources be achieved, a decrease in the load of emergency services and, accordingly, a reduction in the volume of their financing, the implementation of optimal operating strategies can be intensified by the funds released.

To justify the mechanism of redistribution of funds without deteriorating the quality of operation of water supply systems at each stage of the implementation of optimal operation strategies, as well as to invest them at the initial stage, a methodology has been developed that determines the economic effect of implementation at the end of each stage, performance indicators at this moment, and further direction of material investments.

6. RECOMMENDATIONS:

- The performance of water supply systems should be based on consumer requirements and environmental protection.
- It is necessary to adopt a road map aimed at using the capabilities of reservoirs to provide drinking water to the population and its affinity with the country's housing and communal services.
- These requirements should be set out in one document, which will be used to assess the quality of work of operating (managing) organizations.
- A methodology for managing operating organization is proposed, which allows optimizing its managment to achieve a given quality of operation.

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