DRAINAGE MODULE AS IMPORTANT FACTOR IN DESIGN OF DRAINAGE SYSTEM RECONSTRUCTION AND CONSTRUCTION PROJECTS IN THE POLESIA REGION

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Abstract. The existing drainage systems in Polesia have exhausted their resource and need reconstruction and modernization to improve the overall technological, economic and environmental efficiency of their operation. To study the influence of the main factors of variation of the distance between the drains methods of statistical modeling and the probability theory are used, which developed a mathematical model for determining standard deviation determining factor of the investigated function. According to the results of the studies, it was found that the drainage flow module characterizing the intensity of soil and territory drainage is formed mainly due to the values of the drainage speed, filtration coefficient and the time of excess water drainage and has a significant impact on the distance between the drains, which is 86-98 %. Based on the simulation for the conditions of Ukrainian Polesia dynamics and the average weighted modules in drainage outflow under different weather and climatic conditions for growing different crops on different soils, the considerable variability of their values in time and space are obtained, the normalized curves constructed security module drainage outflow for the main arable crops on mineral and peat soils. The obtained results convincingly show that both current and average values of the drainage flow modulus in the studied conditions have a pronounced variability in climatic conditions, the type of crops grown and the type of soil. With its value for the selected key factors the drainage system substantially differs primarily from the maximum current values and values during the vegetation period calculated from accepted values by more than a few times, what determines the need to take account of this designing reconstruction projects, construction and operation of such facilities.

Keywords: drainage systems, drainage flow module, drainage norms, filtration coefficient, simulation modelling.

Introduction

The European Polesia is characterized by special climatic, relief and soil conditions. The territory of the European Polesia has a large area. It belongs to the hydrological zone of high humidity and is part of the territory of four neighbouring countries (Belarus, Ukraine, Poland and Russia). Drained lands of the European Polesia are important in agriculture, ecology and modern socio-economic development of regions and countries. Reclaimed waterlogged lands in the humid zone are important elements. They guarantee stable farming and livestock feeds, regardless of climatic conditions. Rainfall amounts up to 150 mm or more in rainy periods. This is a prerequisite for flooding and waterlogging. Arable land is 30-40 % of the total land area. Part of this land is permanently or periodically flooded or waterlogged. Therefore, reclamation works make it possible to achieve water balance and improve the natural conditions by regulating the water and air regime of soils.

In Ukraine, the drained lands are located in Polesia and in the western region of the country and they are 62 % of the reclamation fund. Almost 70 % of the area is reclamation systems with subsurface drainage.

The complex of reclamation works on the territory of Polesia influenced the water regime of waterlogged lands – the duration of spring and summer-autumn flooding and the depth of groundwater levels decreased. They with the drainage module were the main criteria for the calculation of the water regime of the active soil layer during the design of drainage systems and management of water regulation.

Existing drainage systems (DS) in the Polesia region have used their resource and need to be reconstructed and upgraded to improve the overall technological, economic and environmental efficiency of their operation. The operating level of the DS is reduced. The condition of the drained lands is deteriorating. On drainage systems that were built 30-50 years ago, agricultural land productivity decreased by 25-50 % of the design. 29.6 % of the Polesia drained lands have good amelioration regime, 56.6 % – satisfactory, 13.8 % – unsatisfactory. This adversely affects the hydrological condition of the territories and necessitates the reconstruction and modernization of reclamation systems [1]. Drainage systems with a satisfactory ameliorative condition should be referred to as "conditionally satisfactory" systems. They can increase the area of drained land with unsatisfactory condition by 3-4 times.

The total value of reclamation systems in the humid zone of Ukraine is 1660. Depending on the structural and technological characteristics, they are divided into the main types: drained systems of unilateral action (8 %); double-acting irrigation systems (34 %); water circulation systems (47 %) and polder type systems (11 %). Land reclamation fund is 3.7 million hectares: peat-bog soils make up almost 0.95 million hectares, mineral waterlogged soils – 2.75 million hectares. This makes up 68.5 % of waterlogged lands in Ukraine. Therefore, the Polesia zone of Ukraine is the main territory of drainage reclamation.

The main criteria for designing drainage systems are their economic, technical and environmental efficiency. They are determined by the conditions of drainage rate formation of the territory.

At the territory of Polesia the atmospheric type of water supply prevails. Therefore, the drainage rate has periodic character. Its total value depends on the climatic conditions of the territory, namely the amount of precipitation and evaporation. In addition to climatic factors, drainage rate is affected by other natural conditions, including soil and relief. These natural conditions form the hydrological conditions. Hydrological conditions are precipitation, evaporation, filtration coefficient, soil drainage, depth of groundwater, slope, etc., which determine the calculated drainage parameters [2-4].

The most important drainage parameters are the distance between the drains and the depth of the drains. These parameters depend on many factors that are interrelated and may be independent of probabilistic content.

The drainage system must maintain a given water regime in the area. Requirements for the water regime are determined by drainage rate. Drainage rate is the required depth of groundwater for a particular crop and should be maintained in the drained area in separate phases of plant development. To determine the water regime of the drainage system, the permissible duration of land flooding, soil conditions and soil filtration properties, drainage parameters is important.

The drainage module [5] is one of the three main indicators of the hydrological effect of drainage and the second most important expenditure element of the water balance of drained soils. The drainage module is included in the equation for the calculation of inter-river distances due to the drainage rate, filtration coefficient and the time of excess water removing.

The analysis of the results of the drainage rate study shows that the duration of drainage rate, its volume and drainage modules differ greatly on systems with different distances between the drains and the depth of their laying.

Observations of drainage rate in the study territories having different inter-interstitial distances B confirm the general pattern. As the distances between the drains decrease, the drainage modules increase. The magnitude of drainage modules on the variant with $B = 10$ m is much larger than at $B = 20$ m. With the $p = 2.0$ % probability, which T.N.Shkinkis recommends as a calculated one, the drainage module at distances between drains of 10 m has value of 0.78 $\mathrm{l \cdot s^{-1} \cdot ha}$, and at $B = 20$ m it has a value of 0.36 $\mathrm{l \cdot s^{-1} \cdot ha}$. The difference between drainage modules is even greater when the probability is less than 2 %. That is, the maximum values of drainage rate have the greatest influence on the drainage parameters, namely the distance between the drains.

Calculated drainage runoff module, given in the current standards in most countries of Western Europe, USA, Japan and others is determined by the analytical method. The above mentioned principle was followed by A.M. Kostyakov, V.G. Heitman and H.A. Pisarkov, A.I. Ivitsky, S.F. Averyanov et al.

Due to the more intensive use of agriculture on drained lands, widespread use of farming practices and with transition of the upper layer large part runoff to the drainage one, at the end of 70-80 years a tendency to increase the value of calculated drainage runoff modules appeared. Similarly, in the Latvia's current regulations the meaning of the drainage runoff module was increased up to 0.7-0.8 $\mathrm{l \cdot s^{-1} \cdot ha}$ [6].

To compare all the above mentioned, we note that the calculated drainage runoff module in Western Europe countries was accepted within 0.8-4.0 $l \cdot s^{-1} \cdot ha$, with higher values 2-4 $l \cdot s^{-1} \cdot ha$ specific to foothill areas and mountainous provinces with annual rainfall over 1000 mm.

According to the German standard, drainage runoff modules for collector diameter hydraulic calculation and the distance between the drains are calculated on average annual rainfall and are accepted within 0.8-2.0 $l \cdot s^{-1} \cdot ha$. Among European countries, the largest calculated runoff modules are accepted in Sweden - 7 $l \cdot s^{-1} \cdot ha$ [7].

In the USA regulations the calculated drainage runoff module depending on the type of soil, crop rotation and conditions of the surface water flow is taken also within 0.8-4.0 $l \cdot s^{-1} \cdot ha$. In Japan, German standards have been accepted, they were recalculated on average annual rainfall of 1000...2800 mm, 2.0-5.0 $l \cdot s^{-1} \cdot ha$ [8].

In Belarus drainage is allowed for a full section only for 2 days, which corresponds to 0,5 % of the average daily modules probability. As a result, the following drainage runoff modules that correspond to estimated probability are recommended: by the distance between the drains in B = 10 m q_0 = 0.82 $l \cdot s^{-1} \cdot ha$; B = 14 m, q_0 = 0.68 $l \cdot s^{-1} \cdot ha$; B = 20 m, q_0 = 0.48 $l \cdot s^{-1} \cdot ha$ [9].

In addition, the distances between the drains are related to their depth, since the relationship between the depth and the frequency of drainage elements determines the dynamics of the groundwater level between the drains and the drainage condition of the soil and the territory.

Thus, different intensity of drainage (drainage condition of the soil and territory) is formed depending on the hydrological effect of drainage. The determining factor is the performance of drainage modules by which the structures and parameters of drainage systems and their elements are calculated.

At the present stage, when designing a drainage system to achieve the optimum level of drainage of the territory should be laid such a level of reliability of the system, which is provided by the technical, economic and environmental performance indicators of its operation. Multiparameter and multifunctionality of drainage parameters are determined by a number of factors. This has led to the development of a large number of methods and models. Therefore, it is advisable to analyze the approaches and equations for determining the distance between the drains, and to determine the influence of the basic parameters that affect the distance between the drains.

As a result of the development of reclamation science, two main methods of calculating the parameters of agricultural drainage were identified: hydromechanical and empirical. The hydromechanical method is based on the theoretical foundations of water movement in natural and technical systems. The empirical method is based on the statistical processing of data from numerous field studies. Each of them has its advantages and disadvantages.

The theoretical foundations of drainage condition of the soil have been described in the writings of Darcy, Dupuit and I. Bussinessk. They have developed the theoretical basis for calculating the basic parameters of agricultural drainage. These works were developed by such scientists as O.M. Kostyakov, S.F. Averyanov, V.V. Shestakov, O.J. Oliynyk, M.G. Pivovar, V.L. Polyakov, O.I. Ivitsky, A.I. Murashka, V.T. Klimkov, V.A. Ionat, A.M. Engol, S.A. Brusilovsky, O.I. Golanovov, V.Y. Shapran, L.F. Kozhushko, M.A. Lazarchuk, V.G. Muranov, R. Egelsmann, D. Kirkham, R. Glover and others. The equations proposed by O.M. Kostyakov, S.F. Averyanov, A.M. Angel, O.Y. Oliynyk, V.L. Polyakov, V.S. Kozlov, A.I. Ivitsky, V.A. Ionat, A.I. Murashko and others [6; 7] have been used in drainage design.

In Western Europe, Hooghaudt and Ernst equations are used for single- and multilayered soils.

The hydromechanical method of calculating distances between drains is the most theoretically sound, but it has several disadvantages. A significant disadvantage of hydromechanical equations is the neglect of conditions for formation of drainage runoff in the phase of raising the groundwater level, which is more intense than the recession phase.

The hydromechanical method of calculating distances between drains has not economic and environmental justification.

The disadvantages of the hydromechanical method do not mean that this method cannot be used. This method is most theoretically justified. It gives a qualitative analysis of the factors of hydrological action of drainage, hydrodynamic processes taking place in soils. Hydromechanical equations are of great importance in summarizing drainage field studies.

The practice of designing drainage systems is a common empirical method. According to this method, the distance between the drains is calculated by factors that influence the intensity of drainage (granulometric composition, physical and chemical properties of soil, intensity of precipitation, water permeability of rocks, etc.).

This method is based on the assumption that the heavier the soils and lower their filtration properties, the smaller the distances between the drains.In the domestic practice of designing drainage on the drained lands on the basis of the empirical method, the equations proposed by T.N. Shkinkis, H.A. Pysarkov, A. Dumblyauskas, V.P. Kubishkin are used [6; 7].In Western Europe, Cornell and Mitcherlich equations are used to determine distances between drains using the empirical method.

A significant advantage of the empirical method of calculating distances between drains is its ease of use. This method also has disadvantages. As practice shows, the empirical method of determining the distance between the drains requires costs of its implementation. It has a range of applications that are defined by the zonal conditions of the object being studied.

An analysis of the basic methods and models for determining distances between drains shows that many equations have been developed due to the complexity of the various processes occurring in drained territories. These equations take into account many factors of design conditions that influence calculation of drainage parameters. However, it should be noted that the hydrological conditions of formation of drainage rate territory are indefinite in time. They have an influence on the water regime of the territory and the ecological and economic effect of the drainage system. The economic and environmental performance of the drainage system is determined by its technical characteristics (design parameters of the drainage). These parameters are calculated on the basis of many multivariate factors of the hydrological effect of drainage. Therefore, the complexity and multivariate model of the distance between the sods necessitates the study of the importance of the influence of different factors of the hydrological effect of the drainage and determines the need to study each individually and in interaction.

Figure 1 shows a structural and logical scheme that reflects the influence of hydrological conditions (climatic, soil, relief) and the hydrological effect of drainage on the drainage parameters of the drained lands of many factors (drainage module, drainage rate, time during which the water layer from the soil is discharged, the distance from the drainage axis to the water confining stratum, the drainage diameter and the drainage filter characteristic).

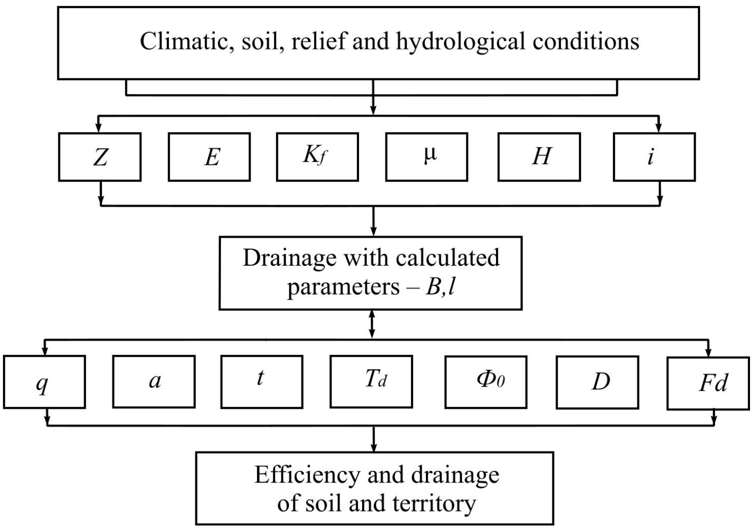

Fig. 1. **Structural and logical scheme of formation of factors that affect drainage parameters:** k_f – filtration coefficient; Z – precipitation layer; E – evaporation layer; μ – dewatering coefficient; H – depth of the groundwater level; i – slope of the surface of the earth; Φ_0 – filtration supports according to the nature of the aquifer; q – drainage module; a – drainage rate; t – time during which water from the soil is discharged; T_d – distance from the axis of the drain to the water confining stratum y; D – diameter of the drainage; F_d – drainage filter characteristic

Thus, the hydrological effect of drainage is a determining factor in the efficiency of the drainage system. The hydrological effect of the drainage depends on the calculated drainage parameters, namely the distance between the drains. The distance between the drains is a multi-parameter function (Fig. 1), in which it is necessary to determine the parameters that have a great influence on the final result of its formation.

Therefore, it is necessary to investigate the influence of variability of the main factors on the distance between the drains. To solve this problem, it is necessary to apply statistical modeling methods and methods of probability theory, the essence of which is as follows.

Materials and methods

The design of hydroelectric system objects is based on deterministic equations. The determining parameter Y, which characterizes the performance of the system, is a function often of several arguments x_i, that is, we have the function [8-10; 12].

$$Y = F(x_1, x_2, ..., x_n)\,. \tag{1}$$

In most cases, function (1) is nonlinear. However, in the range of changing their arguments, nonlinear functions can be replaced by linear ones. To do this, the method of linearization of the function is used [15]. If the values are uncorrelated, then the variance and the root mean square deviation of the function are equal to:

$$D_Y = \sum_{i=1}^{n} \left(\frac{\partial F}{\partial x_i} \right)^2 D_{x_i} \quad ; \tag{2}$$

$$\sigma_Y^2 = \sum_{i=1}^{n} \left(\frac{\partial F}{\partial x_i} \right) \sigma_{x_i}^2 \quad . \tag{3}$$

Equations for determining partial derivatives are obtained by differentiating the analytic deterministic dependence of function (1).

According to the results of the analysis of the equations for calculation of the drainage parameters, it is established that due to the complexity and multifactoriality of the phenomenon, a considerable number of methods and models have been developed to determine the distances between the drains. To identify the influence of the factors on the parameters of the values of the distances between the drains in the conditions of Polesia, it is necessary to use the general equation according to DBN V.2.4-1-99 [16], taking into account the developments of O.Y.Oliynyk and A.I. Murashko. This equation takes into account the structural features of material horizontal drainage. The effectiveness of its application has been confirmed by other researchers and practices in both the drainage and irrigation areas.

For the analysis of the magnitude of the distances between the drains in homogeneous soil at atmospheric and soil nutrition the equation was used for the case where the distance from the axis of the drain to the water confining stratum $T_d \le B / 4$, where B is the distance between the drains, which is determined by the equation

$$B = 4\left(\sqrt{\Phi^2 + \frac{HT}{2q}} - \Phi \right) \quad , \tag{4}$$

where Φ – total filtration resistance

$$\Phi = \frac{T_d}{\pi} \ln\left(\frac{2T_d}{\pi D} \right) + \frac{2h_0}{\pi} \ln \frac{4h_0}{\pi D} + \frac{T_d \Phi_0}{\pi} + \frac{2h_0}{\pi} \Phi_0 \ , \tag{5}$$

where D – outer diameter of the drainage, m;
Φ_0 – filtration resistance by the nature of the aquifer;
H – design head, m;
T – layer conductivity, $m^2 \cdot day^{-1}$;
q – intensity of infiltration supply, $m \cdot day^{-1}$.

Analyzing the relationship between the parameters of formulas (4) and (5), it is obtained

$$B = f(H_d; T_d; k_\Phi; a; \Phi_0; t; D) \;, \tag{6}$$

where H_d – depth from the soil surface to the drainage axis, m;
T_d – distance from the axis of the drain to the water confining stratum, m;
k_f – filtration coefficient, m·day^{-1};
a – drainage rate, m;
Φ_0 – filtration resistance by the nature of the aquifer;
t – duration of the groundwater level decrease;
D – outer diameter of the drainage, m.

The parameters t and D for each case are constant values. Other parameters of function (6) are by their nature random values, that is, they have variation over the area of the system.

Given formula (3) and functional dependence (6), the mean square value of the distances between the drains is

$$\sigma_B{}^2 = \left(\frac{\partial B}{\partial H_d}\sigma_{H_d}\right)^2 + \left(\frac{\partial B}{\partial k_\Phi}\sigma_{k_\Phi}\right)^2 + \left(\frac{\partial B}{\partial T_d}\sigma_{T_d}\right)^2 + \left(\frac{\partial B}{\partial a}\sigma_a\right)^2 + \left(\frac{\partial B}{\partial \Phi_{01}}\sigma_{\Phi_0}\right)^2 . \tag{7}$$

The analysis of the influence of the parameters of the indicators on the magnitude of the distances between the drains was performed by a machine experiment on variants that consider the following variable conditions:

- by the drainage rate a = 0.5; 0.6; 0.7; 0.8 m;
- by the duration of the groundwater level decrease t = 2; 4; 7; 10 days;
- by the filtration coefficient k_f = 0.5; 1.0 m·day^{-1};
- by the depth of drainage H_d = 1 m;
- distance from the axis of the drain to the water confining stratum T_d = 2 m.

Drainage from pottery tubes was considered. The outer diameter of the pipes is D = 0.055 m. Filtration supports Φ_0 = 1. The values and a number of intermediate values are indicated as follows:

$$\Pi_H = \left(\frac{\partial B}{\partial H_d}\sigma_{H_d}\right)^2; \Pi_k = \left(\frac{\partial B}{\partial k_f}\sigma_{k_f}\right)^2; \Pi_T = \left(\frac{\partial B}{\partial T_d}\sigma_{Td}\right)^2\;;\; \Pi_a = \left(\frac{\partial B}{\partial a}\sigma_a\right)^2; \Pi_\Phi = \left(\frac{\partial B}{\partial \Phi_0}\sigma_{\Phi_0}\right)^2 . \tag{8}$$

According to the results of the machine experiment, we constructed a histogram of the influence of natural and structural factors of drainage parameters on the magnitude of distances between the drains, which is shown in Fig. 3. The corresponding Π_i parameters in Figure 2 are presented as percentage from $\sigma_B{}^2$.

The above data show that the most influential parameter on the distance between the drains is the drainage rate, which specific gravity in $\sigma_B{}^2$ is 84-94 %. The value of the filtration coefficient is 2-4 %.

Thus, according to the research results it is determined that the drainage module, which characterizes the intensity of soil and territory drainage, is formed mainly from the values of the drainage rate, filtration coefficient and the time of excess water removing. It has a significant effect on the distance between the drains, which is 86-98 %.

Therefore, there is a need to study the question of conditions of formation and justification of drainage modules that affect drainage parameters, drainage of the territory, hydrological effect of drainage and the total cost of the drainage system in the design of its reconstruction and construction.

According to the analysis of literary sources and conducted researches, different methods and models for determining the drainage module are used in the drainage calculations. According to these models, they are determined by ***empirical***, ***analytical***, ***water-balance*** methods or adopted according to recommendations that do not meet modern requirements (A.M. Kostyakov, V.G. Heitman, H.A. Pysarov, A.M. Yangol, A.I.Ivitsky, R.A.Tumas, S.F.Averyanov, A.P.Likhasevich, A.Y. Oliynyk, V.L.Polyakov, M.A.Lazarchuk, L.F.Kozhushko, etc.).

The disadvantage of the empirical method of determining the drainage module is the approximate establishment of amendments that take into account the peculiarities of the natural conditions of the drainage object and the inability to consider the full range of variable weather and climatic conditions and possible settlement drainage modules.

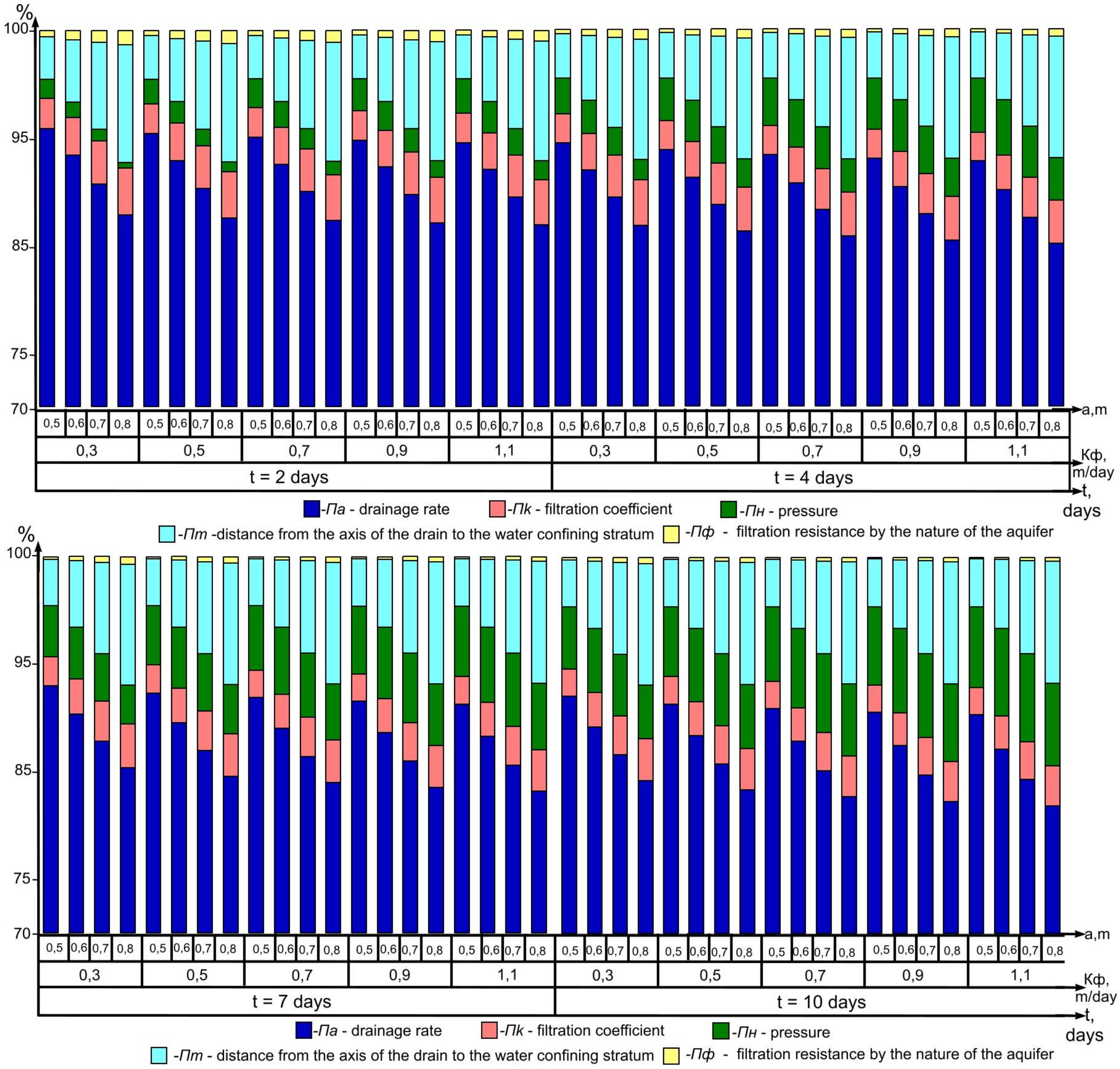

Fig. 2. **Histogram of influence of factors of drainage parameters on the distance between drains**

Scientists point to a methodological error that arises in the field determination of the drainage module. Due to the stochastic variability of soil properties and conditions of their moisture content, long-term observations of the water regime of drained lands and drainage rate are required to calculate the empirical values of the drainage module. For determination of drainage runoff of 5-20 % probability with accuracy not less than 20-25 % it is necessary to make observations for 15-20 years (by analogy with hydrological observations of river runoff). Such lengthy observations are time consuming and costly. In addition, there is usually no time and cost to organize such long-term observations when deploying land-reclamation work.

Later, the analytical method of determining the drainage module, based on determination of the amount of water discharged over a period of time, was given preference. This principle was the basis of the Silesian Instruction (1957).

At present, the best method is the water-balance method of estimating the drainage module, which equates to the average daily intensity (estimated probability) of infiltration inflow of water to the dehumidifiers.

Comparison of the calculated values of the drainage module with the observations showed a satisfactory result. At the same time, it was found that on objects with a soil filtration coefficient of more than 1 m·day^{-1} and deep water-confining stratum deposition, account should be taken of groundwater inflow from the territory (values of the drainage modules, determined by field observations, 10-15 % exceed the calculated values).

According to the generalized results of researches for the Polisia zone of Ukraine, when calculating the drainage parameters, the values of drainage modules were taken within: for mineral soils 0.4-0.6 l·s^{-1}·ha, for peat soils 0.2-0.5 l·s^{-1}·ha. The drainage parameters determined by the recommended values of the drainage modules take into account only the technological conditions of operation. However, the conditions of economic formation and the conditions of the ecological effect are not fully taken into account. That is, it is not economically and environmentally optimal for the calculation of drainage systems [3; 7].

The requirements for the forecasts are different for operated drainage and for projected drainage. These requirements depend on the natural depth of the groundwater, the degree of drainage of the soil, which is characterized by a drainage module.

The hydrological effect of the drainage and the degree of drainage of the soil can be considered as the natural or artificial intensity of drainage of water from the estimated layer of soil or a certain area and to evaluate it by the indicators and parameters of the corresponding values of the drainage module. Therefore, there is a need to consider not only the drainage, but the drainage system as a whole, when the drainage module reflects the drainage of the territory, taking into account the operation of channels and the wired network, climatic, hydrogeological, agro-technical, technological, technical, economic and environmental conditions, as well as species, values, productivity and profitability of cultivated crops [3; 7].

In order to accomplish this task, a scale machine experiment was planned and carried out. The experiment is based on a set of predictive-imitation models of basic structural and technological variable parameters of drainage systems, climatic conditions of the territory, water regime, technologies of water regulation (drainage) and productivity of the drained lands for schematized natural, agro-technical and reclamation conditions. The models were developed at the Department of Water Engineering and Water Technology at the National University of Water and Environmental Engineering. Their practical application is regulated by the relevant industry standards of the State Water Agency of Ukraine [3; 6; 7].

The machine experiment based on predictive-simulation modeling was performed under the conditions and averaged data of climate change (meteorological stations or posts in the West Polisia zone of totality $\{\omega\}$, $\omega = \overline{1, n_\omega}$; the periods calculated on the terms of heat and humidity of vegetation of the totality $\{p\}$, $p = \overline{1, n_p}$,very wet periods (p = 10 %), wet periods (p = 30 %), average-wet periods (p = 50 %), dry periods (p = 70 %), very dry periods (p = 90 %)); for the two main most common types of soil in the Polesia region of Ukraine: sod-gleyed sandy-loam soils (k_Φ = 0.8 m·day^{-1}) and peat soils (k_Φ = 0.4 m·day^{-1});crops of crop-rotation: winter wheat with yield (40 c·ha^{-1}), the share of crops in crop-rotation 0.2 %; potatoes (400 c·ha^{-1}), 0,3 %, perennial grasses (400 c·ha^{-1}) 0.5 %; water regulation methods of totality $\{s\}$, $s = \overline{1, n_s}$, (s = 1 – drainage).

Results and discussion

On the basis of predictive-simulation modeling, the variable character of the values of drainage runoff modules formed during the period of operation of the drainage system by crops, soils and years in the Western Polesia region of Ukraine was determined (Fig. 3).

Determined by the complex of forecasting-simulation models [3; 7], the dynamics and values of the weighted average drainage modules, which are presented in Fig. 2, show that for different weather and climatic conditions, when growing different crops on different soils, there is a significant change in their values over time and space.

In the sowing period of the accounting years, the values of drainage runoff modules for grain and perennial grasses for mineral soils are 0.40-0.62 l·s^{-1}·ha, and for peat soils – 0.74-0.96 l·s^{-1}·ha, respectively, for potatoes 0.40-0.62 l·s^{-1}·ha and 0.40-0.96 l·s^{-1}·ha.

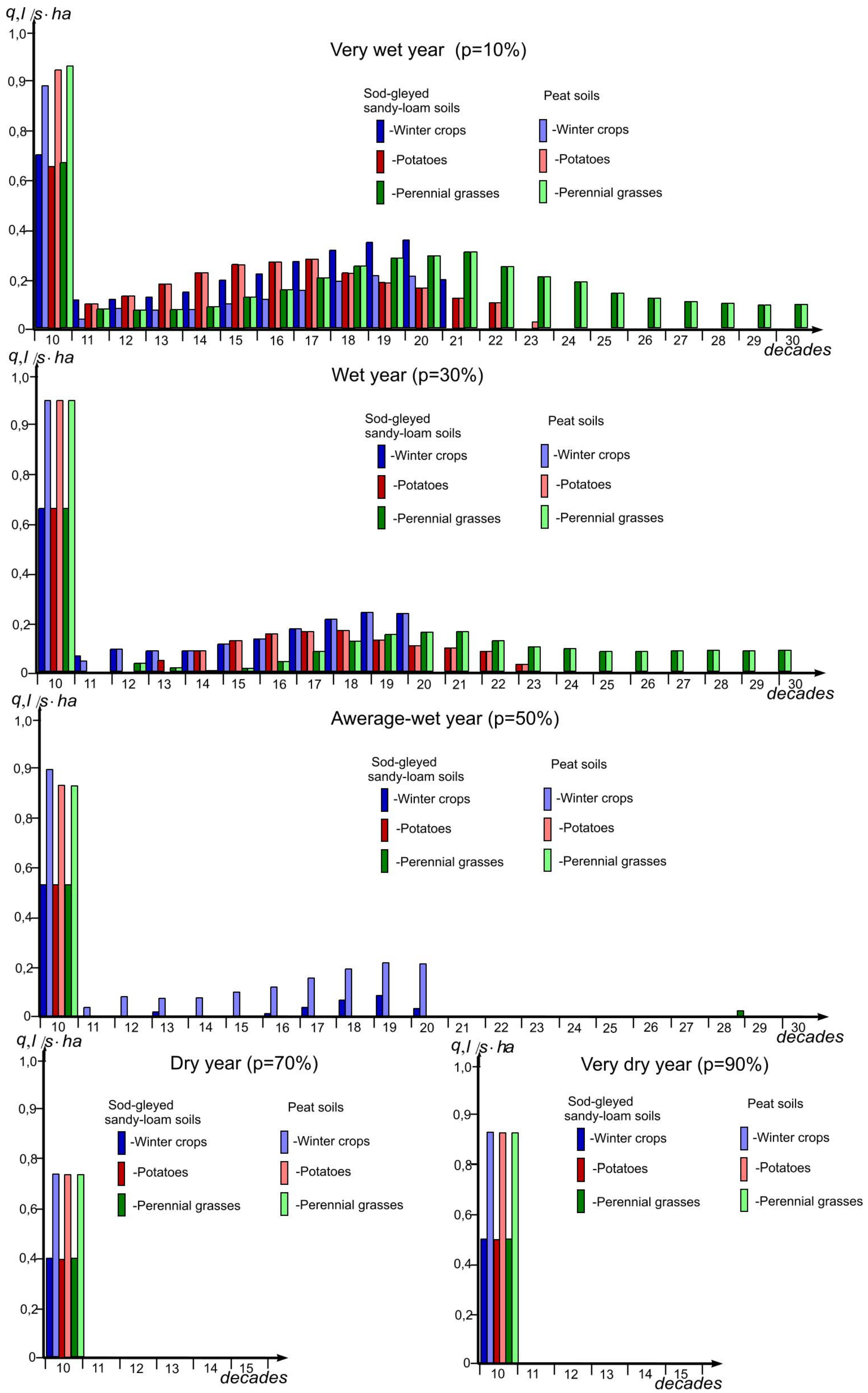

Fig. 3. **Values of weighted average drainage runoff modules that are formed during the period of operation of the drainage system for the main crops, for mineral and peat soils under changing climatic conditions of the Polesia region of Ukraine**

During the growing season, the dynamics and values of drainage modules are determined by the mode and intensity of rainfall by year, as well as the type of soil. Thus, for mineral soil the modules are 0.25-0.02 $l \cdot s^{-1} \cdot ha$; for peat soil – 0.30-0.015 $l \cdot s^{-1} \cdot ha$. Changes in the average values of drainage modules, which are formed during the period of operation of drainage systems in terms of changing climatic conditions and cultivated crops for sod-gleyed sandy soils and peat soils of the Polesia zone, are presented in Table 1.

Table 1

Generalized results on the variability of the average values of drainage modules, which are formed during the period of operation of drainage systems by variable weather-climatic, soil and agro-reclamation conditions of the Polesia region of Ukraine

Crops	Part of crops in crop-rotation	Calculated drainage modules, $l \cdot s^{-1} \cdot ha$					Weighted average values, $l \cdot s^{-1} \cdot ha$
		Calculated years with probability, p, %					
		10	30	50	70	90	
Mineral soils							
Winter crops	0.2	0.62-0.17 0.41	0.52-0.18 0.32	0.46-0.02 0.16	0.45-0 0.11	0.40-0 0.06	**0.41-0.03 0.21**
Potatoes	0.3	0.57-0.09 0.38	0.52-0.02 0.28	0.46-0.02 0.11	0.45-0 0.10	0.40-0 0.06	**0.41-0.01 0.19**
Perennial grasses	0.5	0.59-0.08 0.51	0.53-0.06 0.35	0.47-0.02 0.12	0.44-0 0.10	0.41-0 0.06	**0.42-0.01 0.23**
On the system as a whole	**1.0**	**0.59-0.10 0.45**	**0.52-0.06 0.32**	**0.47-0.02 0.12**	**0.44-0 0.10**	**0.41-0 0.06**	**0.48-0.03 0.21**
Peat soils							
Winter crops	0.2	0.96-0.17 0.46	0.86-0.18 0.39	0.81-0.02 0.25	0.75-0 0.18	0.74-0 0.11	**0.82-0.07 0.28**
Potatoes	0.3	0.92-0.09 0.43	0.86-0.02 0.35	0.84-0 0.20	0.81-0 0.18	0.74-0 0.12	**0.83-0.02 0.26**
Perennial grasses	0.5	0.93-0.08 0.56	0.86-0.06 0.42	0.84-0 0.20	0.81-0 0.18	0.74-0 0.12	**0.84-0.03 0.30**
On the system as a whole	**1.0**	**0.94-0.10 0.50**	**0.86-0.07 0.39**	**0.83-0.05 0.21**	**0.80-0 0.19**	**0.74-0 0.12**	**0.83-0.03 0.28**

Note: 0.62-0.17 - *maximum and minimum values of drainage modules*;
0.41 - *weighted average values of drainage modules.*

The results obtained indicate that the averaged values of the drainage module in the studied conditions, as in the previous calculation, have a variable nature with respect to the changing climatic conditions during the calculated years, the type of crops grown and the type of soil in time and space are significantly different from the calculated values.

Based on the processed simulation results, probability curves were constructed for averaged maximum values of drainage modules at the beginning of field work (Fig. 4).

The binomial curve of type III Pearson is most suitable as the distribution curve

$$y = y_m \cdot (1 + x / a)^{a/d} \cdot \exp(-x / d) \,, \tag{9}$$

where y – frequency values (ordinates of the distribution curve);
y_m – modular ordinate (highest frequency);
x – variable value of the hydrological characteristic under consideration (abscissa of the distribution curve);
d – radius of asymmetry (distance between the mode and center of distribution);
a – distance from the beginning of the distribution curve to the mode of distribution.

The values of the parameters a and d depend on the coefficient of variation C_v and the asymmetry coefficient C_S, which are shown in Table 2.

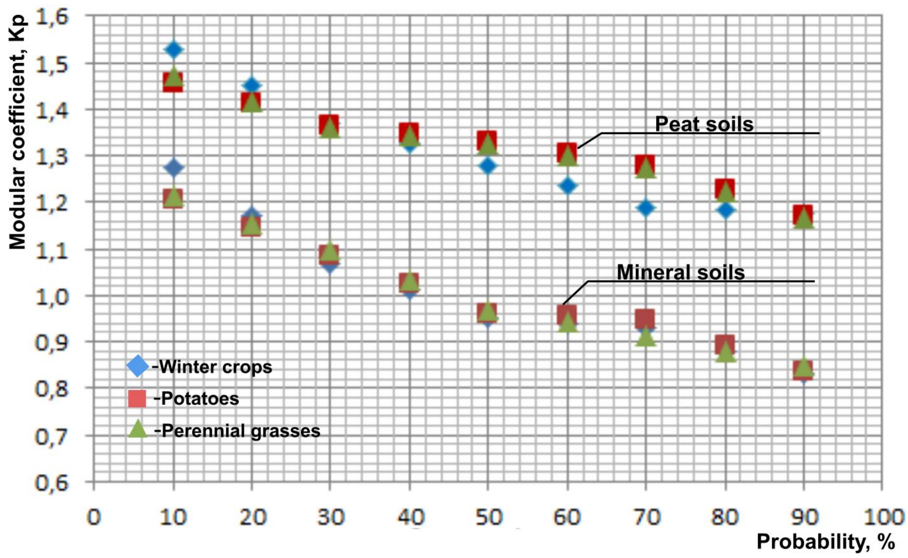

Fig. 4. **Probability curves of drainage module by main crops on mineral and peat soils**

Table 2

Characterization of variation C_v and asymmetry C_S for maximum values of drainage modules

Crops	**Coefficients of variation and asymmetry**	
	C_v	C_S
Winter crops	<u>0.17</u> 0.37	<u>1.34</u> 1.84
Potatoes	<u>0.14</u> 0.37	<u>0.68</u> 1.65
Perennial grasses	<u>0.15</u> 0.38	<u>0.87</u> 1.68

Note: <u>0,17</u> - *coefficients of variation and asymmetry for mineral soils*
0.37 - *coefficients of variation and asymmetry for peat soils*

This coincides with our regularities of distribution of basic climatic characteristics (precipitation, temperature, deficit of relative humidity) in the studied conditions and confirms the dependence of formation of drainage modules first of all on climatic factors [11; 18-20].

Conclusions

1. The territory of the European Polesia has a large area. It belongs to the hydrological zone of high humidity and is part of the territory of four neighbouring countries (Belarus, Ukraine, Poland and Russia). The developed drained territories perform an important role in agrarian production, ecology and modern socio-economic development of regions and countries.
2. Existing equations for calculation of distances between the drains are analyzed. The basic methods of calculating the parameters of agricultural drainage (hydromechanical, empirical) and methods of calculating the drainage modules (empirical, analytical, water-balance method) are presented.
3. The normalized probability curves of the drainage module for the main crops on mineral and peat soils are constructed. The results obtained indicate that the averaged values of the drainage module are variable under changing climatic conditions, types of crops and soil.
4. The results obtained show that the averaged values of the drainage module under the studied conditions, as in the previous case, have a variable nature of the changing climatic conditions during the calculated years, the type of crops grown and the type of soil. Its value differs from the maximum values and values during the growing season more than several times. All this must be taken into account designing projects for the reconstruction, construction and operation of such structures.

References

[1] Цуман Н.В. Оцінка ефективності сучасного використання осушених земель в зоні Полісся (Assessment of the efficiency of the modern use of drained land in the Polesie region Scientific and practical journal. Environmental sciences, 2014. No. 6, pp. 62-68. (In Ukrainian).

[2] X Chen, D Wang, M Chopra. Constructing comprehensive datasets for understanding human and climate change impacts on hydrologic cycle. Irrigation and Drainage systems Engineering, No. 2 (1), 106 p.

[3] Anatoliy Rokochinskiy, Pavlo Volk, Oleg Pinchuk, Vasyl Turcheniuk, Nadiia Frolenkova, Ievgenii Gerasimov. Forecasted estimation of the efficiency of agricultural drainage on drained lands. Journal of Water and Land Development, 2019, No. 40, Issue 1, pp. 149–153.

[4] Шевченко А.Л., Осадчий В.И., Нестеровский В.А. Режим, водообмен и ресурсы подземных вод Полесья и Лесостепи в контексте глобальных изменений климата (Regime, water exchange and groundwater resources of Polesie and Forest-Steppe in the context of global climate change). Actual problems of earth sciences. Studies of cross-border regions: collection of materials. IV International scientific-practical conf. (Sep 12-14, 2019, Brest), 2019, pp. 33-37 (In Russian)

[5] Peter Kovalenko, Anatoliy Rokochinskiy, Jerzy Jeznach, Pavlo Volk, Roman Koptyuk, Nataliia Prykhodko Evaluation of climate change in polissia region and ways of adaptation to it. Journal of Water and Land Development, 2019, Volume 41. Issue 1. pp. 72-82.

[6] Шкинкис Ц.Н. Гидрологическое действие дренажа (Hydrological effect of drainage). Leningrad. Gidrometeoizdat, 1981, 311 p. (In Russian).

[7] Шрейдер В.А. Осушение земель закрытым дренажем (Land drainage by closed drainage). Moscow: VNIITEISH, 1970, 8 p. (In Russian).

[8] Schilfgaaroe J. Drainage for agriculture. Wisconsin. USA: Puubl. Madison, 1974, 700 p.

[9] Вентцель Е.С. Теория вероятностей (Probability theory). Moscow: Nauka, 1969, 576 p. (In Russian).

[10] Маслов Б.С. Мелиорация и водное хозяйство (Land reclamation and water management). Drainage: Handbook. Moscow: Agropromizdat, 1985, 447 p. (In Russian).

[11] Rothe I. Strangentfernung bei Draungen. Landmirtshafliche Jahrbucher, 1924, 304 p.

[12] Костяков А.Н. Основы мелиорации (Fundamentals of Land Reclamation), Moscow: Selhozgis, 1960, 622 p. (In Russian).

[13] Янголь А.М. Рекомендации по увлажнению осушаемых земель (Humidification recommendations for drained lands). Kiev: Urogay, 1965, 88 p. (In Russian).

[14] Олейник А.Я., Поляков В.Л. Дренаж переувлажненных земель (Waterlogged land drainage). Kiev: Naukova dumka, 1987, 280 p. (In Russian).

[15] Rares Halbac-Cotoara-Zamfir, Ioana-Alina Costescu. Calculation of distance between drains in controlled regime. Research Journal of Agricultural Science, 42 (3), 2010. pp. 154-160.

[16] Науменко І.І. Надійність споруд гідромеліоративних систем (Reliability of structures of irrigation systems). Kiev: ISDO, 1994, 424 p. (In Ukrainian).

[17] Науменко І.І., Токар Л.О. Розрахунок віддалей між дренами осушувально-зволожувальних систем як функції випадкових величин (Calculation of distances between drains of dehumidification and humidification systems as a function of random variables). Hydro amelioration and hydraulic engineering. Collection of scientific works, 2001. No. 26. pp. 83-94. (In Ukrainian).

[18] Лихацевич А.П. Мелиорация земель Белоруси (Land reclamation of Belarus). Minsk: BelNIIMiL, 2001, 308 p. (In Russian).

[19] Гадзало Я.М., Сташук В.А., Рокочинський А.М. Меліорація та облаштування Українського Полісся (Reclamation and arrangement of Ukrainian Polesie). Herson: ALDI PLUS, 2017, 932 p. (In Ukrainian).

[20] Мажайский Ю.А., Рокочинский А.Н., Волчек А.А., Мешик О.П., Езнах Е. Природообустройство Полесья (Environmental management of Polesie). Ryazan: Meshcher.f-VNIIGiM them. A.N. Kostyakova, 2017, 902 p. (In Russian).

[21] A. Rokochinskiy, I. Korobiichuk, L. Kuzmych, P. Volk, A. Kuzmych. The system optimization of technical, technological and construction parameters of polder systems. Conference on Automation. Automation 2020: Towards Industry of the Future, 2020, pp 78-86.