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WAYS OF RATIONAL USE OF WATER RESOURCES IN THE CONDITIONS OF POST-WAR RECLAMATION SYSTEMS IN THE SOUTH OF UKRAINE

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Abstract. After the explosion of the Kakhovka hydroelectric power station, the problem of restoring damaged areas of reclamation systems and rational use of water resources in the de-occupied territories of southern Ukraine is extremely relevant today. An integral part of solving this problem is the theoretical justification and assessment of filtration losses in damaged areas of open drainage channels with interception of this flow by drainage structures. This study presents a methodology for calculating the filtration losses of water from a main canal that runs in an excavation with a channelside pipe drainage. The calculations take into account the pressure drop on the canal lining. The filtration water losses per linear metre of the main channel of the Ingulets irrigation system were determined, taking into account the filtration resistance of the screen, which is economically feasible to restore from local water-resistant natural materials. In this case, the channel drainage performs two functions. Firstly, it prevents flooding of the territory; secondly, it is possible to use innovative technologies to return part of the filtration effluent for use in various water supply sectors of the region. The research results will allow us to further develop recommendations for effective engineering protection of water resources from pollution and depletion in this region.

Keywords: reclamation systems, restoration, filtration losses, ditch drainage.

1. Introduction

The issue of restoring irrigation systems in the de-occupied territories of southern Ukraine to improve food security is very acute today. The undermining of the Kakhovka hydroelectric power station dam has significantly affected the level of environmental safety in the region, causing a deterioration in the quality and quantity of water resources. The operational information on water levels in water bodies according to the Department of Water Relations and Cadastre shows that in the period from 6.06.2023 to 13.06.2023, the maximum rise in water levels in the Ingulets River (Snihurivka) was recorded at 2.31 m, and in the Dnipro River (Kherson) – at 2.88 m. Under such conditions, it is clear that the lands of the Ingulets irrigation system received a lot of hazardous substances with the flood water, as well as a lot of waste from economic activities as a result of the hostilities. After the water receded and the pumping stations began operating, the system needed to fill the main canal with water for irrigation, the lining of which was significantly damaged as a result of the occupation of the territory.

Damage to the canal lining as a result of long-term operation (Voroshnov et al., 2018) (destruction of concrete and expansion joints, slab slippage, vegetation germination, damage to the integrity of the plastic film) was compounded by damage caused by military operations on the territory (removal of reinforced concrete lining by the occupiers to construct defences in large areas, craters and holes from bombs and shells, changes in the canal perimeter parameters due to additional structures, etc.) In such conditions, the issue of operating reclamation systems in the South of Ukraine with prompt restoration of the impervious lining becomes urgent. At the same time, research on the use of local natural materials and kaolins from nearby deposits will be useful as a more economical option for arranging protection, requiring less time for restoration work.

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The scarcity of water resources in the region requires their economical use, so the issue of using drainage water for various needs after appropriate water treatment is relevant. In this study, we considered the possibility of using filtration runoff through lining to reuse and reduce filtration losses from the reclamation canal, which can be significant in unlined areas. According to experts from the Institute of Hydromechanics of the National Academy of Sciences of Ukraine, the estimated losses from the Ingulets Canal at the initial stage, when its route was completely in the earthen channel, were quite significant and amounted to approximately 58.83 million m^3 of water per season (with the canal operating for 188 days) (Telyma, 2006; Telyma, 2014). The possibilities of drainage runoff reuse in the reclamation systems of the South of Ukraine and the rational use of water resources are considered in (Kozlenko et al., 2021; Khoruzhiy et al., 2020; Matseliuk et al., 2021; Morozov, 2020). In order to make an optimal decision on the reuse of drainage runoff for various needs through canal drainage, it is necessary to have its estimated value of filtration losses from the canal.

The aim of the research is to theoretically substantiate the methods and calculations of filtration losses from the main channels of reclamation systems and their interception by the canal drainage for the purpose of their further rational use as an additional source of power.

2. Experimental part

The issue of determining filtration losses from lined land reclamation structures is covered in the works of many domestic and foreign researchers, such as Oleynik (1984), Telyma et al (2015, 2023), Bereznitska, Voloshkina (2011), Manzoor et al. (2004), El-Molla D., El-Molla, M. (2021), Elkamhawy et al. (2021), Zhang et al. (2017) and many others (Telyma, 2014; Telyma et al., 2015; Oleynik, 1984; Manzoor et al., 2004; Elkamhawy et al., 2021; El-Molla, 2021; Zhang et al., 2017; Bereznitskaya, Voloshkina, 2011; Telyma et al., 2023).

The design scheme of a drainage channel that runs in an excavation and is typical of the Ingulets irrigation system. The drainage is located near the bottom slope and its effectiveness is such that the depression curve will pass below the bottom of the slope. In this case, there will be no rise in the filtration flow to the canal slope and beyond. The condition for the existence of such a scheme is represented by equation (1):

$$m_0 > \sqrt{\frac{h_1^2(L_1'') + h_g{}^2(L_1 - L_1'')}{L_1}}. \tag{1}$$

In the above equations, $L_1 = L + \mathrm{F_{obl}} + \mathrm{F}_q - 0{,}5r$; $L_1" = L" - 0{,}5r$; r is the working radius of the drainage, m; F_{obl} is the filtration resistance of the lining, the value of which, depending on its type and thickness, is recommended to be taken according to the methodology set out in the Manual to DBN B2. 4-1-99 “Land reclamation systems and structures”, 2006 (DBN B2.4-1-99); F_q – is the filtration resistance to imperfections in tubular drainage, determined by the equation:

$$F_q = 0{,}366m\, lg\frac{h_g}{\pi r}, \tag{2}$$

where *m* is the thickness of aquifers, m, with filtration coefficient K, m/day

Other designations are shown in Fig. 1.

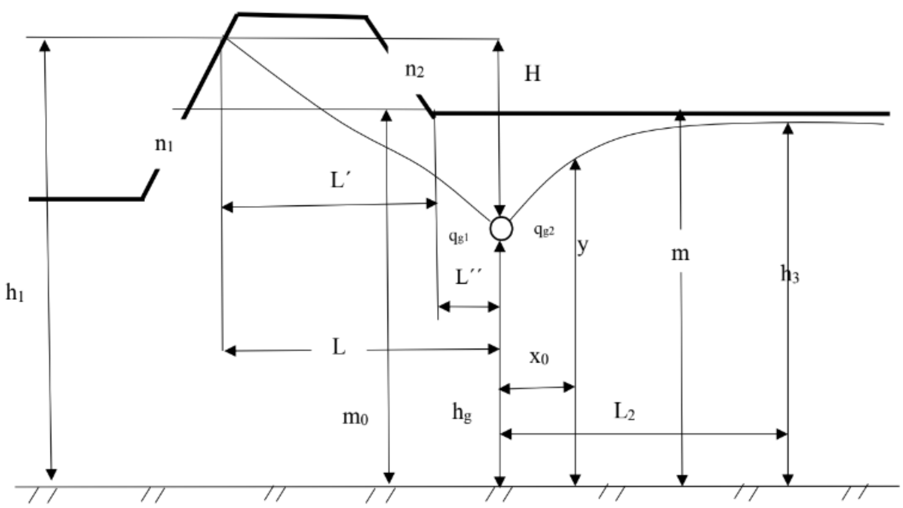

Fig. 1. Design scheme of a drainage channel with and without interceptor drainage

The flow rate of water entering the pipe drainage from the main channel can be determined by equations (3) and (4):

$$\frac{q_{g_1}}{K} = \frac{h_1^2 - h_g^2}{2L} + \frac{h_g H}{L + F_q}; \qquad (3)$$

$$H = h_1 - h_g. \qquad (4)$$

In the case of two- and three-layer aquifer structure, the formulas presented in can be used to determine the filtration resistance F_q and the averaged filtration characteristics.

When we have the flow rate into the pipe drainage from the side of the irrigated massif, we can apply equation (5):

$$\frac{q_{g2}}{K} = \frac{h_3^2 - h_g^2}{2L_2} + \frac{h_g(h_3 - h_g)}{L_2 + F_q}. \qquad (5)$$

The ordinates of the depression curve Y in the direction of the irrigation system are determined by the equations (Oleynik, 1984):

$$Y = h_g + \left[\frac{1-\alpha_1}{1+\alpha_1}\left(h_1 - h_g\right) + \frac{\left(1 + \frac{\alpha_1}{\alpha_y}\right) q_2 x_0}{(1+\alpha_1)T}\right], \qquad (6)$$

where $\alpha_1 = \frac{1}{1+\frac{h_g}{L}A}$, $\alpha_y = \frac{1}{1+\frac{h_g}{x_0}A}$, $T = km$, $m = \frac{h_K + h_q}{2}$

$A = 1{,}47 \frac{1}{\sin\frac{\pi dy}{2h_g}}$ is determined from Table 1.

Table 1

Determination of the coefficient A in the calculation of the ordinates of the depression curve of the irrigated massif

d_g/h_g	A	d_g/h_g	A	d_g/h_g	A	d_g/h_g	A	d_g/h_g	A
0.01	2.64	0.07	1.41	0.18	0.81	0.40	0.34	0.80	0.03
0.02	2.20	0.09	1.25	0.20	0.75	0.50	0.22	1.00	0.00
0.03	1.95	0.12	1.07	0.25	0.61	0.60	0.14	–	–
0.04	1.76	0.14	0.97	0.30	0.50	0.70	0.07	–	–
0.05	1.62	0.16	0.89	0.35	0.41	–	–	–	–

3. Results and Discussion

Using the proposed methodology, we calculate the filtration parameters for a typical cross-section of the Ingulets main canal with an interceptor tube drainage, the arrangement of which is proposed to intercept filtration losses.

The geotechnical conditions along the canal route are characterised by three layers of loess loam: light to medium brownish-yellow loam (up to 2.5 m) in the first layer; light to medium brownish-yellow loam (up to 4.5 m) in the second layer; dark brown and reddish-brown heavy loam in the third layer, which is a water-resistant layer for the non-pressure groundwater aquifer.

The third layer is distributed along the entire canal route and can serve as a material to protect damaged sections of the canal. Examples of the possibility of using similar rocks pretreated with chemicals in impervious surfaces were studied in (Klimov, 2018; Trach et al., 2021). The effectiveness of the use of soil lining on damaged sections of the Ingulets main canal is presented in (Marshall, 2023).

The filtration coefficient of loam filtration is assumed to be 0.22 m/day (Voroshnov et al., 2018; Telyma, 2006; Telyma, 2014). The results of calculations for two types of lining (soil and soil-film) and a channel without lining in an excavation are presented in Table 2. Using the proposed methodology of filtration parameters, the following initial data were taken for the cross-section of the main channel with intercepting drainage: h_1=10 m, m=9.1 m, L=32 m, L"=20 m, HK=15 m, n_1=n_2=1.5, h_g=5.5 m, r=0.25 m.

It should be noted that the flow rate into the ditch drainage depends on the distance it is located from the bottom of the embankment.

A diagram of the channel's river profile with a depression curve in the channel drainage is shown in Fig. 2.

Table 2

Calculation of filtration runoff into pipe drainage per linear metre of the main channel of the Ingulets irrigation system for types of lining with natural materials

Type of cladding	Filtration coefficient of the lining, m/day	The efficiency of the cladding	F_{obl}, m according to (DBN B2.4-1-99) and by calculations	F_q+F_{obl}, m	Filtration runoff per 1 linear metre into the canal drain from the side of the main canal, m^2/day
Channel without lining	–	–	–	2.8	1.763
Primer film	$1 \cdot 10^{-8}$	0,85	92	94.8	0.274
Cladding made of local materials	$1 \cdot 10^{-6}$	0,46	40.7	43.5	0.347

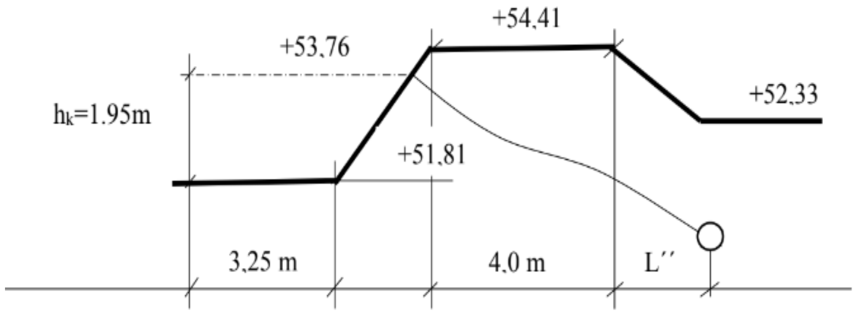

Fig. 2. Cross-sectional diagram of the main canal of the Ingulets irrigation system

Taking into account the economic feasibility of restoring the irrigation systems in the south of Ukraine, the use of local materials (red kaolin) is justified. Undoubtedly, the reconstruction of the open drainage network using reinforced concrete structures and innovative lining methods will significantly reduce filtration losses along the entire canal route. However, the actual loss of water from the Kakhovka Reservoir has drastically reduced water resources for reclamation systems in southern Ukraine and has necessitated the resumption of the development and implementation of water management technologies on productive land. The construction of on-channel drainage will minimise filtration losses and return part of the water for various economic needs after appropriate water treatment.

According to the source (Voroshnov, 2018), the estimated value of specific filtration losses per 1 m2 of wetted surface of the main channel ranges from 0.116 to 0.08 m^2/day, which indicates the legitimacy of this approach for preliminary analysis and forecasting of filtration inflow to the channel drainage of the reclamation structure using possible protection options from natural materials.

4. Conclusions

Assessment of the quantitative and qualitative state of water resources in the de-occupied territories of irrigation systems in southern Ukraine requires the use of theoretical modelling methods for filtration processes and prevention of the spread of pollution in surface and groundwater.

Studies of recent years of long-term operation of canals and military operations on the territory have led to the fact that most main canals have virtually no impervious lining due to its destruction. Therefore, at the preliminary stages of design and survey work on the reconstruction of reclamation systems and forecasting the impact of filtration from canals on adjacent territories and migration of contaminants into groundwater, mandatory works on their lining using modern impervious materials should be envisaged. In this case, the arrangement of canal drainage allows to return part of the drainage runoff, after its preliminary treatment, to the region's water supply needs.

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