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Research paper

GROUNDWATER LEVEL ESTIMATION USING GMS SOFTWARE

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Abstract

The primary goal of this paper is to develop a mathematical model that describes groundwater flow within a porous medium. By employing mathematical modelling techniques for fluid flow analysis, valuable insights can be gained into complex flow conditions that are often difficult to assess using conventional analytical methods. Given that the spatial and temporal variations of parameters relevant to the system can be expressed through specific mathematical formulations (typically in the form of complex partial differential equations) it is advisable to apply appropriate numerical methods, as they provide a strong strategy for effectively addressing the challenges associated with the system.vOne of the significant challenges encountered in groundwater research is the lowering of groundwater levels (GWL) during the construction of buildings. Before the construction begins, it is required to lower the GWL in the foundation pit to ensure dry working conditions. The most requested data for this purpose are groundwater flow and GWL. This paper focuses on the process of lowering the GWL for a specific object while ensuring that the stability of surrounding buildings remains unaffected. To achieve this objective, it is crucial to design and implement a drainage system with adequate capacity, considering the characteristics of the aquifer. Additionally, it is important to assess filtration stability, particularly to prevent suffusion, by carefully selecting an appropriate protective filter course. The analysis of groundwater flow at the specified location was conducted using a 3D model to simulate the flow regime within a porous medium. Both conceptual and numerical groundwater modeling were performed using the GMS 10.7 software. Based on the adopted filtration coefficient from the geotechnical study, several solutions were developed. In each case, it was necessary to ensure that the GWL was lowered to the required elevation and to prevent suffusion by controlling the maximum velocities at the entrance of the filter structure.

Key words: *Groundwater Flow Model, GMS, Filtration Coefficient*

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1. INTRODUCTION

Creating a comprehensive mathematical model that considers all factors affecting the groundwater flow would require a vast amount of input data and significant computing power. Given the extensive effort and investment involved, such modeling may ultimately become impractical and lose its significance. Effective models acknowledge the primary laws and factors affecting the phenomenon while simplifying or excluding less significant parameters. Therefore, every model is based on specific assumptions and simplifications, meaning that each one has limited applicability, defined by the assumptions and conditions established during its development. Consequently, a model serves, at best, as a conditional representation of real-world conditions and processes.

When initial and boundary conditions are too complex for analytical solutions to be achievable, numerical computational models become valuable due to their flexibility. The advancement and widespread accessibility of computers have enabled numerical models to become the most used tools for solving practical problems posed by both nature and human activities.

A groundwater flow model refers to a tool used to describe the flow dynamics in a hydrogeological system. Once calibrated, it can be used to predict how an aquifer will respond to natural processes and changes due to human activities, and subsequently, for managing water resources. The primary objective of this modeling is to determine the piezometric level at a specific point within the aquifer and, indirectly, to assess the distribution of flow velocities in the current field. The first step in the modeling process is creating a conceptual model. Once this is established, the conceptual model is converted into appropriate mathematical expressions, which are then combined with boundary conditions to form a mathematical model. One of the most widely used numerical modeling software packages is GMS, based on MODFLOW 2005, developed by Aquaveo, LLC in Provo, Utah, USA. Many researchers have utilized MODFLOW in groundwater modeling for various purposes, and some have integrated it with other models and software to enhance the reliability of their research findings [1-4].

Within this paper, the lowering of the groundwater level at the site of interest was examined without compromising the stability of nearby buildings. To achieve this, the drainage system needs to be designed and executed with sufficient capacity, considering the characteristics of the aquifer from which the water is drawn. It is also important to prevent suffusion by appropriately selecting the protective filter course. When developing a groundwater flow model, it is essential to have an accurate soil profile for the specific location, which can only be obtained through geotechnical boreholes. Furthermore, correctly estimating the filtration coefficient is crucial for establishing the model and ensuring its accuracy. Considering two static groundwater levels — the level identified through exploratory drilling at an elevation of 71.85 meters above sea level and the maximum expected level determined through hydrological analyses, which was 74 meters above sea level — it can be concluded that the necessary lowering of the groundwater level at the location of interest was approximately 4.85 meters for the first case and 7 meters for the maximum expected level. Since a significant lowering of the groundwater level was required, a groundwater flow analysis was conducted using a 3D model to simulate the flow regime in a porous medium.

2. HYDRAULIC CALCULATION

2.1. Establishment of the GMS model

The initial step in establishing the model involves defining the dimensions of the area being modeled, using data from the available measuring wells. When determining this area, the dimensions of the object are crucial, as they indicate where lowering the groundwater level is necessary. In other words, defining the model's boundaries depends on the object's dimensions, requiring the boundary line to be placed in a zone beyond the well's influence. This means that the boundary line must be set where the influence of the depression cone is not felt. Since the dimensions of this cone are undefined at the beginning of the calculation, determining the boundary line along which the boundary conditions will be implemented is an iterative process that involves testing different model dimensions depending on the configuration of the wells. After defining the model's dimensions, a computational grid was created. Given that this area is significantly larger than the location of interest, primarily due to the boundary line positions, a different grid resolution approach was chosen for the grid formation. Namely, as the object and its immediate surroundings require a higher level of detail, a denser grid was used in these zones, while a higher-resolution grid was applied in the remaining areas. In this way, the model is optimized in terms of required computing resources while maintaining the required accuracy and detail at the location of interest. Thus, a grid cell size of 7.5 × 7.5 m was used for the wider area, while within the narrow zone around the object itself, at the wells' location, grid cells of 0.25 × 0.25 m were used.

To define the vertical stratification, data on soil stratification at the location in question, obtained from one exploratory well, were used. Thus, in the vertical direction, one layer (the soil layer from which the water is drawn) with a total length of about 19 m was adopted for simulation purposes. Additionally, the impermeable floor level was set at 52 masl. To complete the mathematical model, the filtration coefficient of this layer of soil was determined based on a geotechnical study. Figure 1 shows a 3D view of the adopted computational grid.

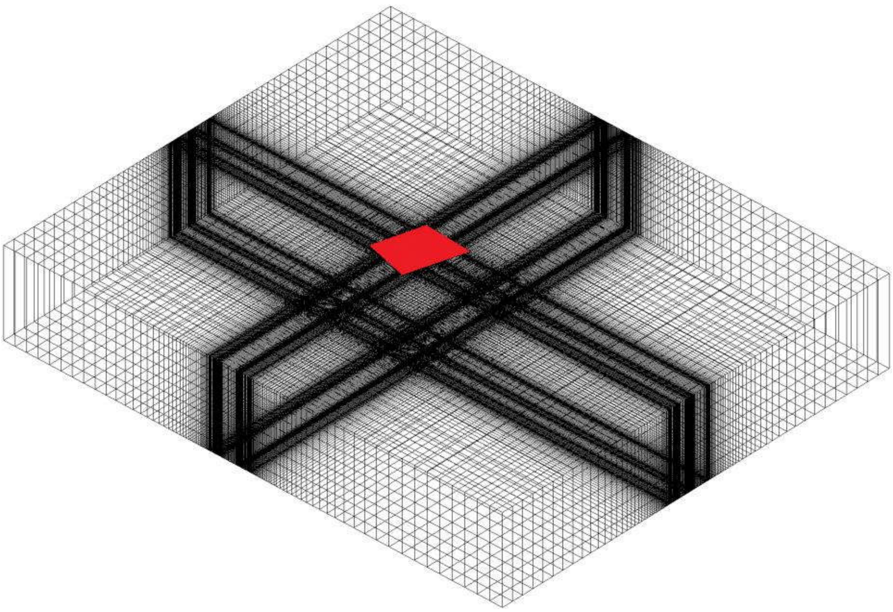

Figure 1. 3D view of the adopted computational grid

2.2. Modeling of groundwater level lowering

For the previously defined model, the next step was to determine the arrangement of the wells around the foundation pit in order to lower the groundwater level to the required elevation. Although the foundation level was estimated at 68.00 m, the request was to lower the groundwater level to 67.0 m. In addition to achieving this elevation, in order to select the optimal number of wells, it was necessary to check the filtration stability. Filtration stability was evaluated by estimating the velocity at the entrance of the well's filter and comparing it to the limit value (critical speed) adopted according to Abramov. Therefore, the configuration of wells and their flow rates were defined not only based on the required lowering level but also on the critical gradients at the contact between the soil and the well strainer. The center point of the foundation pit served as the reference point for monitoring the groundwater level lowering. However, to determine the velocity at the well's strainer, the maximum velocity value recorded at the nearest calculation point to the well was compared with the critical value.

After defining the model boundaries and the filtration coefficient, to carry out further calculations, it was necessary to define the initial level, the disposition of the wells, and the flow rates for each well. Considering the two estimates of the initial water level (71.85 meters above sea level and 74 meters above sea level), analyzes were conducted for both levels. In one set of simulations, a value of 71.85 m was adopted for the initial level, while for the second set of simulations, an elevation of 74 m was used. During the modeling process, several different well configurations and nominal flow rates were tested. For each set configuration, predefined conditions were checked after the simulation regarding the required groundwater level and maximum velocity at the well's entrance. If the configuration did not meet both criteria, the arrangement of wells was changed, and additional wells were added. Since three different values of the filtration coefficient (10^{-2} cm/s, 10^{-3} cm/s and 10^{-4} cm/s) were suggested in the geotechnical study, several iterations were conducted, resulting in one or two solutions for each of the three values of the filtration coefficient. All tested configurations are listed in Table 1.

Table 1. Tabular representation of the tested configurations.

Initial level	71.85 masl			74.00 masl		
filtration coefficient [cm/s]	1.0×10^{-2}	1.0×10^{-3}	1.0×10^{-4}	1.0×10^{-2}	1.0×10^{-3}	1.0×10^{-4}
Variant 1	4 wells Q = 6.8 l/s	4 wells Q = 0.7 l/s	6 wells Q = 0.05 l/s	8 wells Q = 5.4 l/s	8 wells Q = 0.53 l/s	8 wells Q = 0.0463 l/s
Variant 2	**6 wells Q = 5.0 l/s**	6 wells Q = 0.5 l/s	8 wells Q = 0.04 l/s	/	/	/

Several variants for lowering the groundwater level were evaluated. The most practical solution was the configuration of six wells, each with a flow rate of Q = 5.0 l/s. The values of soil and well parameters for the adopted case are presented in Table 2. The groundwater levels of the foundation pit after pumping are shown in Figures 2 and 3.

Table 2. Adopted values of soil and well parameters (k = 10^{-2} cm/s, Q = 5.0 l/s, 6 wells)

Parameters	Values
terrain elevation at the object's location	~76.55 m.a.s.l.
static groundwater level	71.85 m.a.s.l.
excavation level of the foundation pit	68.00 m.a.s.l.
min lowering level at the well site	61.69 m.a.s.l.
max elevation at the object's area (foundation pit)	66.76 m.a.s.l.
aquifer capacity (sand)	~19 m
filtration coefficient, K, of the aquifer	1.0 x 10^{-2} cm/s
required lowering of the GWL at the level of excavation of the pit	67.00 m.a.s.l.
maximum permittable depression in the well up to an elevation	61.50 m.a.s.l.
well depth to elevation	52.00 m.a.s.l.
filter length L = 6 m	55.00 – 61.00 m.a.s.l.
diameter of the well	0.25 m
the maximum capacity of the well without the occurrence of suffusion	5.0 l/s

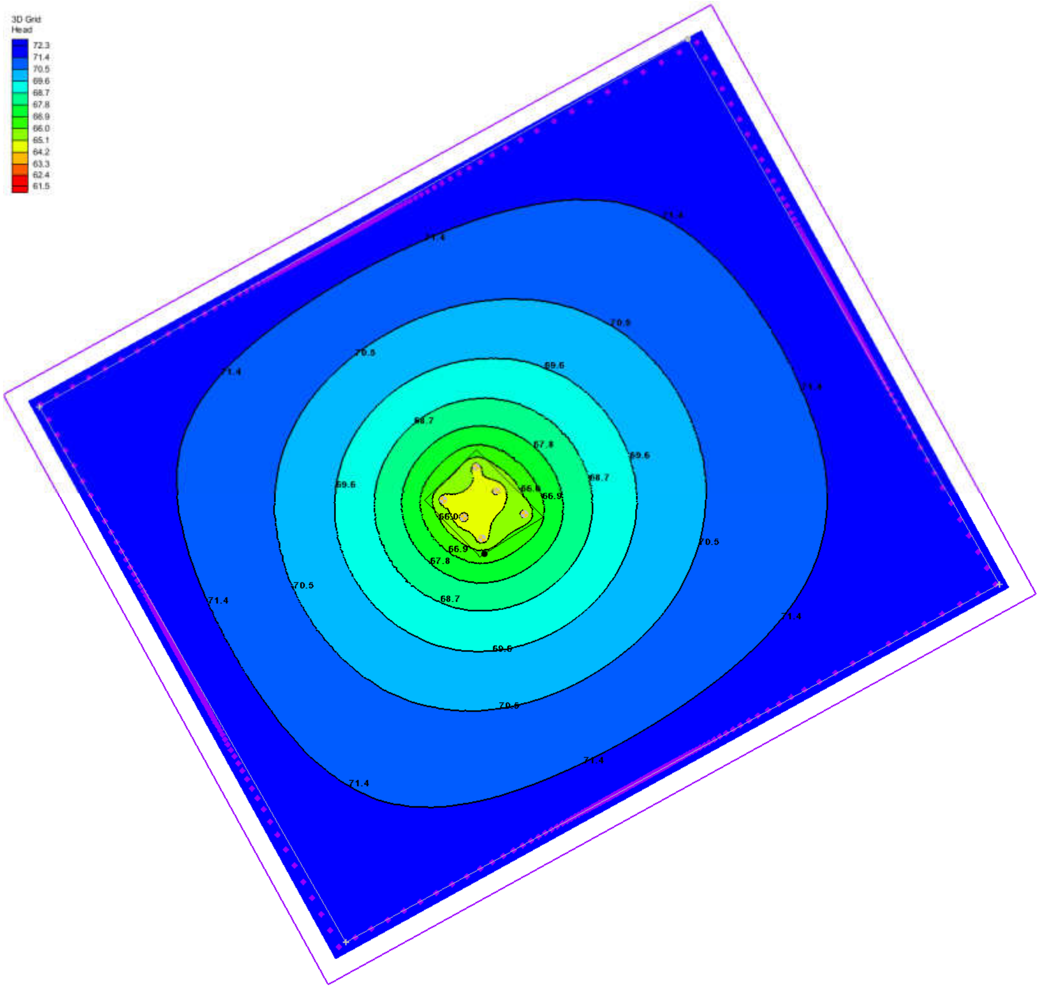

Figure 2. Display of the depression cone in the area of the foundation pit for the adopted well configuration (k = 10^{-2} cm/s, Q = 5.0 l/s, 6 wells)

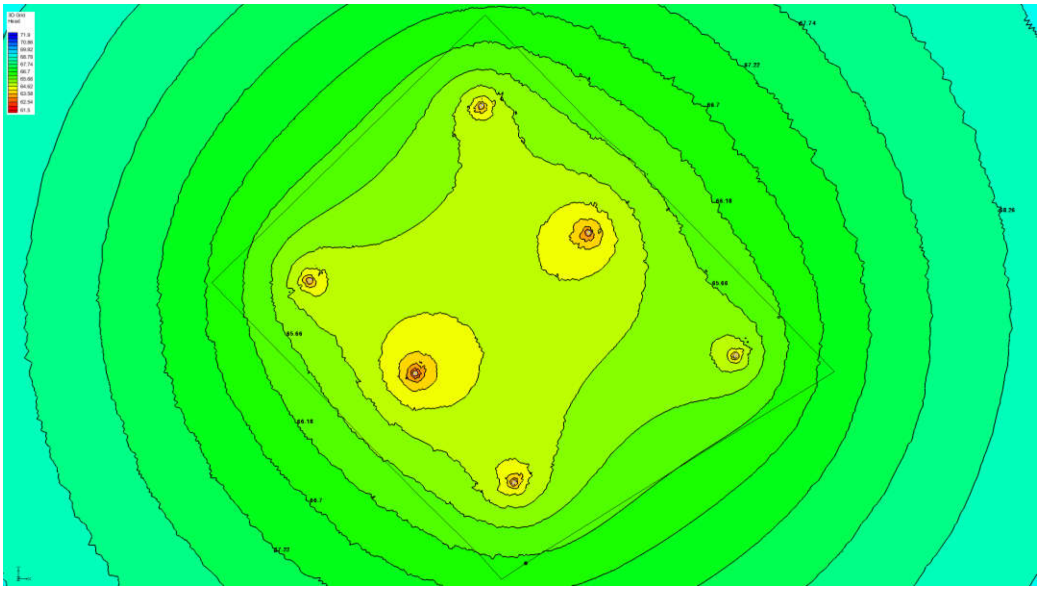

Figure 3. Detail of the depression cone in the area of the foundation pit for the adopted well configuration (k = 10^{-2} cm/s, Q = 5.0 l/s, 6 wells)

The images indicate that the required water level has been reached in the foundation pit area. After stopping the pumping process, the water level rises due to the formation of a depression cone. Therefore, the pumps are turned back on once the maximum permittable water level is reached, and this process continues cyclically. Since this is a cyclical process of periodic switching pumps on and off, it is managed by installing pumps with frequency regulation. It should be noted that the selection of the well configuration and the nominal flow was made according to the required lowering level and the critical velocity, calculated according to the Abramov criterion.

Additionally, the accuracy of flow calculations in the porous medium largely depends on the filtration coefficient. This coefficient can be determined through various methods, with the trial pumping method being the most accurate. In contrast, the least reliable method involves using formulas based on the material's granulometry. It is important to emphasize that for the hydraulic calculation of groundwater level lowering in this study, recommendations from the geotechnical analysis were used. The values obtained were based on empirical expressions; therefore, there may be discrepancies between the actual site conditions and the results obtained in this study.

3. CONCLUSION

This paper presents a mathematical modeling of the groundwater level using the GMS software package, specifically for the construction of a residential building in Novi Sad. The execution of works at the site requires lowering the groundwater level from the initial static groundwater level to an elevation of 67.00 m above sea level. Since there were two estimates of the initial water level: 71.85 meters above sea level (determined through exploratory drilling) and 74 meters above sea level (the maximum expected level based on hydrological analyses), analyses were performed for both static groundwater levels. The analysis of groundwater flow at the given location was carried out with a 3D model for simulating the flow regime in a porous medium using GMS 10.7 software. The model incorporates soil type data and groundwater levels determined from geotechnical wells to reconstruct the soil profile at the location accurately.

Two scenarios were analyzed for each of the three selected values of the filtration coefficient and the initial groundwater level of 71.85 m. For a filtration coefficient of 10^{-2} cm/s, one scenario included four wells, each with a flow rate of 6.8 l/s, while the other scenario featured six wells with a flow rate of 5.0 l/s per well. In the case of a filtration coefficient of 10^{-3} cm/s, one scenario consisted of four wells, each with a flow rate of 0.7 l/s, while the alternative involved six wells with a flow rate of 0.5 l/s each. For a filtration coefficient value of 10^{-4} cm/s, one solution consisted of six wells, each with a flow rate of 0.05 l/s, while the other solution included eight wells with a flow rate of 0.04 l/s per well. Then the analysis was carried out with the initial level of 74 m and all three values of the filtration coefficients. The resulting configurations are: eight wells with a flow rate of 5.4 l/s per well (for a filtration coefficient of 10^{-2} cm/s), eight wells with a flow rate of 0.53 l/s per well (for a filtration coefficient of 10^{-3} cm/s) and eight wells with a flow rate of 0.0463 l/s per well (for a filtration coefficient of 10^{-4} cm/s).

In addition to lowering the groundwater level to the desired elevation, the filtration stability process was also controlled. The criterion for permissible velocities at the entrance of the well's filter is crucial for ensuring filtration stability and practically determines the capacity of the designed well. Given that this situation involves wells with limited exploitation time, the Abramov criterion (based on the relation between the maximum velocities at the entrance to the filter construction and the filtration coefficient of the aquifer) was used to determine the maximum permittable velocity. Although all solutions meet the established conditions, the configuration with six wells and a flow rate of 5.0 l/s per well (for the initial groundwater level of 71.85 m and the filtration coefficient of 10^{-2} cm/s) is recommended as the most realistic solution. This recommendation is based on the optimal pumping flows typically observed in this local area.

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