Approximate evaluation of the reliability of CDN on the derivation of excess water from irrigated lands

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Abstract: This paper is devoted to the approximate evaluation of the reliability of collector - drainage network on the derivation of excess drainage water from irrigated lands. According to the reliability theory, it was found out that in the first years of network operation its reliability was low. As indicated in the project, in order to get the distance between the drains to be $B = 200m$, in terms of remaining the other parameters unchanged, average supply intensity must be $q = 0{,}00136 m / day$. In this case, it is impossible to reduce the level of ground waters to the crisis depth by the drainage network within the required period. In other words, the effectiveness of the existing network is low. This is for the reasons, such as the level of ground waters rises in planting areas and as the result, salination and marshes and etc. complications occur, production of goods decreases. Increase of the distance between regulatory drains raises the probability of humidity of the land. And the decrease of the distance between the drains reduces the risk of marshy lands. Increasing the probability of high production, leads to increase in the initial cost of regulatory network per unit area. In other words, increasing the reliability of CDN is not only technical, but also an economic matter. If bringing the reliability of the system to the required level requires too much expenditure, this expense will proof itself and lead to the income on the next stages. However, raising the reliability of the system to the certain limit is significant in an economic sense, which is called the reliability rate. Selection of the distance between the drains in the studied problem as $B = 156m$ corresponds to the reliability rate. This was due to the fact that while designing CDS the load on the drainage network was too low, as the result of which the distance between the drains increased up to 200 m. In fact, an optimal distance between the drains in this area varies from 150,4 to 156m and reliability increased to 0,94, above the standard. The paper also suggests the ways of drawing the water balance to determine the intensity of the drainag power accurately

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1. Introduction

For the first time the theory of reliability was created and used in the middle of the last century in radio engineering and a military industrial complex of the USA. Through some time this theory began to extend and in the former USSR. In the same time there was a fundamental literature in the field of the theory of reliability which is recommended to application and to this day [1,2,3,4]. In various known scientific magazines, namely, "Statistical Science", "quality management Methods" and others began to be published scientific articles according to reliability theory. At last, now the theory of reliability began to be applied practically in all areas of production. Reliability is the most important indicator in modern production and equipment operation. Various systems and constructions are considered effective when they have a high degree of reliability. To conform to requirements of reliability reliability calculation at design of technical systems and a construction, and as the correct directions of its use is necessary. One of the weak directions of use of reliability is objects of hydromeliorative systems and constructions. In agriculture various drainage systems are used the following purposes:

- In drainage zones in irrigated lands to combat repeated salinization;
- For preservation and regulation of level of ground waters;
- Clarification of pochenny and ground waters from harmful salts.

The soils exposed to salinity at the background of collector - drainage networks (CDN) emerge the necessity of investigating the effectiveness of the same networks. According to the materials of the research carried out during the first years of CDN operation, we can come to such conclusion that the network reliability is $P = 0{,}82$ i.e., lower than the norm ($P = 0.90$) [5], and that the errors occurred in the projecting or construction phase.

The most significant report among all the report work (engineering, hydrological, economical, etc.) carried out CDN projecting is the report related to the distance determination between drains. Thus, significance of the drainage module, drying rate, soil moisture, and melioration system from the economical point of view and the productivity of agricultural crops depend on the distance between drains indirectly. The study of CDN reliability covers the appointment of its effectiveness in terms of decreasing the level of ground waters in a certain period of time, as well. Therefore, along with the determination of the distance between the drains, which is one of the key factors influencing the effectiveness of the drainage system, calculation of reliability is of significant terms.

Object and method of the study. The object of the study is covered horizontal CDN used in Yevlakh district. Basing on the hydrogeological conditions, as the report scheme, water resistent layer is closer. Dependences (A.N. Kostyakov, S.F. Averyanov, S.V. Hooghoudt and etc.) [6] proposed to define the distance between the drains in accordance with this scheme and the research materials [7] were used; quantitative indicator of the probability of derivation of excess water from the land was calculated in accordance with the known method [8].

Analysis and discussions. The following formula offered by A.N.Kostyakov (modified by S.F.Averyanov) to determine the distance between the drains for particular scheme was used [6]:

$$B = \sqrt{\frac{2\pi\kappa h T}{q}} \cdot \sqrt{\left[\frac{h}{T} + \frac{1 + 0{,}8 \cdot \ln(B/2T)}{\ln(B/d) - 1}\right]}; \quad (1)$$

$$q = \frac{2\pi k T h \{h \cdot [\ln(B/d) - 1] + T[1 + 0{,}8\ln(B/2T)]\}}{B^2 \cdot T[\ln(B/d) - 1]}, \quad (2)$$

Here κ - is filtration coefficient, $h-$ the average pressure, $T-$ the distance from drain pipe to the water-resistance layer, $d-$ the diameter of drainage pipe.

According to the project, the distance between the drains in the studied object is $B = 200m$, filtration coefficient - $k = 0{,}5m/day$, location depth of the drains - $H_d = 3m$, drainage pipe diameter - $d = 0{,}2m$. The initial level of ground water in the area decreased from $H_n = 0{,}67m-$ up to $H_k = 1{,}69m$ within approximately eighteen days. The initial pressure from the location depth of the drain up to the ground water level was $h_o = (2{,}33 + 1{,}31)/2 = 1{,}82m$. However, within eight days the ground water level decreased for $1{,}02m$ and was $H_{k_q} = (2{,}33 - 1{,}02)m = 1{,}69m$. During this period the average pressure over the drains was $h_o = (2{,}33 + 1{,}31)/2 = 1{,}82m$. The distance from the location depth of drain pipe to the water-resistance layer in the project was $T = 20m$.

In this case, using (2) the average supply intensity of the drainage system was determined to be $q = 0{,}00136m/day$, that is the value specified in the project. Taking into account above mentioned, the reliability of the system is $0{,}81$, while the distance between the drains is $205m$. In other words, CDN reliability was found out to be under the norm according to both the experimental and theoretical calculations. The reason for this is improper appointment of average supply intensity of the drainage.

While determining the distance between the drains, an infiltration intensity, evaporation, pressure supply, amount of the water entering the drain from the other sides, and so on factors should be taken into account, which cause increase or decrease of the distance between the drains. All of this is not an easy task.

Previously, scientists used empirical dependence for filtration reports. For example, empirical formulas proposed by B.G.Gateman, Kh.A.Pisarkov, V.A. Rozin and others were used in the reports of reclamative networks in those times. However, there existed theoretical formulas by V.V. Vedernikov in 30 – 40s of the previous century, they were very complex from the point of theoretical view. Thus, these formulas were not used in projecting reclamative systems so widely. Simplifying these theoretical formulas A.H.Kostyakov and S.F.Averyanov shaped them into engineer form.

The key parameter in determining the distance between the drains is an average supply intensity of the drainage. This parameter is found with the formula of water balance of the drainage area [9, 10, 11].

$$W = A + O_p + (\underline{\Pi} - \underline{O}) - (И + T_p) + P + Ф_к - (\overline{\Pi} - \overline{O}) \quad (3)$$

here A - is atmosphere sediments; O_p - irrigation norm; $\underline{\Pi}$ and $\underline{O}$ - underground flows incoming and outgoing in certain speed; $И$ - evaporation; T_p - plants transpiration; $\overline{\Pi}$ and $\overline{O}$ - incoming and outgoing surface water; P - supply of ground waters with pressure water; $Ф_к$ - leakage losses from all kinds of channels.

Some scientific sources provide different views based on a logical explanation of the structural analysis of the equation (3) and ongoing processes. For example, [10] reference puts forward the following principal provisions:

1. $O_p = T_p$ should fulfill the terms, as the irrigation rate in the overall water balance was determined according to the needs of plants;
2. The total incoming and outgoing surface flows in arid areas are extremely few, and they are almost equal to each other, i.e. $\overline{\varPi} = \overline{O}$;
3. As the natural balance is always taken into account, incoming underground flow equals to outgoing underground flow, i.e. $\underline{\varPi} = \underline{O}$;
4. One of the factors that cause soil salinity in irrigated lands is the physical evaporation of the soil. For this reason, physical evaporation should equal to zero in the balance equation to prevent re-salination process, i.e. $И = 0$.

Taking into account above mentioned, equation for overall water balance for arid zones is expressed as follows:

$$W = A + \Phi_к + P. \quad (4)$$

In case of non-pressure waters in the area, the following simple equation is proposed to define the supply intensity of the drainage [8]:

$$W = A + \Phi_к \quad (5)$$

The research shows, that conditions 2, 3 are acceptable. However, it is difficult to accept conditions 1 and 4:

Thus, as the territory of the republic is located in arid zone, $И$ evaporation can never equal to zero, that is, the terms $И \neq 0$ and $И > A$ should be fulfilled. While defining the irrigation rate the condition

$$O_p = T_p + (И - A) \quad (6)$$

should be taken into account, in order to satisfy water supply of the plants, to compensate the evaporation, and to prevent the process supply the ground waters by the surface waters. If we sign as $(И - A) = a$, then equation (6) will be as follows:

$$O_p = T_p + a \quad (7)$$

here a - is an aridity limit. As the amount of annual evaporation and rainfall varies in different regions, the aridity limit will have various values.

If we take into account the equation (3) in the equation (6), average supply intensity of the drains should be calculated according to the following equation:

$$q = W = \Phi_к + P \quad (8)$$

However, as the irrigation norms, techniques and technologies are not followed properly in practice, excess waters raise the level of ground waters to the surface by supplying them, and as the result of evaporation it causes re-salination of the soil.

The average annual evaporation in the Garabagh steppe is - $950mm$ or $9500m^3/ha$, average annual transpiration - $760mm$ or $7600m^3/ha$, amount of rainfall - $450mm$ or $4500m^3/ha$ $\eta = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4$ - is an efficient operation coefficient of inter-agricultural, internal-agricultural, areal and temporary channels and varies between $0{,}5 - 0{,}7$.

Let's calculate irrigation rate according to (6):

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In this case, the leakage losses of the channels are as

$$O_p = T_p + (И - A) = 7600 + (9500 - 4500) = 12600m^3/ha = 0{,}00345m/day$$

follows:

$$\Phi_к = O_p(\frac{1}{\eta} - 1) = 0{,}00345(\frac{1}{0{,}6} - 1) = 0{,}00231day$$

Aridity limit for Garabagh steppe is

$$a = (И - A) = 9500 - 4500 = 4000m^3ha = 0{,}00104m/day$$

.

The average supply intensity of drainage from the equation (8) is

$$q_s == \Phi_к = 0{,}00231m/day$$

.

Replacing this value in the formula (1) the distance between the drains will be $150{,}4m$. Selection method is used for it.

However, according to the actual information, the average intensity of the drainage system within six months was $q = 0{,}12l/san \cdot ha \approx 0{,}001m/day$ [5], i.e. less than expected in the project. It shows that depression curve was not in the form that expected in the project, ground waters were not remained in the crisis depth and finally, re-salination occurred in the middle parts of the distance between the drains.

At the same time, in order to obtain precision, and to determine the distance between the drains in the European countriesin in accordance with the given scheme, the most frequently used S.V.Hooghoudt formula was also used [6]:

$$B^2 = 8\frac{k}{q}h_c^{'}(h - h_0) + 4\frac{k}{q}(h^2 - h_0^2) \quad (9)$$

here the figures in formulas (1) and (2); $h_c^{'}$ – the power in the active layer of ground waters, from which the water enters the drain. In case of $h_0 = 0$ S.F.Averyanov used the formula (3) as follows [6]:

$$B = 2h\sqrt{\frac{k}{q}} \cdot \sqrt{1 + \frac{2h_c^{'}}{h}} \quad (10)$$

the quantity $h_c^{'}$ included into the formula (9) is defined as follows [2]:

$$h_c^{'} = T \cdot \alpha, \text{ if } B/T \geq 8/\pi = 2{,}55 \quad (11)$$

$$h_c^{'} = T_0 = \frac{\pi \cdot B}{8 \ln \frac{2B}{\pi \cdot d}}, \text{ if } B/T < 2{,}55. \quad (12)$$

coefficient α included into the formula (11) is calculated as follows:

$$\alpha = \frac{1}{1 + \frac{2h_c}{B}} \cdot Б \quad , \quad Б = \frac{2}{\pi} \ln \frac{1}{\sin \frac{\pi \cdot d}{2h_c}} \quad ,$$

$$h_c = T + h \text{ , (13)}$$

Let's imagine $B/T \geq 8/\pi = 2{,}55$ in the observed object (11). Using formulas (12) and (13)

$$B = 2 \cdot 1{,}82 \cdot \sqrt{\left(\frac{0{,}5}{0{,}00231}\right)} \cdot \sqrt{\left(1 + \frac{10000 \cdot B}{1{,}82 \cdot (250 \cdot B + 9457 \cdot 10^4)}\right)} \approx 54m.$$

was obtained from the expression (10).

Average value of supply intensity of the middle part of the inter-drains distance for arid zones should be greater or equal to the average value of the physical evaporation to prevent re-salination process. In a specific condition the value of the physical evaporation varies between $10 - 12 \min m^3 / ha$ and $0{,}0027 \div 0{,}0033 m/day$. According to the project, the value of the overall supply intensity in the middle of the inter-drain distance in the investigated object is $q = 0{,}00136 m/day$. Obviously, this value is less than the intensity of physical evaporation for 2-3 times.

The calculations carried out on the basis of the project data shows that the reliability of constructed CDN is low in accordance with the accepted values, and it is $P = 0{,}82$ [5]. Therefore, we can suppose that at the background of existing CDN, the salination process was associated with that the supply intensity of the drainage is less than the evaporation intensity.

One of the main goals of the horizontal systematic drainage is to reduce the level of ground waters to required level, and to extract excess waters from the fields in a certain period of time. Depending on the variation of changing probabilities of the factors that are significant for this process, in most cases the reporting information differs from the observation data. Let us study the problem solution according to the known method [8].

Let's suppose that, inter-drain distance was adopted $B = 156m$ entirety. Then the account intensity was $q_h = 0{,}00216 m/day$ according to the formula (2).

Taking into account that the values (except π) included into the q function are variable, then we will try Taylor series method around the nominal and average values of the included parameters in order to solve the problem. According to the minority of the quantities characterizing the parameter changes, we can satisfy with the first composition members of the series:

$$\Delta q = \frac{\partial q}{\partial k}\Delta k + \frac{\partial q}{\partial h}\Delta h + \frac{\partial q}{\partial B}\Delta B + \frac{\partial q}{\partial d}\Delta d; \quad (14)$$

Here

$$\frac{\partial q}{\partial h} = \frac{2k\pi(10h\ln(\frac{B}{d}) + 4T\ln(\frac{B}{2T}) - 10h + 5T)}{5B^2(\ln(\frac{B}{d}) - 1)};$$

$$\frac{\partial q}{\partial d} = \frac{2hTk\pi(4\ln\frac{B}{2T}) + 5)}{5dB^2(\ln(\frac{B}{d}) - 1)^2};$$

$$\frac{\partial q}{\partial B} = -\frac{2hk\pi(2\ln(\frac{B}{d}) \cdot (4T\ln(\frac{B}{2T}) - 10h + 3T) - 4T\ln(\frac{B}{2T}) + 10h\ln(\frac{B}{d})^2 + 10h - T}{5B^3(\ln(\frac{B}{d}) - 1)^2};$$

$$\frac{\partial q}{\partial k} = \frac{2h\pi(5h\ln(\frac{B}{d}) + 4T\ln(\frac{B}{2T}) - 5h + 5T)}{5B^2(\ln(\frac{B}{d}) - 1)}.$$

Replacing the values $k = 0{,}5m/day$, $d = 0{,}2m$, $h_o = 1{,}82m$, $B = 150{,}4m$ given in the project for the drainage report in the above mentioned expressions we find out $\frac{\partial q}{\partial h} = 0{,}00152;$ $\frac{\partial q}{\partial d} = 0{,}00165;$ $\frac{\partial q}{\partial B} = -0{,}0000275;$ $\frac{\partial q}{\partial k} = 0{,}00462$. The mean-square deviation of the account intensity is defined by the following expression [4]

$$\sigma_{q_h} = \sqrt{((\frac{\partial q}{\partial h})^2 \sigma_h^2 + (\frac{\partial q}{\partial d})^2 \sigma_d^2 + (\frac{\partial q}{\partial B})^2 \sigma_B^2 + (\frac{\partial q}{\partial k})^2 \sigma_k^2)},$$
(15)

here $\sigma_h^2, \sigma_d^2, \sigma_B^2, \sigma_k^2$ – is a dispersion of $k -$ filtration coefficient , of $d -$ drainage pipe diameter, $B -$ inter-drain distance, $h -$ medium pressure.

In the absence of the required statistical data to define mean-square deviation, it can be found by three Sigma rule and acceptance limit. Mean-square deviation in the given problem is found as $1/6 -$ of fields.

If we take into account that the acceptances consist 10% of the average values of the parameters in the first approximation, then

$$\sigma_h = \frac{1}{6} \cdot 0{,}10 \cdot 1{,}82 = 0{,}030;$$

$$\sigma_d = \frac{1}{6} \cdot 0{,}10 \cdot 0{,}2 = 0{,}0033;$$

$$\sigma_B = \frac{1}{6} \cdot 0{,}10 \cdot 150{,}4 = 2.51;$$

$\sigma_k = \frac{1}{6} \cdot 0{,}10 \cdot 0{,}5 = 0{,}0083$. Replacing these values in the formula (15) we found:

$$\sigma_{q_h} = 0{,}000091 m/day$$

If we suppose that the acceptance level of the last limit of supply intensity is in the 10% interval, σ_{q_s} will take the following value:

$$\sigma_{q_s} = \frac{1}{6} \cdot 0{,}10 \cdot 0{,}00231 = 0{,}000039.$$

Uninterrupted operation probability of the water to be thrown from the fields in the defined level was found out by the following formula:

$$P = \Phi(\frac{q_l - q_h}{\sqrt{(\sigma_{q_l}^2 + \sigma_{q_{s...}}^2)}}) = \Phi(\frac{0{,}00231 - 0{,}00216}{\sqrt{(0{,}0000385^2 + 0{,}000091^2)}});$$

$$P \approx 0.94 .$$

Thus, according to the average supply intensity, if the distance between the drains is $B = 156m$, probability of the water to be thrown from the fields through the network equaled to 94%.

Thus, according to the given parameters, normal distance between the drains varies within $150.4m \prec B \prec 156m$. However, due to the improper operation with the irrigation norms in practice, excess waters supply ground waters, and it emerges additional pressure on the drainage. If we also take into account the volume of the excess water, then the probability of a reduction in the distance between the drains must also be taken into account during the projecting. As indicated in the project, in order to get the distance between the drains to be $B = 200m$, in terms of remaining the other parameters unchanged, average supply intensity must be $q = 0{,}00136 m/day$. In this case, it is impossible to reduce the level of ground waters to the crisis depth by the drainage network within the required period. In other words, the effectiveness of the existing network is low. This is for the reasons, such as the level of ground waters rises in planting areas and as the result, salination and marshes and etc. complications occur, production of goods decreases.

Increase of the distance between regulatory drains raises the probability of humidity of the land. And the decrease of the distance between the drains reduces the risk of marshy lands. Increasing the probability of high production, leads to increase in the initial cost of regulatory network per unit area. In other words, increasing the reliability of CDN is not only technical, but also an economic matter. If bringing the reliability of the system to the required level requires too much expenditure, this expense will proof itself and lead to the income on the next stages. However, raising the reliability of the system to the certain limit is significant in an economic sense, which is called the reliability rate. Selection of the distance between the drains in the studied problem as $B = 156m$ corresponds to the reliability rate.

Do not forget that the main purpose of CDN construction is achieving more effective use of water and land resources, creating conditions for sustainable and high agricultural plants harvest, protecting environment and ecological balance. For this purpose, in order to ensure fulfillment of the functions entrusted to CDN, it is important to distinguish its technical condition, performance and effectiveness, and to estimate them separately.

Technical condition of CDN means good or bad condition of all the elements included into the network, compliance of their parameters with the project indications.

Performance of CDN means performance of the functions of all the elements included into the network, compliance of their parameters with the project indications.

Effectiveness of CDN means creation of water, salt, air, temperature, supply regimes, regulation and management in its location.

Consequently, on the last stage, technical condition and performance of CDN must ensure its effectiveness.

2. Results.

1. The paper puts forward new proposals for the calculation of irrigation rate and the overall water balance of the area.
2. Researches show that the most optimal value of the distance between the drains in the studied field varies within $150.4m \prec B \prec 156m$.
3. Low reliability of CDN located in Yevlakh district, Garabagh steppe, during the initial period of its exploitation, was found to be associated with the inaccurate calculation of the average supply intensity of the drainage in the project.

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