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Monitoring of monuments of the Kyiv-Pechersk Lavra in the conditions of flooding processes development

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SUMMARY

One of the main processes that leads to the deformation of the architectural monuments of the Kiev-Pechersk Lavra is their flooding by both groundwater and surface water, a significant impact on the technical condition of buildings and structures is caused by the flooding of groundwater. Therefore, the study of hydrogeological conditions (groundwater regime and the nature of the distribution of aquifers) is one of the main in the system of integrated monitoring of historic areas. Research in this paper is aimed at assessing the current hydrogeological conditions of the building № 47 - Church of the Living Source, the study of general patterns of formation, distribution and movement of groundwater, as well as forecasting changes in hydrogeological conditions of the site and adjacent area in connection with drainage.

Introduction

One of the main processes leading to the deformation of the architectural monuments of the Kyiv-Pechersk Lavra is their flooding by both groundwater and surface water. As the most significant impact on the technical condition of buildings and structures is caused by groundwater flooding, the research topic is extremely relevant, and the study of hydrogeological conditions (groundwater regime and the nature of aquifers) is a major factor in the system of integrated monitoring of historic areas.

The aim of the work is to determine the factors of influence that lead to the violation of hydrogeological conditions of the Kyiv-Pechersk Lavra and to determine the impact of changes in groundwater regime on the state of architectural monuments and this protected area.

Method and Theory

For high-quality performance of these tasks it is necessary to analyze and optimize technological schemes of application of geoinformation technologies in modeling and forecasting.

Modeling - replacement of the studied object (original) with its conditional image, description or other object (model) and knowledge of the properties of the original by studying the properties of the model (*Tomashevskyi, 2005*).

A model is an object of any nature, which in research is able to replace an actual object in order to obtain new information about the latter (*Kumar & Surjeet, 2015*).

With a mathematical model of the hydrogeological system, it is possible to predict, test and compare reasonable alternative scenarios for the development of flooding of the object.

Groundwater models describe groundwater and transport processes using mathematical equations based on certain assumptions, which include flow direction, aquifer geometry, inhomogeneity or anisotropy of precipitation or rocks within the aquifer, pollutant transport mechanisms and chemical reactions.(*Tauxe, 1994*). Due to the simplified assumptions inherent in mathematical equations, and the many uncertainties in the data values required by the model, the model should be considered as an approximation rather than an exact duplication of field conditions (*Zatserkovnyi et al., 2017*). Groundwater models are a useful research tool for a number of applications, such as:

- to determine the water balance (in re-calculation on water volume);
- to determine the quantitative aspect of the unsaturated zone;
- for modeling water flow and chemical migration in the saturated zone, including the river-soil ratio;
- to assess the impact of changes in groundwater regimes in the environment;
- for creation / optimization of monitoring networks and creation of groundwater protection zones.

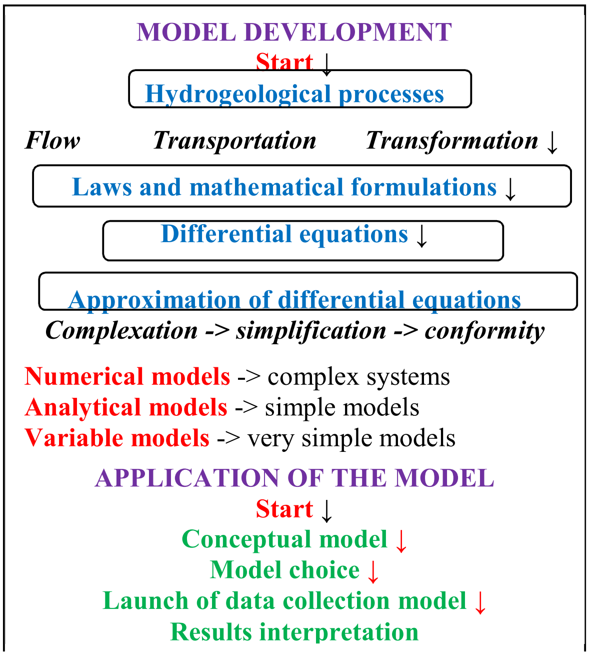

Figure 1 *Model development process.*

The first process is the development of a model that leads to a software product, and the second is the use of this product for a specific purpose. Groundwater models are most developed in a logical sequence (Fig. 1).

Simulation sometimes requires the use of several types of software. If we talk about the modeling of groundwater, the different types include (*Kumar, 2019*): "model" script that solves the equation of groundwater flow and / or transportation of solutes; GUI, which facilitates the preparation of data files for the model script, runs the model code and allows visualization and analysis of results (model forecasts);

Software for spatial data processing, such as GIS, and software for the presentation of hydrogeological conceptual models; Software that supports model calibration, uncertainty analysis; Software that allows you to perform additional calculations.

Research in this paper is aimed at assessing the current hydrogeological conditions of the building № 47 - Church of the Living Source, the study of general patterns of formation, distribution and movement of groundwater, as well as forecasting changes in hydrogeological conditions of the site and adjacent area in connection with drainage.

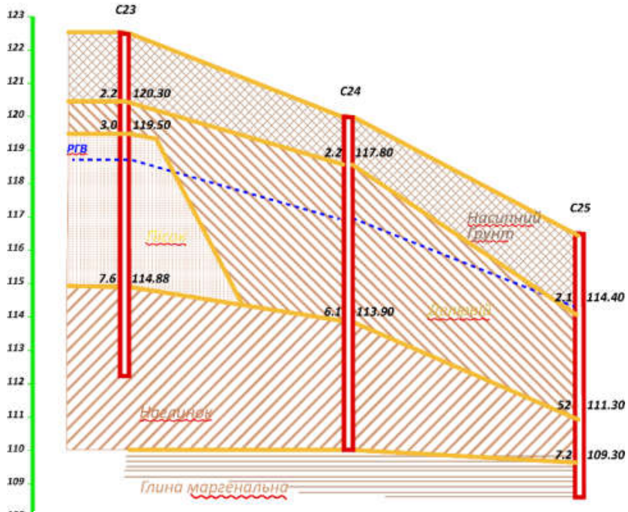

Figure 2 *Engeineering and geological section (cut) of the study area.*

Hydrogeological conditions of the research area are complex (Fig. 2). This stratum is characterized by hydrogeological inhomogeneity due to alternation in cut (section) and plan of layers of unsustainable power with different filtration coefficients (*Cherevko, 2019*). Therefore, in this case, for predictive calculations, it is advisable to use the method of mathematical modeling of geofiltration processes (*Hudak, 2020*). Application of a method of mathematical modeling allows to avoid rough schematization of natural hydrogeological conditions, to consider the complexity and diversity of boundary conditions of soil flow, and thus give a more realistic assessment of the impact of engineering methods to reduce the level of groundwater on the hydrogeological conditions of the territory.

Methodical substantiation of hydrogeological models construction

The research used the software package PMWIN-5.1 Processing MODFLOW-2000 for Windows, which allows you to create a multilayer model of geofiltration. Modeling of geofiltration processes at the site was performed in the following sequence:

- a space-time natural hydrogeological model of the territory was built, which was evaluated on the basis of the study of archival materials and survey works: geological structure of the territory; conditions of occurrence and distribution of aquifers and water-resistant layers; basic hydrogeological parameters of aquifers and water-resistant layers and patterns of their change in section and plan; conditions of feeding and unloading of groundwater;
- a geofiltration model was created on the basis of natural. It formalizes the real hydrogeological situation with the selection and quantitative characterization of the main factors of groundwater formation (aquifers, poorly permeable layers and their boundaries, power sources, distribution of parameters, boundary conditions at its boundary).
- on the basis of geofiltration a calculated mathematical model was created, which takes into account the filtration regime, the need to divide the aquifer into several calculation layers, the planned division of the filtration area into calculation blocks, infiltration of precipitation and man-made water.

The solution of geofiltration problems on mathematical models was performed with the initial conditions of distribution of groundwater levels, their supply and unloading (*Cherevko, 2019*). After that, the study of the conditions of groundwater formation by the method of mathematical modeling consisted of two stages: refinement of the original geofiltration model by solving the inverse problem; solving predictive problems.

Creation and adjustment of the original calculated mathematical geofiltration model

Modeling of hydrogeological conditions of the studied area was carried out in two stages: the first created a model of the territory bounded by natural boundaries that ensure equality of positive (incoming) and negative (expendable) elements of groundwater balance - the model covers the area where the whole groundwater flow, formed due to infiltration, on its borders and is unloaded. At the second stage, on the basis of the constructed general model, the forecast modeling of decrease in level of ground waters taking into account a radial drainage was carried out.

All mathematical calculations were performed for stationary filtration mode. To implement the mathematical geofiltration model it was used the following mathematical description of the process:

$$d/dx\,(k \cdot h \cdot dH/dx) + d/dy\,(k \cdot h \cdot dH/dy) + W = 0,$$

where k - is the filtration coefficient of the soil layer, m / day, h - is the groundwater flow capacity, m; W - intensity of infiltration supply of groundwater, m / day; H - hydrodynamic pressure (absolute mark of groundwater level), m.

The finite difference method is used to solve the equation, so the geofiltration area is divided into calculation blocks. To display the hydrogeological conditions with the lowest degree of schematization, the dimensions of the blocks were taken to be 1 × 1 m. The filter area in the plan is divided into blocks of 200 × 200, which is 40,000 blocks for the entire model.

The model of this scale allows to characterize the conditions of groundwater formation of the whole study area and to make forecasts of changes in their regime, taking into account the relationship of all natural and man-made sources and boundary conditions.

To obtain reliable forecasts, the solution of the inverse planned geo-filtration problem was solved under conditions of the stationary regime of geo-filtration to determine and substantiate the calculated values of geo-filtration parameters and boundary conditions (Fig. 3).

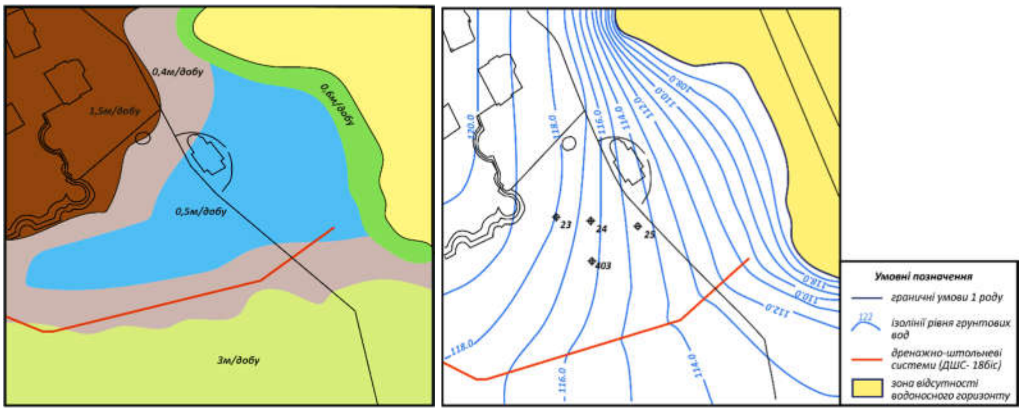

Figure 3 *Hydroisogypsum (absolute marks of groundwater level) according to the solution of the inverse problem.*

A direct indicator of the model's compliance with real natural conditions is the coincidence of the actual and obtained on the model values of hydrodynamic pressures in hydrogeological wells and the cost of existing drainage.

The solution was carried out under conditions of stationary pressureless flow by the method of multivariate selection of values of infiltration supply of groundwater and geofiltration parameters of the aquifer. The obtained geofiltration model is a two-layer (layer containing an aquifer and a water-resistant layer), piecewise-inhomogeneous (layers are not sustained in terms of capacity and water permeability).

The constructed initial mathematical geofiltration model was used by the authors as a basis for assessing the impact of the designed beam drainage on the hydrogeological conditions of the study area.

Two variants of forecast tasks were solved. In the first option, the radial drainage is given in the form of a system of imperfect drains, the boundary condition of the first kind (H = const) is applied. In this variant, two predictive problems were solved, where the depth of drainage was taken into account.

At a drainage depth of 1 m below the groundwater level, the forecasted decrease was 0.7 m in the area of the building № 47 (Fig. 4). At the same time, the total flow rate of the designed drainage was 10.25 m^3/day, the specific flow rate in blocks varies in the range of 0.02-0.06 m^3/day.

The greatest decrease in groundwater levels was obtainewhen the drain is located 2 m below the groundwater level, i.e. on the roof of the waterproof layer (Fig.4).

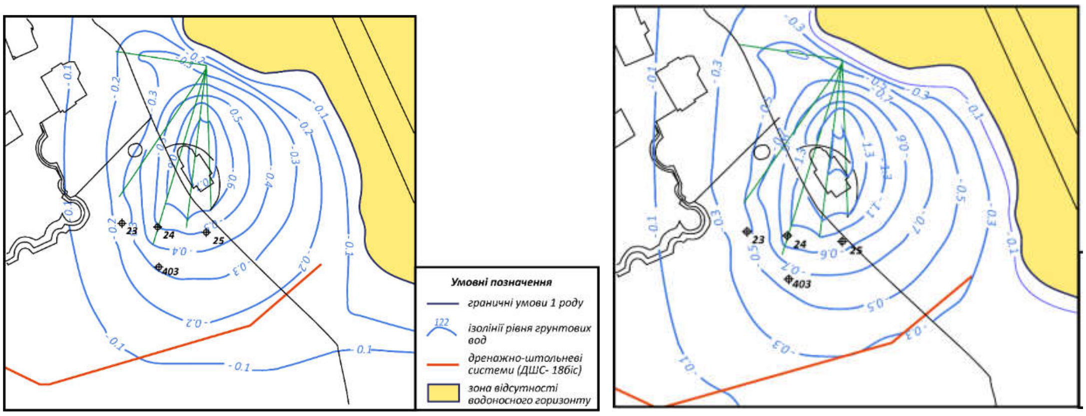

Figure 4 *Maps-schemes of groundwater level decrease in comparison with inverse problem at work of designed drainage located on 1m (above) and 2 m (below) groundwater level.*

The amount of reduction is about 1.5 m, at the same time the total flow rate of the designed drainage is 19.85 m^3/day, the specific flow rate in blocks varies in the range of 0.05-0.1 m^3/day. Expenditure and income parts of the balance are equal, the error of decision - 0%.

The coincidence of geofiltration parameters during the solution of different variants of forecasting tasks testifies to the correctness of the created model and the correctness of the solution.

Thus, the maximum predicted decrease in the groundwater level in the area of the building № 47 is achieved if the radial drainage is 2 m below the groundwater level (on the roof of the waterproof layer).

Conclusions

Geoinformation approach to solving hydrogeological problems involves the use of GIS in the collection, processing and storage of information to create hydrogeological mathematical models and spatial analysis in GIS. That is, GIS is used for information support in the creation and operation of hydrogeological mathematical models (mostly permanent) and hydrogeological monitoring systems. Assessment of the possibilities of the applied software to identify areas of distribution and development of economic and geographic position and their analytical analysis showed the possibility and feasibility of their use in practice.

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