# MODELING GROUNDWATER FLOW IN HETEROGENEOUS SOILS IN RIVER TERRACES

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***Abstract:*** *Modeling is one of the methods used to solve practical hydrogeological problems associated with movement and assessment of groundwater sources. It is has long been in place in hydrogeology with the first well-described modeling methods dating back to the beginning of the 20th century. Analog and digital techniques advancements in the late sixties made it possible to apply them more actively. Nowadays it is unthinkable to address such type of scientific problems without the use of contemporary software tools for geological and hydrogeological modeling. Coupled with modules used in GIS media such tools enable resolution of specific tasks aiming to describe underground filtration flow.*

*Combing innovative technologies for a detailed three-dimensional reconstruction (approximation) of a geological medium with detailed calculation procedures for a mathematical description of groundwater flow in such medium enable solving a wide spectrum of hydrogeological tasks of great complexity.*

*Numerous are the research institutes, universities and private organization worldwide that focus on developing contemporary software products for mathematic modeling. Specialized modules are designed to support hydrogeological surveys. The products developed operate on a very high level input data automation, graphic interface, visualization, etc. Some of the companies employ MODFLOW which is one of the most frequently used computer codes in groundwater flow modeling. It is module-type software based on the finite difference methods, and has been created by US Geological Survey McDonald and Harbaugh (USGS) [6], the output code being free software.*

*The approach employed in the case presented involves calculations and 3D visualization by means of our own simplified software (VISMAT) developed on the grounds of modern software and hardware solutions in combination with numerical methods. Part of MODFLOW code is also used in VISMAT development.*

**Keywords**: GROUNDWATER, MODELLING, GIS APPLICATIONS, OPEN SOURCE SOFTWARE

## *1. Introduction*

Maintaining the balance in nature, including the atmosphere, biosphere and hydrosphere, is a major task in front of the humanity which is responsible for the survival of the planet.

Groundwater is a natural resource having an environmental and economic value which is essential to maintain life, sustainable development and ecosystem integrity. The man, through his activity, plays the role of an active factor exerting both direct and indirect impact on the quantity and quality of this vital natural resource.

In this regard, the study of groundwater is within the scope of interest of many researchers worldwide. One of the methods that are used to solve applied hydrogeological tasks is modelling. As a method in hydrogeology it has been applied since the beginning of the XX century, but its active application began after the 60s of the last century, which is mainly related to the development of analogue and digital technology. In recent years, with the boom in the development of computer technology, it has become even more feasible to create simulations of groundwater flow, and 3D visualizations[1].

Combining an innovative technology for a detailed three-dimensional representation of the geological environment on the one hand, and on the other hand the detailed calculation procedures for modelling the groundwater flow, enables the solving of a wide range of hydrological tasks of high complexity.

Especially valuable and irreplaceable are hydrogeological models for solving problems related to:

- Migration of pollutants in groundwater;
- Identification of local groundwater resources and opportunities for groundwater abstraction by single water intake facilities or systems thereof;
- Balance assessments to determine regional resources or reserves of groundwater in groundwater bodies;
- etc.

One of the main hydrogeological problems is the study of groundwater flow and its protection from pollution as groundwater is one of the sources of potable water. Studying the patterns of groundwater flow, water quality changes and conditions of groundwater pollution are the major hydrogeological problems.

The purpose of this task is to make a mathematical modelling of groundwater flow in heterogeneous soils in river terraces, applying the study to a particular section of the Tundzha River valley. The sequence in solving the problem can be conditionally divided into the following main parts:

- Theoretical rationale – description of hydrodynamic parameters (velocity, pressure, etc.), basic laws, differential equations, use of finite difference and finite element numerical methods;
- Gathering and processing databases – description of the chosen area, relief and geological maps of the areas, GIS of the areas, water levels, data from surveying, measurement and abstraction drills, using data from field measurements, etc.
- Developing VISMAT software for mathematical modelling and 3D visualization;
- Experimental part – creating a 3D hydrogeological model of the selected area; simulations of the groundwater flow in the area concerned; 3D visualization.

## *2. Theoretical rationale – numerical methods*

The diverse multi-component (heterogeneous) media and the complexity of the processes therein lead to considerable differences in the study and construction of models for determining the hydrodynamic parameters. Most often multi-component media are regarded as continuous and their study results in the well known equations of filtration (Darcy's law).

The methodology of preparing hydrogeological models and making estimates is a process of sequential steps. There are

different kinds of hydrological models, and the mathematical models and their numerical solution have a substantial position among them. The difference between numerical and analogue modelling is that in the latter case the filtration medium is not regarded as continuous and having the same parameters, and it is discretized into separate terminal volumes or areas, each having its specific characteristics.

The mathematical model described in a differential form and its solution turns into a task written in a discreet form.

Considering the complexity of solving the tasks of filtration for limited areas that occur frequently in practice, in the case of integration of differential equations it is more promising to use numerical rather than analytical methods. When examining an area of complex geometry, numerical methods are the only ones with the help of which tasks of this kind can be solved. Taking into account the fact that porous media in most cases are heterogeneous, the problem becomes even more complex and the need for using numerical methods for solving this type of problems is obvious.

To solve this particular task an approach has been adopted that uses a combination of two methods – the Finite Difference Method (FDM) and the Finite Element Method (FEM) [3].

## *3. Database*

Nowadays, the study of this kind of scientific problems is impossible without the use of advanced software tools for geological and hydrogeological modelling, combined with the application of modules in GIS environment solving private specific tasks detailing the underground filtration flow.

***Geographic information systems are a key tool*** providing geo-referenced and synthesized digital information, such as specialized maps, data in relational form and graphically presented results and modular solutions in GIS environment performing specific mathematical procedures for solving specific geospatial tasks.

In recent years, to solve problems and tasks in the field of natural engineering, especially with engineering and geological, hydrogeological and environmental focus, Internet-based GIS applications have been actively developed.

For the present task, GIS of the Tundzha river valley has been used, separating a section along the river, starting after the town of Yambol and ending at the village of Hanovo, for which data of observation drills (Nos 815S1, 816T1, 818S1, village of Hanovo) and a hydro-meteorological station (HMS No 74800, town of Yambol) has been used concerning the water levels in the river. The information has been provided by NIMH-BAS. Additional independent measurements in boreholes in private abstraction sources have been also made. For the characterization of the area, the Master plans for water use in Bulgaria, Water use and water resources balance of the Tundzha river valley [2] and official information of the Municipality of Tundzha concerning water resources and geological structures [7] have been used.

***Figure 1*** *Relief of the Tundzha river valley*

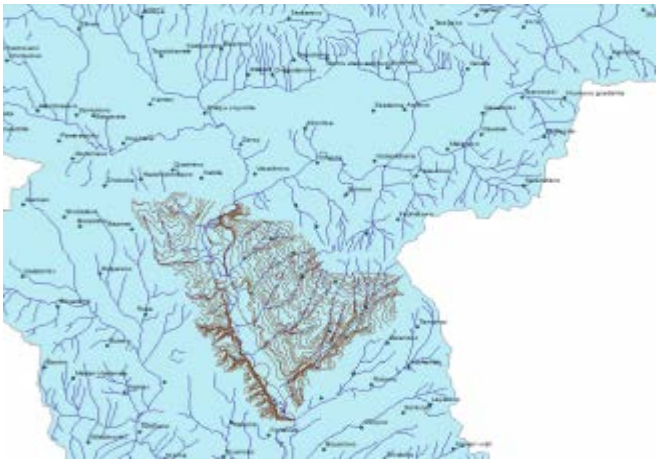

***Figure 2*** *GIS river Tundzha*, village of Hanovo

Regarding the geological structure, geological maps of the area have been used, and in the chosen area 68 point measurements have been made by the method of vertical electrical sounding. For each point, its exact GPS position and the geological structure of the layers at an approximate depth of 50 m. have been specified. The geological lattice of the layer structure of the research area has been shaped by means of the results obtained. In the methodical aspect, geo-tectonic studies of the whole area have been initially made; in the geological aspect, it is known that the area combines the Yambol and Elhovo synclinal forms of similar tectonic and geological structure, that are filled by *Neogene sedimentary* deposits and alluvial deposits of the Tundzha river and its tributaries the Popovska river, Kalnitsa river, Arapliyska river and Yavuz dere.

Geophysical measurements have been made with highly sensitive equipment by the VES method. Measurements by the Method of Vertical Electrical Sounding are carried out by running a low-frequency electric current (5 Hz) through two current electrodes by a generator with a constant force of 10 to 30 mA, and the voltage (mV) between two other receiving electrodes is measured by an electronic amplifier. A unilateral three-electronic measurement scheme A...M 1.0 N….B -∞ has been chosen.

***Figure 3*** *Equipment for field measurements method VES*

Diagrams have been drawn from which it is seen that the electrical resistance of rocks from the geological incisions varies within certain values depending on the layer structure. Next to the diagrams, interpreted lithological columns which show the layers have been compiled.

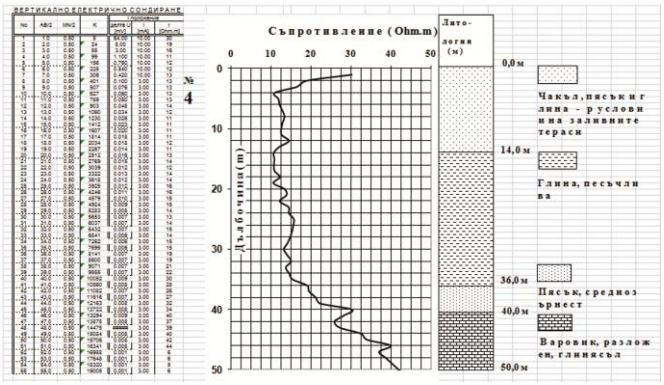


***Figure 4*** *Diagram method VES*
*(point № 4 N 42,23275, E 26,30587, H 119m )*

The combination of the relief of the GIS area, geological maps and geological lattice of field measurements provide the necessary information to form a 3D visualization of the area with *Software* that works with *VISMAT* file *extension.*

## *4. VISMAT – software for mathematical modelling and 3D visualization*

As a result of the work done, a visualization module has been created enabling the check up of evolution over time of selected variables in a random incision (such as location and angle with the vertical). One of the most advanced platforms for parallel computing and a programming model of NVIDIA CUDA [5], which is extremely effective for numerical modelling of this type of tasks, has been used. **OpenGL** (Open Graphics Library) [4] – application programming interface (API) for rendering 2G and 3G graphics has also been used. It is compatible with different operating systems and computer platforms. It is suitable for applications requiring high image quality combined with good performance to enable image generation in real time. The programming language used is C++.

General idea of the algorithm:

- The section under study is divided into elementary volumes as per desired accuracy and a certain size;
- Each elementary volume is recognizable depending on the input data;
- Step size over time is selected depending on the desired accuracy;
- Initial data is copied to the RAM memory of the graphics card;

For each step over time, in parallel groups of 1344 volumes, the values for the next time step for each volume are calculated, taking into account previous values over time for a given volume and its neighbouring volumes. Using a combination of finite difference methods and finite element methods the calculations are compiled. The new values are copied into the global memory.

- End of calculation for each step over time.

**Input data:**

- 3D model of the geological layers;
- Topography;
- Initial levels – water level in the river and groundwater (drilling level).

**Output data:**

Time and space series that for each point and each step over time expresses:

- Level of groundwater;
- Other values interesting for the scientific work.

For the purpose a computer configuration has been used having the following characteristics:

- Graphics card NVidia GTX 670 with 1344 CUDA computational cores, 2 GB of RAM memory and 524Kb of L2 cache.
- Intel Core processor i7920 with eight cores, each with a frequency of 2.74 GHz.

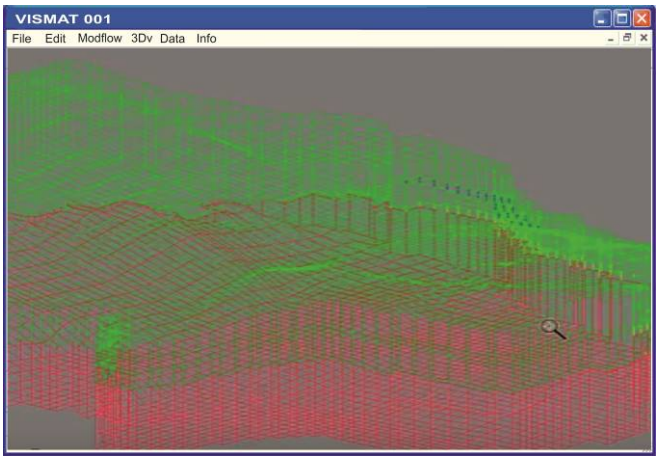


***Figure 5*** *3D preview*

## *5. CONCLUSION*

Combining innovative technology for a detailed three-dimensional reconstruction (approximation) of the geological environment and detailed calculation procedures for the mathematical description of the groundwater flow therein allows solving a wide range of hydrological tasks of high complexity. In this case, the approach chosen is the one by which calculations and visualization are to be made with the help of proprietary simplified software, using modern software and hardware solutions in combination with numerical methods.

The ability to use open source software and the ever more accessible machines with high hardware characteristics give a chance to a greater range of users to do their own research and development, which in turn stimulates the development of the methods of modelling and studying the physical regularities in various fields.

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