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METHODS FOR DETERMINING EXPENSES OF HORIZONTAL DRAINAGE UNDER PRODUCTION CONDITIONS

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Abstract

Currently horizontal drainage is a key ecological reclamation measure aimed at regulating water and salt regimes of soils, especially under conditions of irrigated agro-landscapes. Taking this measure becomes especially important under conditions of global and regional climate change. The operating conditions for horizontal drainage have changed resulting in changes in its efficiency. It is especially important for durable drainage, when its efficiency decreases it could even stop functioning. It requires a considerable number of research activities, but very few Ukrainian farmers can carry out monitoring research on the performance of horizontal drainage, constructed on their plots. It prevents from finding out negative aspects in horizontal drainage in time and taking appropriate measures. These difficulties can be avoided in case of using the developed and approbated methodology of recovering a number of horizontal drainage expenses through expenses of the research plots, determining the performance of horizontal drainage by these results and developing appropriate ecological reclamation measures to increase productivity of irrigated drained agro-landscapes.

Key words: *horizontal drainage, drainage outflow, methods for recovering expenses.*

INTRODUCTION

Land reclamation in the modern context is a system of economic organizational and technical measures, aimed at comprehensive improvement of lands to create the most favorable conditions for agricultural development or general improvement of a territory. There are hydro-technical, agro-technical, forest-engineering, chemical measures and land clearing operations depending on the operating conditions and their effect on plants and soil (Lavrenko et al., 2014).

Changing water and air regime of soil, agricultural hydro-technical reclamation (irrigation, watering and drainage) has the most considerable impact on improving environmental conditions. With this aim, large and small irrigation and drainage canals, pipelines and chutes, storage reservoirs and dams are constructed. Implementing hydro-technical reclamations is associated with considerable investments therefore it requires technical and economic argumentation. The highest efficiency of reclamation is achieved while using a complex of measures when irrigation is combined with drainage and drainage is accompanied by periodical land irrigation (Beauchamp, 1987; Bueno et al., 2020; Doke et al., 2020; Helmers, 2016; Panuska, 2015; Schwab & Fouss, 1999; Shakya & Singh, 2010; Zinkernagel et al., 2020).

A similar situation is examined in the studies of many other scientists (Bueno et al., 2020; Doke et al., 2020; Mahapatra et al., 2020; Wahba & Amer, 2017; Wojewodzic et al., 2020; Zucker & Brown, 1998). Such a balanced approach allows applying drainage water to irrigate agricultural crops (corn, rice etc.) systematically and efficiently, using natural resources more effectively. This approach requires additional financial resources to support the performance, maintenance and updating of the system of drainage operation (Dementieva & Lavrenko, 2017; Dementieva & Lavrenko, 2018; Dementieva & Lavrenko, 2018; Lavrenko et al., 2019; Lavrenko et al., 2019; Lykhovyd et al., 2019; Ushkarenko et al., 2018).

While using drainage systems it is important to maintain them. The research conducted in a tile-drained field in Harrow, Ontario from June 2008 to December 2011 shows that the application of Simultaneous Heat and Water (SHAW) model to improve its hydrological responses to cold climates makes it possible to evaluate drainage performance and its impact on productivity of agricultural crops accurately with error within 15%, Nash-Sutcliffe model efficiency coefficient (NSE) > 0.5 and the index of agreement (IoA) > 0.75 (Qianjing et al., 2020).

Considering infiltration processes and the impact of polluted groundwater, inefficient land use, vegetation cover and agro-physical soil properties is also an important element for efficient use of drainage systems (Mahapatra et al., 2020).

Currently the efficiency of reclamation systems has decreased considerably. The reason for this phenomenon is a great number of factors, the first of them being out-of-date systems. A large number of mistakes have been found out in the process of exploitation and the need of correcting them may cause considerable financial expenses (Balyuk & Romashchenko, 2006; Golovanov et al., 2011).

Nowadays designing and using the systems of agricultural modeling is a main factor for analyzing the problem and assessment of quantitative impact of management methods in agricultural production. The application of such methods allows obtaining quick information to determine the most efficient management method (Singh et al., 2020).

Restoration and professional application of drainage will allow using land resources efficiently, taking reclamation measures (irrigation, drainage) effectively, perform soil desalinization, minimizing the risk of polluting groundwater (Luthin, 1957; Savchuk et al., 1992; Zinkernagel et al., 2020).

Currently, taking into account the economic condition of farms, agro-ecological conditions and institutional factors, scientists think that it is necessary to stimulate commodity producers in making decisions, ensuring appropriate management of land resources to increase agro-ecological sustainable agricultural production (Abera et al., 2020).

In Ukraine, whose considerable part is located in the zones of unsteady and insufficient moisture, the largest area (2.6 million ha) was occupied by irrigated lands at the beginning of the 90s in the past century, making 8% of the tilled soil area. At that time the real productivity corresponded to its planned level for almost 80% of the irrigated lands, and crop production was up to 30% of its gross production in Ukraine, and irrigated lands played the role of a peculiar insurance fund in food supply of the country, especially in dry years because of a high level of their exploitation.

Irrigation against the background of horizontal drainage is an obligatory factor of maintaining soil fertility on territories without outflows and poorly drained territories, including the South of Ukraine. A reliable method for preventing secondary soil salinization is closed horizontal drainage. Engineering drainage must provide optimal water and salt regimes and the balance of both irrigated land and surrounding landscape. The character and intensity of changes in hydrogeological ecological reclamation condition of irrigated lands of Ukraine prove the necessity of permanent control over ecological reclamation condition of irrigated lands, including reclamation efficiency of horizontal drainage. However, the regime of horizontal drainage operation has changed. Its performance is considerably affected by regional climate change. It requires permanent monitoring research that is ignored under present production conditions, there are time intervals when the efficiency of horizontal drainage operation has not been evaluated. The emergence of this problem explains the topicality of the research given below.

Under conditions of arid climate in the South of Ukraine, closed horizontal drainage is a necessary measure to prevent salinization of both irrigated lands and the adjacent dry lands on irrigated territories with poor natural drainage. When there is a lack of drainage under the water table of 1.5-2.0 m and its mineralization of 5-20 g/dm^3 within the aeration area in the course of 10 and more years of irrigation under conditions of the South of Ukraine, salts accumulate up to 20-100 t/ha (Tupitsin et al., 1987), causing an increase in the amount of secondarily salinized soils.

The regime of closed horizontal drainage operation depends on the degree of soil salinization, the type of an agricultural crop and the availability of irrigation. Mineralization of drainage water depends on the value of drainage outflow, caused by infiltration feeding from irrigation and precipitation, soil salinization in the aeration zone that changes in the course of time, mineralization of groundwater that is the most stable factor.

The main indicator of reclamation efficiency of horizontal drainage is drainage outflow. However, when the lands are shared and there are changes in land owners, not every land owner (or a farmer) is able to continue monitoring research with respect to the performance of horizontal drainage, constructed on their production plots (PP). It, in its turn, allows identifying negative aspects in drainage operation in time and taking appropriate measures.

It can be avoided at certain stages of agro-landscape development, when using the developed and approbated methodology of recovering a number of horizontal drainage expenses through expenses of research plots (RP) and determining the performance of horizontal drainage by these results and taking appropriate ecological reclamation measures to increase productivity of irrigated drained agro-landscapes.

The research purposes. To determine monthly and annual expenses of horizontal drainage empirically on the basis of modeling hydrographs of drainage outflow by selected data.

MATERIALS AND METHODS

In order to conduct our research, we chose and equipped research plots with well-known history. The main research method was a complex field agricultural experiment of many years. The undrained and drained territories are characterized by general direction of groundwater rises and falls in different periods of a year, but the height of rises and the duration of water table position at certain depth are different. It requires a comprehensive approach to choosing research plots. Research objects are located within Kherson (Henichesk district) and Crimean (Dzhankoi district) Prysyvashshia, the Right Bank (Chaplynka district) and the Left Bank (Bilozerka district) of the Dnipro within Kherson region and are typical by the generally accepted methods (Figure 1).

The regime of groundwater on all the research plots with horizontal drainage by a genetic type, according to the world-famous and generally accepted classification by Katz D.M. (Katz, 1976), is referred to the irrigation-climatic group and characterized by mainly one peak and one fall per year. The lack of outflows on the most research territories shows that this territory is hardly suitable for irrigation without additional measures (drainage), because it is potentially dangerous in terms of flooding. The research plots are located in the zone of moderately hot, arid climate. Dark chestnut and chestnut soils comprise the main fund of farmlands, prevailing on the research territory.

Figure 1. The scheme of the location of the research plots with horizontal drainage: 1 - Henichesk district, Pavlivka; 2 - Dzhankoi district of Crimea, Aprelivka village; 3 - Chaplynka district, Strohanivka; 4 - Bilozerka district, Stanislav

The research on irrigated and drained plots covers a wide range of issues: water and salt processes in soils, improvement of drain construction elements, soil desalinization, determination of optimal parameters of drainage, reclamation efficiency of drainage, productivity of agricultural crops.

Drainage outflow, being one of the main components of water balance on a drained territory and an indicator of reclamation efficiency of horizontal drainage, has been examined on the research plots with the drain spacing of 240 m, 300 m and 400 m under the equal drain depth of 3 m.

Drainage outflow and its dynamics were determined by the data on measuring drain expenses with a volume method in wellhead that were performed with three replications every decade (on the 10^{th}, 20^{th}, and 30^{th} days of every month) and additionally in a day and in three days after each irrigation over a drain or after substantial (more than 20 mm) rain. Using the measurement data, we determined water expenses and modules of drainage outflow for

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typical periods of drainage operation by months and periods of the year.

The research was conducted on the territory of Kherson Prysyvashshia (Henichesk district) with the following approbation on other RP. The error of the complex research did not exceed 3.0-4.3%.

Irrigation on all the research plots was performed using the closed internal network DMF-К «Frehat», «Western Irrigation», Zimmatic 434M.

The main method used in the research was an approximation method with the following interpolation of the desired values on the basis of the analysis of the hydrographs of drainage outflow.

RESULTS AND DISCUSSIONS

The main preconditions for developing the methodology were the basic characteristics of drainage outflow and the factors affecting its changes.

It is well-known that drainage outflow depends on groundwater head between drains (Duplyak et al., 1992; Oleynik, 1981; Savchuk et al., 1992) and, at the same time, it affects changes in water tables as a result of water-diversion purpose of drainage.

The analysis of drainage outflow on each research plot with different drain spacing shows that there was a decrease in its value on all the plots in 2009-2019.

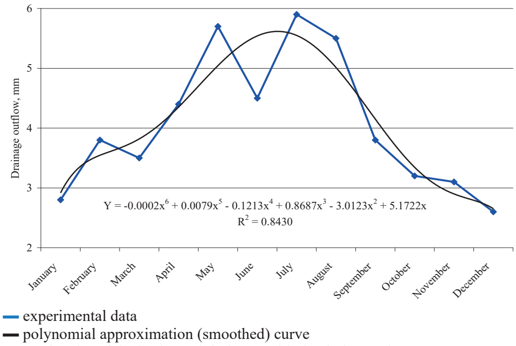
As the research shows, the change in drainage outflow (and the module of drainage outflow) does not depend on the amount of precipitation in the years of the research, but it mainly depends on irrigation norm and the location of water tables. The provision (P, %) of the annul amount of precipitation in Kherson Prysyvashshia in the research period varies considerably from P = 96.0% in 2011 to P = 12% in 2019.

The calculated value of drainage outflow for a closed internal irrigation network is 0.040-0.045 l/s from 1 ha. On the whole, the module of drainage outflow for the research zone is a value varying considerably from 0.05 to 0.25 l/s from 1 ha.

The annual outflow of drainage water is 10–15% of the total water intake of irrigation water from a source of irrigation. The maximum of outflow coincides with the total rise of water tables in the regions and makes 30-40% of the annual drainage outflow. Annually from 700 to 2000 m^3 is taken from 1 hectare.

The analysis of the modules of drainage outflows for each research plot with different drain spacing shows that the direction of changes in the modules of drainage outflow on the research plots with B = 240 m and B = 400 m coincides, however, the value of the module of drainage outflow on the plot with B = 400 m is 2.0 times higher than on the plot with B = 240 m.

These research plots are characterized by a decrease in the value of the module of drainage outflow in the second period of the research by 2.4 times with its following stabilization. The value of the module of drainage outflow is almost unchangeable - 0.038 l/s from 1 ha on the research plot with B = 300 m in the research period (Figures 2 to 9).



Note: the plot of the horizontal drainage with the drain spacing a - B = 240 m.

Figure 2. Hydrograph of drainage outflow for a calendar year on the research plots with horizontal drainage (the average for 2016-2019)

The analysis of drainage outflow on each research plot with different drain spacing shows that there was a decrease in its value on all the plots in the course of 10 years.

Maximum values of the module of drainage outflow (l/s from 1 ha) and drainage outflow (mm) for all the drains under study were characteristic of the year with much precipitation (the beginning of the research – by the efficiency of the horizontal drainage performance), and minimum values were recorded in the last period of the research - 2016-2019.

For the period of 2016-2019, in order to examine the distribution of drainage outflow, corresponding hydrographs were created (Figures 2 to 9)

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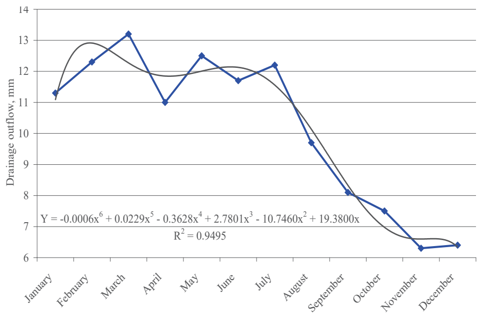
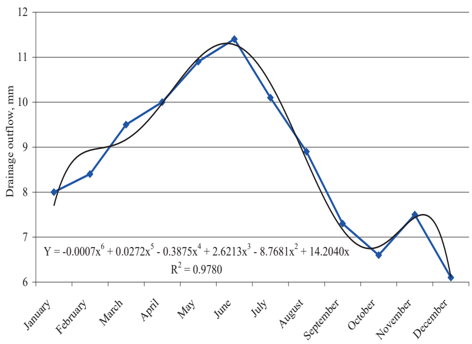
(the research was conducted under the following conditions: 2016 - large amount of precipitation, 2017 - medium amount of precipitation; 2018 - small amount of precipitation; 2019 - large amount of precipitation).

The hydrographs were created by taking into consideration a calendar year (the 1st-12th months) and a hydrological year (the 9th-3rd months) of the distribution of drainage outflow.



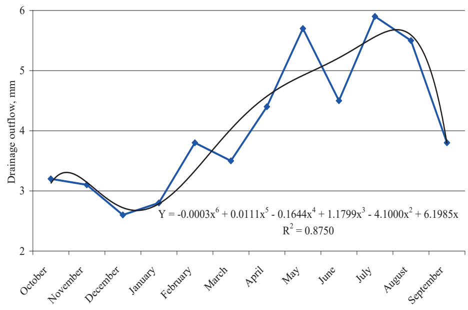
— experimental data
— polynomial approximation (smoothed) curve
Note: the plot of the horizontal drainage with the drain spacing a - B = 300 m.

Figure 3. Hydrograph of drainage outflow for a calendar year on the research plots with horizontal drainage (the average for 2016-2019)



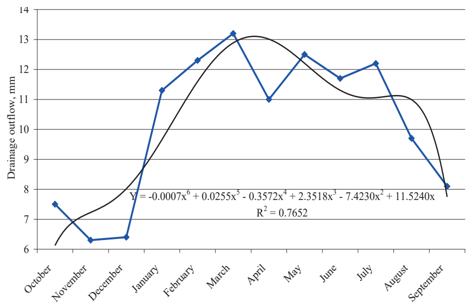
— experimental data;
— polynomial approximation (smoothed) curve
Note: the plot of the horizontal drainage with the drain spacing a - B = 400 m

Figure 4. Hydrograph of drainage outflow for a calendar year on the research plots with horizontal drainage (the average for 2016-2019)



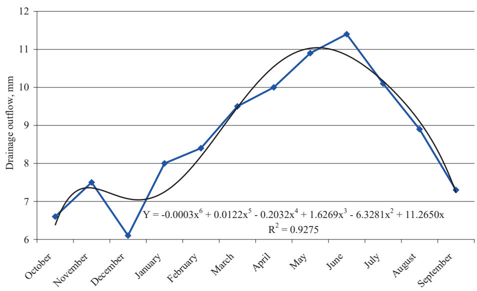
— experimental data
— polynomial approximation (smoothed) curve
Note: the plot of the horizontal drainage with the drain spacing a - B = 240 m.

Figure 5. Hydrograph of drainage outflow for a hydrological year on the research plots with horizontal drainage (the average for 2016-2019)



— experimental data;
— polynomial approximation (smoothed) curve
Note: the plot of the horizontal drainage with the drain spacing a - B = 300 m

Figure 6. Hydrograph of drainage outflow for a hydrological year on the research plots with horizontal drainage (the average for 2016-2019)



— experimental data;
— polynomial approximation (smoothed) curve
Note: the plot of the horizontal drainage with the drain spacing a - B = 400 m

Figure 7. Hydrograph of drainage outflow for a hydrological year on the research plots with horizontal drainage (the average for 2016-2019)

When analyzing the drainage outflow, we used an approximation method with the following drawing a trend line and determining the value of approximation reliability (R^2). The polynomial trend line proved to be of the highest quality. The obtained results for determining the approximation reliability value for the hydrographs of drainage outflow with different drain spacing for the hydrological and calendar years are presented in Table 1.

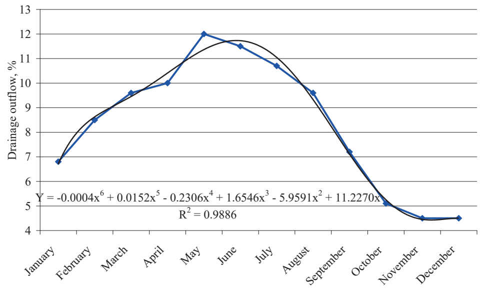
Table 1. Values of approximation reliability (R^2) for hydrographs of drainage outflow with different drain spacing for hydrological and calendar years

Years	Drain spacing, m					
	240		300		400	
	Hydrological year	Calendar year	Hydrological year	Calendar year	Hydrological year	Calendar year
2016	0.779	0.730	0.782	0.964	0.947	0.943
2017	0.883	0.923	0.907	0.881	0.651	0.932
2018	0.441	0.324	0.426	0.796	0.963	0.960
2019	0.755	0.841	0.862	0.982	0.972	0.978
The average	0.875	0.843	0.765	0.950	0.928	0.978

On the plots with the drain spacing of 240 m there is uneven distribution of drainage outflow during both hydrological and calendar years (R^2=0.324-0.923), indicating to inhomogenous drainage outflow, especially in the first years after construction. On the plots with the drain spacing of 300 m there is uneven drainage outflow for the hydrological year (R^2 = 0.426-0.907) and an increase in its uniformity for the calendar year (R^2 = 0.796-0.982). On the plots with the drain spacing of 400 m there is an increase in its uniformity for the hydrological year (R^2 = 0.651-0.972) and the distribution is almost uniform for the calendar year (R^2 = 0.932-0.978).

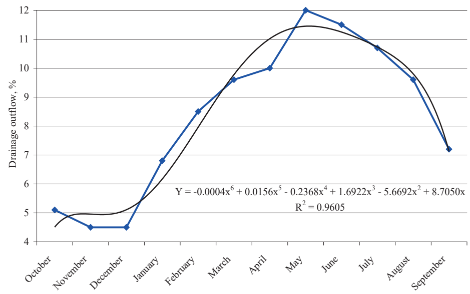
It is confirmed by the comparison of hydrographs of drainage outflow for calendar and hydrological years on the research territory (Figures 8 and 9).

Thus, with an increase in drain spacing, drainage outflow, despite different amount of precipitation in the years of the research, becomes more uniform and determining the distribution of drainage outflow under conditions of a calendar year becomes the most topical task in order to solve the research problem.



experimental data;
polynomial approximation (smoothed) curve

Figure 8. Hydrograph of drainage outflow for a calendar year for the research territory with horizontal drainage



experimental data;
polynomial approximation (smoothed) curve

Figure 9. Hydrograph of drainage outflow for a hydrological year for the research territory with horizontal drainage (the average for 2016-2019)

Therefore, the hydrograph of drainage outflow characterizing the average percent distribution of drainage outflow in the course of a year can be used for ascertaining the value of drainage outflow in the field production crop rotations for a certain period of time by its selective measurements.

Further the research problem is solved with interpolating the desired values using the following correlations.

1. Recovering annual expense

1.1. A direct problem. Annual expense is determined by the correlation 2:

$$Q_{PP} = \sum_{i=1}^{n=11} q_X^{PP} + \sum_{i=1}^{n=11} q_i^{PP} \quad (1)$$

$$\frac{\sum_{i=1}^{n=12} q_i^{RP}}{\sum_{i=1}^{n=11} q_i^{PP}} = \frac{\sum_{i=1}^{n=12} q_X^{RP}}{\sum_{i=1}^{n=11} q_X^{PP}} \quad (2)$$

where:

- Q_{PP} - the annual expense on the production plot;

- $\sum_{i=1}^{n=11} q_i^{PP}$ - the sum of known monthly expenses on the production plots (PP);
- $\sum_{i=1}^{n=11} q_X^{PP}$ - the sum of unknown monthly expenses on the PP;
- $\sum_{i=1}^{n=12} q_X^{RP}$ - the sum of monthly expenses of the RP with the indexes corresponding to the indexes of unknown monthly expenses on the PP;
- $\sum_{i=1}^{n=12} q_i^{RP}$ - the sum of monthly expenses of the RP with the indexes corresponding to the indexes of known monthly expenses on the PP.

The correlation (1) results in:

$$\sum_{i=1}^{n=11} q_X^{PP} = \frac{\sum_{i=1}^{n=11} q_i^{PP} * \sum_{i=1}^{n=12} q_X^{RP}}{\sum_{i=1}^{n=12} q_i^{RP}}$$

Therefore:

$$Q_{ВД} = \sum_{i=1}^{n=11} q_X^{PP} + \sum_{i=1}^{n=11} q_i^{PP}.$$

1.2. An indirect problem. Annual expense is determined by the correlation 3:

$$\frac{\langle Q^{RP} - \sum_{i=1}^{n=12} q_i^{RP} \rangle}{\langle Q^{PP} - \sum_{i=1}^{n=11} q_i^{PP} \rangle} = \frac{\sum_{i=1}^{n=12} q_i^{RP}}{\sum_{i=1}^{n=11} q_i^{PP}}$$

Consequently,

$$Q^{PP} = \frac{\langle Q^{RP} - \sum_{i=1}^{n=12} q_i^{RP} \rangle * \sum_{i=1}^{n=11} q_i^{PP}}{\sum_{i=1}^{n=12} q_i^{RP}} + \sum_{i=1}^{n=11} q_i^{PP} \quad (3)$$

2. Recovering a number of monthly expenses

Having a number of these expenses of the RP and some monthly expenses of the PP, we can determine monthly expenses of the PP by the correlation 4:

$$x_n = \frac{\langle Q^{PP} - \sum_{i=1}^{n=11} q_i^{PP} \rangle * \langle \sum_{i=1}^{n=12} q_i^{RP} + y_n \rangle}{\langle Q^{RP} - \langle \sum_{i=1}^{n=12} q_i^{RP} + y_n \rangle} \quad (4)$$

where:

- Q^{RP} - the annual expense on the research plot;
- $x_n = q_n^{PP}$ - the expense on the production plot for n-month;
- $y_n = q_n^{RP}$ - the expense on the research plot for n-month.

It is necessary to start determining the desired monthly values of drainage outflow from the peak values on the hydrograph: for the year with small amount of precipitation – from maximum peak values, for the year with large amount of precipitation – from minimum peak values.

CONCLUSIONS

The research results make it possible to establish that it is necessary to use the distribution of drainage outflow as a basis for the compared values under conditions of a calendar year to solve the research problems. It allows increasing accuracy of the desired values on typical production drainage plots by 15-18% (depending on drain spacing) in comparison to the distribution of drainage outflow under conditions of a hydrological year.

The calculations show that the relative error for two known values of drainage outflow expenses on the production drainage plots makes 10-11%. At the same time, the relative error makes 4-5% for eleven known values of drainage outflow expenses. Application of this methodology will allow evaluating the current state of agro-landscapes to develop and implement timely ecological reclamation measures aimed at its improvement, with minimum research expenses (reduction by 80%) and less time (up to 20 minutes when using the computer program developed on the basis of this methodology).

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