# Methods and Software Tools Used to Designate Geometry for Regional Hydrogeological Model of Latvia

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***Abstract*** **– In 2012, the hydrogeological model (HM) LAMO of Latvia has been developed by scientists of Riga Technical University (RTU). LAMO comprises an active groundwater zone that provides drinking water. 3D-body of LAMO is approximated by the 951×601×25 size finite difference grid. Its plane approximation step is 500 metres and HM accounts for 25 geological layers.**

**The commercial software Groundwater Vistas (GV) is used to run LAMO. The GV system contains tools used worldwide for hydrogeological modeling.**

**The most time consuming and troublesome part of developing a HM is to designate its geometry that is represented by thicknesses of geological layers composing the HM body. For LAMO, most of these layers are outcropping. They are not continuous and, for this reason, they are not present everywhere in the area of the HM. After emerging at the surface, such layers have zero thickness.**

**Thicknesses of the layers are not used by GV as initial data. A modeller must prepare the set of z-maps that presents elevation surfaces of the layers. The GV system uses z–maps for obtaining thicknesses of the layers.**

**To prepare z-maps for primary geological layers, three steps of data interpolation were performed:**

1. **selecting and checking borehole data that describe stratigraphy of the geological environment; the EXCEL system was applied, to carry out this step;**
2. **by using the graphical system SURFER, the preliminarily set of z-maps was prepared;**
3. **the final version of z-maps was obtained by the Geological Data Interpolation (GDI) system.**

**It was rather difficult to create z-maps for the Quaternary layers, because borehole information describing their geometry was waste and contradictory. For this reason, mainly pointwise data and a few lines were applied as sources for obtaining z-maps of the Quaternary System.**

***Keywords*** **– regional hydrogeological model, MODFLOW, digital maps of initial data**

## I. INTRODUCTION

Detailed description of LAMO is given in [1] and it is not reported here. The present publication focuses on the problems of creating the geometry of LAMO.

Obtaining of LAMO geometry was the most difficult process, because geological information (mostly borehole data) about stratigraphy of geological layers had not been verified before as the initial data for developing of the HM for the whole territory of Latvia. It was necessary to extract trustworthy information from the mess of contradictory data.

It was known before that borehole information to be used for creating of LAMO was contradictory. This feature was discovered during developing of various local HMs in Latvia [2, 3]. The borehole data are incomplete for many reasons: mismatch of borehole top elevation mark with the real ground surface elevation; wrong plane coordinates, wrong and incomplete information of stratigraphy obtained during making of a borehole; incorrect interpretation even of faultless stratigraphical data (wrong attachment to geological layers).

It is almost impossible to discover these failures if only a single borehole is considered. Discordances of the borehole data show up when a group of boreholes is inspected. Because sources of borehole data discordances are so different, it is not realistic to check applicability of all available data. To overcome the problem, the method of geological profiles (cross sections) was used for preparing data representing the HM geometry. The method combines the borehole data with knowledge of a hydrogeologist about stratigraphy of the place under consideration. The geological profile enables to discover and to mend possible errors of borehole data. Extra information can be added that fills data gaps not only along a borehole axis but also along the profile. Information carried by the set of profiles was used to prepare digital maps of geometrical surfaces of geological layers that serve as initial information for the GV system [4]. Special data interpolation tools have been used to approximate surfaces of geological layers [5, 6, 7].

## II. METHODOLOGY APPLIED FOR CREATING SURFACES OF GEOLOGICAL LAYERS

The geometry of LAMO is based on the geological information accumulated by the Latvian Environment, Geology and Meteorology Centre (LEGMC). The information includes stratigraphical data of boreholes, geological maps and descriptions regarding geology of Latvia. LAMO geometry results in the set of z–maps. It includes 26 surfaces for 25 geological layers presented in the HM. The top surface of the HM (z=0) is the digital hydrogeological relief of Latvia. It includes the hydrographical network (river, lakes, sea). The z=1 surface is the digital geological relief. It represents the ground surface elevations. For LAMO this map accounts for depths of the sea and three artificial lakes of hydro electrical power plants of the Daugava River (Riga, Kegums, Plavinas).

These two maps were created by using data provided by the Geospatial Information Agency of Latvia [8].

The LEGMC specialists have prepared two important geological maps: the prequaternary surface (z=6), the D2pr surface (z=24). They are presented in Fig. 1 and Fig. 2 accordingly. The volumes of the Quaternary and primary geological layers are included between the z=0, z=6 and z=24 surfaces, correspondingly.

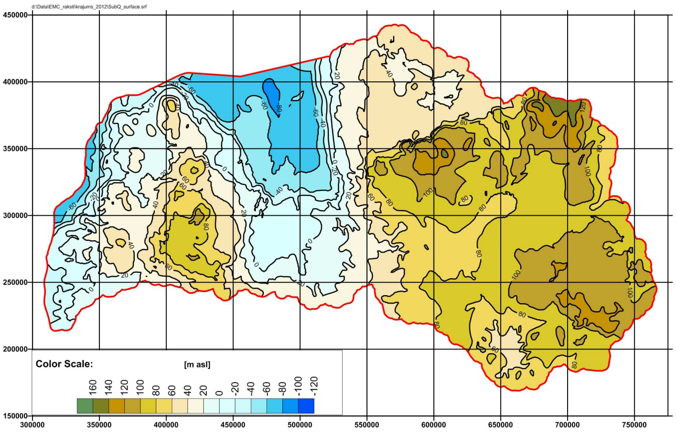


Fig. 1. The prequaternary surface (z=6)

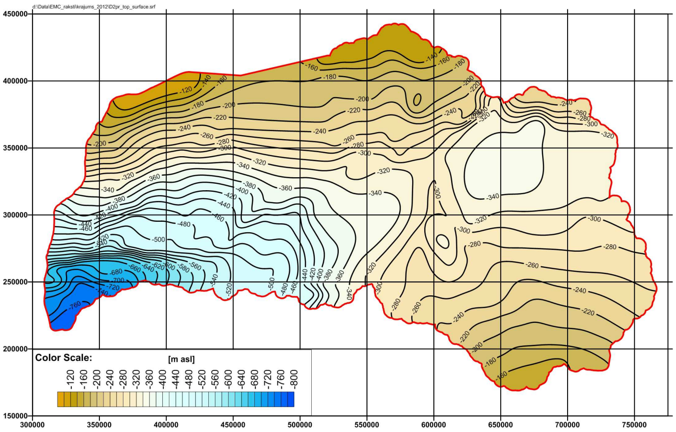


Fig. 2. The D2pr top surface (z=24)

The most time consuming and difficult task was creating of z–maps for the primary geological layers (z=7, 8, …,25). In Fig. 3, the scheme used for this process is shown. The basic stratigraphical information is carried by the boreholes and elevations of geological borderlines located on the subquaternary surface (Fig. 1). The number of boreholes provided by LEGMC is large (about $20\times10^3$). However, very often data of these boreholes are contradictory and it is not always possible to mend them. To reduce laborious work of checking the quality of all available borehole data, the set of representing geological cross sections was used where the chosen boreholes with trustworthy data were located (see Fig. 3). Deep boreholes were used, which provided stratigraphical data for all geological layers of the HM. As a rule, data gaps occurred along a section laterally and vertically (along a borehole axis). These gaps were filled by additional data that were concordant with the existing borehole data. Z–maps must always give positive thicknesses $m$. For this reason, the data of the sections must match this condition for all layers of the HM. The $m$=0 areas of discontinuous layers also must be accounted for. It is done by using $m=\varepsilon=0.02$ instead of zero thickness. There are three main reasons why the value of $\varepsilon$ must be small for the $m$=0 areas of geological stratum:

- geometrical distortions are minimal even if the number of overlaying $m$=0 areas is large (northern part of Latvia);
- transmissivity $T=\varepsilon k$ of aquifers is small even if their permeability $k$ is considerable;
- vertical conductivity $g_v$ of aquitards $g_v=h^2k/\varepsilon$ ($h$=500 for LAMO) is large even if their permeability $k$ is small.

If $\varepsilon$=0.02, then all geological layers of LAMO in their $m$=0 areas behave normally without special control measures for outcropping strata. This first stage of preparing data for creating z–maps was performed by using the EXCEL system [5].

During the second stage of creating z–maps, the SURFER system [6] was applied for obtaining a preliminarily version of the maps. The pointwise data prepared by EXCEL and spaced out pointwise data carried by the geological borderlines were used by SURFER. Unfortunately, the SURFER system cannot provide good z–maps, because of the following reasons: only pointwise data can be processed and their number is limited; the maximum – minimum principle is not insured for data; the condition m>0 is often violated; for the m=0 areas, the requirement ε=0.02 is neglected. However, results obtained by SURFER provide valuable information for correcting possible errors of initial data.

The final version of z–maps was obtained by the Geological Data Interpolation (GDI) system [7]. GDI uses points, lines and surfaces as data carriers. By interpolating pointwise data along lines of cross sections, much more informative linewise data are obtained. GDI applies the data of the cross sections, of the geological borderlines and surfaces that are extracted from the prequaternary surface map (Fig. 1). For example, GDI reproduces the whole top surface of D3ktl aquifer. For other, deeper layers, GDI uses fragments of surfaces that are enclosed between neighboring borderlines on the map of Fig. 1.

Geometry of buried valleys and cuts of rivers in the body of primary geological layers were not simulated by LAMO. Accounting for the buried valleys is difficult and the data about the material that fills them are uncertain. The cuts of rivers are taken into account indirectly when the rivers are input into LAMO [9].

## III. EXAMPLES OF LAMO GEOMETRY

The geometry of the geological environment simulated by LAMO is very complex, especially, for the primary layers. This fact is demonstrated by the set of four geological profiles: W_E (Fig.4); 1S_1N (Fig. 5.); 2S_2N (Fig. 6); 3S_3N (Fig.7).

Profile W_E (Fig. 4) shows that primary geological strata are dipping westwards for eastern and middle parts of Latvia. They are almost horizontal in the east of Latvia.

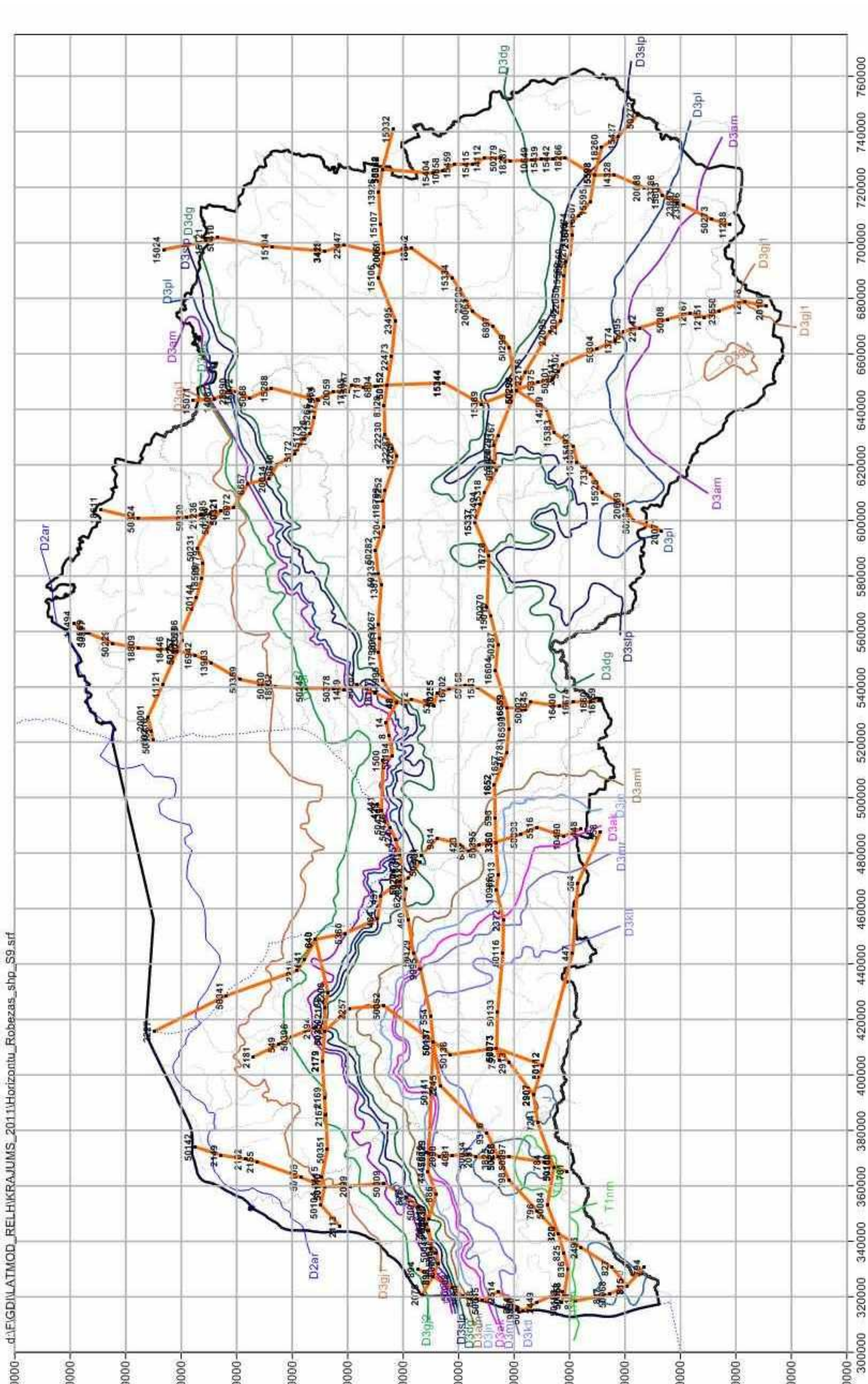


Fig. 3. Initial data used for creating z-maps of primary geological layers: boreholes with the indicators; vertical cross sections based on the boreholes; geological borderlines

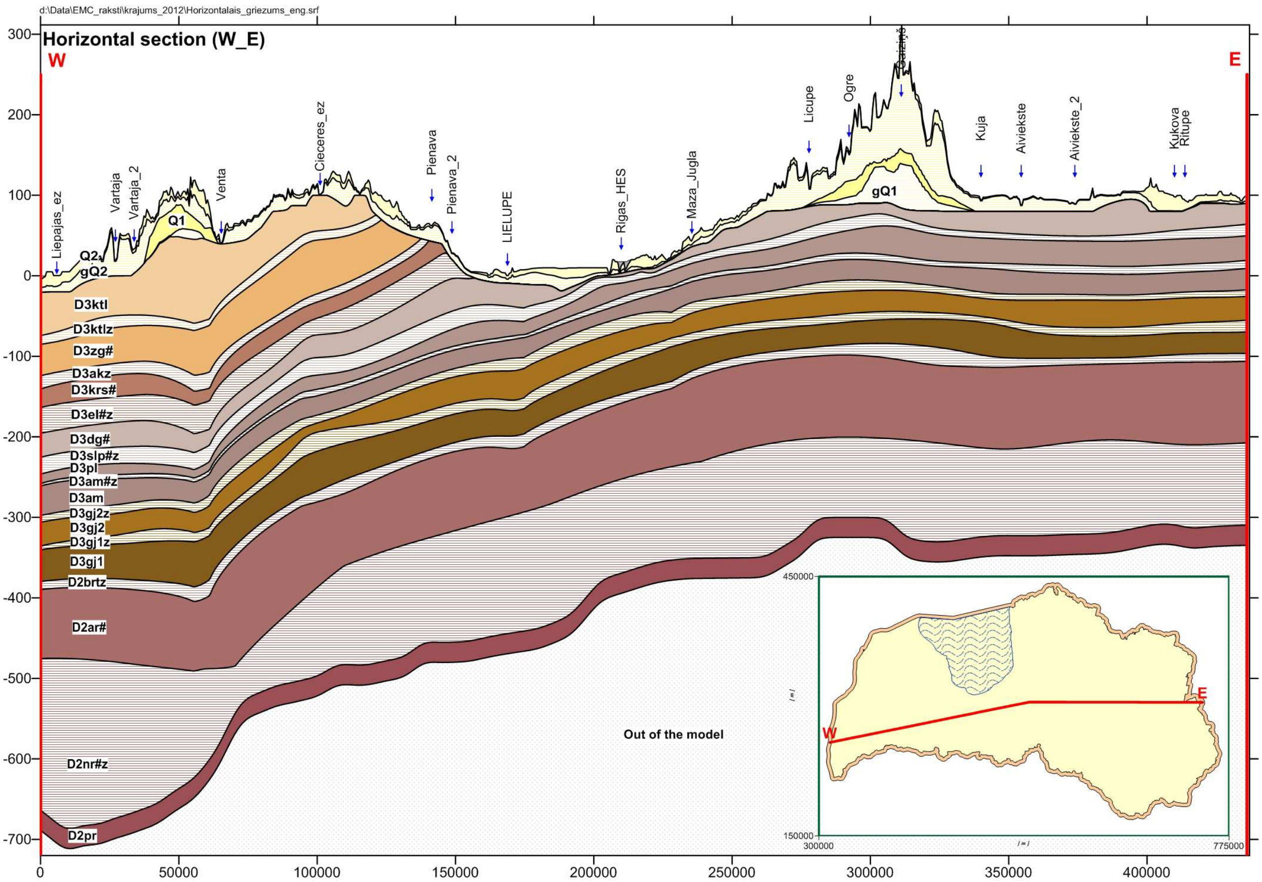


Fig. 4. Geological profile W_E

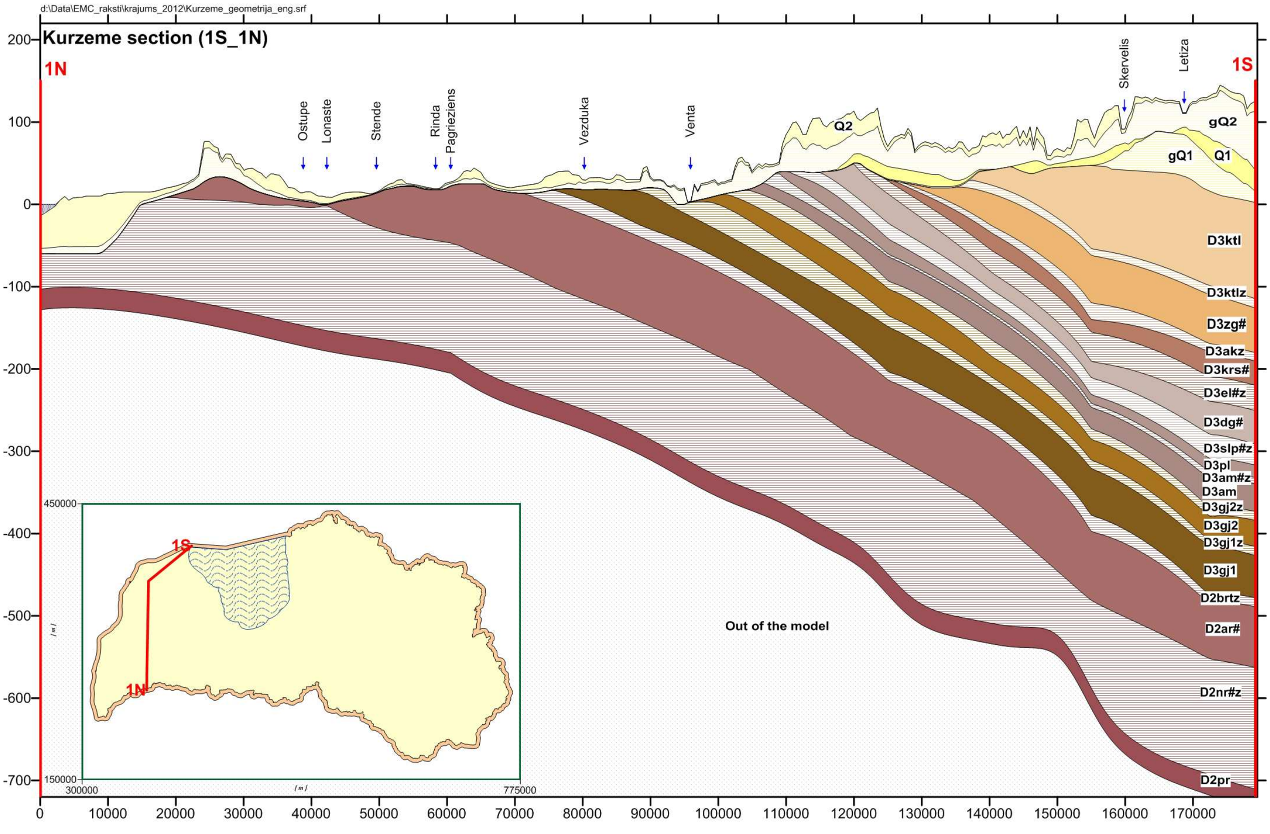


Fig. 5. Geological profile 1S_1N

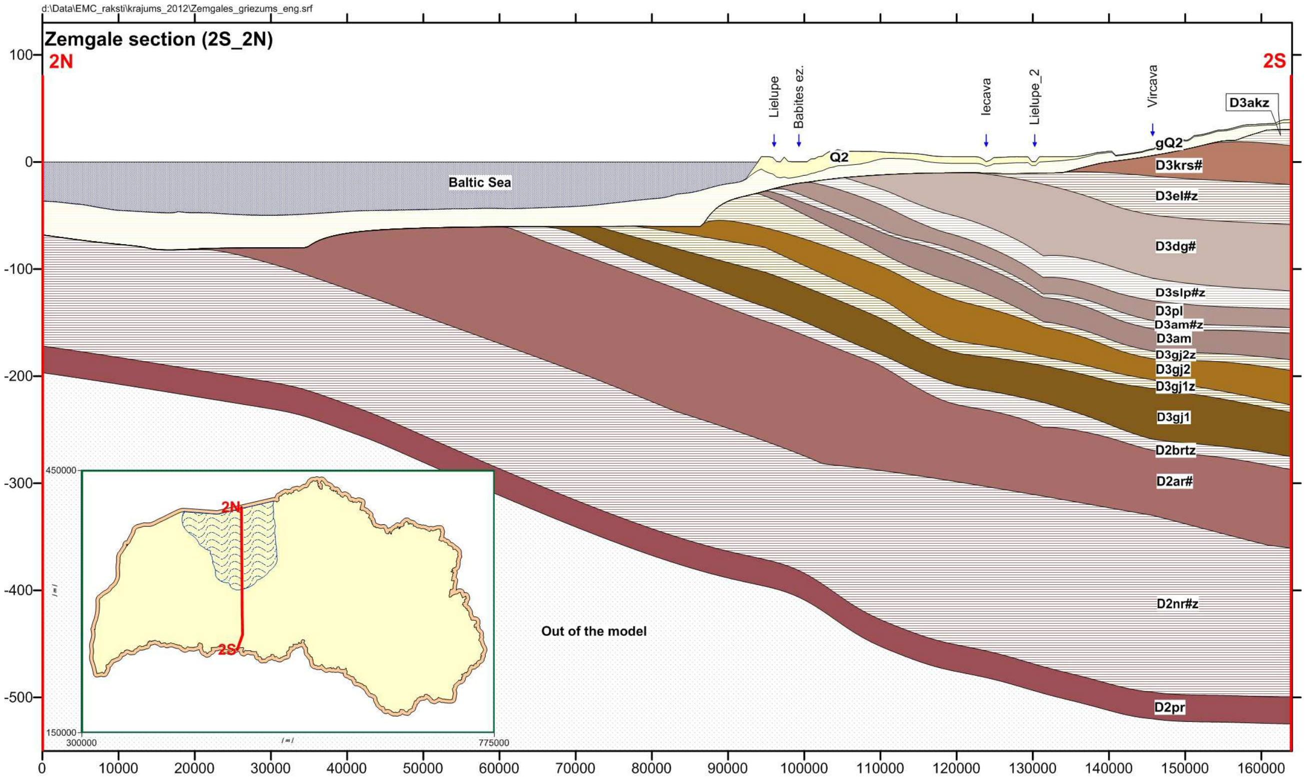


Fig. 6. Geological profile 2S_2N

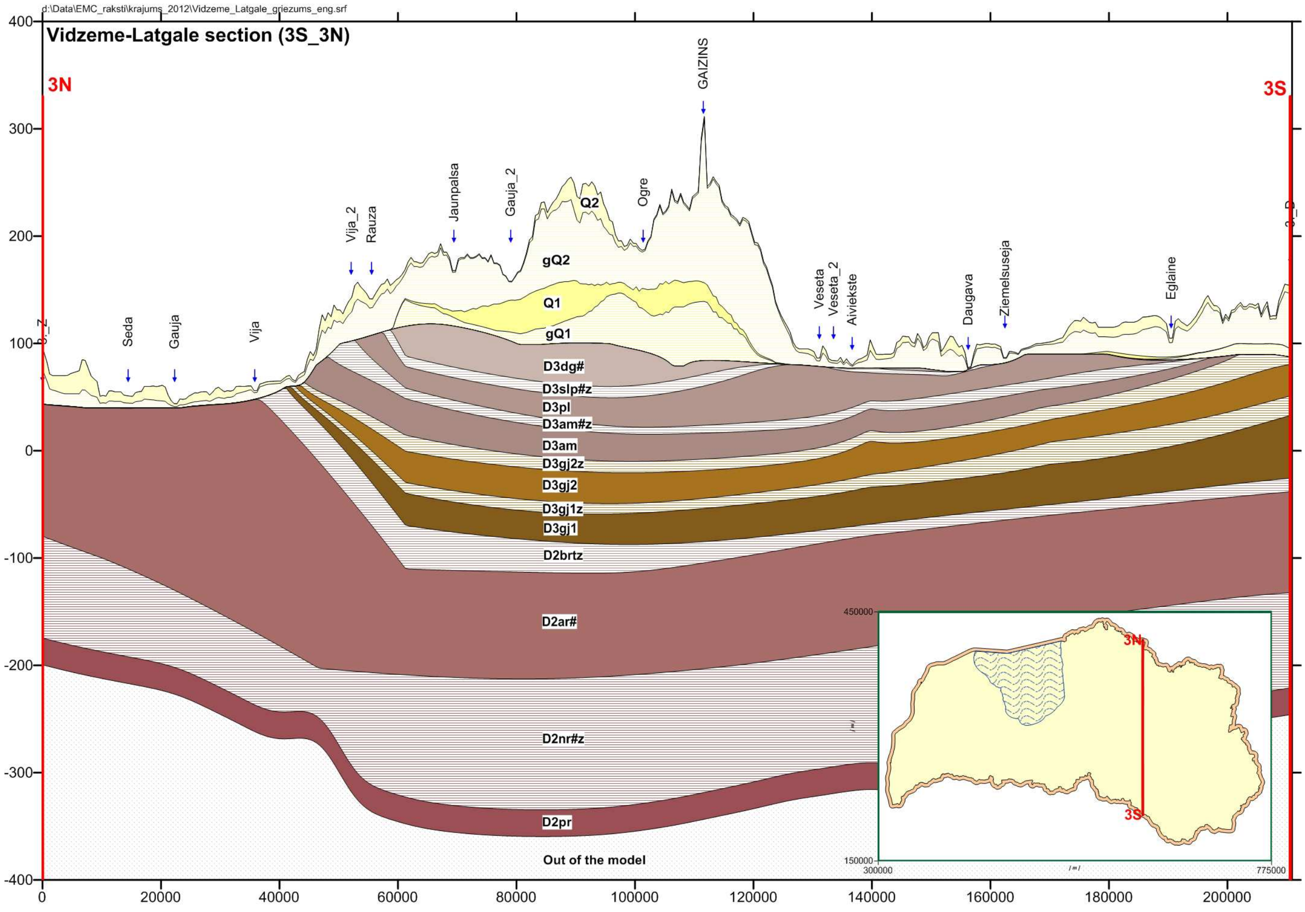
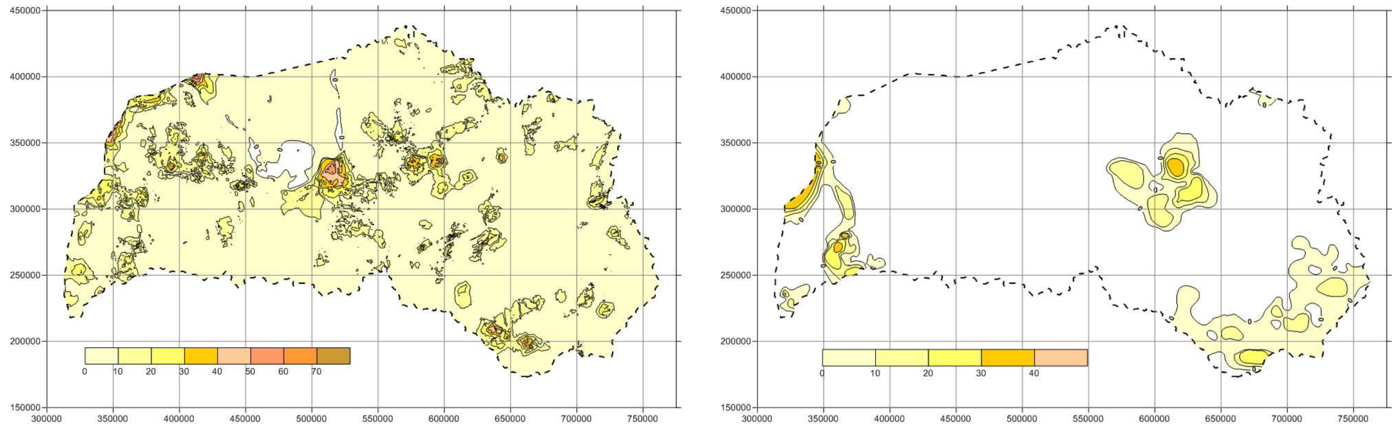
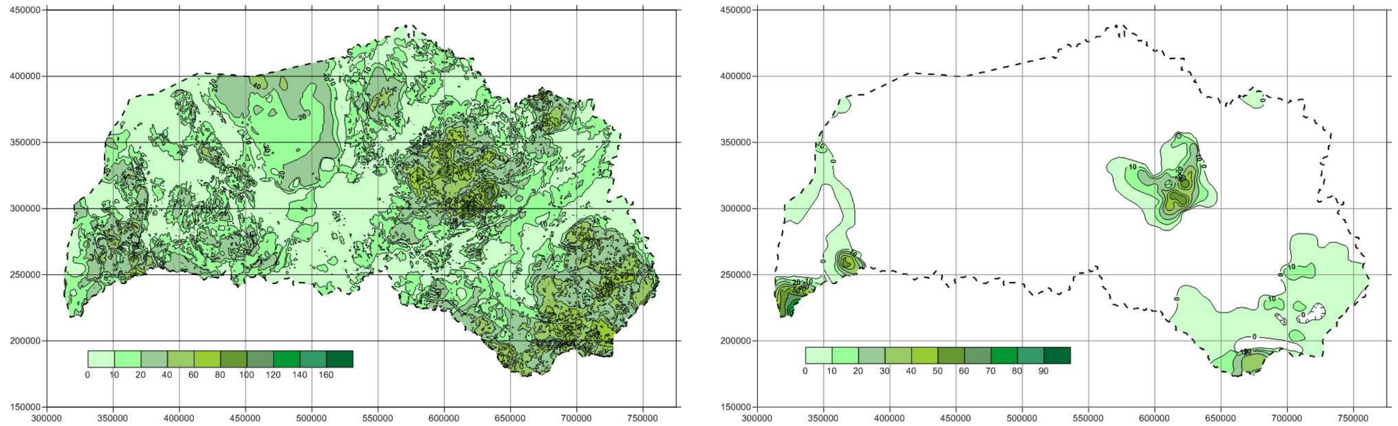


Fig. 7. Geological profile 3S_3N



a) thickness of the Q2 aquifer.

c) thickness of the Q1 aquifer.



b) thickness of the gQ2 aquitard

d) thickness of the gQ1 aquitard

Fig. 8. Distribution of thicknesses for the Quaternary geological layers

The western part includes all geological layers that are presented in the HM. Six primary strata (D3ktl, D3ktlz, D3zg#, D3ak#, D3krs#, D3el#z) are outcropping.

The Devonian Zone of Latvia, like in all Baltic States, is divided into the Western Region (Fig.5, 6) and the Eastern one (Fig. 7) [10]. The Eastern Region belongs to the Baltic syncline and it contains the Western and Middle Parts of Latvia where geological strata are dipping southward.

Its thickness reaches 1000m. The geological profile there contains a full set of geological layers (Fig. 5 and the western part of Fig. 4), Fig. 5 shows, that in Northern Latvia only two Devonian Layers (D2nr, D2pr) are continuous. The other seventeen primary strata are discontinuous and they are outcropping. Due to the application of thickness $\varepsilon$=0.02 for their $m$=0 areas, the geometrical distortion in the northern part of the HM does not exceed 0.02×17=0.34 [metres].

Eastern Latvia forms the Latvian Saddle [10]. For Eastern Latvia, (geological section 3S_3N of Fig. 7)), only three (D2pr, D2nr, D2ar) of thirteen primary layers are continuous. Six of them are outcropping at their northern and southern sides.

One can conclude from the above-presented short exanimation of geological profiles that stratigraphy of primary strata is quite different for various parts of the country.

In Fig. 8, the distribution of thicknesses for the Quaternary geological layers is shown. The Q2 and gQ2 layers exist everywhere and their thickness varies. Their maximal values are located in hilly areas of Latvia. The strata Q1 and gQ1 exist only in the hilly areas of the country.

Creating geometry of the Quaternary System was difficult, because its borehole information was waste and contradictory. Mainly pointwise data and few lines were applied to obtain z–maps of the Q–system.

In LAMO, the aeration zone thickness $m_{aer}$=0.02 is kept unchanged during HM calibration. For that reason, the real geometry for the aeration zone and the Q2 aquifer is distorted. If necessary, the real geometry can be recovered [1, 9]

## IV. CONCLUSIONS

Scientists of Riga Technical University have developed hydrogeological model LAMO for the whole territory of Latvia. The most time consuming and difficult was the task of creating digital maps that describe the geometry of the geological environment. It is shown how the initial data have been prepared and then used for creating the maps by data interpolation. Examples of characteristic geological profiles have been considered.

This publication is a part of the Project (agreement Nr.2010/0220/2DP/2.1.1.1.0/10/APIA/VIAA/011) entitled *Creating of hydrogeological model of Latvia to be used for management of groundwater resources and for evaluation of their recovery measures*. The Project is co-financed by the European Regional Development Fund.

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