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 established by scientists of Riga Technical University (RTU). LAMO comprises the active groundwater zone that provides drinking water. The 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 establishing 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 on the area of HM. After emerging at the surface, such layers have the zero thickness.

Thicknesses of 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 the z–maps for obtaining thicknesses of layers.

To prepare the 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 the z-maps was prepared;**
3. **the final version of the z-maps was obtained by the Geological Data Interpolation (GDI) system.**

It was rather difficult to create the 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 the z-maps of the Quaternary system.

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

I. INTRODUCTION

Detailed description of the LAMO is given in [1] and it is not reported here. The present publication focuses on problems of creating 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 establishing of HM for the whole territory of Latvia. It was necessary to extract trustworthy information from this 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 establishing of various local HM 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 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. The LAMO geometry results in the set of z–maps. It includes 26 surfaces for 25 geological layers presented in HM. The top surface of 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 on 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.

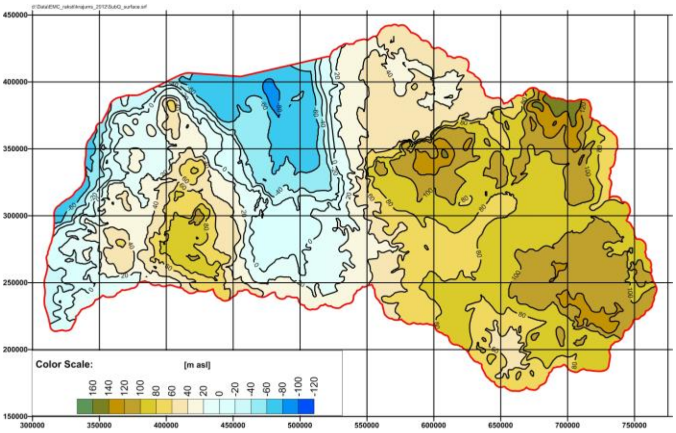


Fig. 1. The prequaternary surface (z=6)

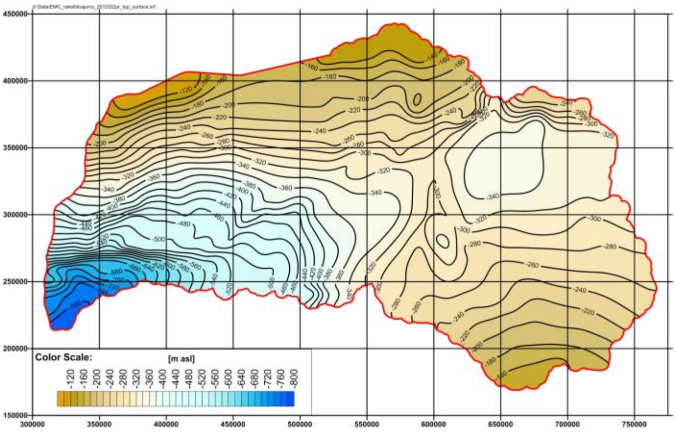


Fig. 2. The D2pr top surface (z=24)

The most time consuming and difficult task was creating of the 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 20×10^3). However, very often data of these boreholes are contradictory and not always it is possible to mend them. To reduce laborious work of checking 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 that provided stratigraphical data for all geological layers of 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. The z–maps must always give positive thicknesses m. For this reason, data of sections must match this condition for all layers of HM. The m=0 areas of discontinuous layers also must be accounted for. It is done by using $m=\varepsilon=0.02$ instead of the zero thickness. There are three main reasons why the value of ε 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 are 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 ε=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 the z–maps was performed by using the EXCEL system [5].

During the second stage of creating the 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 the 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, the much more informative linewise data are obtained. GDI applies 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 the 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 data about material that fills them are uncertain. The cuts of rivers are taken into account indirectly when the rivers are immersed into LAMO [9].

III. EXAMPLES OF LAMO GEOMETRY

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). The profile W_E (Fig. 4) shows that primary geological strata are dipping westwards for the Eastern and Middle parts of Latvia. They are almost horizontal in the East of Latvia. The western part includes all geological layers that are presented in HM. There six primary strata (D3ktl, D3ktlz, D3zg#, D3ak#, D3krs#, D3el#z) are outcropping.

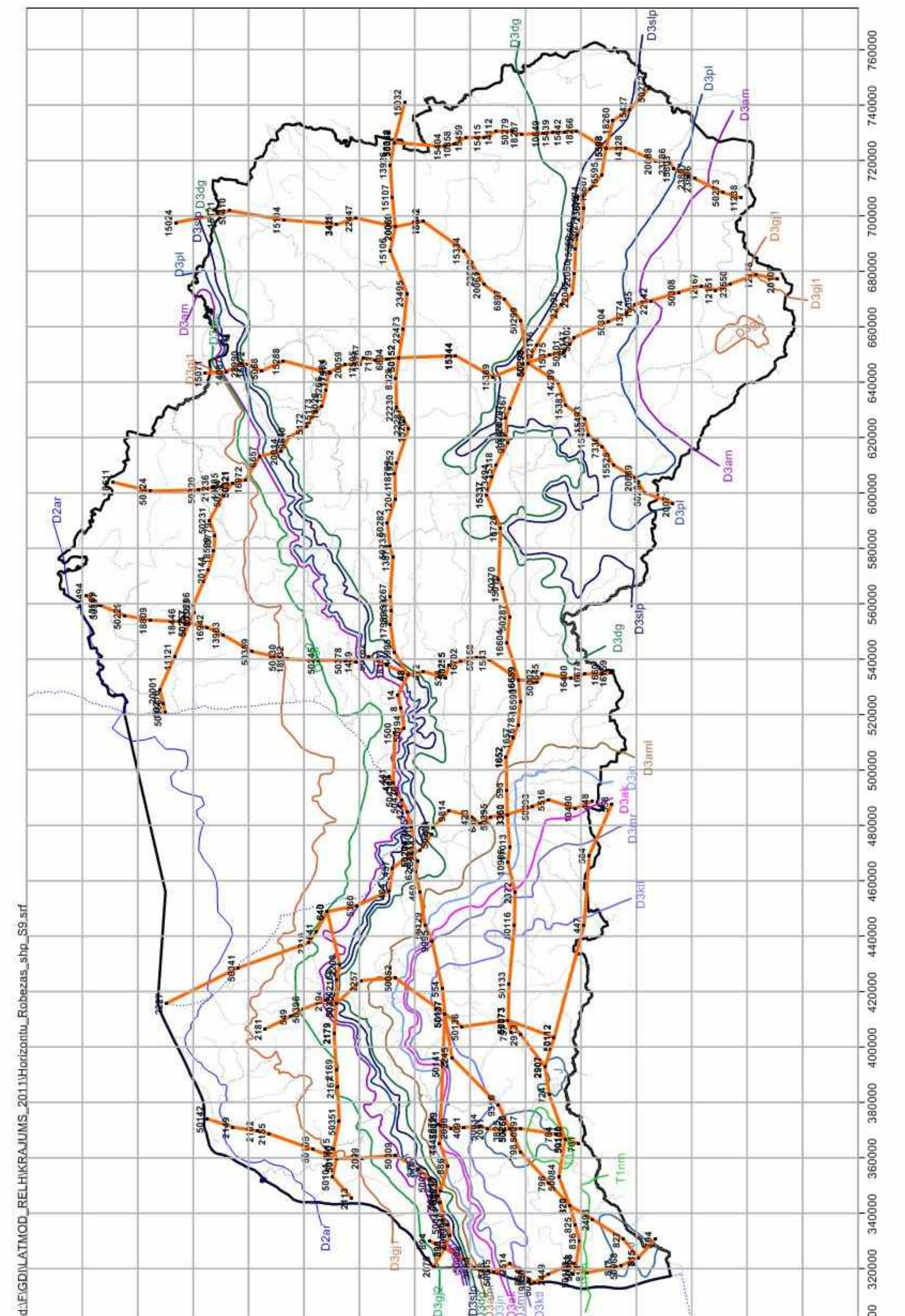


Fig. 3. Initial data used for creating z-maps of primary geological layers: boreholes with the indicators; vertical cross sections based on the boreholes; geological borderlines

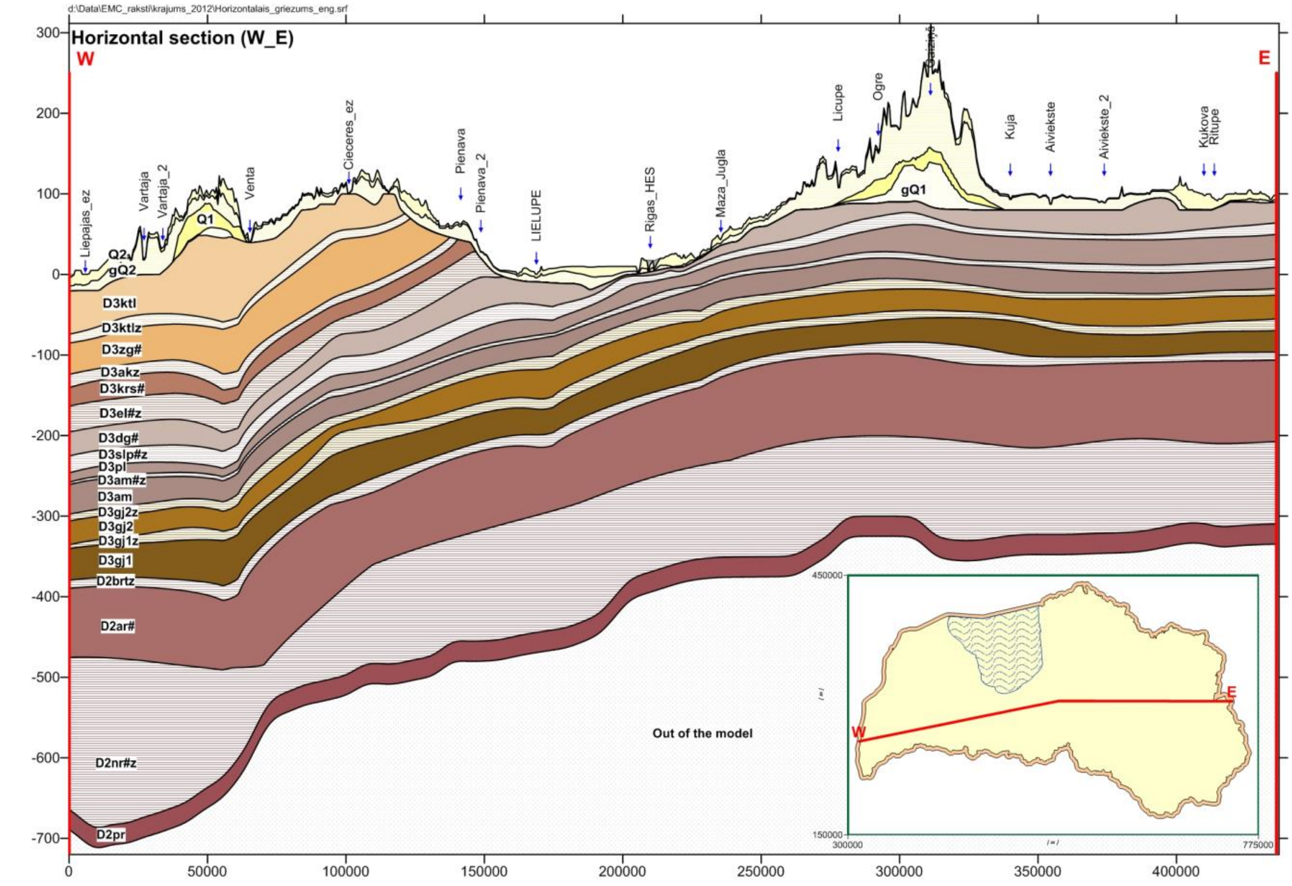


Fig. 4. Geological profile W_E

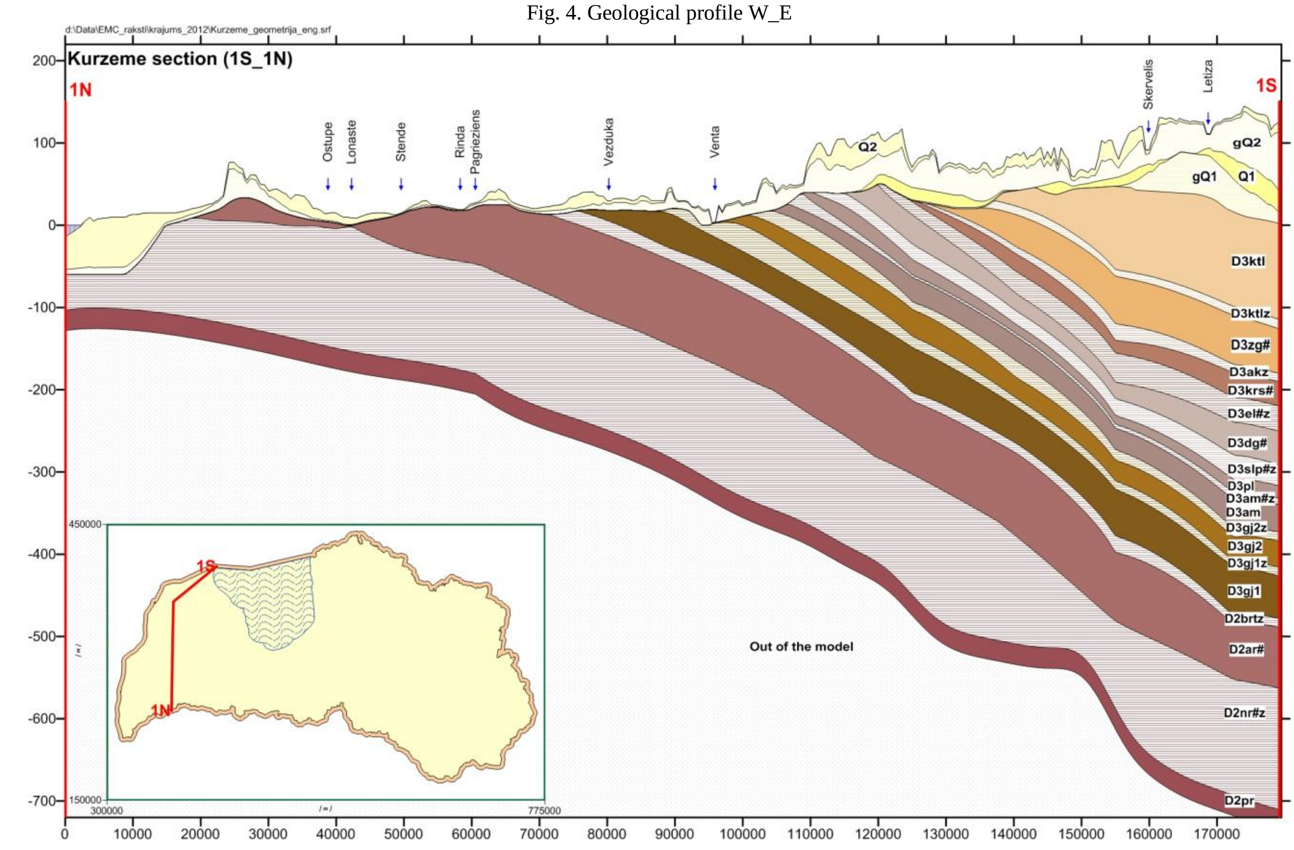


Fig. 5. Geological profile 1S_1N

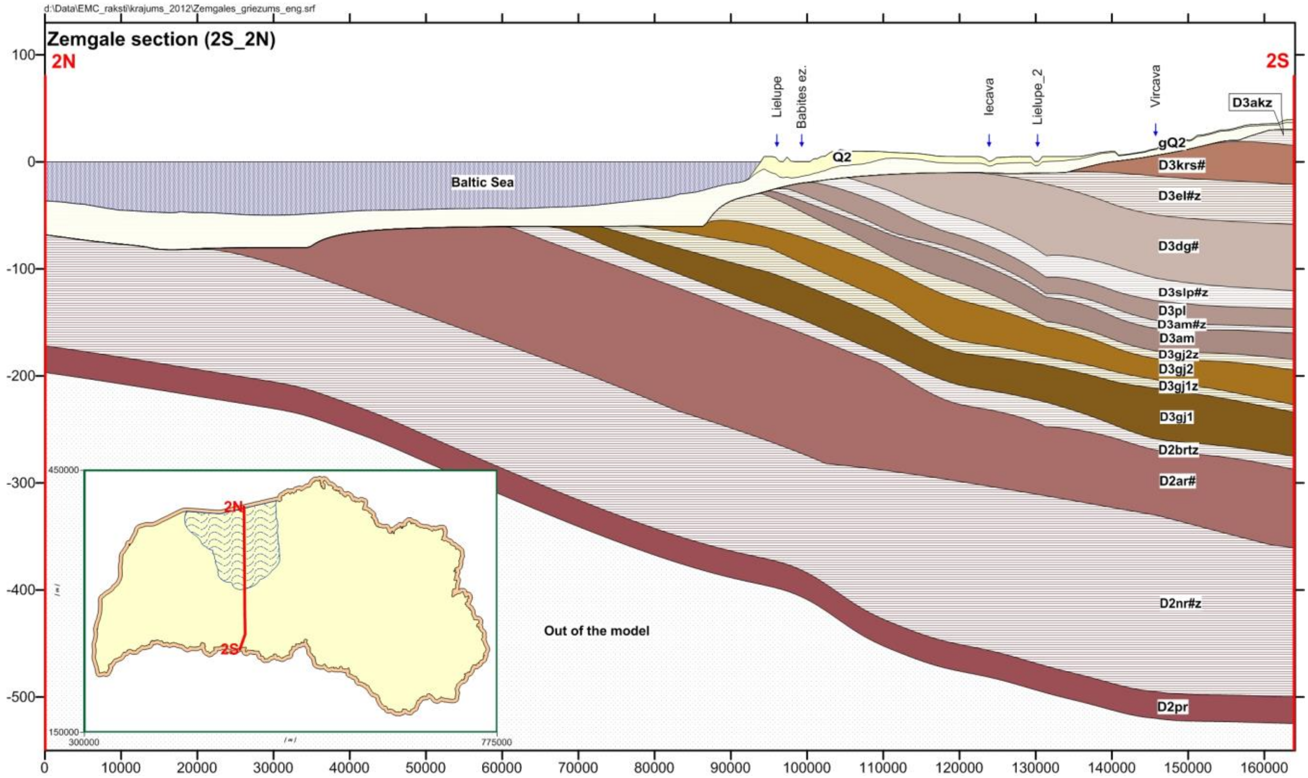


Fig. 6. Geological profile 2S_2N

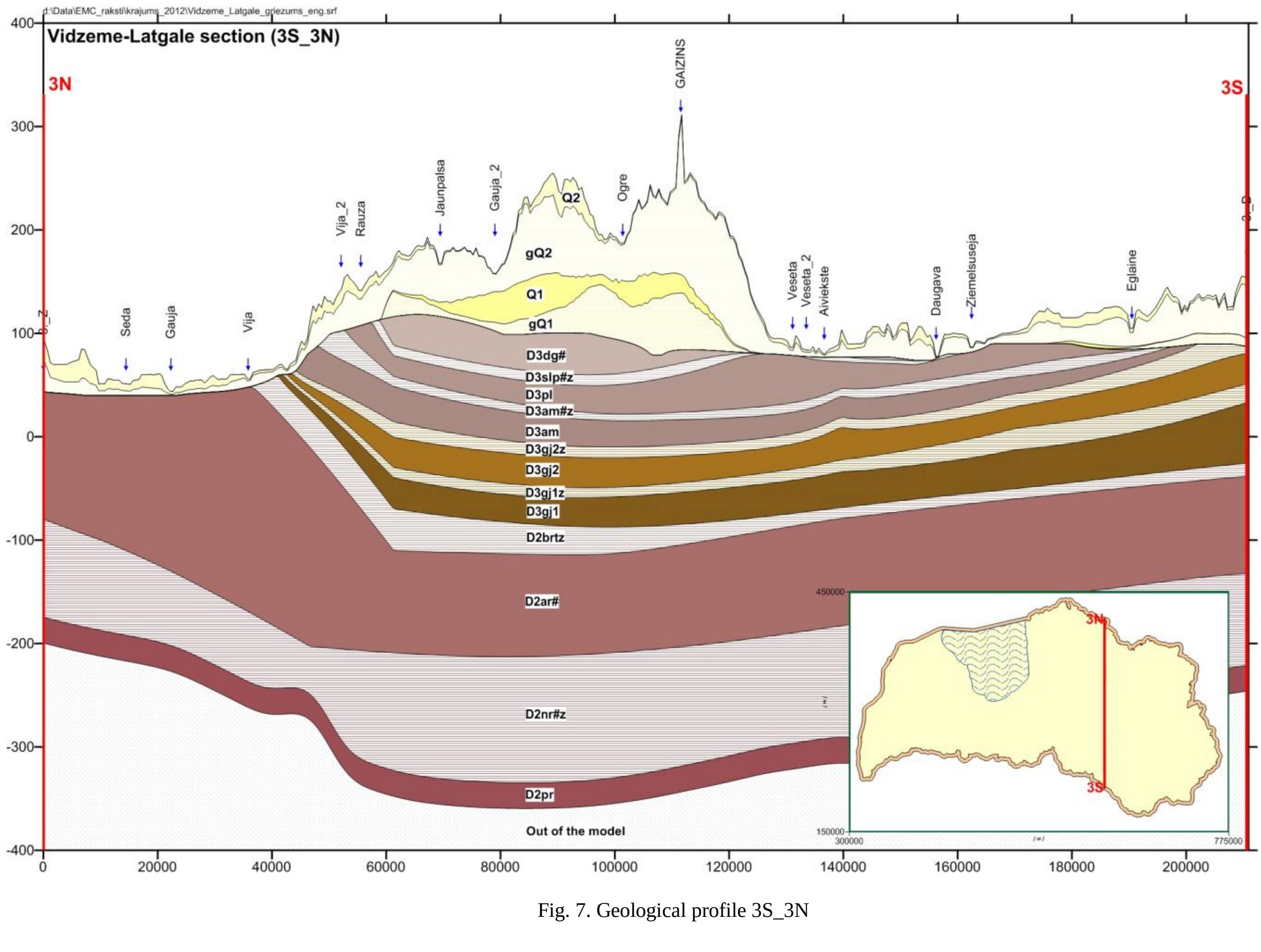
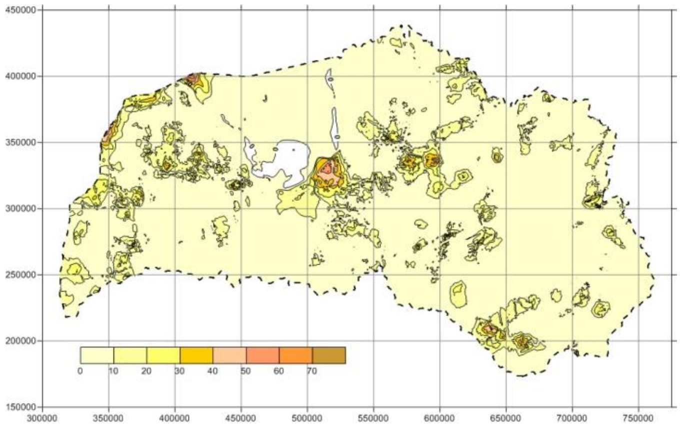
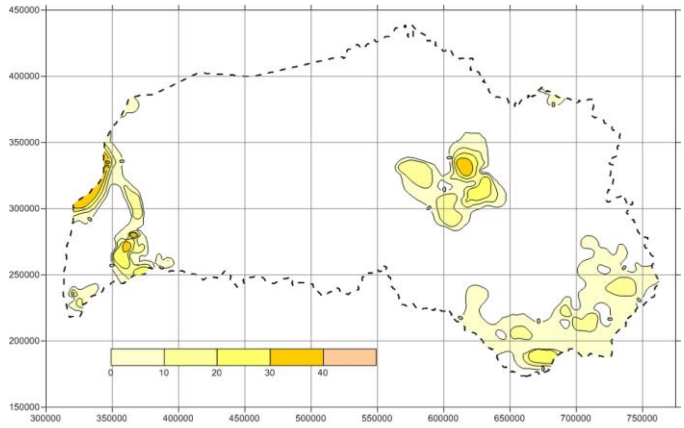


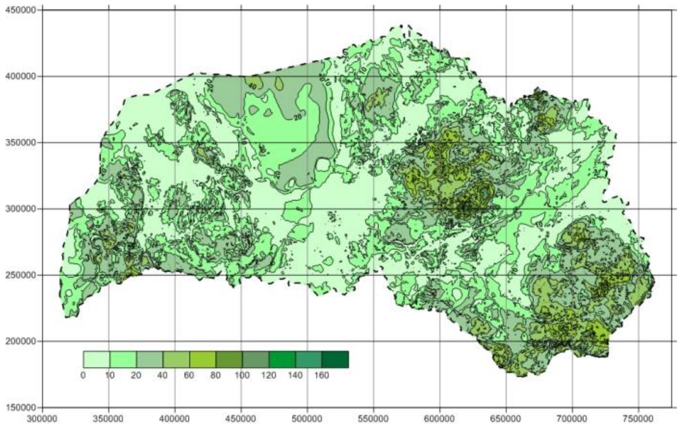
Fig. 7. Geological profile 3S_3N



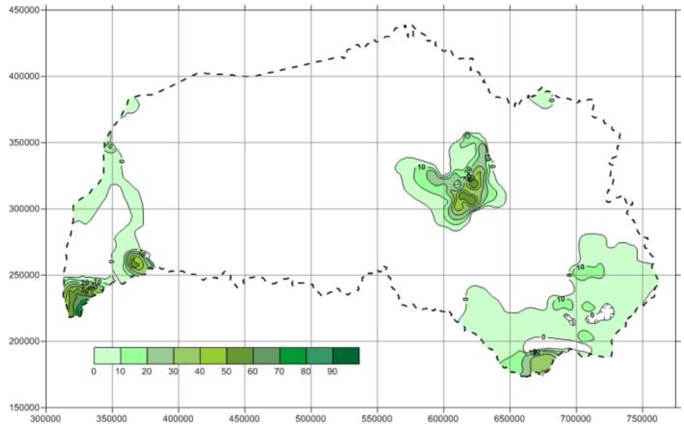
a) thickness of the Q2 aquifer.



c) thickness of the Q1 aquifer.



b) thickness of the gQ2 aquitard



d) thickness of the gQ1 aquitard

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

The Devonian zone of Latvia, like in the 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 the full set of geological layers (Fig. 5 and the western part of Fig. 4), Fig. 5 shows, that in the North Latvia only two Devonian layers (D2nr, D2pr) are continuous. The other seventeen primary strata are discontinuous and they are outcropping. Due to appliance of the thickness ε=0.02 for their m=0 areas, the geometrical distortion at the northern part of HM, does not exceed 0.02×17=0.34 [metres].

The East Latvia form the Eastern Region (the Latvian saddle) [10]. For the East 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 short exanimation of geological profiles that stratigraphy of primary strata is quite different for various parts of the country.

In Fig. 8, the distributions of thicknesses for the Quaternary geological layers are 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 the 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]

V. 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 the digital maps that describe the geometry of geological environment. It is shown how the initial data have been prepared and then used for creating the maps by the data interpolation. Examples of characteristic geological profiles are considered.

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