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MODELING AS A METHOD FOR STUDYING EROSION

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Abstract: *Modeling is one of the main methods of studying the surroundings reality and a tool in scientific and practical human activities. Among the types of physical modeling in erosion, modeling using physically similar models belonging to the category of hydraulic modeling, the principles of which are quite well developed has become widespread. In hydraulic modeling must satisfy the conditions of geometric, kinematic and dynamic similarity. In erosion studies, predominantly functional Math models are common, among which the largest groups are so-called washout models, or erosion losses. Currently, the number of mathematical models of soil erosion losses of various types developed in the world are measured in many dozens and continue to increase. For erosion studies water erosion, as a process, geoinformation technologies are the most effective tools for research and evaluation, forecast and justification of management decisions.*

Key words: *modeling of erosion, physical modeling, hydraulic modeling, Math modeling.*

1. INTRODUCTION

Significant place in the methodological arsenal of erosion study is modeling - the method of knowledge, in which the real system, or process (original, nature, prototype) is studied using its substitute - a simplified copy, scheme, sample or analog, which is called a model. The modeling process, therefore, consists in building the model of the object, of study (system, or process) and its subsequent study. The results obtained in the process of such study are transferred according to certain rules to the real object.

Modeling is one of the main methods of studying the surrounding reality and a tool in scientific and practical human activities.

As a way of reflecting reality, it actually originated simultaneously with the development of scientific knowledge, but plays special role in the study of complex systems - natural, economic, social, technical, where it is difficult and often impossible, to use other methods. For example, it is impossible to destroy the dam of the existing reservoir in order to determine the consequences of its breakthrough in the earthquake for the settlement, that is located downstream of the river. Moreover, this is impossible to do if we are talking about a reservoir, that is just being designed.

2. THE BODY OF THE ARTICLE

A unified classification of models does not exist. There are many classifications developed by representatives of various sciences in relation to the relevant features of the application of the modeling method. The general framework of this classification can be built as follows. First of all, it is customary to divide all models into two large categories: material (real, objective) and ideal (figurative, sign). Material models, in turn, are divided into spatially similar, physically similar and mathematically similar and ideal models into figurative (iconic), figurative-sign and symbolic (symbolic).

Modeling phenomena, or processes using material models is usually called physical, or natural. The term “physical modeling” is not limited to physics, but also applies to any other sciences. The term “natural modeling” in this context is not entirely successful, since it is more correct to call physical modeling in laboratory conditions “laboratory modeling” and physical modeling in natural conditions - “natural modeling”. In erosion studies, such a division of physical modeling - into laboratory and natural - is fully justified, since the methods, equipment and modeling capabilities in the laboratory and in nature are significantly different.

The Physical modeling

Among the types of physical modeling in erosion, modeling using physically similar models belonging to the category of hydraulic modeling, the principles of which are quite well developed has become widespread.

In physical modeling, a linear relationship between model and kind is usually used:

$$\mathrm{X}_m = \mathrm{M}_X \mathrm{X}_n \tag{1}$$

Where X_m relevant model specifications; M_X - scale coefficients (scale characteristics) of X; X_n - characteristics of nature.

In hydraulic modeling must satisfy the conditions of geometric, kinematic and dynamic similarity. Geometric similarity is ensured by the constancy of the scale of the linear characteristics of the model and nature — the depth and width of the flow, the dimensions of roughness and sediment. To achieve kinematic similarity, the proportionality of speed and acceleration must be ensured, as well as the coincidence of their directions on the model and in nature. Dynamic similarity is determined by the proportionality and unidirectionality of the acting forces.

The main similarity criteria for modeling open free-flow flows are the numbers (criteria) of Reynolds (Re), Froude (Fr), Strouhal (Sh) and Euler (Eu):

$$Re = \frac{VL}{v} \tag{2}$$

$$Fr = \frac{V^2}{FL} \tag{3}$$

$$Sh = \frac{L}{VT} \tag{4}$$

$$Eu = \frac{P}{\rho V^2} \tag{5}$$

where *V* is the flow velocity, m/s; L is the characteristic size (depth) of the flow, m; *F* - force (in the case of free-flow movement - the force of gravity of the mass unit *F* = g, where g is the acceleration of gravity, m/s^2); *T* - time, with; *P* — pressure, *Pa*; *ν* - coefficient of kinematic viscosity of water, m^2/s; ρ is the density of water, kg/m^3.

The flows on the model and in nature will be similar if the above criteria for the model and nature are the same, i.e. $e_{\text{м}} = Re_{\text{н}}$, $Fr_{\text{м}} = Fr_{\text{н}}$, $Sh_{\text{м}} = Sh_{\text{н}}$, $Eu_{\text{м}} = Eu_{\text{н}}$ or Re=idem, Fr=idem, Sh=idem, Eu=idem. (lat idem is the same).

When modeling flows in eroded channels (the essence of modeling erosion processes), criteria, that characterize the density and/or hydraulic size of sediment particles should be added to the above criteria and when studying the destruction of soil by rain drops, energy characteristics of precipitation should be added.

It is known, that the simultaneous fulfillment of all, or even part of the similarity criteria in hydraulic modeling is almost impossible. Of the four main similarity criteria, the Euler criterion ("pressure coefficient") in most practical problems turns out to be insignificant and the Strouhal criterion ("homochronicity criterion") can be disregarded, when studying the field of averaged steady-state flow. Most often, when modeling, only two similarity criteria are used - Froude and Reynolds. However, there are also difficulties with their simultaneous implementation.

In order to simultaneously ensure the identity of the Frud and Reynolds criteria for model and nature, the scale of linear quantities (M_L) must be equal to:

$$M_L = M_v^{2/3} M_g^{-1/3} \quad (6)$$

Where M_v and M_g are scale factors for the kinematic viscosity of a fluid and gravitational acceleration, respectively.

The scale factor for the acceleration of free fall is always one, i.e. $M_g = 1$

Then from (6) it follows, that with physically homogeneous modeling (in which water is used as a model liquid and $M_v = 1$), the scale factor of the linear dimensions of the model M_L should also be equal to one, i.e. the model should have exactly the same linear dimensions, as well as the simulated object.

It is clear, that for large objects, such as a river catchment, or even a separate slope, this condition is practically impossible.

The Math modeling

In erosion studies, predominantly functional models are common, among which the largest group are so-called wash-out models, or erosion losses. By the nature of the mapping relationships in the simulated system, mathematical models are divided into static and dynamic. Static models make it possible to characterize the structure and connections in the system either at a certain point in time or, on average, for a certain period of time (in erosion studies, most often for a long-term period). Static models include most empirical models of soil erosion. Dynamic models describe the process change in time and in erosion studies, as a rule, model the erosion-accumulative process as a result of a separate rainfall (shower period) or during a snowmelt period of a particular year.

By the nature of the spatial schematization of the object of study, models are divided into zero-dimensional (0D), one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D). Zero-dimensional models, or models with lumped parameters, do not take into account the spatially distributed nature of the object — all its characteristics are taken spatially averaged (for example, over the area of a slope or catchment). One-dimensional models (profile) take into account the change in the characteristics of the model only in one of the space coordinates (in erosion models - along the length of the slope). Two-dimensional models take into account changes in the characteristics of the model on the plane - by the X and Y coordinates (such models are usually called spatially distributed). Finally, three-dimensional models take into account changes in the characteristics of the simulated process in all three space coordinates - X, Y and Z. These models include the so-called hydro mechanical runoff models, which are based on the complete system of Navier-Stokes equations, which take into account the change in flow characteristics not only by area, but also in depth.

Currently, the number of mathematical models of soil erosion losses of various types developed in the world is measured in many dozens and continues to increase.

By now, simulation modeling is one of the most effective methods for researching and optimizing the management of complex natural and natural-economic systems. An imitative simulation idea [1] should be considered the imitation system (imitation model). Imitation models can be used both in simulation and optimization modes. In the first case, the model is used to select a particular strategy by conducting numerical experiments with it for certain values of variables, that characterize the state of the original system (endogenous or internal variables) and external influence (exogenous or external) variables. If for a given objective function, using the model, they try to find the optimal strategy, i.e. the values of variables, that provide the optimal values of the selected criterion or criteria, the model is called optimization.

In relation to the optimization problem of agro-landscape systems due to insufficient formalization of the procedure for selecting the optimal values of endogenous variables, with the presence in general of several (economic, environmental, social) optimization criteria, the complexity and nonlinearity of mathematical models, that describe their functioning, the application of formal optimization procedures is difficult.

Currently, simulation modeling is successfully used to solve various theoretical and applied erosion problems in the USA [2, 3, 4] and other countries.

The range of application of geo-information technologies in erosion studies covers almost the whole range of their functions - information and reference, monitoring, automated mapping, space-time analysis and modeling, creation of spatial decision support systems in planning, design and management.

Using geoinformation technologies, spatially distributed (cartographic) data is divided into homogeneous layers (topography, hydrographic network, genetic soil varieties, soil erosion, spatial structure of land use, crop rotation, anti-erosion measures, etc.) and entered into a computer as electronic files with using raster (as a set of cells covering the whole territory), or vector (with the formalization of spatial information using a set of elementary graphical objects - points, lines, segments (arcs) and the polygon) spatial model data.

Modern instrumental GIS allow you to edit and up-to-date information, form new data layers based on a transformations or a combination of existing ones, as well as display them on the screen and (or) as a solid copy in a two, or three-dimensional representation.

The function of geo-information technologies is to ensure the monitoring of natural and natural-economic territorial systems, which implemented mainly through computer processing of remote sensing data (aerial and space imagery) and geo-information field mapping.

The function of the Earth remote sensing data processing (RSD) is currently implemented in many commercial GIS packages for universal use, such as, for example, the GIS package and image processing IDRISI (Clark University, USA) and in specialized RSD data processing packages, such as software ERDAS IMAGINE, ER Mapper, LPS and other ERDAS companies (ERDAS Inc., Sweden), the ENVI system of ITT Visual Information Solutions (USA), the software of ScanEx RDC (Russia) (ScanMagic, ScanEx Image Processor). Digital images of high (2-10 m) and, especially, ultrahigh (less than 2m) spatial resolution open wide opportunities for remote monitoring and mapping of erosion processes. Another promising area of application of geo-information technologies in erosion studies is the automation of thematic mapping. It includes the preparation and publication using the capabilities of modern computers of traditional maps of soil erosion, erosion control measures, etc., that meet modern requirements for cartographic products, as well as the creation of various thematic cartograms and chart diagrams.

The potential of geo-information technologies for modeling water erosion and assessing erosion losses of soil was demonstrated in the 1980s.

This was first apparently done in [5], where using the GIS package and image processing VICAR / IBIS (USA) the spatial implementation of the Universal Soil Loss Equation - USLE using remote sensing data (Lansat satellite imagery) and provided the erosional soil loss forecast for a test site located in the state of California (USA).

Currently, there are many spatial implementations of the Universal Soil Loss Equation and its subsequent version of RUSLE [6], performed using different GIS packages (IDRISI, ArcView GIS, ArcGIS, etc.) in various countries of the world, including those located in Asia, Africa, Latin America.

Since the mid-90s, geo-information technologies have been used for the spatial implementation of algorithmically much more complex models of water erosion.

Examples include: spatial implementation of a modified version of the logical-mathematical model of soil flushing made using the PCRaster package at Odessa State University. Dynamic Limburg Soil Erosion Model (LISEM) developed at the University of Utrecht (Netherlands) using the PCRaster spatial analysis and modeling package [7]; development of a model of a slope erosion process based on the numerical integration of the system of diffusion wave equations in the GRASS GIS package [8].

3. CONCLUSION

For erosion studies water erosion as a process, its consequences for the environment and economic activities and develop ways to prevent them, which have a pronounced spatial-distributed nature, geoinformation technologies are the most effective tool for research and evaluation , forecast and justification of management decisions.

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