Maintainability of a self-pressurized closed irrigation network

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Abstract. This article presents the issues of maintainability of a self-pressurized closed irrigation network, which is one of the main most important characteristics of their reliability. The indicators of maintainability have been determined, the patterns of distribution of the time to restore the network operability have been established, bottlenecks have been identified during repair and restoration work. The obtained data is recommended for use in predicting the operability and developing regulatory requirements for network reliability.

1. Introduction

The growing shortage of water and energy resources, environmental problems in the Central Asian region of the country require the development of energy-resource-saving irrigation technologies. The self-pressurized closed irrigation network (CIN) being introduced in the foothill regions of Central Asia can significantly increase the efficiency of water use and raise the technical condition of irrigation systems to a new level.

With the development of modern irrigation systems - the complication of the structure, the lengthening of pipelines and the introduction of various devices (introduction of redundancy), the introduction of new equipment and technology for irrigation, automation and telematics with increased requirements for their uninterrupted and trouble-free operation, the problem of ensuring reliability becomes especially relevant, since the quality of the system's work is directly reflected in the final result - the yield of agricultural crops.

The main task of a self-pressurized ZEP is to ensure that plants are reliably provided with the required amount of water within a given time within the permissible deviations, while maintaining and increasing soil fertility without negative environmental consequences.

The main advantage of a self-pressurized irrigation system in comparison with a temporary irrigation network in an earthen bed is that a self-pressurized irrigation system allows to reduce the irrigation rate by 1.5-1.7 times, increase the productivity of irrigators by 3-4 times, and improve the useful use of land by 6% , maintain a given irrigation regime and thereby increase the yield of agricultural crops by 20-40% [1].

Irrigation from a self-pressurized CIN allows for any of the advanced technologies of irrigation along through furrows: a variable jet, impulse or differentiated water supply to any point of the site at the request of a water user, to somewhat reduce the requirements for the quality of the surface level of irrigated areas.
However, insufficient design experience, poor quality of construction and installation works, violation of operating rules reduce the advantages of such systems; there is a decrease in the yield of agricultural crops due to failures of network elements and uneven moisture along the length of the furrow. The elements of a self-pressurized CIN (pipelines, shut-off and control valves, water outlets, etc.) work periodically, and their failures lead only to a partial disruption of the entire system. The complete failure of the system is caused by the failure of the main channel or pipeline. Frequent failures of network elements can lead to long periods of network failure and the failure of the system to fulfill its main function - to ensure irrigation of crops for a given time. Thus, the issues of ensuring the reliability of such systems is of great economic importance.

The practice of operating irrigation systems shows that the development of measures to improve reliability is a complex task and it must be carried out at the stages of design, construction and operation [2-5].

In this regard, the need for research to assess the reliability of a self-pressurized CIN during furrow irrigation and the development of measures to ensure the reliability, maintainability, preservation and durability of the network is very relevant.

One of the most important characteristics of the reliability of a closed irrigation network (CIN) along with reliability is maintainability.

A self-pressurized CIN is a recoverable object, that is, damages and failures that have arisen during operation can be eliminated by means of repair. It should be borne in mind that maintenance and repair of the network, carried out in a preventive or emergency manner, is accompanied by network downtime, and, as a rule, significant economic losses. Therefore, it is important to increase the maintainability of the network, since its level depends on the reliability indicators during the period of normal and increased wear [6].

According to GOST 27.002-2015, maintainability is a property of an object, which consists in its adaptability to maintaining and restoring the state in which the object is capable of performing the required functions through maintenance and repair [7].

Considering that timely repairs on the system plays an important role in ensuring reliability, we carried out studies to establish indicators of maintainability of the on-farm self-pressure closed irrigation network of the Samgar massif.

Maintenance, current repairs and elimination of emergency damages and failures on a closed irrigation network were carried out by a repair team of the farm in the amount of four people. Overhaul was carried out by a construction organization under an agreement with the farm.

The process of restoring operability depends on the organization of the repair service, the technical equipment of the repair teams, their number, the perfection of communication, etc. The duration of recovery is significantly influenced by a number of random factors: the place of the accident, the nature of the accident and the conditions for carrying out recovery work, etc. The quantitative characteristics of the maintainability indicators are random values. In practice, it is customary to use the average recovery time, the probability of recovery at a given time, the complexity of recovery work, the intensity of recovery and cost indicators as an indicator of working capacity [5; 8-18].

2. Methods

As indicators of the network maintainability, we took the average recovery time $\bar{T}_R$, the probability of recovery $F_R(t)$, and the recovery rate $\mu_R(t)$.

The recovery time of the operational state covers the period from the moment of the onset of the failure to its elimination. Therefore, the total recovery time $T_R$ is the sum of the time intervals of all work performed after the onset of a failure:

$$T_R = t_1 + t_2 + t_3$$  \hspace{1cm} (1)

where, $t_1$ - time for failure detection and transmission of information; $t_2$ - time for the arrival of the repair team; $t_3$ - time for repair and testing.
Statistical processing of data on the duration of recovery of the self-pressurized CIN was included in the construction of the empirical distribution function of the parameter $\tau_s$, the assessment of its characteristics and the approximation of the obtained function by one of the theoretical distribution laws of random variables.

The analysis of materials on the establishment of the law of distribution of the time of restoration of the operability of pipelines of various systems shows [2-4; 19] that the description of the recovery time of these system elements in many cases obeys the exponential distribution law:

$$F_n(t) = 1 - e^{-\mu t}$$  \hspace{1cm} (2)

with recovery time distribution density

$$f_n(t) = \mu e^{-\mu t}$$  \hspace{1cm} (3)

3. Results and discussion

Based on the collected static data of restoring the operability of the network elements, time series were compiled $\tau_s$. In this case, $\tau_s$ the interval of possible time values was divided into a number of subintervals with a duration of one hour $h=24$. The number of established durations of repairing pipelines of the self-pressure closed irrigation network of the Samgar massif $n = 58$. Calculations (Table 1) and plotting the statistical distribution function (Fig. 2) showed that the theoretical exponential function satisfactorily approximates the observation series.

The degree of consistency between the theoretical and statistical distribution was assessed by the Kolmogorov criterion [20], where the maximum in absolute value discrepancy between the theoretical and statistical functions is used as a measure of the discrepancy

$$D = \max(F_{n,\text{st}} - F_{n,\text{t}}), D = 0.09$$

The permissible deviation value at the confidence level is

$$D^* = \frac{A_0}{\sqrt{n}} \frac{1.36}{\sqrt{58}} = 0.179$$

where $A_0$ - the critical value of the Kolmogorov distribution function is determined from Table 8.15 [21]$A_0=1.36$; $n$ - sample size or number of recovery cases.

The hypothesis about the correspondence of the statistical distribution to the theoretical exponential distribution is confirmed, since

$$D < D^*$$

$$0.09 < 0.179$$

Table 1. The value of the statistical and theoretical density and the distribution function of the recovery time of the self-pressurized CIN

| Boundaries of intervals | Average time | The number of recovery cases in the interval, $n_i$ | Mathematically recovery expectation, $m_i$ | Static distribution density, $f_{R,\text{st}}(t)$ | Theoretical distribution density, $f_{R,t}(t)$ | Statistical distribution function, $F_{R,\text{st}}(t)$ | Theoretical distribution function, $F_{R,t}(t)$ |
|------------------------|-------------|---------------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 0-24                   | 12          | 16                                          | 3.31                           | 0.0115                          | 0.014                           | 0.276                           | 0.186                           |
| 25-48                  | 36          | 12                                          | 7.45                           | 0.0086                          | 0.0093                          | 0.483                           | 0.461                           |
| 49-72                  | 60          | 11                                          | 11.38                          | 0.0079                          | 0.0061                          | 0.672                           | 0.644                           |
| 73-96                  | 84          | 6                                           | 8.69                           | 0.0043                          | 0.0040                          | 0.775                           | 0.765                           |
| 97-120                 | 108         | 8                                           | 14.89                          | 0.0057                          | 0.0027                          | 0.913                           | 0.843                           |
| 121-144                | 132         | 3                                           | 6.83                           | 0.0022                          | 0.0018                          | 0.965                           | 0.896                           |
| 145-168                | 156         | 2                                           | 5.38                           | 0.0014                          | 0.0012                          | 1.000                           | 0.931                           |
The estimation of the parameters of the obtained distribution functions of the restoration time of pipelines of the self-pressure closed irrigation network of the Samgar massif showed that the generalized average restoration time of pipelines as a whole for the massif is:

$$\bar{R_T} = 57.93 \text{ hour}.$$  

The recovery rate with an exponential distribution law is inversely proportional to the average recovery time:

$$\mu = \frac{1}{\bar{R_T}} = \frac{1}{57.93} = 0.0172 \text{ 1/hour.}$$  

The density of the exponential distribution of the recovery is

$$f_R(t) = 0.0172 \cdot e^{-0.0172t}$$

Exponential distribution function

$$F_R(t) = 1 - e^{-0.0172t}$$
The limits of change in the average recovery time of one failure at a confidence level equal to $P = 0.95$

$$44.6 \text{ hour} \leq \overline{T_R} \leq 78.2 \text{ hour}$$

A similar statistical processing of the source material was carried out for all the constituent periods of the work on the restoration of the object, that is $T_R, t_1, t_2, t_3$. The calculation results and graphs of statistical and theoretical density and distribution function, as well as indicators of maintainability are given in table 2 and fig. 3.

**Table 2. Results of statistical processing of restoration of the self-pressurized CIN of the Samgar massif**

| Indicator name | Unit of measure | Average arithmetic mean | Dispersion | Root mean square deviation | Distribution law |
|----------------|-----------------|-------------------------|------------|---------------------------|-----------------|
| Total network recovery time | Hour | 57.93 | 1239.9 | 35.2 | Exponential |
| Time to detect failure and transfer information | Hour | 11.52 | 25.82 | 5.08 | Laplace Charlier |
| Time for the arrival of the repair team, including the search for materials | Hour | 28.11 | 583.95 | 24.16 | Laplace Charlier |
| Time for repair and testing | Hour | 18.20 | 133.45 | 11.55 | Gamma |

The significance and practical use of the obtained distribution function of the restoration time is determined by the possibility of assessing the probability of restoration of pipelines of a closed irrigation network for the time interval of interest to us $\Delta t$.

The results obtained characterize the distribution of time and operating costs for the elimination of damages and failures of pipelines of a closed irrigation network and can be used by the operation service when planning repair and restoration work.

Analysis of the processing results showed that the main waste of time is spent on the arrival of the repair team at the scene of the accident, including the time spent searching for materials for an hour $t_1 = 28.11$, as well as for repair and testing an hour $t_2 = 18.2$. This speaks of an unsatisfactory supply of basic materials, a low level of organization of repair work and a low level of qualifications of the members of the repair team. And this, in turn, requires the development of organizational and other measures to reduce the length of time $t_2, t_3$, the appointment of the optimal timing for preventive maintenance and repair, and the provision of the required amount of reserve materials.

Such statistical materials obtained as a result of observing the operation of sections of the on-farm closed irrigation network of the Samgar massif can be used as approximate values of the reliability indicators of newly built on-farm self-pressurized closed irrigation systems.
Figure 3. Density and distribution functions of time: \(a\) - to detect failure and transfer information; \(b\) - time for the arrival of the repair team; \(c\) - time for repair and testing; 1 - empirical distribution density; 2 - theoretical distribution density; 3 - empirical distribution function;
4. Conclusion
The obtained numerical estimates of the average recovery time of pipelines of the closed irrigation network of the Samgarsky massif are recommended to be used in calculating the reliability of the CIN, as well as in the design comparison of options for ensuring the reliability of such systems. These data can also serve as the initial experimental material in the development of regulatory requirements for the reliability of self-pressurized closed irrigation systems.

The obtained functions of the distribution of the restoration time of pipelines of the closed irrigation network of the Samgar massif are recommended to be used by the operation service of the on-farm self-pressurized closed irrigation network when planning repair and restoration work.

References
[1] Surin V.A. Mechanization and automation of surface irrigation. - M.: Kolos, 1982. P- 127.
[2] Abramov N.N. Reliability of water supply systems. - M.: Stroyizdat, 1984. P- 216.
[3] Ilyin Yu.A. Calculation of the reliability of water supply. - M.: Stroyizdat, 1987. P- 320.
[4] Ionin A.A., Alibekov K.S., Zhila V.A., Zatikyan S.S. Reliability of gas supply systems. - M": Stroyizdat, 1980. P-231.
[5] Zyubenko S.Sh. Investigation of the operation of canal trays of irrigation systems on subsidence loess soils: Abstract of a thesis. ... Candidate of Engineering Sciences, 05.23.07 / VNIIGiM. - M., 1972. P-24.
[6] Mirtskhulava Ts.E. About the reliability of large channels. - M.: Kolos, 1981. P- 318.
[7] GOST 27.002-2015 Reliability in technology (SSNT). Terms and Definitions. M.: Standartinform, 2016.
[8] Zainutdinova N.Kh. Ways to improve the operational reliability of vertical drainage systems: Abstract of the thesis Candidate of Engineering Sciences, 06.01.02 / SANIIIRI. - Tashkent, 1988. P-23.
[9] Kattakulov, F., Muslimov, T., Khusainov, A., Sharopov, S., Vokhidov, O., Sultanov, S. Water resource saving in irrigation networks through improving the efficiency of reinforced concrete coatings. IOP Conference Series: Materials Science and Engineering. 2020. 883. Pp. 012053. DOI:10.1088/1757-899X/883/1/012053
[10] Zyubenko S.Sh. Maintainability of irrigation and drainage facilities // Hydraulics and calculations of hydraulic structures / Tr. VNIIGiM. - M., 1984. P-111-115.
[11] Ibatullin S.R. Investigation of the reliability of irrigation systems in the zone of semi-desert pastures // Questions rational use and protection of water resources in the conditions of Kazakhstan / Tr. TIIMSKh. - Tashkent, 1983.- Issue 129. P-154-162.
[12] Ivanov V.V. Closed irrigation systems. Methodology for organizing the collection, processing and accounting of statistical information about reliability // Methodical instructions. - M.: V / O Soyuzvodproekt, 1982. P-49.
[13] Ivanov V.V. Methodology for calculating and planning preventive maintenance and repair of irrigation systems (increasing reliability). - M.: V / O Soyuzvodproekt, 1983. P-80.
[14] Senchukov G.A. Assessment of the reliability and operational efficiency of open irrigation systems. Abstract of a thesis. ... Candidate of Engineering Sciences, 06.01.02 - Novocherkassk, 2001. P-23.
[15] Obidov, B., Vokhidov, O., Shodiev, B., Ashirov, B., Sapaeva, M. Hydrodynamic loads on a water drain with cavitation quenchers. IOP Conference Series: Materials Science and Engineering. 2020. 883. Pp. 012011. DOI:10.1088/1757-899x/883/1/012011.
[16] Sokol P.G. Restoration of the operability of steel pipelines by the trenchless method // Melioration and water industry, no. 2. - 2000.
[17] Obidov, B., Choriev, R., Vokhidov, O., Rajabov, M. Experimental studies of horizontal flow effects in the presence of cavitation on erosion – free dampers. IOP Conference Series: Materials Science and Engineering. 2020. 883. Pp. 012051. DOI:10.1088/1757-899x/883/1/012051
[18] Cunningham K., Cox V. Methods of ensuring maintainability: Per. from English. Ed. O.F. Poslavsky. - M.: Sov. Radio, 1978. P. 312.
[19] Howard R.A. Dynamic programming and Markov processes. - M.: Soviet radio, 1964, P. 182.
[20] Wentzel E.S. Probability theory. - Moscow: Nauka, 1969, P. 576.
[21] Kozlov B.A., Ushakov I.A. Handbook for calculating the reliability of radio electronics and automation equipment. - M.: Soviet radio, 1975. P. 470.