

CREATION OF HYDROGEOLOGICAL DATA PROFILES FOR GROUNDWATER SYSTEMS

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ABSTRACT

In 2014-2018, scientists of Riga Technical University (RTU) have updated the hydrogeological model (HM) of Latvia. Its current version LAMO4 simulates the steady state average groundwater regimes. The commercial program “Groundwater Vistas 6” (GV) is used for running LAMO4. Unfortunately, the GV graphical programs cannot provide correct profiles on hydrogeological data that are obtained by HM. In 2014, the first RTU results were reported on creating profiles for groundwater heads and infiltration. Since 2014, the methods for the profiles have been innovated. To minimize the risk of obtaining false results due to human factors, the programs for creating profiles operate automatically with minimal involvement of a modeler. Essence of the methods for exposing data on profiles is considered and their practical appliance is reviewed. The research was supported by the Latvian state research program EVIDenT.

Keywords: geological profiles, hydrogeological model, interpolation of data

INTRODUCTION

The LAMO4 area is $475\text{km} \times 300\text{km} = 142.5$ thous. km^2 (see Fig. 1.). Its active part (71.3 thous. km^2) includes, the Gulf of Riga, the land territory of Latvia and geological layers of the intensive groundwater zone (Fig. 2.) [1]. The border territories with neighbouring countries can be used for implementation of transboundary projects.



Fig. 1. Location of LAMO4.

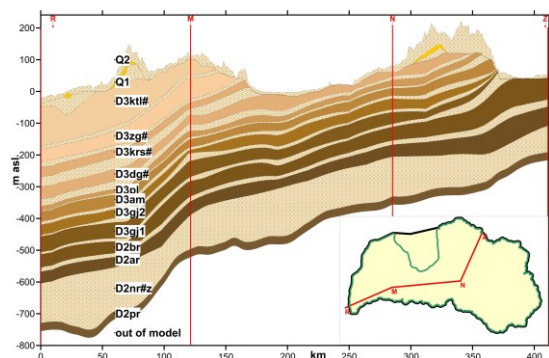


Fig. 2. Geological cross section R-M-N-Z

The GV program [2] includes the programs: MODFLOW (supports HM) [3], MODPATH (tracking groundwater particles) [4], MT3D (simulates contaminant movement in groundwater) [5].

In HM, the geological environment is approximated by the spatial 3D grid. It is built by using the $(h \times h \times m)$ sized blocks (h is the plane approximation step, m is the variable thickness of a geological layer). The block centres are nodes of the 3D grid. The model constitutes a rectangular p -tiered xy -layer system where p is the number of layers. For LAMO4, $p=27$, $h=250$ metres. The 3D body of LAMO4 was approximated by the xyz -grid of the size $1900 \times 1200 \times 27 = 61.56 \times 10^6$.

The framework of the geological layers is formed by their surfaces (z -maps) and by their hydraulic permeability (k -maps).

The model computes groundwater heads (φ -maps) in nodes of the HM grid and the flows (q -maps) that intersect the surfaces of the HM blocks..

For the i -th HM block, the GV system computes its thickness m_i :

$$m_i = z_i - z_{i+1} > 0, \quad z_{i+0.5} = 0.5 (z_i + z_{i+1}) \quad i=1, 2, \dots, p \quad (1)$$

where z_i and z_{i+1} are the top and bottom surfaces, accordingly, of the block; the grid node is located on the surface $z_{i+0.5}$; in discontinuous layers, the $m = 0$ areas exist; for LAMO4, there $m = 0.02$ metre is used.

The infiltration inf_i [mm/year] on the block top surface z_i is, as follows:

$$inf_i = v_{z,i} \times 365 \times 10^3, \quad v_{z,i} = q_{z,i} / h^2 \quad (2)$$

where $v_{z,i}$ [m/day] is the velocity of the vertical flow $q_{z,i}$ that intersects the top surface z_i .

The z , k , φ , inf - maps of HM are the 2D objects in the xy - space. Various graphical programs have been developed for exposing these hydrogeological data, for example, the SURFER system [6].

Unfortunately, no commercial programs are available for exposing the data provided by HM on the profile (2D zl - space) where l is the distance along the profile line L . To obtain the HM data profile, the following three successive steps must be accomplished:

- creating of the zl - map as the base on which the HM data will be exposed; the map represents the geometry (stratigraphy) of the geological environment along the profile and also the presence of aquifers and aquitards where the behaviour of the various HM data is different;
- obtaining of the HM data on the profile;
- the final design of the profile.

In 2014, the first version of the method for creating profiles was developed by RTU [7]. Since 2014, the method has been considerably updated. These innovations are described in the paper.

CREATING OF THE BASE MAP

The base map of the profile is the zl - map that is created by the interpolation of the z -maps along the profile line L . The base map can be obtained by using the option "slice" of SURFER [6]. In the Fig. 3., the base map of the profile W-E at the northern part of Latvia is shown.

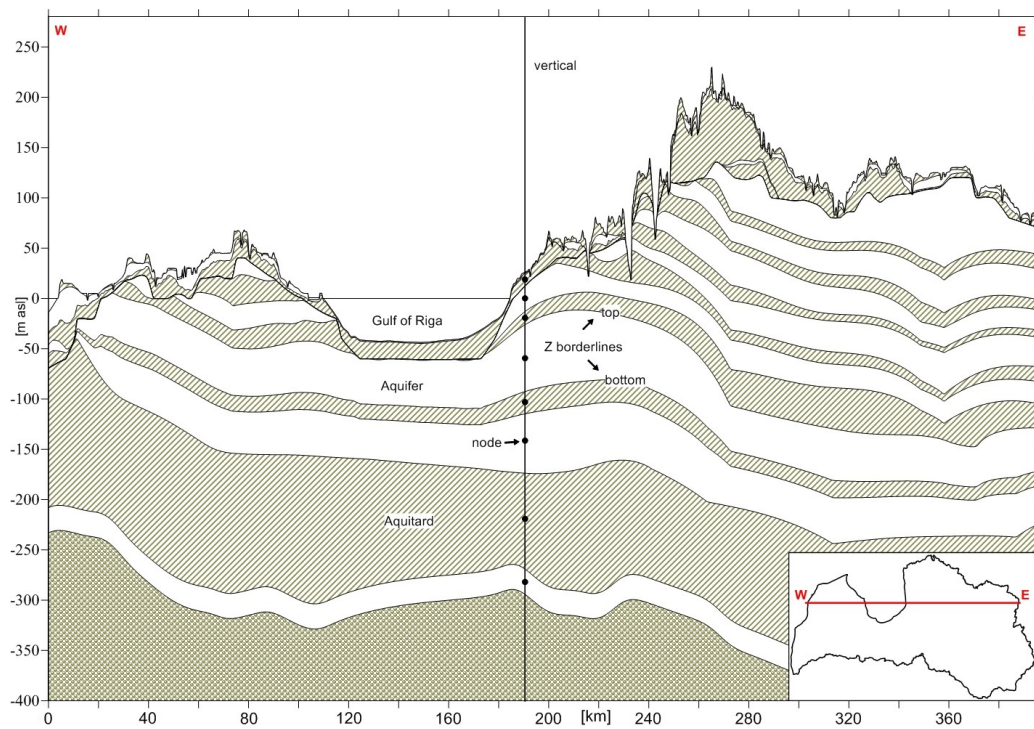


Fig. 3. The base map for the profile W-E

The base map is the set of the z_i borderlines that presents the intersections of the z -maps with the line L . Each layer has its top and bottom borderline. The nodes of the HM grid are located on the verticals (see Fig. 3). If the L line is not parallel to x or y axes or it is torturous then the distances between the verticals on the base map will not be $h = 250$ metres everywhere. This fact is accounted for when the hydrogeological data for the profile will be prepared.

It is necessary to denote aquifers and aquitards in the profile base map.

OBTAINING OF THE HEAD AND INFILTRATION DATA

Mainly two types of the HM data are exposed on the profile: head distributions (φ -maps) and the infiltration (inf – maps). The data provided by MODPATH (profile along pathline) and MT3D (concentration of a substance) also can be displayed on profiles. The case of the MODPATH data will be considered later.

It was shown in [7] that on the profile, the φ and inf isolines must be vertical within the aquifers and aquitards, accordingly. It follows from this condition that the φ and inf isolines must alter linearly, within aquitards and aquifers, respectively. The dual charter of the φ and inf isolines was accounted for in the course of creating their profiles.

To compute the φ and inf distributions for the profile, the arbitrary 2D z grid must be used. For Fig. 3, the size of the grid must be $400\text{km} \times 650$ meters. The grid approximation steps h_l , h_z must be chosen. For LAMO4, $h = h_l = 250$ metres. The choice of h_z defines now exactly the break points of the isolines will coincide with the locations of the z -surfaces of geological layers. At the break point, the direction of an isoline changes abruptly from vertical to askew. For the considered cases, the value $h_z = 1.0$ metre is applied. Then the number of nodes in the z – grid is $1600 \times 650 = 1.04 \times 10^6$.

It was found that no numerical method could provide the correct result which complied with the both above conditions on verticality and linearity of the data isolines. The reason for this setback was the large ratio $h_l / h_z = 250$.

To obtain the correct φ and inf distributions, two successive 1D linear interpolation procedures are accomplished for the z and l directions, correspondingly. On the verticals, the initial data for the φ and inf data interpolation are fixed in the points of its intersection with the z_i and z_{i+1} borderlines:

$$\text{for aquifers, } \varphi_i = \varphi_{z,i} = \varphi_{z,i+1}; \text{ for aquitards, } inf_{z,i} = inf_{z,i+1} \quad (3)$$

where $\varphi_{z,i}$, $inf_{z,i}$ and $\varphi_{z,i+1}$, $inf_{z,i+1}$ are the initial data in the intersections with the z_i and z_{i+1} borderlines, accordingly.

The first procedure results in obtaining the φ and inf distributions on the z -lines. The second interpolation for the l - direction, ensures that the set of the verticals coincides with nodes of the zl grid. Otherwise, the φ and inf distributions will be distorted. The both interpolation procedures were carried out automatically by using the SURFER Scripter.

In Fig. 4., the φ – map for the profile W-E is shown. The direction of water flows that is pointed by arrows, in aquifers and aquitards are lateral and vertical, accordingly. In [8], the absence of lateral flows within aquitards was ignored. There wrongly the flow direction arrows created by SURFER were orthogonal with the φ – isolines (not pointed vertically).

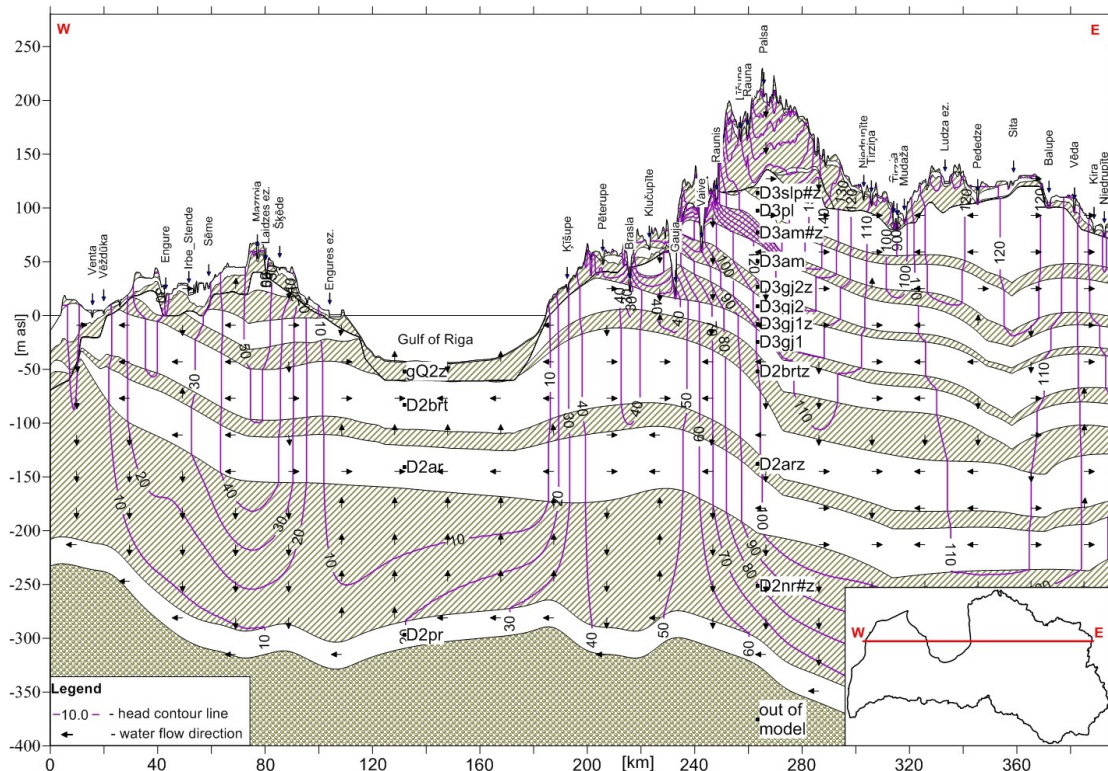


Fig. 4. The φ – map for the profile W-E

In Fig. 5, the combined inf and φ map for the profile W-E is shown. The combined map often provides information that is necessary for better knowledge of groundwater processes and for the calibration of HM.

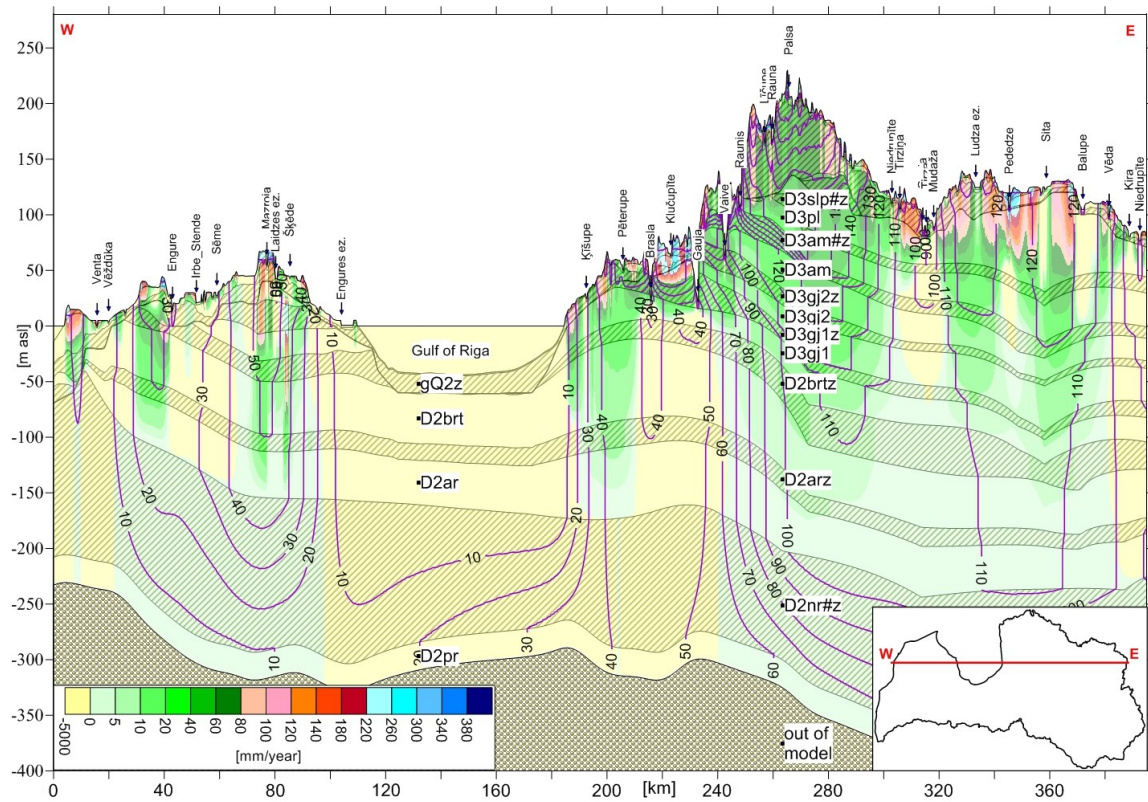
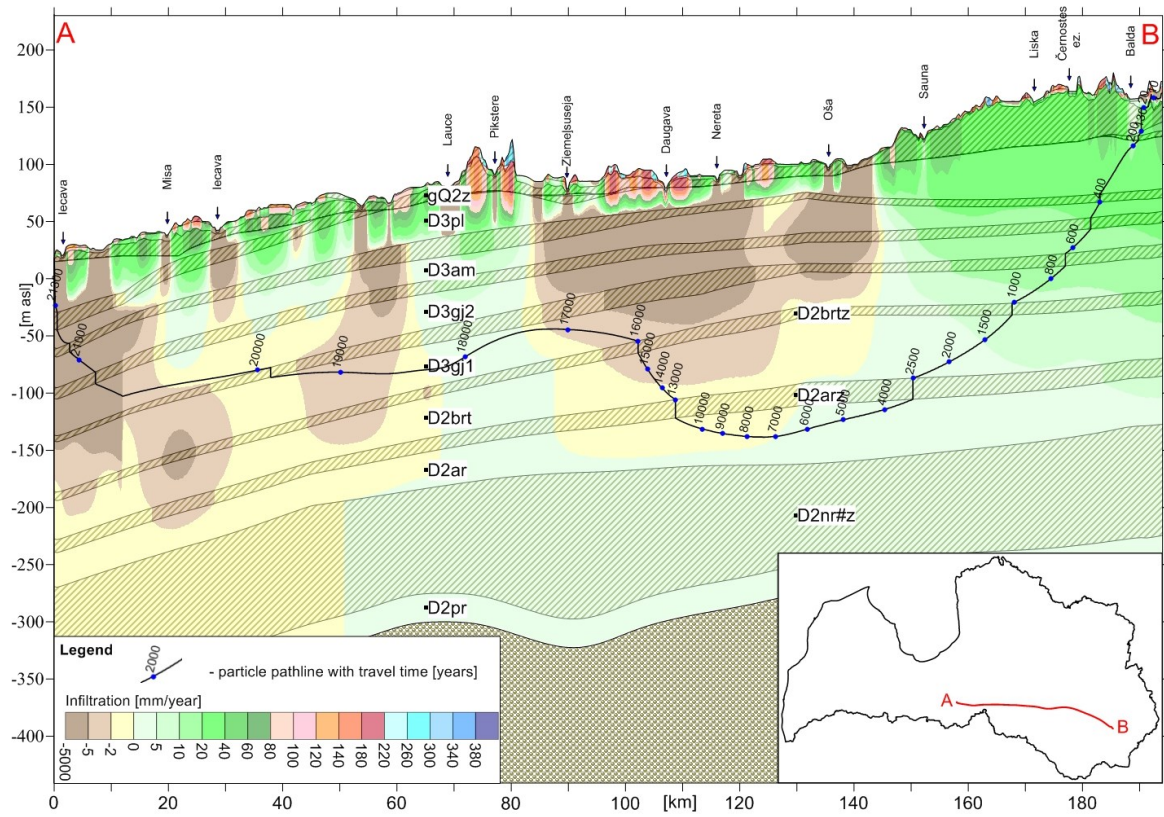
Fig. 5. The combined *inf* and ϕ map for the profile W-E

Fig. 6. The combined map of the infiltration and the MODPATH pathline data for the profile A-B

OBTAING OF DATA THE MODPATH RESULTS

The MODPATH program is often used for instigations of spatial groundwater flow systems. In [9], the case of finding the Iecava river base flow sources was considered.

It was found out that for the river, some part of its base flow sources was located very far from the river drainage basin. In order to understand reasons of the phenomenon, the profiles for the longest water particle pathlines were created.

In Fig. 6., for the profile A-B the combined map for infiltration and for the long pathline is shown. The particle has spent ~21000 years to cover the ~200 km distance from the hilly area at the SE part of Latvia (B) to the Iecava river (A). Due to the downward water flow, the particle in ~2500 years has reached the D2ar aquitard. In the year 7000, the particle passed the lowest point of its travel in the D2ar aquifer. During the next 10000 years, due to the upward flow, the particle climbed up to the D3gj1 aquifer. For the last ~4500 years, the particle found the Iecava river. The profile of Fig. 6. gives the full understanding of causes that controlled movement of the particle at each stage of its long travel.

FINAL DESIGN OF THE PROFILE MAPS

By considering Fig. 4., Fig. 5. and Fig. 6. one can conclude that there numerous headings and other auxiliary data are present. Arrangement of the set for these data is an important part of the final design of the profile. The manual design is labour consuming and may result in unnoticed mistakes. The most complex was the task of locating the intersections of rivers and lakes with the profile line *L* and lodging the names of rivers and lakes. Fortunately, the task was accomplished by using computer aided procedure that also lodged the geological codes of aquifers and aquitards.

CONCLUSION

Scientists of RTU have improved the methods for obtaining hydrogeological data profiles. The data can be provided by LAMO4 and also by other models. Creating of the profile maps is accomplished by performing three successive stages: building of the base map for the geological environment stratigraphy, obtaining of the hydrogeological data for the profile; the final design of the map. The most informative are the profiles for the groundwater head and infiltration distributions and also their combined profiles. The profiles can be created for data provided by the MODPATH and MT3D systems. The updates are focused on automation of the data processing, to minimize the risk caused by involvement of a modeller. The essence of the innovations is explained and their practical appliance is reviewed. The research was supported by the Latvian state research program EVIDEnT.

REFERENCES

- [1] Spalvins, A., Slangens, J., Lace, I., K., Aleksans, O., Krauklis, Improvement of Hydrogeological Models: a Case Study, International Review on Modelling and Simulations (IREMOS), ISSN 1974-9821, Vol.8 N.2, April 2015, pp. 265-275. http://www.emc.rtu.lv/issues/2015/IREMOS_2015_raksts.pdf
- [2] Environmental Simulations, Inc. *Groundwater Vistas. Version 6*, Guide to using, 2011.

- [3] Harbaugh W., MODFLOW-2005, *U.S. Geological Survey Modular Ground-Water Model: the ground-water flow process*, chap 16, book 6, US Geological Survey Techniques and Methods 6-A16, USGS, Reston, VA., 2005.
- [4] Pollok D. W. *User's Guide for MODPATH/MODPATH-Plot, Version 3. A particle tracking post-processing package for MODFLOW, the US Geological Survey finite-difference groundwater flow model*, U.S. Geological Survey, September 1994.
- [5] Zheng C., MT3D99 A modular three dimensional transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems. USEPA report, USEPA, Washington, DC., 1999.
- [6] Golden Software, Inc., "SURFER-11 for Windows, Users manual, Guide to Using," 2012.
- [7] Spalvins, A., Slangens, J., Aleksans, O., Lace, I., Krauklis, K., Geological profiles as efficient means for expounding results provided by hydrogeological model of Latvia, 14th Geo Conference on Science and Technologies in Geology, Exploration and Mining (SGEM), 17-26 June, 2014, Bulgaria, Conference Proceedings Vol.II, Published by STEF92 Technology Ltd., pp. 401-408, ISBN 978-619-7105-08-7, ISSN 1314-2704, DOI 10.5593/sgem2014B12. http://www.emc.rtu.lv/issues/2014/SGEM-2014_Spalvins.pdf
- [8] Report, Mapping for the Gauja river basin district by using results of hydrogeological model of Latvia", Riga Technical University, 12p., 49 maps, 6 tables, (in Latvian). http://www.emc.rtu.lv/ERAF/LVGMC/Pielikums_LAMO.pdf http://www.emc.rtu.lv/ERAF/LVGMC/Gaujas_parskats_2013.pdf
- [9] K. Krauklis, A. Spalvins, J. Slangens, The Hydrogeological Model of Latvia LAMO4 as a Tool for Investigating the Processes of Nature. Sources of Groundwater Inflow for the Iecava River, Scientific Journal of Riga Technical University, Boundary Field Problems and Computer Simulation, RTU Press, Riga, 2015, vol. 54, pp. 43-50. http://www.emc.rtu.lv/issues/2015/06_VMC_DITF_54_2015_Krauklis.pdf