Ecological Communication

Justification of Choosing and Making Managerial Decisions Concerning Land Reclamation Measures: A Probabilistic Model

Igor Alexandrovich Prikhodko

Construction and Water Object Management of the Faculty of Hydro-Technical Melioration, Kuban State Agrarian University, Krasnodar, Russian Federation

ABSTRACT

In the last decade, the Russian economy has shown a steady trend towards increasing the profitability of agricultural production. The production of agricultural products almost completely ensures the food security of Russia. One of the main agricultural crops is rice. Effective management of the rice irrigation system is impossible without the involvement of a mathematical simulation of the functioning of the water resource management system. Management tasks are multifactorial and multicriterial in nature with probabilistic source information. The peculiarity of evaluating the effectiveness of environmental projects requires taking into account the probabilistic nature of the occurring processes. The authors developed a mathematical (probabilistic) model for the functioning of the irrigation system with a stepwise change in the price of planned activities. The model was tested during 2016-2019 in the Chernoerkovskoe JSC of the Slavyansky district of the Krasnodar Territory (Russia). The use of the developed probabilistic model to manage scheduled activities will allow employees of the agribusiness industry to reduce the risks of uncertainties when making managerial decisions, and take into account the stochastic nature of the impact of natural and climatic factors. To form the options of agricultural crops growing technologies, reclamation measures were considered as the Poisson flow of certain intensity. The article determined the average time necessary to reach the satisfactory state of the system, as well as solved the optimization problem of determining the price change pattern of the satisfactory state of the system that would provide maximum profit taking into account losses caused by the unfavorable state. The mathematical model described in the article can be considered as a reasonable choice for improving the efficiency of land reclamation management.

KEY WORDS: LAND RECLAMATION MEASURES, MANAGERIAL DECISIONS, PROBABILISTIC APPROACH.

INTRODUCTION

Human activity is a powerful factor affecting the ecological state of agricultural landscapes (Safronova and Sokolova, 2017; Degtyareva, et al., 2017). Any agricultural activity consists in obtaining guaranteed high crop yields (Degtyareva, et al., 2009; Kuznetsov, et al., 2017). To obtain such results, it is necessary to use all available material and technical, energy, labor, soil, and natural resources with the greatest efficiency (Safronova and Prikhodko, 2019a). The present study aims at developing a model for managing land reclamation measures that prevent the extension of soil degradation. The implementation of high-performance management information technologies is one of the main areas in the development of high-tech industries (Efrosinin et al., 2018). The key indicators of hydrogeological land reclamation include the depth of groundwater and its mineralization (Kuznetsov et al, 2005). Groundwater is a sensitive indicator of all anthropogenic impacts carried out in reclaimed territories. The accumulation of salts in the aeration zone can be regulated by the amount of water supply and the intensity of drainage runoff (Chebotarev and Prikhodko, 2013; Safronova and Prikhodko, 2019a; Safronova et al., 2020a; ; Prikhodko et al., 2021b).

Therefore, the groundwater level can be considered as a function of these two factors, which, in turn, are determined by the cost of construction and operation of irrigation and drainage networks, as well as the availability of water resources. The reason for the decline in soil fertility and manifestations of degradation phenomena is explained by the overload of drainage and escape network, the deterioration of the oxidizing regime of the soil, leaching of humus and nutrients from the root zone of the soil, as well as by flooding of the surrounding space occupied by both rice and upland rice-based cropping rotations (Dyachenko and Prikhodko,

2007). Nature management at any stage of its development implies various forms of impact on natural systems and their transformation (Safronova et al., 2020b).

Management can be "hard", grossly violating natural processes, and "soft", using natural mechanisms of self-regulation of the natural environment. Hard management gives a high and quick effect, providing an increase in the volume of production or a decrease in the costs of the activities used. However, over time, environmental and economic losses occur (Degtyareva et al., 2019; Safronova et al., 2020c).

It is necessary to combine both forms of management to ensure environmental protection activities within the framework of the permissible impact on the environment, which is experiencing degradation and can restore its qualities. In the Krasnodar Territory, land resources are subject to the impact of various sources of pollution. Therefore, in the state programs for the development of the region, special attention is paid to measures to restore soil fertility. The more difficult, more expensive the planned event, the less permissible "volitional" decisions in it, and the more important are the methods that allow assessing the consequences of each decision in advance, excluding unacceptable options, and recommending more suitable situations and measures (Prikhodko et al., 2021a).

For example, the task of optimizing meliorative activities with uncertain parameters will increase the efficiency of water, light, air, heat, and food regimes control. In the work, the estimated parameters are considered as random variables (Vladimirov et al., 2019a). This allows the uncertainty associated with the parameter estimation to be estimated in terms of probability distributions. The requirements – to get the maximum effect quickly – contradict each other. Therefore, the researcher first focuses on high efficiency and then gradually reduces it until an acceptable efficiency is achieved. With this formulation of the problem, the rate of reduction in the cost of activities is important (Vladimirov et al., 2019c; Safronova et al., 2020b; Prikhodko et al., 2021b).

MATERIAL AND METHODS

Eight indicators (criteria) of soil reclamation status were selected in the present research:

Groundwater level and salinity;The pH of the soil;The content of humus;The provision with hydrolyzable nitrogen;The provision with mobile phosphorus;The provision with mobile potassium;The content of aggregates:from 0.25 to 10 mm; less than 0.25 mm;Degree and type of soil salinity.

Technological maps for the implementation of an ecological-adaptive complex of technological agro techniques have been developed for each reclamation state of soils. Carrying out an eco-adaptive complex of technological operations during the nonvegetative period on five experimental fields of Chernoerkovskoye JSC in the Slavyansky District of the Krasnodar Territory over four years of research has shown its effectiveness, which was expressed in reducing the rate

of leaching of the arable horizon; lowering the groundwater level by 0.4 m; reducing the mineralization by 0.39 g/l; and increasing the content of humus up to 4.5%, mobile potassium – by 8%; mobile phosphorus – by 11 %, soil alkali-hydrolyzable nitrogen – by 7 %, while the increase in crop yield amounted to 10 %.

Assessment of the optimal level of groundwater and its management within each system on reclaimed lands is one of the main tasks of hydrogeological and reclamation service and operation, whose solution requires comprehensive information about the state of the object (Safronova et al., 2019b). The main management principles in land reclamation are based on a systematic approach; consideration of the uncertainty of many influencing factors; basin-based approach and reliance on serious scientific research and reliable data; and analysis of contemporary water resource systems (Safronova et al., 2020c). Another important prerequisite for applying the system-based approach and mathematical simulation is a sharp increase in the number of environmental and economic parameters that must be taken into account when analyzing and making managerial decisions (Vladimirov and Prikhodko, 2019b).

RESULTS AND DISCUSSION

Let us consider one of the most common criteria at the regional level which is the minimum of total reduced costs for agricultural production.

$$\text{Find min } [CQQ + CxX + CyY], \tag{1}$$

where X is the area of cultivated crops (ha), Y is the reconstruction area (ha), Q is the volume of water resources used, thous. m3, CQ is the specific reduced costs for water supply, and flow control, rub/m3, Cx is the agricultural costs, rub/ha, Cy is the specific reduced reconstruction costs, rub/ha.The minimum total losses are sought under the conditions:

$$A_1^1 X + A_1^2 Y \geq B_1 \tag{2}$$
$$A_2^1 X + A_2^2 Y \leq B_2, \tag{3}$$
$$X, Y, Q \geq 0. \tag{4}$$

In inequalities (2) and (3), the A_1^1, A_1^2, A_2^1, A_2^2

matrices include technical and economic standards, namely, agrotechnological coefficients, irrigation standards, and labor costs.

The list of state parameters and factors that determine the difference in the manifestation of ecological functions of soils should be improved, while environmental regulation should provide not only control of the state but also warnings about the onset of the very first signs of significant changes in the soil, leading to its degradation (Vladimirov,

2015; Safronova et al., 2019b; Safronova et al., 2020b; Vladimirov and Alexandrov 2021).

In the article (Safronova and Prikhodko, 2007), the same authors describe a model of continuous changes in the event price. This article considers the case of a stepwise price change. Let Si is the costs associated with the regulation or complete elimination of negative consequences of land reclamation measures. Let us assume that at the start of work, reclamation measures are scheduled for the duration of operation T1, and the price of these measures is S1. If during time T1 the negative consequences of reclamation measures are not eliminated, new reclamation measures are scheduled, whose price is S2, and the duration of operation is T2. If the negative consequences are not eliminated during the time T2 then, new reclamation measures are scheduled with the duration time T3 whose price is S3, etc. Let's call each time period a phase. The duration of the phase depends on the number of scheduled activities.

Let at the initial time moment the price is . Reclamation measures are being put into operation and the number of possible measures is . If the satisfactory result is reached, the process will be finished. If the selected events do not lead to a satisfactory condition, then the following events are scheduled, whose price is S2. If the scheduled activities bring the system to an acceptable state, the process is finished, if not, then other possible activities are selected, whose price is S3, etc. To develop various technology options for growing agricultural crops, the authors consider reclamation measures as a Poisson flow of certain intensity (Kitaeva and Stepanova, 2013; Safronova et al., 2020; Vladimirov and Alexandrov 2021).

Let us determine the average time needed by the system to reach a satisfactory state.
The probability density of time intervals τ has the following form:

$$p(\tau) = \lambda R e^{-\lambda R} \quad (5)$$

If the satisfactory state has been reached within the time interval of length T, then the conditional probability density of the time interval from the beginning of the phase to this time point will be equal to:

$$p(\tau \mid \tau \leq T) = \frac{p(\tau)}{P(\tau \leq T)}, \quad 0 \leq \tau \leq T.$$

Presenting in more details, one gets:

$$p(\tau \mid \tau \leq T) = \frac{R\lambda e^{-\lambda R\tau}}{\int_0^T R\lambda e^{-\lambda R\tau} d\tau} = \frac{R\lambda e^{-\lambda R\tau}}{1-P}$$

Next, let us write down an expression for the mathematical expectation:

$$M\{\tau \mid \tau \leq T\} = \frac{\int_0^T R\lambda\tau e^{-\lambda R\tau} d\tau}{1-P} \quad (7)$$

After calculating the integral in the numerator, one gets:

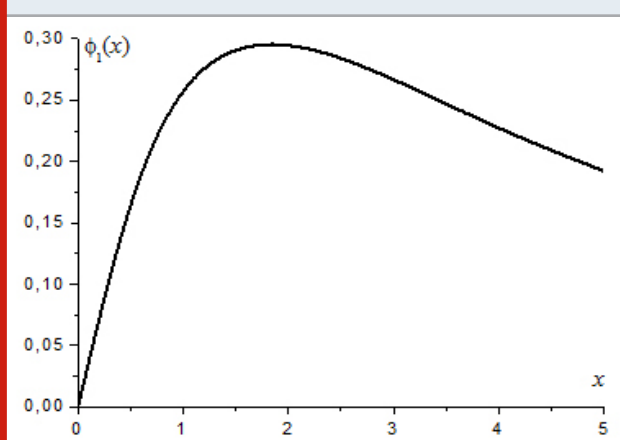$$M\{\tau \mid \tau \leq T\} = \frac{T}{1-P} \cdot \varphi_1(\lambda RT) \quad (8)$$

In (8), the following function is used:

$$\varphi_1(x) = \frac{1-(1+x)e^{-x}}{x} \quad (9)$$

The curve corresponding to the function (9) is shown in Fig. 1. Note that

$$M\{\tau \mid \tau \leq T\}(1-P) = T \cdot \varphi_1(\lambda RT) \quad (10)$$

Figure 1: Graphical representation of the $\varphi\_1(x)$ function

Now let us compose an expression for the mathematical expectation of the time needed for the system to reach the satisfactory state. Since the satisfactory state is reached during the period T_n with the probability $Q_n = \prod_{i=1}^{n-1} P_i \cdot (1 - P_n)$

$$M\{\tau\} = \overline{\tau} = \sum_{n=1}^{\infty} \left[(T_1 + T_2 + \dots + T_{n-1})\prod_{i=1}^{n-1} P_i(1-P_n) + T_n\varphi_1(\lambda R_n T_n)\prod_{i=1}^{n-1} P_i \right] \quad (11)$$

which after simplification can be written as:

$$\overline{\tau} = \sum_{n=1}^{\infty} (1-P_n)\prod_{i=1}^{n-1} P_i\left(\sum_{k=1}^{n-1} T_k\right) + \sum_{n=1}^{\infty} T_n\varphi_1(\lambda R_n T_n)\prod_{i=1}^{n-1} P_i \quad (12)$$

By rearranging the sum in the first term, one gets:

$$\sum_{n=1}^{\infty} (1-P_n)\prod_{i=1}^{n-1} P_i\left(\sum_{k=1}^{n-1} T_k\right) = \sum_{k=1}^{\infty} T_k \sum_{n=k+1}^{\infty} (1-P_n)\prod_{i=1}^{n-1} P_i \quad (13)$$

But

$$\sum_{n=k+1}^{\infty} (1-P_n)\prod_{i=1}^{n-1} P_i = \left(\prod_{i=1}^{k} P_i - \prod_{i=1}^{k+1} P_i\right) + \left(\prod_{i=1}^{k+1} P_i - \prod_{i=1}^{k+2} P_i\right) + \dots = \prod_{i=1}^{k} P_i,$$

since $\prod_{i=1}^{\infty} P_i = 0$. And now one can write:

$$M\{\tau\} = \overline{\tau} = \sum_{n=1}^{\infty} T_n P_n \prod_{i=1}^{n-1} P_i + \sum_{n=1}^{\infty} T_n\varphi_1(\lambda R_n T_n)\prod_{i=1}^{n-1} P_i = \sum_{n=1}^{\infty} T_n\psi_1(\lambda R_n T_n)\prod_{i=1}^{n-1} P_i \quad (14)$$
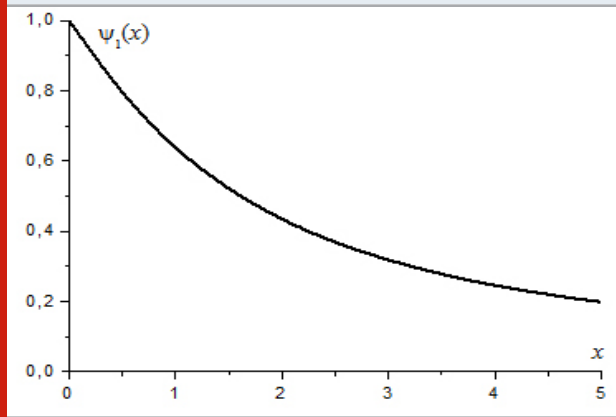
Where

$$\psi_1(\lambda R_n T_n) = P_n + \varphi_1(\lambda R_n T_n) = e^{-\lambda R_n T_n} + \varphi_1(\lambda R_n T_n) \quad (15)$$

From the latter one gets the following expression for the function:

$$\psi_1(x) = e^{-x} + \varphi_1(x) = \frac{1-e^{-x}}{x} \quad (16)$$

which can be used to calculate the average time needed by the system to reach the satisfactory state. A curve representing the average time needed to reach the satisfactory state is shown in Figure 2.

Figure 2: Plotted function for finding the average time needed to reach the satisfactory state by the irrigation system

Thus, ultimately, the following expression is obtained:

$$\bar{\tau} = \sum_{n=1}^{\infty} T_n \psi_1(\lambda R_n T_n) \cdot \exp\left(-\sum_{k=1}^{n-1} \lambda R_k T_k\right),$$

where it is believed that

$$\sum_{k=1}^{0} \lambda R_k T_k = 0 \qquad (17)$$

Let us consider the optimization problem of reclamation activities at each phase. Let us compose an expression of the mathematical expectation of total income from the use of the agricultural landscape:

$$\Phi = \sum_{n=1}^{\infty} (S_n - K_n)(1 - P_n)\prod_{i=1}^{n-1} P_i \qquad (18)$$

Here, K_n is the loss, if the satisfactory state is reached at the n-th phase (Kitaeva and Stepanova, 2013). The problem of optimizing ϕ based on $\{S_n\}$ is reduced to solving the following system of equations:

$$\frac{\partial \Phi}{\partial S_m} = 0, \quad m = \overline{1, \infty}.$$

Consider the explicit form of these equations. Initially, the value occurs in the summand equal to:

$$(S_m - K_m)\left(1 - e^{-\lambda R(S_m)T_m}\prod_{i=1}^{m-1} P_i\right)$$

Since $\prod_{i=1}^{m-1} P_i$ does not include S_m, the derivative of this term

is equal to:

$$\left[1 - e^{-\lambda R(S_m)T_m} + (S_m - K_m)\lambda R'(S_m)T_m e^{-\lambda R(S_m)T_m}\right]\prod_{i=1}^{m-1} P_i \qquad (19)$$

When $n > m$, the value S_m in the summands is present only in the cofactor $P_m = \exp(-\lambda R(S_m)T_m)$, and the corresponding derivative is equal to:

$$P'_m = -\lambda R'(S_m)T_m \cdot P_m \qquad (20)$$

Writing down $\frac{\partial \Phi}{\partial S_m}$, one gets:

$$\left[1 - e^{-\lambda R(S_m)T_m} + (S_m - K_m)\lambda R'(S_m)T_m e^{-\lambda R(S_m)T_m}\right]\prod_{i=1}^{m-1} P_i - \lambda R'(S_m)T_m \cdot \sum_{n=m+1}^{\infty} (S_n - K_n)\prod_{i=1}^{n-1} P_i(1 - P_n) \qquad (21)$$

After equating this expression to zero, dividing by $\prod_{i=1}^{m-1} P_i$, the following expression is obtained:

$$\left[1 - e^{-\lambda R(S_m)T_m} + (S_m - K_m)\lambda R'(S_m)T_m e^{-\lambda R(S_m)T_m}\right] - \lambda R'(S_m)T_m \cdot F_m = 0, \qquad (22)$$

where

$$F_m = \sum_{n=m+1}^{\infty} (S_n - K_n)\prod_{i=m}^{n-1} P_i(1 - P_n) \qquad (23)$$

To find a recurrent relation for F_m, it is necessary to extract the first term:

$$F_m = (S_{m+1} - K_{m+1})P_m(1 - P_{m+1}) + P_m \sum_{n=m+2}^{\infty} (S_n - K_n)(1 - P_n)\prod_{i=m+1}^{n-1} P_i .$$

The comparison allows recording the recurrent ratio for F_m:

$$F_m = (S_{m+1} - K_{m+1})P_m(1 - P_{m+1}) + P_m F_{m+1} \qquad (24)$$

Now, a recurrent relation for S_m can be derived. Let us write the expression (23) as follows:

$$\frac{1 - e^{-\lambda R(S_m)T_m}}{\lambda R'(S_m)T_m} + (S_m - K_m)\lambda R'(S_m)T_m e^{-\lambda R(S_m)T_m} = F_m \qquad (25)$$

By analogy:

$$\frac{1 - e^{-\lambda R(S_{m+1})T_{m+1}}}{\lambda R'(S_{m+1})T_{m+1}} + (S_{m+1} - K_{m+1})\lambda R'(S_{m+1})T_{m+1} e^{-\lambda R(S_{m+1})T_{m+1}} = F_{m+1} \qquad (26)$$

Write (26), given (24), and after multiplying by $e^{\lambda R(S_m)T_m}$ one gets:

$$S_m - K_m + \frac{e^{\lambda R(S_m)T_m} - 1}{\lambda R'(S_m)T_m} = S_{m+1} - K_{m+1} + \frac{1 - e^{-\lambda R(S_{m+1})T_{m+1}}}{\lambda R'(S_{m+1})T_{m+1}} \qquad (27)$$

The expression (27) connects S_m and S_{m+1}. This recurrent relation is used as follows. Having been given, S_o it is possible to find numerically S_1, then, knowing S_1, one can find S_2, etc. As a result, the value of ϕ, which depends only on S_0, is obtained. Further, examining the function for the extreme point, the value is determined numerically (Φ – total income from the use of the agricultural landscape).

The iterative planning process proposed in the work can be the basis of a program that corresponds to the optimal production activity, provided that the state of the external environment is maintained at a given level while choosing the optimal combination of various environmental protection measures that meet the requirements of environmental balance. When choosing a control action, the question often arises of replacing some control factors with others that have a similar effect on the transfer of the control object to a given state. The outlined approach allows solving this problem and finding the optimal ratio of measures to prevent environmental damage. The

considered concept of the price of sustainability of the agricultural landscape allows one to objectively choose the optimal solution for the use of resources. During the development of the project, several of its variants are compared. Different versions of the project may differ not only in technical parameters but also in the organizational and economic mechanism of implementation. Therefore, if we consider design as a process of developing the best version of the project, then it should also provide for the development of various options for the organizational and economic mechanism, the most rational of which will be accepted for implementation.

CONCLUSION

The authors have developed a mathematical (probabilistic) model of the irrigation system operation at a stepwise change in the scheduled event price. The model makes it possible to study the features of the system's operation in any real situation, predict the system's behavior when environmental conditions change, as well as reduce the risks of uncertainty when making managerial decisions. The optimization problem of finding the price change pattern of the satisfactory state of the system that would provide maximum profit taking into account losses from the unfavorable state, is considered. A recurrent ratio for total revenue is obtained, linking the scheduled activities at the m-th and (m+1)-th phases. This recurrent relation is used as follows. Having been given S_o, it is possible to find numerically S_1, then, knowing S_1, one can find S_2, etc. As a result, a total revenue function can be obtained that depends only on S_o. Next, examining the function concerning the extreme point, maximum profit is calculated numerically.

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