

# New simulation technologies applied for creating hydrogeological model of Noginsk District, Russia

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ABSTRACT: Since 1993, the team of the Environment Modelling Centre (EMC) of the Riga Technical University is being active in the field of developing methodologies and special software for creating hydrogeological models (HM). In this paper, these tools applied together with commercial ones are described, on the example of complicated HM created for the Noginsk District, Russia.

## 1 INTRODUCTION

This paper shows applications of special and commercial tools used recently by the EMC team for creating Noginsk HM. Practical knowledge combined with scientific approach suggested useful tools (see Table 1) and methodologies reducing HM errors (Spalvins et al., 1999a, Spalvins et al., 1999b, Spalvins et al., 2000a, Spalvins et al., 2000b). Processes of creating HM and results of modelling are shown by the scheme of Fig.1 taken from (Loukiantchikova et al., 2000).

To consider main problems of creating HM, some mathematics is needful. The  $xyz$ -grid of HM is built of  $(h \times h \times h_z)$ -sized blocks ( $h$  is the block plane size;  $h_z$  is a variable block height). They constitute a rectangular  $(2s + 1)$ -tiered  $xy$ -layer system where  $s + 1$  and  $s$  are, accordingly, the number of aquifers and interjacent aquitards (for Noginsk HM,  $s = 6$ , see Fig.1). Its four vertical sides compose the shell of the HM grid. The ground surface (relief) and the lower side of the model are its geometrical top and bottom, respectively.

The vector  $\varphi$  of the piezometric head is the numerical solution of a boundary field problem approximated, in nodes of the HM grid, by the following algebraic equation system:

$$A \varphi = \beta - G \psi, \quad A = A_{xy} + A_z - G \quad (1)$$

where the matrices  $A_{xy}$ ,  $A_z$ , and  $G$  represent, correspondingly, horizontal links  $a_{xy}$  of aquifers (arranged in  $xy$ -planes), vertical ties  $a_z$  originated by aquitards, and elements connecting "free" nodes of the grid with the ones where the piezometric boundary conditions  $\psi$  are specified; in Noginsk HM, the  $\psi$ -distribution exists on the whole HM surface: top + bottom + shell, and the source vector  $\beta$  contains only rates of the groundwater withdrawal via wells. The elements  $a_{xy}$ ,  $a_z$  (or  $g_{xy}$ ,  $g_z$  of  $G$ ) are computed, as follows:

$$a_{xy} = k m, \quad a_z = h^2 k / m, \quad k \geq 0, \quad m_i = h_{zi} = z_{i-1} - z_i \geq 0, \quad i = 1, 2, \dots, 2s + 1 \quad (2)$$

where  $z_{i-1}$  and  $z_i$  are the elevation distributions of the top and bottom surfaces of the  $i$ -th geological layer;  $z_0$  represents the ground surface map with the hydrographical network (lakes, rivers, etc.) included;  $m = h_z$ ,  $k$  are, accordingly, elements of the digital  $m$ ,  $k$ -maps of computed thickness and permeability distributions of layers. The set of the  $z_i$ -maps states the full geometry of HM. If, within some area,  $h_{zi} = 0$  then the  $i$ -th layer is discontinuous. Noginsk HM includes 7 discontinuous layers, and this feature makes creating of this model extremely difficult (Gosk et al., 1999).

## 2 GENERAL SCHEME. SOFTWARE APPLIED

According to Fig.1, the process of creating Noginsk HM conditionally contains the following stages:

- scanning hard copies of necessary maps , in order to convert them into electronic images;
- digitizing electronic images of maps supporting geological z-surfaces of (2); obtaining the full set of these surfaces; this is the most difficult and time-consuming part of the HM formulation process;
- building  $k$ -maps,  $\beta$  and  $\psi$ -distributions; applying them for HM calibration purposes; the modelling system REMO (Spalvins et al., 1996) is applied to accomplish this final stage, when all calibrated HM results become available for further utilization;
- the contaminant mass transport is modelled by the Groundwater Vistas (GV) system (Environmental simulations, 1997);. the HM data for GV are prepared by REMO.

All the above stages are interdependent, and they must be repeated many times, to meet HM calibration targets, which are multifunctional (Spalvins et al., 2000a).

Commercial and special (developed by EMC) software tools were applied, to create Noginsk HM. The following two commercial programs were used:

- the GV system, to investigate the contaminant mass transport in groundwater;
- the SURFER program (Golden Software, 1997) for supporting graphics, digitizing of electronic images, and performing grid mathematics.

It was necessary to develop special tools, listed in Table 1, because the available commercial ones (for example, MODFLOW (McDonald & Harbaugh, 1988) and interpolation modules of SURFER) turned out to be helpless, when faced with practical cases insisting on investigation of complex hydrogeological systems (Atruskievics et al., 1994). Nowadays, the situation has not improved much, hence even the modern modelling programs (like GV) are mostly still based on numerous outdated principles – survivals from the era of slow computers (the zone scheme used for saving memory (Spalvins & Janbickis, 2000);  $\beta$ -conditions applied, as infiltration flows on the HM top (Spalvins, 2000); unnecessarily strong human involvement (Spalvins et al., 1999a), etc).

Table 1. Programs and methods developed by the EMC team for creating HM.

Nr	Name of program or method, its activity, (reference)	Related programs
1	Program REMO, modelling and calibration of (1), (Spalvins et al., 1996)	GV, SURFER
2	Program GDI, creating interpolated data surfaces for (1), (Spalvins & Slangens, 1994)	REMO, GV, SURFER
3	Program CRP, preparing line data and joining them with the HM grid, (Slangens & Spalvins, 2000)	GDI
4	Program CRS, preparing line data of geological sections, (Lace & Spalvins, 2000)	CRP
5	Program INT $\beta\phi$ , interpolates $\beta$ and $\phi$ values from irregularly located wells to nodes of the HM grid and backwards, (Lace et al., 1995)	REMO
6	Program INT $\beta$ , interpolates $\beta$ values from irregularly located wells to nodes of the HM grid, (Gosk et al., 1999)	GV
7	Program GVR, creates images of vertical cross sections of HM results along any line chosen, (Spalvins et al., 1996)	REMO
8	Program NFCG, solves the system (1), (Janbicka et al., 1993)	REMO
9	Method of using the ground surface elevation map, as the $\psi$ -distribution, on the HM top, (Spalvins, 2000)	REMO, GV
10	Method of using the HM shell, as an interpolation device of the $\psi$ -distribution, (Spalvins, et al., 2000)	REMO, GV
11	Method of tuning zone converter modules, (Spalvins & Janbickis, 2000)	GV
12	Method of avoiding unconfined aquifers in HM, (Spalvins, 2000)	REMO, GV
13	Method of masking HM results located within areas ( $h_z = 0$ ) of non-existent layers, (Gosk, et al., 2000)	REMO, SURFER

These special tools are being used mainly for preparing various input maps and distributions of boundary conditions  $\beta$ ,  $\psi$  needed to create HM of (1). In Table 1, the tools are conditionally sorted into programs and methods. The method represents a serviceable algorithm, which can be utilized by any affined program, even the commercial one. The column "Related programs" gives the code of connected program- the user of the results provided by the program (or method) considered. For example, the REMO results may be exported to the GV program, or graphed by SURFER.

It follows from Table 1, that all tools, but Nr 5 and Nr 11, provide data for, or support the REMO program. REMO is a tested novel tool, it is able to accomplish tasks of utmost complexity.

Due to resourceful methods of mathematical physics embodied, the GDI program can provide complicated interpolated surfaces (including the interlinked  $z$ -surfaces of discontinuous layers) by applying minimal sets of input data (Spalvins et al., 2000).

The remarkable GDI-results are also due to extensive use of various line data (isolines, geological boundaries and profiles of sections, long lines of rivers, etc), as the initial ones for GDI. The CRP program computes them, at intersections (crospoints) of lines (carriers) with the HM grid. The novel version of CRP insures high quality both of coordinates and values of data, at the crospoints (Slangens & Spalvins, 2000).

The INT $\beta\phi$  program considerably improves accuracy of REMO results, as follows:

- boundary  $\beta$ -values of irregularly located wells are interpolated to four nearest nodes of the HM grid; (GV roughly moves the  $\beta$ -value to one nearest node!);
- to increase credibility of HM calibration,  $\phi$ -values are computed, at randomly sited observation wells.

The INT $\beta$  program considerably improves the  $\beta$ -distribution for the GV code by applying the REMO interpolated  $\beta$ -values, as the formal production wells at nodes (Gosk et al., 1999).

It was necessary to develop the CRV program, because the GV system could provide sections for HM results only along the HM grid lines. Moreover, these sections are misleading, even erroneous (Spalvins et al., 2000a).

As the REMO solver, the NFCG program has never failed. It is a robust, reliable tool. No adjustments of its regimes are required from a modeller.

The methods Nr 9 and Nr10 of Table 1 present a breakthrough in modelling of hydrogeological processes. Due to them, reliability of HM results has raised drastically.

To prevent damage of data files imported into the GV system, the method of tuning its zone converter was developed.

The method Nr 12 blocks inevitable ruin of (1), during its solution process by the GV system, at cases when HM includes discontinuous layers. In REMO, no regimes of unconfined aquifers are allowed.

In GV, no masking of HM results, located within areas of non-existent layers, is possible. The method Nr 13 solves this problem for REMO and SURFER.

It follows from the above text that, in order to create Noginsk HM, the almost full set of tools developed by EMC has been applied. Even some new ones have been made and used, to accomplish this very difficult task.

### 3 CONCLUSIONS

To obtain reliable HM results for complex practical cases, novel tools have been developed and used by the EMC team. They support the following general ideas:

- model formulation, solving, and post-processing errors can be subdued if special software and methodology are focused on this purpose;
- orientation on teamwork, involving specialists from overlapping science fields, when complex HM is to be created;
- withholding involvement of people in routine processes which can be run much safer by properly designed software;
- applying different, highly effective special tools for creating complex HM, because no single system can cope with such a task.

We hope that our knowledge reported will be of interest for modellers creating complex hydrogeological models.

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**Spalviņš A., Šlangens J., Janbickis R., Lace I., Gosk E., Loukiantchikova L. Jaunas modelēšanas tehnoloģijas, kuras izmantotas Noginskas rajona hidroģeoloģiskā modeļa būvei Krievijā.**

*Kopš 1993. gada Rīgas Tehniskās universitātes Vides Modelēšanas centrs ir aktīvi izstrādājis metodikas un speciālas programmatūras hidroģeoloģisko modeļu izveidošanai. Šajā rakstā ir parādīts, kā šie speciālie līdzekļi un komercprogrammatūras tika izmantoti komplicēta HM izveidošanai Noginskas rajonam Krievijā.*

**Спалвинь А., Янбичкий Р., Шланген Я., Лаци И. Госк Э., Лукянчикова Л. Новые технологии для построения гидрогеологической модели для Ногинской области, Россия.**

*Начиная с 1993. года Центр Моделирования Среды Рижского Технического Университета активно разрабатывал методики и специальные программные средства для построения гидрогеологических моделей (ГМ). В этой статье показано как эти специальные и коммерческие средства используются совместно для построения сложной ГМ Ногинского района, Россия.*