Implementation of modern approaches to evaluating the effectiveness of innovation for water treatment in irrigation

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Abstract

The geographical location and climatic conditions of Ukraine cause the active development of land reclamation, as it enables to ensure stable and high yields. The complexity of forecasting in this area, namely the dependence of the results on the changing weather and climate conditions, does not allow to effectively use the standard instruments for justifying the investment for agricultural and land reclamation innovation.

The necessity of improving methodological approaches to evaluating the effectiveness of investments in projects in the field of agricultural production and land reclamation was substantiated. The proposed approaches were tested on the advanced technology of water treatment in irrigation based on using a vibrating gravitation filter enabling to perform simultaneously the processes of water treatment and filter element regeneration.

The obtained results clearly show that the advanced technology of irrigation water treatment and the developed for this technology design of the vibrating gravity filter are cost-effective. The current payback period for irrigation projects when using the purified water under this advanced technology is 5 years. It is the same as for the irrigation projects when using clean irrigation water.

Thus, our proposed approaches to the evaluation of investments in new water treatment technologies applied in irrigation enable to adapt the modern methodology of analysis of economic and investment efficiency of projects to the domestic needs of agricultural production, namely to take into account the impact of changing weather and climate conditions on the resulting economic parameters.

Key words: *economic efficiency, evaluation, investments, modern methodological approaches, vibrating filter, water treatment*

INTRODUCTION

Many years of ineffective reforms in Ukraine have caused our country's economy to develop disproportionately. Most of the investments, especially private ones, are realized in highly profitable areas with a quick payback period – trade, commerce, services. At the same time, from a long-term perspective, this situation could lead to the destruction of Ukraine's own production, which has long been considered an agrarian country with high potential.

One of the reasons of this situation is the stagnation of economic science in the agricultural sector at the level of the 90s, the lack of scientifically sound methodologies and tools for technical and economic analysis as well as evaluation of economic decisions. This does not motivate either private investors or government agencies to invest in

innovative technologies in agriculture and, in particular, in land reclamation.

The geographical location and climatic conditions of Ukraine cause the active development of land reclamation, as it enables to ensure stable and high yields. The complexity of forecasting in this area [BOICHENKO *et al.* 2000; OPENKO *et al.* 2019; ROKOCHYNSKIY *et al.* 2015; ROKOCHYNSKIY *et al.* 2019; ROMASHCHENKO *et al.* 2003; ROMASHCHENKO *et al.* 2007], namely the dependence of the results on the changing weather and climate conditions, does not allow to effectively use the standard instruments for justifying the investment for agricultural and land reclamation innovation. All-purpose methods require improvement and modification of accounting in the economic calculations of complex and changing meteorological and climatic conditions of functioning of each specific object, as well as certain features of technical structures and parameters of hydro land reclamation systems, their elements, technologies of water regulation, etc.

STUDY METHODS

Transformations of economic relations in Ukraine, the emergence of new sources of financing for investment projects and the need for greening modern production require the revision and improvement of traditional approaches to the selection of environmentally and economically optimal design decisions in the field of environmental management in general and water management (as its component) in particular.

Water-reclamation projects have certain features and differences from the investment projects carried out in other fields:

– primary dependence of the resulting ecological and economic effect on such environmental factor as weather and climatic conditions;
– use, in addition to material and labour, specific types of resources – natural (land, water, etc.);
– application of specific technology as a technology of water regulation of reclaimed land (system of engineering infrastructure objects, major reclamation funds, technological processes) and agrotechnics (system of basic agricultural funds, sowing methods, fertilization, etc. [SHEVCHENKO *et al.* 2017]).

The economic calculations of the above components will allow obtaining the most realistic results based on the fluctuations [OPENKO *et al.* 2017; OPENKO *et al.* 2019] in yield depending on weather and climatic conditions, object structure, water regulation technology, etc.

For this purpose we have developed scientifically grounded principles and approaches to the building and implementation of a complex of forecasting-optimization models. They allow justifying the optimal design solution for the construction, reconstruction and operation of water management and land reclamation facilities, taking into account the impact of meteorological conditions of each year on the formation of yields and, accordingly, all technical, environmental and economic indicators.

These models, methodological and information support for their implementation on the computer were developed in the research laboratory "Optimization and automation of management in water engineering and water technologies" of the National University of Water and Environmental Engineering, Rivne (Ukr. Natsional′nyy universytet vodnoho hospodarstva ta pryrodokorystuvannya). Their application in practice is regulated by the relevant industry standards of the State Agency for Water Resources of Ukraine (Ukr. Derzhavne ahentstvo vodnykh resursiv Ukrayiny).

The analysis shows the economic result of agricultural production on reclaimed land, current agricultural land reclamation costs, water costs, as well as possible losses are variable and depend on many factors. The main of which are the natural and climatic conditions of the object.

Due to the natural seasonal cyclicality of agricultural production on the reclaimed lands, there are different periods of vegetation, which are grouped in the calculated (typical) groups of years, in terms of heat and moisture supply. The distribution of these groups of years within the life cycle of the project is uneven and can be carried out with the help of a corresponding coefficient in the form of unit participation (manifestation probability) of the corresponding group of years within the total project implementation period $\{\alpha_P\}$, $P = 1$, m.

On the basis of generalization of our own research results, data of other authors and methodological data, we have determined the normalized values of the indicator by natural zones for drained lands, which take into account the zonal nature of changes in natural and climatic conditions [KOVALENKO *et al.* 2019; ROKOCHYNSKIY 2010; ROKOCHYNSKIY *et al.* 2008; ROKOCHYNSKIY *et al.* 2019].

We propose the methodological approaches we have tested at different waterworks facilities in different climatic zones. In particular, in recent years, the prevailing crop irrigation methods are sprinkling and drip irrigation for which water is used from open water bodies. The main problem regarding crop irrigation is that such irrigation water does not always meet the established quality standards.

In addition, ongoing climate change significantly deteriorates the quality of surface water and its availability both for drinking water supply and irrigation needs in agriculture. [KOVALENKO *et al.* 2019; ROKOCHYNSKIY *et al.* 2019].

The use of such water leads to clogging of the irrigation nozzles due to various impurities present in irrigation water, which in general has a negative impact on the efficiency of agricultural production (deterioration of irrigation equipment, reducing the efficiency of irrigation water use, reduced crop yields etc.).

RESULTS AND DISCUSSION

Analysis of generalized data on hydrochemical indicators of water (salt composition; physicochemical pollutants; mineral and organic substances) of the Dnieper River basin, obtained from the Central Geophysical Observatory (Ukr. Tsentral′na Heofizychna Observatoriya) named after Borys Sreznevsky showed that in recent years, the mineralization of water has practically not changed and averages $320 ... 650$ mg·dm^{-3}.

As for irrigation water, during the summer time, when there is intense bloom of blue-green algae in the water

source, the content of the suspended particles of biological origin in the pressure pipelines of the irrigation network can be from 50 to 200 mg·dm^{-3}.

This indicates a rather high content of pollutants and the need for appropriate measures to treat and prepare irrigation water.

The process of irrigation nozzles clogging is unpredictable. For today, the sprinkler nozzles are of a different design and differ significantly in technical characteristics. Due to the complexity of sprinkler nozzles design and the presence of pressure regulators, there are a number of problems resulting from the fact that individual solids can be trapped in the nozzle, blocking the passage of water and reducing its flow. The particles of the pollutant can be of different sizes and different nature of origin. Therefore, to improve the quality of irrigation water, additional treatment is recommended to be performed.

As practice and experience show, traditional and most widely used mesh filters installed on sprinkling machines do not cope with their task, especially during the period of water bloom in the warm summer season.

Based on the review and analysis of existing technical solutions for purification of water from different types of pollution, we concluded that it is advisable to use mesh filters with a moving filter element for the treatment of irrigation water.

To develop such an approach to water purification, we have improved the technology and developed the design of a vibrating gravity filter (Fig. 1) on the basis of sprinkler machine "Fregat", which enables to perform two processes simultaneously – water treatment and regeneration of the filter element [BILOKON *et al.* 2018; BILOKON *et al.* 2019].
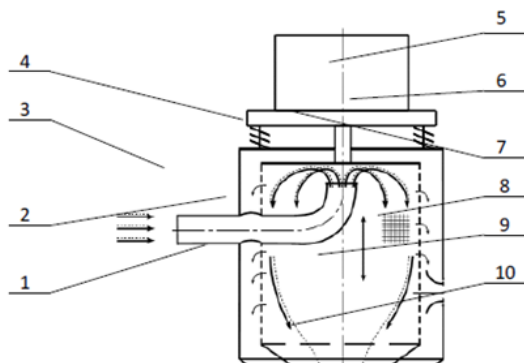

Fig. 1. Schematic diagram of vibrating gravity filter: *1* = filter housing; *2* = filter element; *3* = intake manifold; *4* = top plate; *5* = vibrator; *6* = shock absorbers; *7* = stock; *8* = infiltrate discharge manifold; *9* = wave reflection grid; *10* = sludge discharge manifold; source: own elaboration

Water, which contains suspended particles, passes through the working surface of the filter element *2*, in this case the mesh, and through the filtrate outlet *8* is fed into the pressure pipeline of the sprinkling machine. Suspended particles stuck on the filter element under their own mass and directional flow, fall into the lower part of the filter element, from where they fall through the sludge outlet *10* outside.

To determine the overall technological, economic and investment efficiency of the application of the advanced irrigation water treatment technology, we conducted studies based on a computer experiment, which was carried out for the conditions similar to the irrigation conditions in LLC "S-Rostok" of the Kherson region using sprinkler machine "Fregat".

The carried out experiment is based on the use of a complex of predictive-simulation models, which includes:
– model of changing climatic conditions of the territory;
– model of water regime and water regulation technology;
– crop yield model of cultivated crops on reclaimed land [KOVALENKO *et al.* 2019; ROKOCHYNSKIY *et al.* 2019].

As an example of evaluating the technological, economic and investment efficiency of the application of advanced irrigation water treatment technology, a computer experiment was performed, which is based on appropriate methodological, model and information support. The initial conditions of the performed computer experiment are the following data:
– region – Kherson;
– natural and climatic zone – steppe;
– estimated vegetation periods (very wet – $p = 10\%$, wet – $p = 30\%$, average – $p = 50\%$, dry – $p = 70\%$, very dry – $p = 90\%$);
– total cultivated crops and their share in the planning crop rotation (perennial grasses – 0.4; winter cereals – 0.2; vegetables – 0.2; corn – 0.2);
– soil permeability (loam, $k_{\varphi} = 0.4$ m·day^{-1});
– water regulation technologies (*SI* – sprinkling irrigation when using sprinkler machine "Fregat" with clean irrigation water; *SI*(75) – sprinkling irrigation when using sprinkler machine "Fregat" with the irrigation water with a calculated contamination rate $\rho = 75$ m·dm^{-3}; *SI*(*f*) – sprinkling irrigation when using sprinkler machine "Fregat" equipped with a vibrating gravity filter).

The overall scheme of the research of irrigation technological efficiency for basic crops under the considered conditions is presented in Table 1. There are some irrigation options when using the water of different contamination levels (ρ, mg·dm^{-3}) applying the irrigation rates (m, m^3·ha^{-1}), which depends on the quality of irrigation water. The proper values of irrigation rates were determined by using our developed forecasting and simulation models.

Table 1. System of the study of technological efficiency of irrigation by sprinkler machine "Fregat" on the lands of LLC "S-Rostock" in Kherson region

Rotation composition and structure	Irrigation rate (m, m^3·ha^{-1}) depending on water contamination rate (ρ, mg·dm^{-3})					
	$\rho = 0$	$\rho = 50$	$\rho = 75$	$\rho = 100$	$\rho = 150$	$\rho = 200$
Perennial grasses (green mass) – 40%	600	440	420	400	360	300
Vegetables (tomatoes) – 20%	540	400	380	360	350	300
Winter cereals (grain) – 20%	380	270	260	250	240	200
Maize (grain) – 20%	420	300	290	280	260	220

Source: own study.

It is established that different contamination rate of irrigation water leads to a decrease in the amount of actually used water compared to the calculated irrigation rates for each cultivated crop and crop rotation as a whole. Reducing the required amount of irrigation water does not contribute to the formation of a favourable water regime of soils, leads to an increase in unproductive costs and reduces the effectiveness of irrigation as a whole.

Based on the generalization of the simulation results, we constructed graphs that show the changes in the values of the main indicators of technological and economic efficiency in irrigation when using water of different contamination rate (Figs. 2–5).
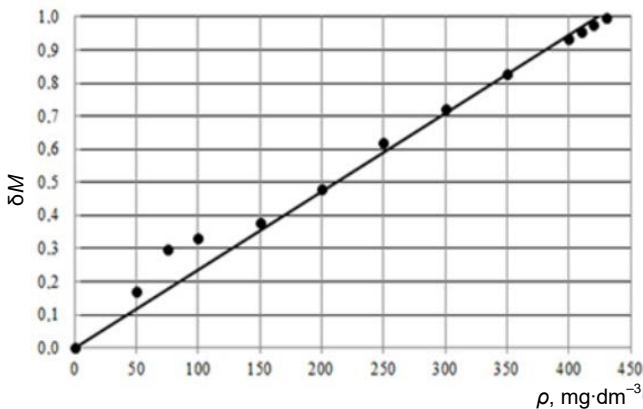

Fig. 2. Cross-plot of irrigation rate decrease (δM) versus the contamination rate of irrigation water (ρ, mg·dm^{-3}); source: own study
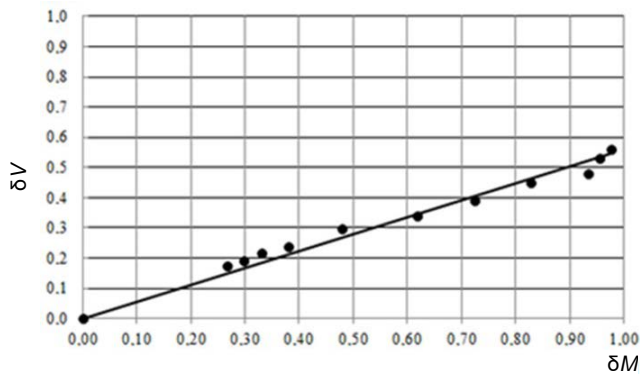

Fig. 3. Cross-plot of gross agricultural production decrease (δV) versus irrigation rate decrease (δM); source: own study

We also obtained calculated empirical dependences that esteem the nature and relationship between the main indicators of technological and economic efficiency and enable to predict their values when using water of different contamination rate for irrigation:
– dependence of irrigation rate on irrigation water contamination:

$$M = 4455.53 - 10.24\rho, \ r^2 = 0.8581 \qquad (1)$$

– dependence of gross crop production value on irrigation rate and contamination rate of irrigation water:

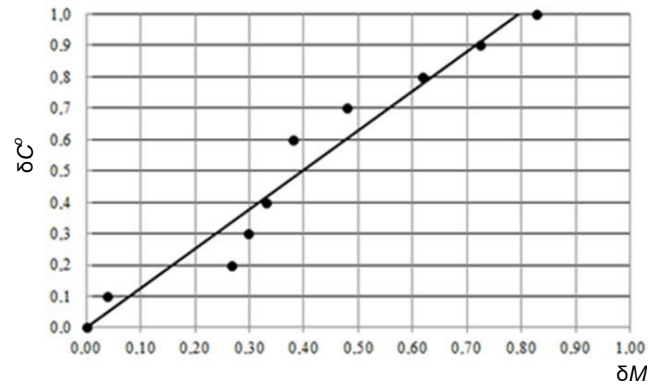$$V = \frac{\rho M}{3.39 + 0.04\rho - 0.0007M}, \ r^2 = 0.9649 \qquad (2)$$

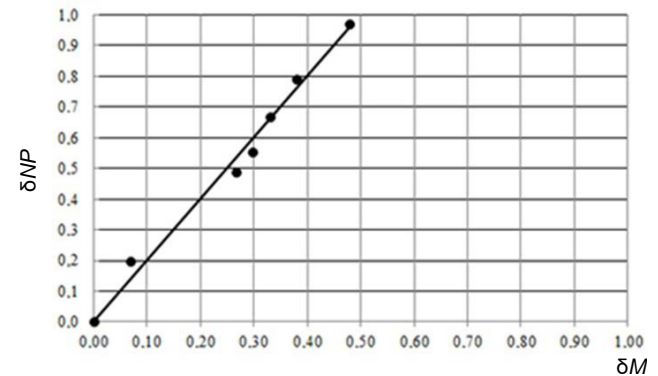Fig. 4. Cross-plot of operating costs increase (δC^o) versus irrigation rate decrease (δM)

Fig. 5. Cross-plot of net profit decrease (δNP) versus irrigation rate decrease (δM)

– dependence of operating costs on irrigation rate and contamination rate of irrigation water:

$$C^o = \frac{\rho M}{88.03 + 0.04\rho - 0.018M}, \ r^2 = 0.9660 \qquad (3)$$

– dependence of net profit on irrigation rate and contamination rate of irrigation water:

$$NP = \frac{\rho M}{-1729.58 + 7.84\rho + 0.34M}, \ r^2 = 0.6715 \qquad (4)$$

The obtained results enable to evaluate and predict the technological and economic efficiency of irrigation at different contamination rates of irrigation water.

Generalized characteristics and total values of the main economic components for the years of estimated heat and moisture supply for the considered options are presented in Table 2.

Based on the principles of modern economic and investment analysis of innovative projects, the selection of indicators and criteria for environmental and economic efficiency at each stage of assessment as well as the methods for their calculation should be made under the following basic conditions:

1. The goal of the project. It is well known that the goal determines the means. Therefore, the selected criteria and indicators of ecological and economic efficiency of water management and land reclamation projects first of all have to be consistent with the chosen goal of its functioning and, as a rule, the goals and interests of its participants.

2. Assessment stage. According to the modern principles of project and investment analysis, the choice of the best pro-

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Implementation of modern approaches to evaluating the effectiveness of innovation for water treatment in irrigation 123

Table 2. System of the study of technological efficiency of irrigation by sprinkler machine "Fregat" on the lands of LLC "S-Rostock" in Kherson region

Rotation composition and structure	Irrigation rate (m, m³·ha⁻¹) depending on water contamination rate (ρ, mg·dm⁻³)					
	$\rho = 0$	$\rho = 50$	$\rho = 75$	$\rho = 100$	$\rho = 150$	$\rho = 200$
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Maize (grain) – 20%	420	300	290	280	260	220

Source: own study.

ject decision is made in stages. That is why the assessment is also made in several stages and the selection of optimality and efficiency criterion depends on the calculation purposes at the appropriate stage of the assessment.

3. Project assessment scope. An environmental and management project can be evaluated at the national, sectorial, regional level or from the perspective of a specific producer, farm, investor or credit provider. Accordingly, the methods of calculating economic indicators will differ.

4. Available data base, availability and level of detail of the necessary data for ecological and economic calculations, the existence of certain conditions and restrictions.

5. Specifics of the calculation of environmental and economic indicators in the water management and land reclamation industry.

We have developed and tested the methodological bases of the ecological and economic assessment of design solutions in the water management industry, taking into account the design stage, features of financing, specifics of natural conditions effect on the results of economic activity.

According to FROLENKOVA *et al.* [2007], the decision making on the optimal design option (DO) when developing projects for construction and reconstruction of water management facilities should be done in two stages:
1) preliminary economic assessment of the optimal option;
2) investment assessment of the optimal design option.

As a criterion and condition of optimizing water regulation on irrigated and drained lands at the stage of construction and reconstruction of reclamation systems in view of the traditional optimization method, it is advisable to use a minimized indicator of the given costs ZP_0 taking into account weather and climatic risk [FROLENKOVA *et al.* 2007; FROLENKOVA, ROKOCHYNSKIY 2015].

$$ZP_0 = \min_i \left[\frac{\sum_{j=1}^{m}\left(C_{ij}^a + C_{ij}^o + A_i + E\,K_i + \overline{R_{ij}}\right)\alpha_{pj}}{\sum_{j=1}^{m} V_{ij}\alpha_{pj}} \right], i = \overline{1, n} \quad (5)$$

Where: C_{ij}^a = current agricultural production costs by the design options of the statistics population $\{i\}$, $i = \overline{1, n_i}$ by the population of the accounting years $\{j\}$, $j = \overline{1, n_j}$ within the project lifetime of the facility, $\sum_{j=1}^{m} \alpha_{pj} = 1$; C_j^o = corresponding value of current operating costs for obtaining products by the design options; A_i = depreciation costs by the design options; α_{pj} = coefficient, which takes into ac-

count the impact of changing weather and climatic conditions by the population of the accounting years $\{j\}$, $j = \overline{1, n_j}$ within the project lifetime of the facility; E = normative coefficient of economic efficiency of capital investments K_i by the respective variants of design options; V_{ij} = corresponding value of the volume of production by the i-th project option; R_{ij} = corresponding value of weather and climatic risk.

Weather and climate risk is an indicator that reflects the rate of yield loss in a maximum potential yield under the most favourable natural conditions within a reclamation facility [FROLENKOVA *et al.* 2007; FROLENKOVA, ROKOCHYNSKIY 2015].

Obviously, this approach, unlike the traditional one, focuses on the selection of such design options, where the costs and losses caused by the negative impact of environmental factors are balanced in an acceptable proportion, and enables to select more technologically advanced water regulation technology. In addition, such technologies ensure the environmental sustainability of the territory and the rational use of natural resources.

The investment evaluation of the optimal project option is performed by the main indicators used in the calculation of the investment attractiveness of the land reclamation project:
– net discounted profit (*NPV*),
– profitability index (*PI*),
– discounted payback period (*DPP*)
– internal rate of return (*IRR*) of investments [BIERMAN, SMIDT (eds.) 2006; FROLENKOVA *et al.* 2007; HAKA 2006; MARTYN *et al.* 2019; OPENKO *et al.* 2020]:

$$PI_0 = \max_{\{i\}} \sum_{j=1}^{m} PI_{ij}\alpha_{pj}, i = \overline{1, n} \quad (6)$$

Provided that

$$\begin{cases} NPV_i \geq 0 \\ IRR_i \geq d_i \\ DPP_i \leq T \end{cases} \quad (7)$$

Where: d_i = discount rate for the project; T = discounted investment payback period acceptable for the investor.

The discount rate is an indicator that is still controversial and there are no conventional approaches to its determination yet. In economic theory, for social calculations it is proposed to use the following: social discount rate, National Bank's discount rate, GDP rate, capital cost of an enterprise, etc. Therefore, in our calculations the average discount rate of the National Bank of Ukraine is used.

Each of the indicators included in the overall model, in turn, is calculated taking into account the variability of weather and climatic conditions and their impact on the main economic parameters.

$$PI_i = \frac{\sum_{t=0}^{T} \frac{E_{ai}}{(1+d_{it})^t}}{\sum_{t=0}^{T} \frac{I_{it}}{(1+d_{it})^t}} + 1, i = \overline{1, n} \quad (8)$$

Where: E_{ai} = annual economic effect for each option of water management and reclamation project, which is calculated by the formula

$$E_{ai} = \sum_{j=1}^{m} \Delta NI_{ij}\alpha_{pj} + \Delta A_i - I_i, i = \overline{1,n} \qquad (9)$$

where: I = the annual amount of investments; ΔNI = increase in annual projected net profit as a result of the investment project realization; ΔA = increase in annual depreciation due to the introduction of new fixed assets.

Other components of the model are similarly calculated.

When using techniques that have become widespread in market economies, it must be borne in mind that they are primarily designed for the conditions of a stable economy, therefore their direct application without taking into account the features of the domestic economy may lead to significant errors in the calculations or it may be impossible to apply them at all due to the lack of the necessary mechanism and information base for their implementation.

Generalized results on the evaluation of economic and investment efficiency by the relevant indicators, criteria and methods, according to FROLENKOVA *et al.* [2007], BIERMAN, SMIDT (eds.) [2006] and HAKA [2006], for the considered options of water regulation technologies, are presented in Table 3.

Table 3. Main indicators of economic and investment efficiency by the studied options

Indicator	Options of water regulation technology		
	SI	SI(75)	SI(f)
Comparative economic efficiency			
Weather and climate risk (USD·ha⁻¹)	337.28	406.52	337.28
Indicator of represented costs with regard to weather and climate risk	1.50	1.78	1.51
Investment efficiency			
Investment return index	2.24	1.60	2.18
Net discounted profit (USD·ha⁻¹)	712.68	342.80	691.64
Discounted payback period (years)	5	8	5

Source: own study.

CONCLUSIONS

The obtained results clearly show that the advanced technology of irrigation water treatment and the developed for this technology design of the vibrating gravity filter are cost-effective. The current payback period for irrigation projects when using the purified water under this advanced technology is 5 years. It is the same as for the irrigation projects when using clean irrigation water.

Thus, our proposed approaches to the evaluation of investments in new water treatment technologies applied in irrigation enable to adapt the modern methodology of analysis of economic and investment efficiency of projects to the domestic needs of agricultural production, namely to take into account the impact of changing weather and climate conditions on the resulting economic parameters.

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Implementation of modern approaches to evaluating the effectiveness of innovation for water treatment in irrigation   125

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