GeoERA
RESOURCE GROUNDWATER

Resources of groundwater, harmonized at Cross-Border and Pan-European Scale

Deliverable 4.4

Report describing the hydrodynamic model for the Polish-Lithuanian cross-border area and map showing the transboundary groundwater flow directions and fluxes in the multi-aquifer system

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Version: final

This report is part of a project that has received funding by the European Union's Horizon 2020 research and innovation programme under grant agreement number 731166. Scientific work is co-funded by the Geological Surveys and national funds allocated for science within the period 2018-2021.

Deliverable Data		
Deliverable number	D4.4	
Dissemination level	Public	
Deliverable name	Report describing the hydrodynamic model for the Polish-Lithuanian cross-border area and map showing the transboundary groundwater flow directions and fluxes in the multi-aquifer system	
Work package	WP4, TRANSFLUX	
Lead WP/Deliverable beneficiary	PIG-PIB	
Deliverable status		
Submitted (Author(s))	29/10/2021	Tomasz Gidzinski
Verified (WP leader)	29/10/2021	Tomasz Gidzinski
Approved (Coordinator)	30/10/2021	Hans Peter Broers

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1 INTRODUCTION

This document is the deliverable for task 4.4 of the TRANSFLUX 4 (WP4) work package which involved the “Set-up of a hydrodynamic model for Polish-Lithuanian cross-border area”. The report summarizes the results of the set-up of the cross-border numerical groundwater flow model, that covers multi-aquifer system of Quaternary sediments within the Polish-Lithuanian cross-border area. In the framework of aforementioned task, we calibrated and verified the numerical hydrodynamic model and interpreted the model simulations. As the result, transboundary groundwater flow directions in the cross-border area were established. This report presents groundwater contours, elevation of groundwater level or hydro-isohypses in the form of maps for each model layer, that corresponds with distinguished Quaternary aquifers. Moreover, the volume of groundwater that flows in each, individual aquifer (related to each model layer) through the state border between Poland and Lithuania was evaluated.

In the task 4.3 of the work package, we prepared a harmonized hydrogeological dataset for transboundary use. The data set was then imported to the modeling software Groundwater Vistas.
In this report the assumptions and scope of task 4.4. are described. Some issues connected with task 4.4. were considered and discussed during Groundwater RESOURCE project group of GeoERA working meeting, that was hold in December 2020.

2 WORKFLOW

2.1 General idea and aims of the WP4 project

The general idea behind the work package 4 (WP4) Groundwater RESOURCE "*TRANSFLUX: Harmonization of data, monitoring and modelling in a transboundary setting*" is to develop a numerical hydrodynamic model for the Lithuanian-Polish cross-border area, that will cover the Quaternary multi-aquifer system for the selected parts of the transboundary river basins.

The object of the project is to verify and determine the transboundary groundwater flow directions in the cross-border area and to estimate the volume of groundwater, that flows through the state border between Poland and Lithuania. The crucial part of the project, which was focused on the numerical model development was preceded by the comparison of the scope of data, that were available in each institution involved in the WP4 and can be used for hydrodynamic modelling purposes for cross-border areas. Task 4.1 of WP4 (*Comparison and unification of methods for groundwater modelling in Poland and Lithuania*) is linked to the task 4.2 and it was carried out between July 1st 2018 and the end of December 2018. The deliverable for task 4.1 covered the comparative tables of data review, that can be used for groundwater hydrodynamic numerical modelling purposes. The tables were developed and provided by all institutions participating in the WP4: Polish Geological Institute-National Research Institute (PIG-PIB), Lithuanian Geological Survey (LGT) and Geoinform of Ukraine. The comparative tables allowed to realize the similarities, as well as obstacles in a common work aimed at development of numerical hydrodynamic models, which will cover cross-border areas in this part of Europe. Some materials needed further clarification in detail among involved cooperators, as well as some data needed to be standardized or adjust for the transboundary use.

3 MODELLING AREA

According to the physico-geographical regionalization (Kondracki J., 2002), the catchments of the Szeszupa (Šešupė in Lithuania), Czarna Hańcza (Juodoji Ančia) and Marycha (Mara) rivers in Poland were included in two macroregions: the Lithuanian Lakeland and the North Podlasie Lowland. Within the Lithuanian Lake District there is a larger, northern part of catchment areas. Two mesoregions were distinguished in this part: in the north - Wschodniosuwalskie Lakeland and in the south - Augustów Plain. Within smaller, southern part of the catchment - the North Podlasie Lowland, mesaregions were distinguished: Biebrza Basin and Sokólskie Hills. In accordance with the hydrographic division, the modelling cross-border area is situated in of the Nemunas River basin. The Nemunas is a river in Europe that rises in central Belarus and flows through Lithuania then along the northern border of Kaliningrad Oblast, Russia's western exclave. It is considered as one of major Eastern European river.

The Nemunas is largest river in Lithuania. The total length of the Nemunas is 937 km. Over its entire length 359 km flows in Lithuania. The other catchments occurring in the Lithuania part of the area are also Šešupė, Baltoji Ančia, Kirsna and some small ones: Mara, Prūdo upelis and Prieglius (Pregolya) (KILKUS, STONEVIČIUS, 2011).

The catchments of the Szeszupa River, Czarna Hańcza River and Marycha River are occupying the north-eastern part of Poland, in the Podlaskie Voivodeship. The catchments of: Szeszupa River, Czarna Hańcza River and Marycha River, according to the hydrogeological regionalization of Paczyński, 2007, are part of the Masurian-Podlasie region (II). Usable aquifers in this unit occur mainly in the Quaternary formations. In terms of the division into the groundwater bodies (GWB's), the catchment area of the Szeszupa River, Marycha River and Czarna Hańcza River are included in the area of groundwater body no. 22. In the Szeszupa, Czarna Hańcza and Marycha catchments were distinguished: the Wigry National Park with a complex of gutter lakes, the Suwałki Landscape Park situated in the Szeszupa (Šešupė) depression.

Fig. 1. Catchments of rivers in the cross-border areas of Poland and Lithuania

The catchments of aforementioned rivers have high natural values and therefore have been included in "the Green Lungs of Europe". "The Green Lungs of Europe" (with area of approximately 760,000 km^2) includes the most valuable natural areas: in north-eastern Poland, areas of Russia (all of the Kaliningrad Oblast and partly Nowogrod, Pskov and Tver), northern regions of Ukraine (Volyn Oblast, Rowieński Oblast, Żytomierski and Kijowski) and the entire territories of Belarus, Estonia, Lithuania and Latvia. There are areas of outstanding natural values, unique in Europe. In a large part of the region there are natural systems close to the natural ones, with high biodiversity.
The catchments of the Szeszupa, Czarna Hańcza and Marycha rivers in Poland are located in the Lithuanian Lake District. These include: East Suwałki Lake District- in the north and Augustów Plain - in the south. Morphology of northern part of the model area, that belongs to the East Suwałki Lake District, is undulated and varied topographically. The final influence on its morphology had the lob of the Szeszupa glaciation during the Leszno-Pomeranian (Grūda-Baltija in Lithuania) stage.
The area of the East Suwałki Lake District is upland. It gradually lowers from the north towards the south. The hilly morainic plateau with highest culmination -the Rowelska Mountain 298,0 m above sea level, are found in the north-eastern part of the lake district. The lowest depressions occur in the area of the Pomorze Lake (123,1 m above sea level). There are a number of lakes in this late-glacial landscape. South of the East Suwałki Lake District the Augustów Plain was distinguished. In this area, meltwater collected from the lob of Szeszupa, creating vast sandres reaching south to the North Polish Lowland.

The surface of the plain was shaped as a result of the accumulative and erosive activity of fluvioglacial waters, while the accumulation had smaller influence. In the morphology mainly is visible the activity of fluvioglacial accumulation in the form of at least several meters layers of sands. South of the Augustów Plain there is a narrow belt of peat plains of the Biebrza Basin. This depression was created in the period preceding the last glaciation, probably in the Warta glaciation.

The Lithuania part of the area is mostly composed of the Sūduva till upland formed in the last glaciation period (Baltija phase) in the western, northern and central parts of the study area. The main geomorphological sub-districts are Vištytis (the western part) and Alytus (the central part) uplands and Kalvarija plateaus (some northern part). The eastern part of the area is composed of so called South-eastern glaciofluvial plain (Dainava sub-district), which touches with Nemunas valley. The latter plain is mostly formed during Grūda (Leszno) phase (GUOBYTĖ, 2000).

Groundwater body (GWB) No. 22 was delineated in the north-eastern part of Poland. The course of GWB borders coincides with the watershed of the 2nd order of the Czarna Hańcza River. The northern and eastern borders continue along the Polish border with Lithuania, and the southern section along the state border with Belarus. The western part of the unit follows the same course as the border of the first-order surface watershed of the Nemunas River (within Poland) and the Vistula River. The modelling area on the Polish side covers eastern part of the Groundwater body GWB No. 22.

Groundwater bodies No. LT005051100, LT005001100 and LT004031100 (or 51100, 01100 and 31100 in short) are located in Lithuanian part of the area (https://www.lgt.lt/epaslaugos/elpaslauga.xhtml). The border of GWB No. 51100 approximately coincides with the border of the South-eastern Lithuania plain and is respectively bordered with the Polish territory in the west, with Belarus in the south and with the Nemunas River being the border of the area in the east. The area of GWB No. 01100 is almost completely located in Sūduva uplands except some northern part is coupled to Kalvarija plateaus. A small part of GWB No. 31100 covers northern part of the area.

Fig. 2. Groundwater bodies (GWB's) in the cross-border areas of Lithuania and Poland

Due to the hydrographic division the modelling area is located in the Nemunas River basin (first-order catchment), which is divided from the Vistula River basin by the first-order watershed.

In the GWB No. 22, the catchments of the second order were distinguished: Szeszupa River, Czarna Hańcza River (with the catchment of the third order of the Marycha River, located in the Polish boundary zone) and Biała Hańcza. An important element of the hydrographic system are numerous gutter, melting and dam lakes.

The GWB No. 51100 in Lithuania partly includes the catchments of Nemunas (2nd order), Baltoji Ančia and Mara (3rd order). Numerous lakes form also important parts of the hydrographic systems there. The GWB No. 01100 covers the parts of the catchments of Baltoji Ančia, Kirsna, Šešupė, Prūdo upelis and Pregolya. The GWB No. 31100 is only related to small part of Kirsna catchment (in the study area).

The terrain relief in the East Suwałki Lake District, that was formed during the last glaciation, is very diversified. In the northern part occurs a moraine plateau with a zone of latitudinal moraine hills and the highest culmination in the Suwałki region - Rowelska Mountain (298 m above sea level). The moraine plateau is cut by a series of glacial gutters, in which there are gutter lakes and valleys of rivers and streams in deep depressions. The relief variations are considerable in this region and reaches up to 120 m.

The lower are situated the terraces of the Szeszupa River and the Marycha River. Wetlands are common in the valleys of the rivers mentioned above. The research area within the East Suwałki

Lake District mesoregion includes the Szczeszupa Depression, northern part of the Suwalski Sandr, the Szurpiły and the Krzemianka Uplands and the Jeleniewska Gutter. The glacial plateau is cut by numerous river valleys and smeltings of ice blocks.

The southern border of postglacial plateau with the area of fluvioglacial (sandr) accumulation overlaps the range of the frontal moraines of the lobes of Sejny and Ogrodniki on the Pogorzelec-Wiereśnie Lake-Giby-Berżniki-Markiszki line. Moraines of the East Suwałki Lakeland have a general direction from north-west to south-east and continue east from the Wigry Lake. Sandr area is flat and undulated. It is cut by valleys of glacial water outflow, adapted by the valleys of contemporary rivers, and melting depressions, partly adapted by lakes. The southern part of the sandr is situated on the Augustów Plain. Sandr of the upper level of the Augustów. Plain has a flat surface, with valleys of rivers visible in the morphology of the area.
The southern part of the study area is located within the Biebrza Basin mesoregion, which belongs to the North Polish Plain macroregion. The valley was formed by the peat and sandral plains of the upper level and the elevations of aeolian origin (KONDRACKI J., 2002).

The Suwalki upland in Poland passes to the Lithuania territory as Sūduva upland. The valley of Šešupė divides the upland into two different parts. They are a western one with being up to 280 m above sea level and an eastern one with a height of 200 m above sea level in the Lithuanian part. The largest part of the upland is composed of glacial (till) hills and ridges. There are also a lot of end-moraines in the central part of the Sūduva uplands (to the west from Lazdijai town in Galadusis lake region). Some glaciolacustrine kame terraces and fluvioglacial terraces are located in the marginal part of Šešupė valley. The southern part of Dainava fluvioglacial plain is formed as a quite large fluvioglacial terrace coupled to the Nemunas valley. In this part are some eolian areas overgrown with forests in the plain. Big swamps are mostly located in the northern part of the area including Šešupė valley area, however, a lot of small peaty lowlands commonly occur over the entire area except for the highest parts of Sūduva uplands (GUOBYTĖ, 2000).

4 LAND USE

In terms of land use, the study area is a typical agricultural region, mainly with individual farms and a low degree of industrialization. Most of the area is used by arable land, meadows and pastures, and locally forests. The Polish border areas with Lithuania are sparsely populated. Objects that may pose a threat to the soil and water environment are usually located in the vicinity of larger towns, not in the direct border zone. The zones in the border of Poland and Lithuania were included into the area of "the Green Lungs of Europe". Borders of this unit include the most valuable natural areas of north-eastern part of Poland, Lithuania, Latvia, Estonia, partly Russia, Belarus and partly Ukraine.
The majority of the area in Lithuania is an agricultural region part as well. However, a lot of sites of the Dainava fluvioglacial plain (in southern part of the area) are forests. It is specific for the above-mentioned glaciofluvial terrace, which is located in the southern part of Dainava plain (www.geoportal.lt/map/).

4.1 Environmental protected areas

The regional park "Vištyčio regioninis parkas" is located on the territory of Lithuania, in the border area with the northern part of the Suwałki Region. Another park is 'Veisiejų regioninis parkas' located close the Polish border, in southern part of the study area (https://vstt.lrv.lt/lt/saugomu-teritoriju-sistema/regioniniai-parkai).
In the border zone of the modelling area, in the framework of the European Ecological Network NATURA 2000 has been established the special area of habitat protection "Ostoja Augustowska" and area of special protection of habitats of birds NATURA 2000 "Augustów Primeval Forest".

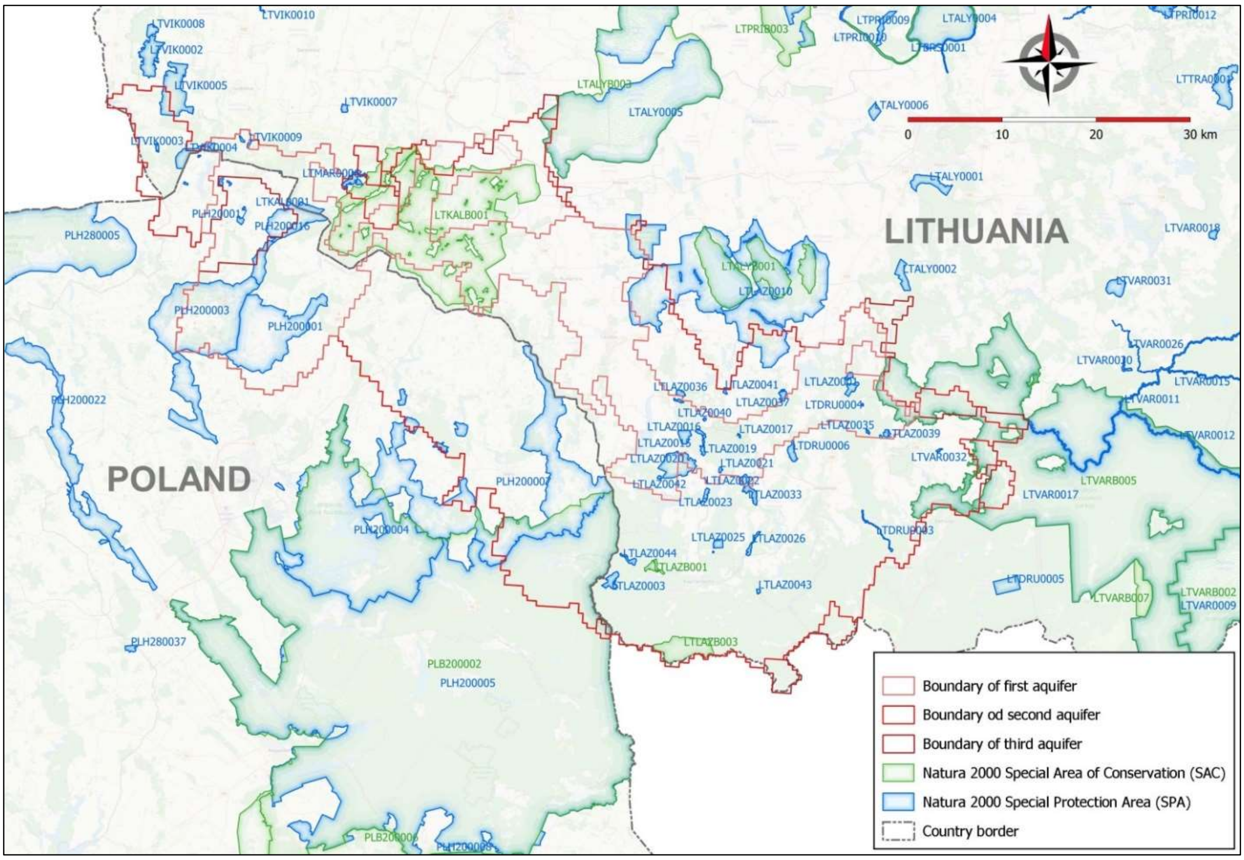

Fig. 3. Natura 2000 Special Areas of Conservation (SAC) and Natura 2000 Special Protection Area (SPA) in

the Polish and Lithuanian cross-border areas

5 GEOLOGICAL STRUCTURE

In terms of the division into geological and structural units, the study area is located in the Mazury-Suwałki Elevation, which is a part of the East European Platform. The crystalline basement, composed of igneous and metamorphic rocks intersected by vein rocks, occurs at a depth ranging from 820 m b.g.l. in the region of Udryń to about 1000 m b.g.l. in the eastern, Polish part of the model area. The depth to the basement rocks is 1000-1100 m and even more in the Vištytis Upland, and more than 600-700 m in the Alytaus Upland (in central Lithuania). The depth to the crystalline rocks in the Dainava Plain area (transition to the Belasus-Mazury Massif (Anteclise) is only 320-500 m.

The oldest rocks found in the study area are: Precambrian gneisses, granodiorites, diorites, granitoids, norits and anorthosites. In the Polish borderland, the total thickness of sedimentary cover is approximately 560 m. Gneisses, granitogneisses and amphibolites are widespread in the area of Lithuania (MOTUZA, 2000).

The crystaline basement is overlain by the Lower and Middle Cambrian rocks (sandstones and shales), Lower and Middle Ordovician (sandstones), Upper Ordovician (dolomites and limestones), Silurian (claystones and marls), Permian (limestones), Lower and Middle Triassic formations (shales, claystones, sandstones, limestones, oolitic marls, as well as mudstones), Middle Jurassic (sandstones and mudstones), Upper Jurassic (limestones and marls), Lower Cretaceous (sands, sandstones and mudstones), Upper Cretaceous (chalk, marls, limestones), Dan of Paleocene (marls and sands and sandstones and marls in the Lithuanian part), Upper Eocene and Oligocene (mainly sandstones of local occurrence). The total thickness of the Mesozoic structural level in the GWB No. 22 is about 350 m (SZEWCZYK J., GIDZIŃSKI T., GIENTKA D., 2003; ČYŽIENĖ ET AL., 2006).

The topmost Cretaceous is composed of glauconite sandstones passing into limestone-marl series. The Paleogene deposits are represented by marly-muddy-sandy facies.

5.1 Quaternary sediments

5.1.1 *Pleistocene*

The result of glacial erosion and exertion in the Suwałki region is the diverse relief of the top surface of the pre-Pleistocene deposits. Locally, Paleogene-Neogene sediments have been completely removed. The formation of the sub-Quaternary bedrock surface relief was also influenced by neotectonic processes related to the prolongation of Alpine epeirogenic movements. They led to the activation of cracks in the rocks of deeper basement. Complete sections of Quaternary deposits are known primarily from mapping boreholes drilled during the preparation of map sheets for the Detailed Geological Map of Poland, 1: 50,000. The thickness of the Quaternary sediments is constrained by the sub-Quaternary surface relief.

The variable thickness of the Quaternary formations is also related to the diversity of the top surface relief of sub-Quaternary rocks. The greatest total thickness of the Quaternary deposits, locally reaching up to 280 m, was reported from the northern part of the Suwałki Lake District, in the area of the sub-Quaternary depressions. The relief of the northern part of the area is very diverse and this is a postglacial plateau zone. The surface of the Pleistocene deposits has been shaped during the advance, stagnation and retreat of the ice-sheet front of several glaciations, (festoon and valley-side glaciotectonics) and neotectonic phenomena.

In the southern part of the GWB No. 22, in the Sejny region, the total thickness of Pleistocene and Holocene deposits decreases to 180 - 120 m.

In the model study area, there are several levels of tills and clays separated by fluvioglacial and glaciolacustrine formations. Glaciotectonic, deglaciation and erosion processes contributed to disturbing the top layers of the Pleistocene complex represented by Middle Polish and North Polish glaciation deposits.

Particularly strong erosional processes occurred in slope zones and within the Szeszupa River valley. Surface sediments in the study area are represented mainly by glacial tills and sands. Numerous terrain depressions within the hilly moraine plateau are filled with fluvial sediments (sands and muds) and peats.

In the Lithuanian part of the model area, the greatest thickness of the Quaternary complex - up to 305 m (Norvydai-4 borehole) – is recorded in the Vištytis Upland area near the border with Poland. At the remaining sites of the upland, the thickness of Quaternary deposits is 160-200 m. The depth range of the Pleistocene complex is ca. 120-170 m in the Alytaus Upland, decreasing to about 110-120 m in the Kalvarija Plain. The thickness of Pleistocene deposits in the Dainava Plain is relatively variable, ranging from 80 to 160 m. However, these deposits may occur to a depth of even 180 m in the glaciofluvial terrace in the southern part of the model area. In the slope zones of the Szeszupa River valley, erosional transformations took place, while the accumulation processes were inherently associated with the marginal sites of the valley, creating glacial and kame terraces in these regions (GUOBYTĖ, 1998; GUOBYTĖ, 2000). In terms of stratigraphy, the Pleistocene deposits include several beds of glacial tills separated by glaciofluvial sediments, and in places also by lacustrine and fluvial deposits, the deposition of which took place during subsequent glacial periods.

6 HYDROGEOLOGICAL CONDITIONS

In terms of the subdivision into water regions (PACZYŃSKI ED., 2007) the Polish part of the modelling area is included in the Narew, Pregoła and Niemen region. Regional groundwater runoff in GWB No. 22 takes place towards the Nemunas River, the Czarna Hańcza River, the Szeszupa River, the Biała Hańcza River, the Marycha River and the Pregoła River valleys (- in the northern part). The study area is characterised by high diversity of hydrogeological conditions. The Cretaceous and Jurassic aquifers are poorly explored and are monitored by observation wells of the 1st-order hydrogeological station at Sidorówka. The Cretaceous and Jurassic aquifers are poorly studied.

The top of water-bearing deposits of the Cretaceous aquifers was drilled at a depth of about 300.0 m b.g.l. The aquifer is composed of marls. The top of the Upper Jurassic aquifer occurs at a depth of 471.0 m. The aquifer is represented by limestones. The aquifers of the Paleogene-Neogene multi-aquifer formation, represented by Miocene and Oligocene sediments, do not play a significant role in the water supply process. On the Polish-Lithuanian border, the Cretaceous and Paleogene-Neogene aquifers are locally of usable significance (GRANICZNY, SATKUNAS, 1996).

6.1 Quaternary sediments

6.1.1 *Pleistocene*

Hydrogeological knowledge of the cross-border area is not good enough and usually limited to the first and second productive aquifers, which are composed of the Pleistocene sediments. Pleistocene aquifers are exploited by drilled wells. Aquifers, especially shallow, are characterised by different thicknesses, variable lithological structure and grain size distributions, and often by a limited extent (locally, there is no continuity of aquifers), which is confirmed by the hydrodynamic diversity. The distribution of filtration coefficient in each water-bearing bed varies depending on its lithological variability and homogeneity. The Quaternary deposits form a continuous cover over the entire area of the modelling studies (Figures 4, 5 and 6).

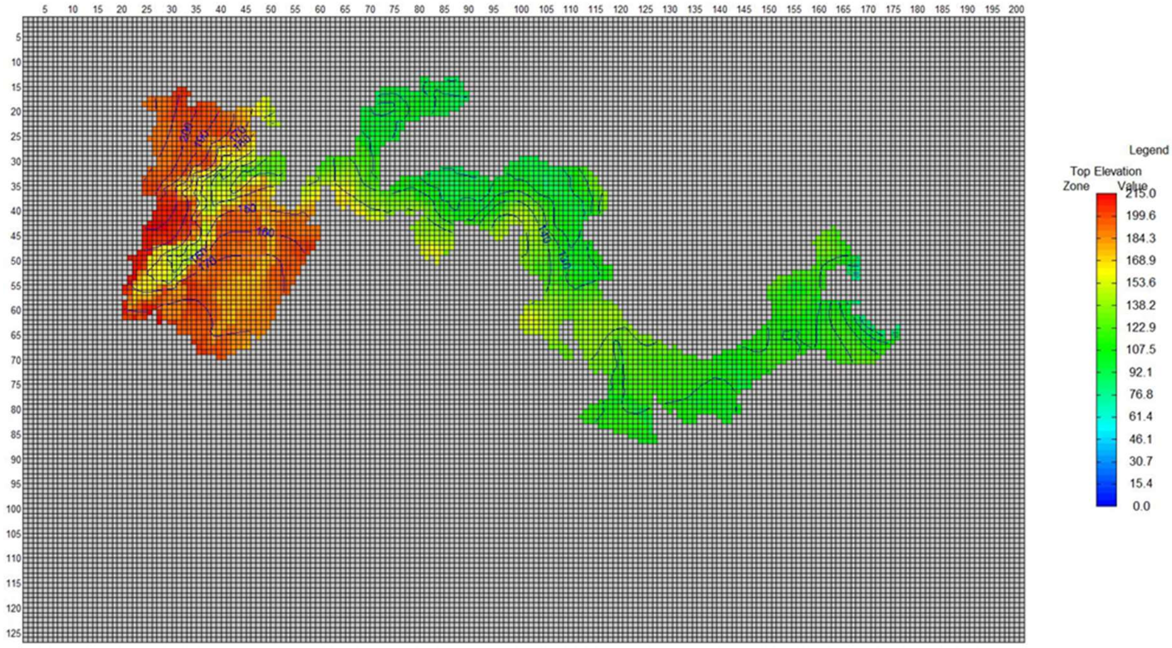

Fig. 4. Top of elevation of the first (shallow) aquifer

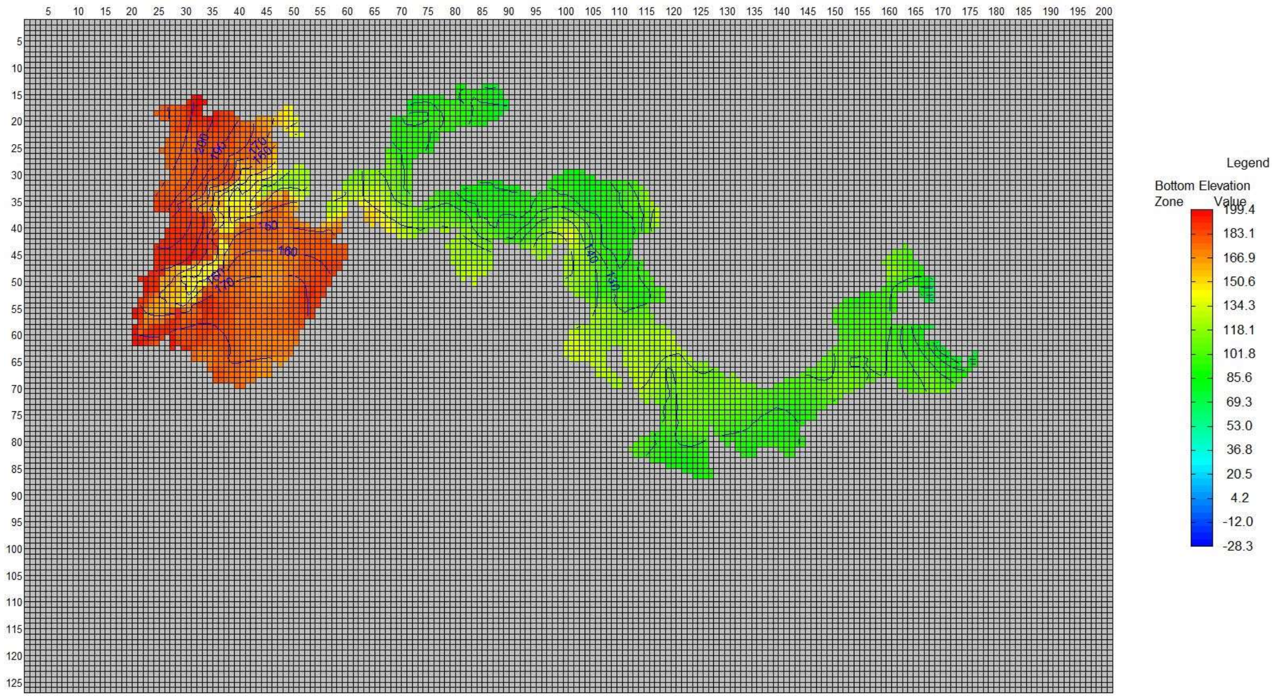

Fig. 5. Bottom of elevation of the first (shallow) aquifer

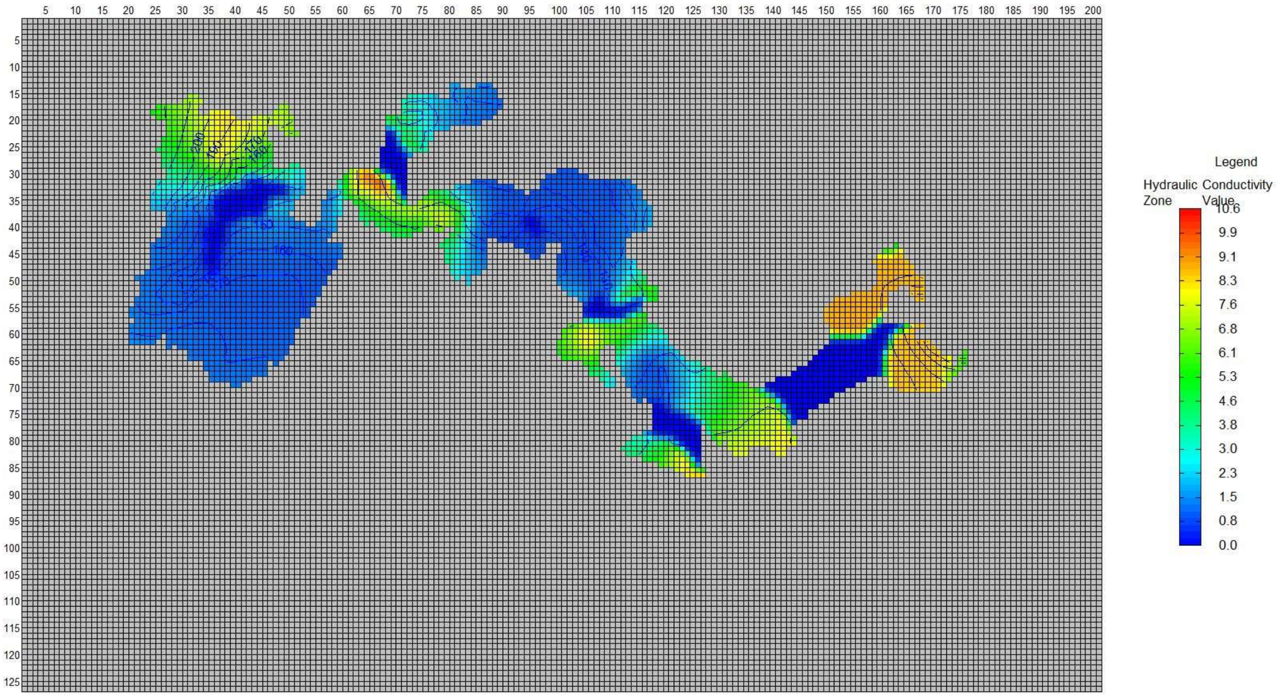

Fig. 6. Distribution of hydraulic conductivity in the first aquifer

In the northern part of the research area, considerable relief variations and the presence of deep river valleys (e.g. Szeszupa River valley) and depressions cutting the aquifers led to the appearance of numerous springs and spring areas draining the aquifers.

The recharge of sub-surface aquifers mostly takes place as a result of the infiltration of rainwater. The deeper-seated aquifers are recharged due to infiltration of groundwater from the shallower aquifers through semi-permeable sediments and as a result of vertical inflow of groundwater in the areas of hydrogeological windows, which have erosive or sedimentary origin. In places, e.g. in the Szeszupa (Šešupė) and Kirsna valleys, groundwater of the deeper Quaternary aquifers occurs under high piezometric pressure, locally showing the artesian-type groundwater table (PŪTYS, 2014).

Thickness variations of the aquifers over short, often several hundred metre long sections, result in a change of directions of groundwater filtration. In the Quaternary multi-aquifer system, there are usually two to three main aquifers separated by semi-permeable and poorly permeable sediments (aquitards). The top surface of the first, usable Quaternary aquifer, which plays the role of the main usable aquifer in the study area, is usually at a depth ranging from 30 to 80 m,, descending to a depth of 200-240 m in the uplands of the Suwałki Lake District (MITRĘGA, PACZYŃSKI, PŁOCHNIEWSKI, 1993).

Due to the complicated geological structure of the border area, a significant role in the process of recharging the deeper Quaternary aquifers is played by direct hydraulic contacts between individual aquifers. In aquifers that are characterised by considerable hydraulic gradients and locally in hydraulic windows, there is a groundwater flow with a dominant vertical component. The component of lateral groundwater flow in the deeper aquifers is difficult to determine and often reflects no relationship with the ground surface relief and with the hydrographic structure of the study area (MITRĘGA, 1984). Groundwater flow directions in individual aquifers also often show no clear relations with the topography, and they differ from each other in some regions (MITRĘGA, PACZYŃSKI, PŁOCHNIEWSKI, 1993). Intense recharge may occur in the hydrogeological structures found at a depth of 70 - 80 metres. They belong to local groundwater circulation systems, with a zone of intense drainage reaching 40 m (GRANICZNY, SATKUNAS eds., 1996). Water-bearing structures that occur at greater depths of 80-120 m have often small vertical hydraulic gradient and are included in the regional groundwater circulation systems (MITRĘGA, HORDEJUK, PACHLA, 1989). Groundwater of the aquifers occurring at a depth of more than 120 m belongs to the regional circulation system. They recharge the bottom structures of the Quaternary multi-aquifer system and is partly included in the lateral filtration.

The thickness of the active zone of freshwater exchange in the Polish-Lithuanian border area is variable: locally, from its absence in some parts of the Nemunas River valley in the territory of Lithuania, up to 300, among others in the southern part of the study area (GRANICZNY, SATKUNAS eds., 1996).

The Quaternary usable aquifers are represented by sand and gravel layers. On a regional scale, the Quaternary multi-aquifer system usually contains 3 aquifers, including two intermoraine ones and the shallow (first) aquifer, which are separated by semi permeable sediments. The Quaternary multi-aquifer system of the study area encompasses several sandy and sand-gravelly horizons:

- ✓ Sub-surface (first) aquifer (I), see Figures 4-6
- ✓ Upper intermoraine aquifer (II), see Figures 7-9
- ✓ Lower intermoraine aquifer (III), see Figures 10-12.

In the area under consideration, the majority of drilled wells abstracts water from groundwater-bearing horizons of upper inter-moraine aquifer. This aquifer is of basic usable significance, predominantly in the northern and central parts of the study area.
Aquifers have been distinguished in the northern and central parts of the modelling area within the sub-surface zone. Aquifers have also developed in alluvial sediments of the valleys and terraces of contemporary rivers.

Sub-surface aquifers are generally of no importance for water supply and are used only on a local sale. Groundwater from this aquifer is mainly abstracted by shallow dug wells of individual users, and is used for the needs of farms. In the southern, Polish part of the study area, within the Augustów sandr, the first aquifer is represented by fluvioglacial sands and gravels of the Middle and North Polish glaciations. Generally, it is characterised by the lack of continuous cover of semi-permeable and low-permeable sediments. The groundwater table is usually unconfined here. This aquifer is in connection with the upper intermoraine aquifer that occurs in the northern part of the model area. The degree of vulnerability to contamination of the sub-surface aquifer is high due to the lack of overburden of layers, composed of semi permeable sediments. The sub-surface aquifer in the Augustów Plain area is of usable significance, and the groundwater is abstracted by dug wells and drilled wells of rural water intakes and recreation centres.

Groundwater abstraction from the sub-surface aquifer by dug wells is also characteristic in the Lithuanian part of the model area, with the exception of some extremely high-elevation areas located in the west (Vištytis Upland) and the above-mentioned forested the Dainava plain - in the southern part of the model area (RADZEVIČIENĖ ET AL., 2006).

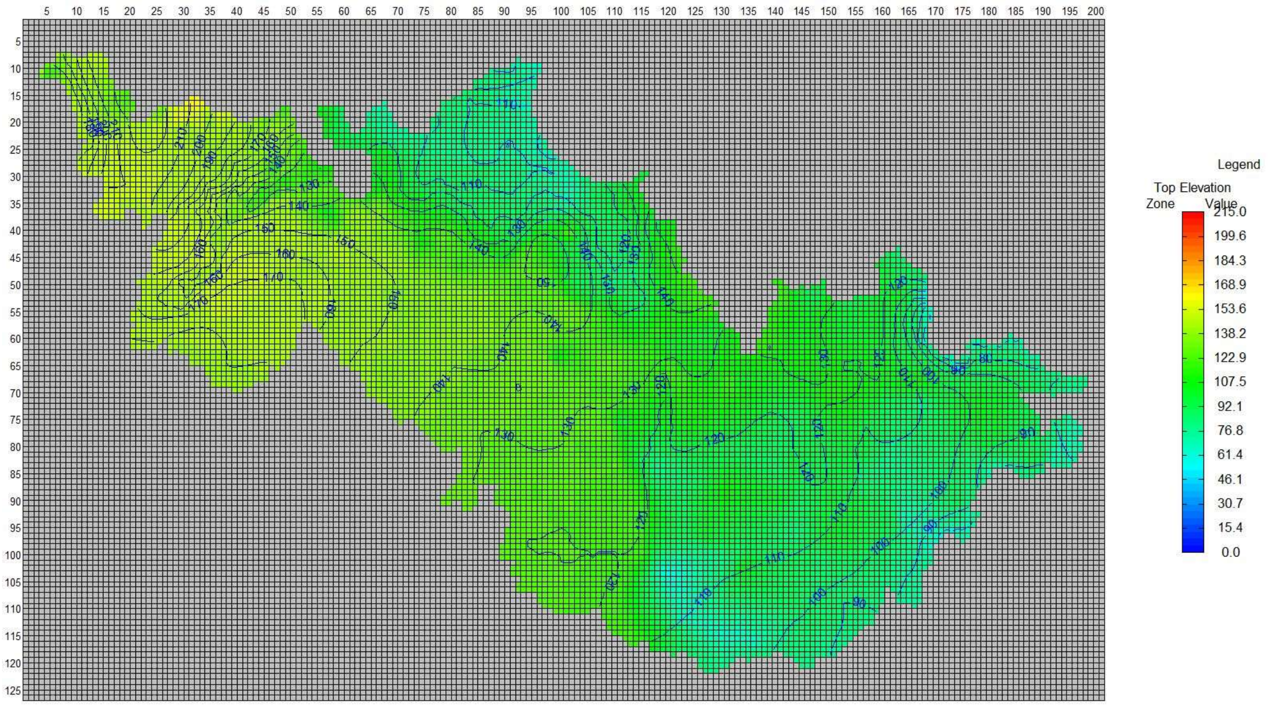

Fig. 7. Top of elevation of the second (Upper-Intermoraine) aquifer

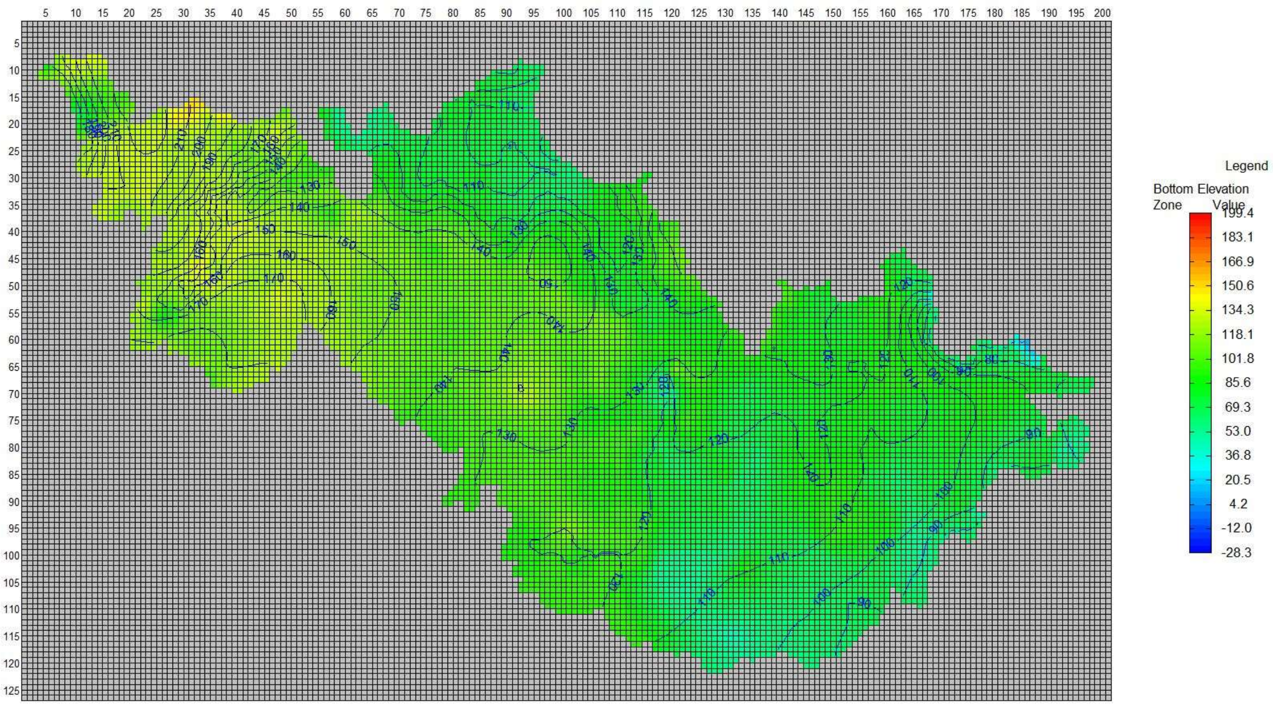

Fig. 8. Bottom of elevation of the second (Upper-Iintermoraine) aquifer

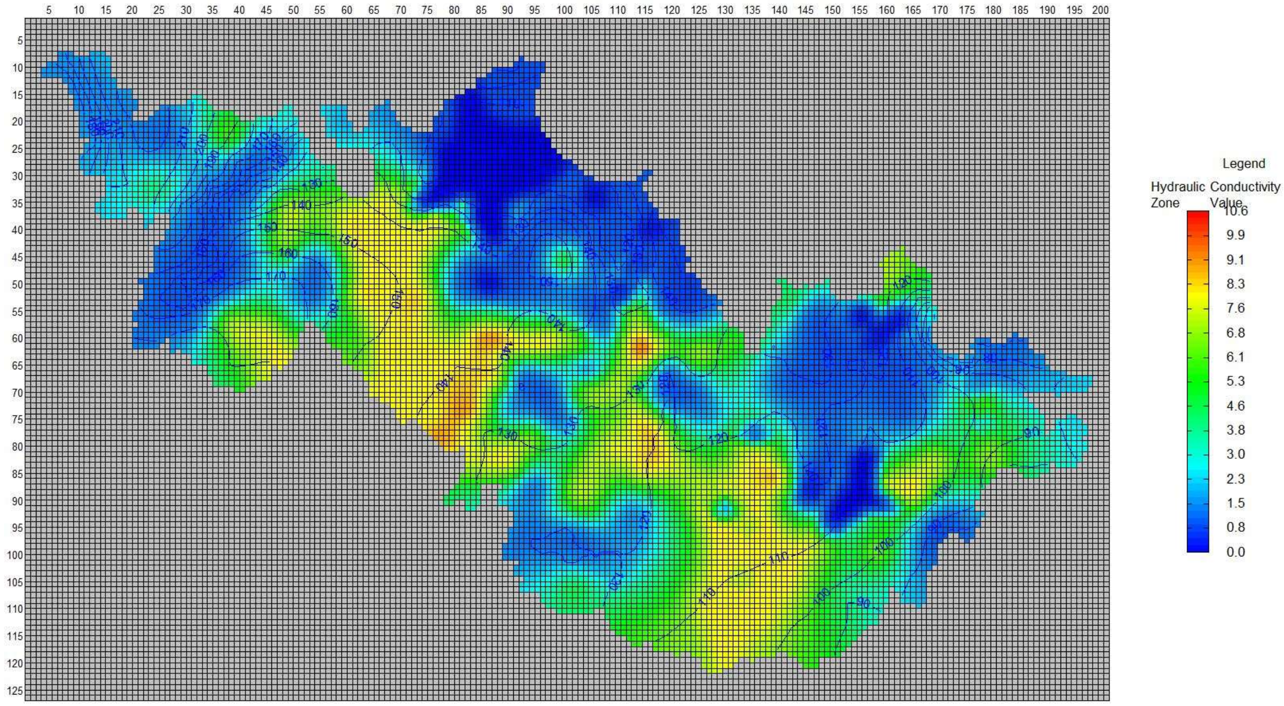

Fig. 9. Distribution of hydraulic conductivity in the second (Upper-Intermoraine) aquifer

The Quaternary intermoraine (Upper intermoraine and Lower intermoraine) aquifers play the role of productive aquifers in this region. Two intermoraine aquifers can be distinguished: the Upper Intermoraine aquifer (Figures 7-9) and the Lower intermoraine aquifer (Figures 10-12). Each of those includes several layers of sandy and gravel sediments, separated by semi-permeable sediments (aquitards) of a small thickness.
The most widespread and commonly used aquifer in this area is the upper inter-moraine aquifer. These deposits form a widespread water-bearing formation on a regional scale. Water from the aquifer is used for local purposes and is abstracted by wells of municipal and rural groundwater intakes. It is associated with sediments of various origins: sands and gravels of buried valleys, a continuous series of fluvioglacial gravels and sands filling subglacial tunnel valleys. The upper intermoraine aquifer was formed in the fluvioglacial sediments, which underlie the tills and clays of the North Polish Glaciation. Water-bearing beds of this aquifer form an extensive groundwater formation on a regional scale.

The thickness of aquifers of the upper intermoraine aquifer in the northern part of model area ranges from several to more than 70 meters- within the subglacial gutter in the vicinity of the Bolcie village (Poland). The groundwater table usually is confined.

In the southern part of the study area, the upper intermoraine aquifer, present in the northern part of the study area, passes into the first aquifer that is not covered by tills. In the contact zone with the

Augustów Sandr, the groundwater table is unconfined. In the south part of the model, the upper intermoraine aquifer has continuous extent, with a thickness ranging from 10 to over 40 m. The groundwater table is unconfined here. The degree of groundwater vulnerability of this aquifer to pollution has been assessed as low.

The transmissivity of the Upper Intermoraine aquifer is usually 100-200 m^2/24h and increases significantly in the northern part, where it is 500 - 1000 m^2/24h. In the Potopka and Szeszupa depressions, the upper intermoraine aquifer occurs above the valley bottom, which results in the presence of numerous springs on the slopes and in the lower parts of valleys (FELTER A., ŚMIETAŃSKI L., 2004).

In the northern part of GWB No. 22, the Szeszupa River is the main drainage base of the upper intermoraine aquifer. The Upper Intermoraine aquifer is recharged through the vadose zone as a result of rainwater infiltration in the Augustów sandr area, while within the postglacial plateau– due to the groundwater percolation into the usable aquifer through low-permeable interlayers of the overburden, which are composed of tills and other poorly permeable deposits, separating the aquifers.

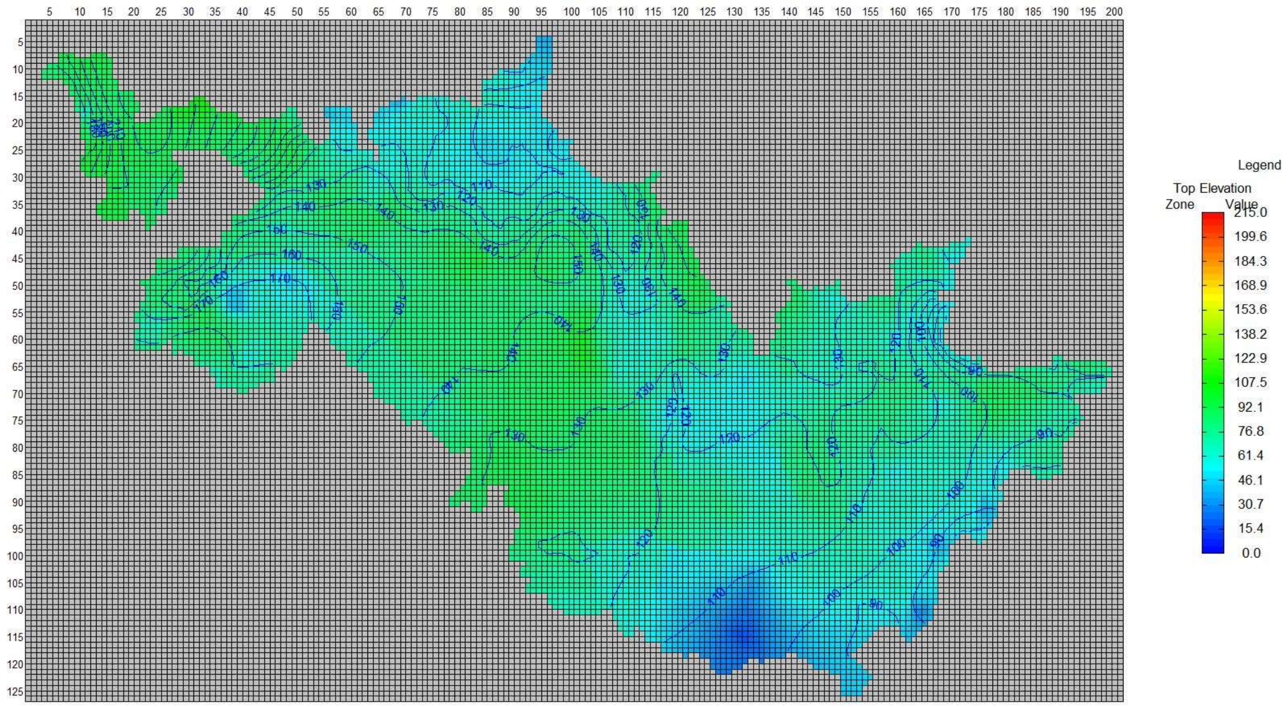

Fig. 10. Top of elevation of the third (second Lower-Intermoraine) aquifer

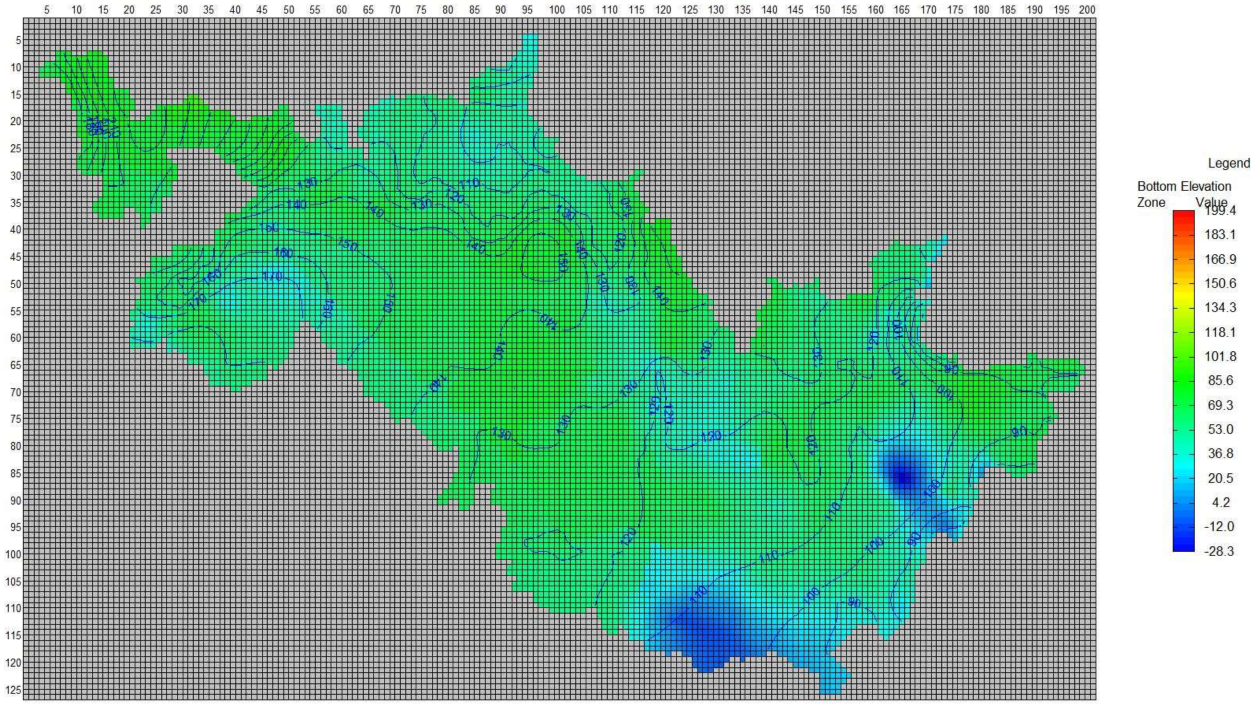

Fig. 11. Bottom of elevation of the third (Lower-Intermoraine) aquifer

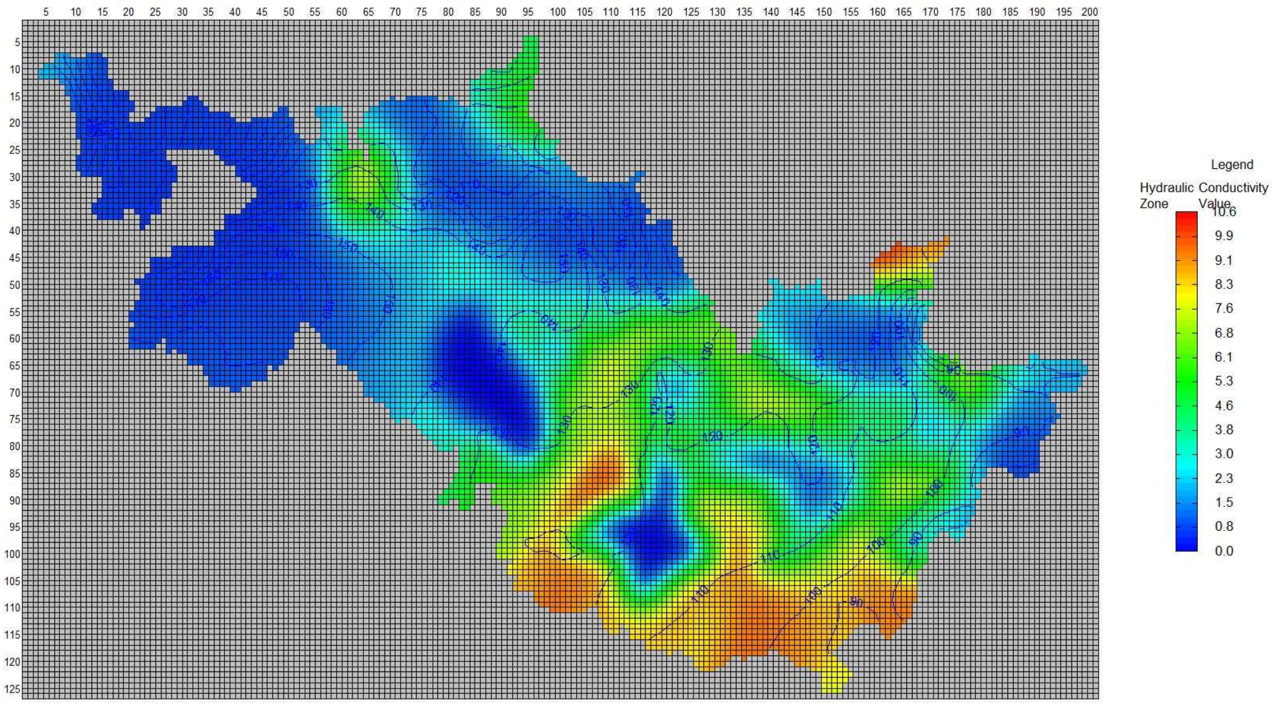

Fig. 12. Distribution of hydraulic conductivity in the third (Lower-Intermoraine) aquifer

The upper intermoraine aquifer and the lower intermoraine aquifer are locally in hydraulic connection. Within the area of buried valleys and subglacial tunnel valleys, which intersect the clays of the Middle

Polish Glaciation, e.g. in the Sejny region, the connected intermoraine aquifers have formed a joint aquifer, the thickness of which reaches 80 m (in the vicinity of the Wigry Lake). Locally, the aquifers are separated by a discontinuous layer of glacial tills and clays of the Odra and Warta glaciations, attaining a thickness of several metres. Transmissivity of the joint intermoraine aquifer ranges 200-500 m^2/24h.

The upper intermoraine aquifer is locally absent in the Lithuanian part of the model area, e.g. in the western part of the Vištytis Upland, in the Szeszupa and Kirsna river valleys (due to erosional processes), and also in some regions of the eastern part of the study area. The second. lower intermoraine aquifer spreads throughout the area except some parts of Šešupė and Kirsna catchments and Nemunas valley as well (RADZEVIČIENĖ ET AL., 2006).

The lower intermoraine aquifer is represented by a series of glaciofluvial sands and gravels of the Middle Polish and South Polish glaciations. The water-bearing deposits of the northern part of the study area, in the Szeszupa depression, are overlain by glaciolacustrine deposits. The aquifer is commonly characterised by an confined groundwater surface and is isolated from the ground surface by a series of semi-permeable deposits: clays, muds and tills, with a total thickness of 20 - 30 m. Muds and silty sands occur locally in the upper parts of the water-bearing deposits. This horizon is glacio-tectonically disturbed (FELTER, 2004).

The other intermoraine aquifer generally occurs throughout the analysed area, except in some parts of the Szeszupa and Kirsna catchment areas and locally in some sections of the Niemen River valley (RADZEVIČIENĖ ET AL., 2006). The lower intermoraine aquifer is recharged by water percolation from the upper intermoraine aquifer through poorly permeable deposits and by vertical flows in the area of hydrogeological windows.

7 GROUNDWATER CIRCULATION

The groundwater circulation in the sub-surface aquifer is determined by the near-surface lithology. The aquifer is recharged in the result of rainwater infiltration, while the drainage take place to local topographic depressions and valleys of minor rivers (Figure 13).

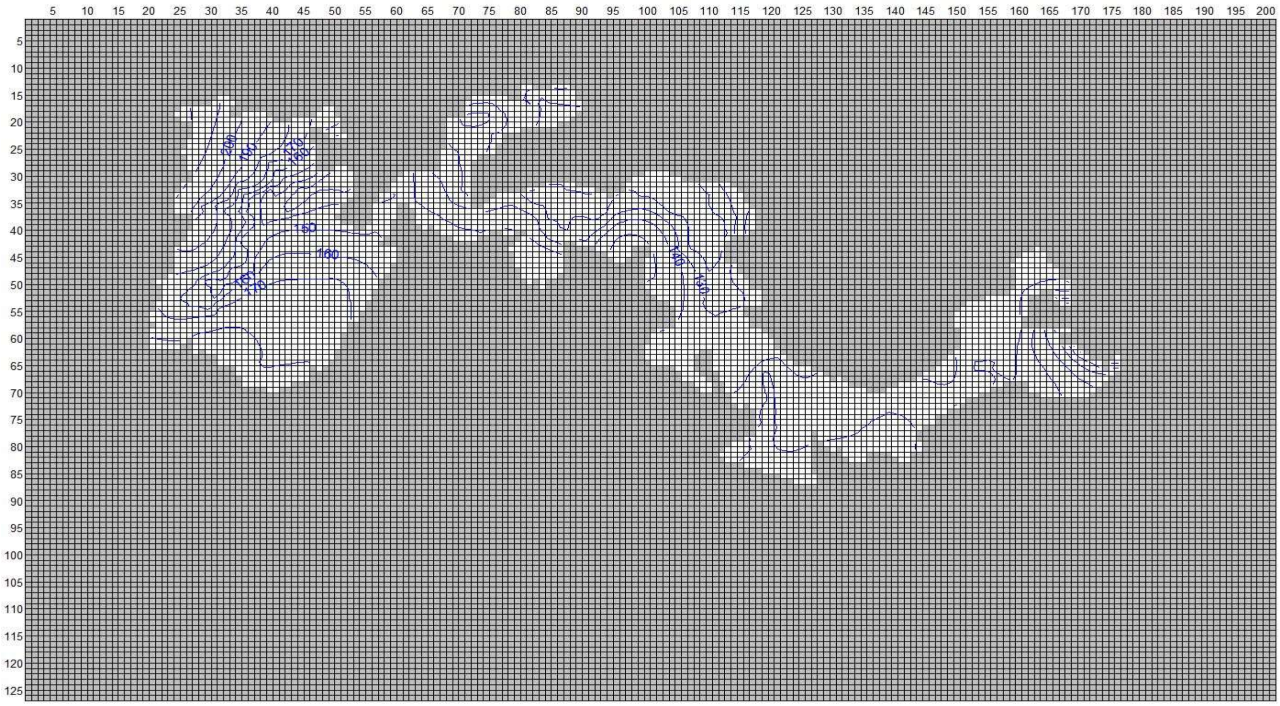

Fig. 13. Groundwater level contours of the first (shallow) aquifer, obtained in hydrodynamic numerical modelling

In the northern and central part of GWB No. 22, groundwater in the main usable aquifer generally flows from the north-west to the south-east, towards the Szeszupa river valley and its tributaries: Wigra and Szurpiłówka. The Szeszupa River, which is the main base of drainage in this part, flows into the Nemunas River on the territory of Lithuania, after crossing the state border. South from the Szeszupa catchment, the drainage effect of the Szelmentka River and its tributaries on the Quaternary aquifers is visible (Figures 14 and 15).. The Szelmentka River starts its course from the Szelemnt Wielki Lake, then it flows northwards through the lakes: Szelment Mały and Iłgiel and flows into the Szeszupa River. In the area of Puńsk, Widugiery, Sejny, Rudawka and Rygol, in the southern art of study area, groundwater of the Quaternary aquifers is drained by the Marycha river valley with its tributaries.

In the Lithuanian part, in the GWB No. 01100 groundwater flows mostly towards to Šešupė and Kirsna-Raišupis Rivers. Directions of groundwater flow depend on location, with northwest–southwest directions, which are characteristic for the Šešupė River and southwest–north-east directions for the Kirsna-Raišupis River. The groundwater fluxes GWB No. 31100 can be characterized as radial flow, because some terrain elevation occurs in the center of the area. In the GWB No. 51100 groundwater flow directions are from northwest to southeast (towards the Nemunas valley) with some exceptions related to the local elevations (RADZEVIČIENĖ ET AL., 2006).

Detailed maps of the isohypses of groundwater heads in the 3 aquifers are provided in the Appendix.

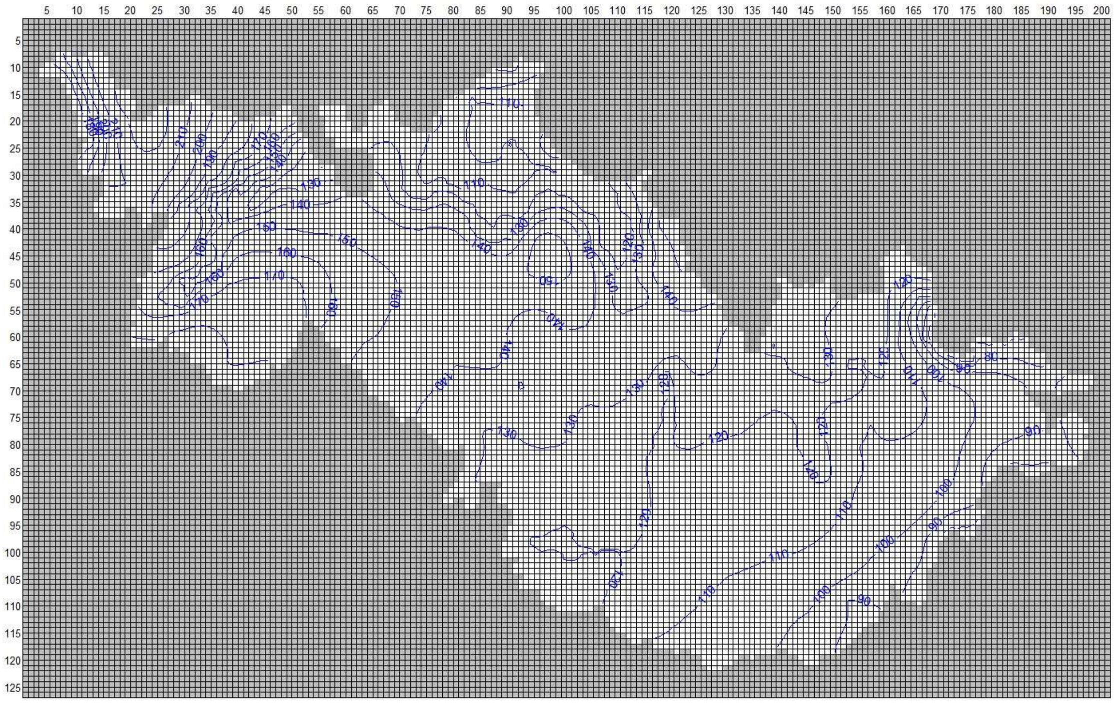

Fig. 14. Groundwater level contours of the second (upper-intermoraine) aquifer, obtained in hydrodynamic numerical modelling

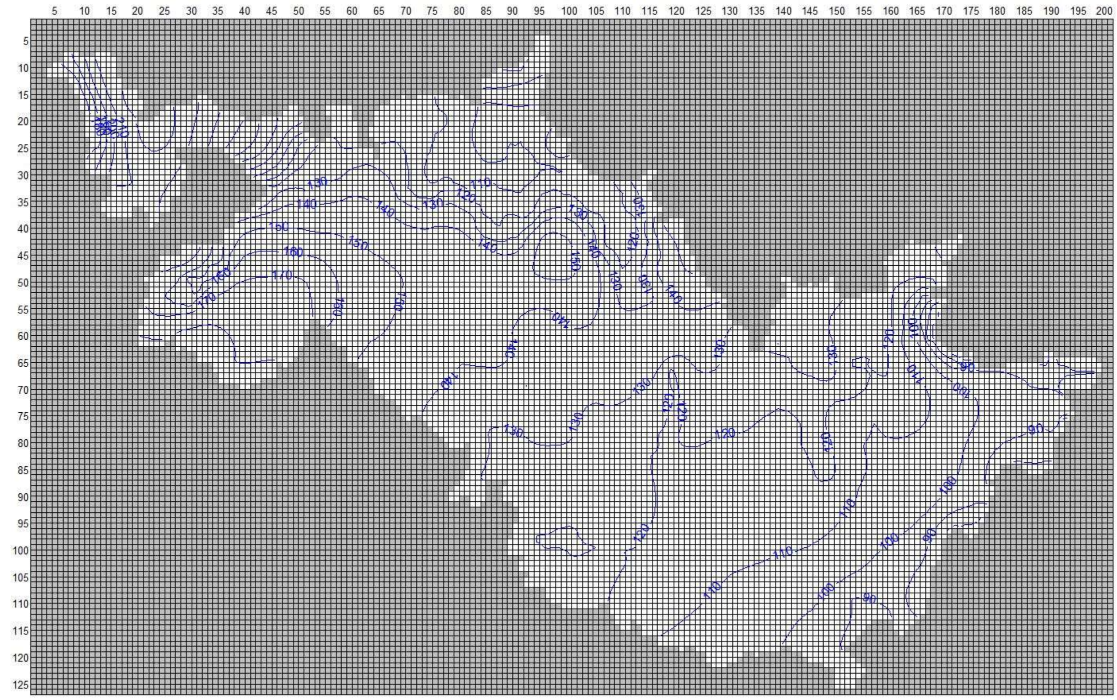

Fig. 15. Groundwater level contours of the third (lower-intermoraine) aquifer, obtained in hydrodynamic numerical modeling

8 MODEL CHOICES AND PROJECT TASKS

The first workshop of the WP4, was hold at the Sidorówka hydrogeological station of the Polish Geological Institute-National Research Institute on October 16th 2018. In this meeting attended representatives of the Polish Geological Institute-National Research Institute (PIG-PIB) and the Lithuanian Geological Survey (LGT). At the working meeting, a proposal for the GIS layers was presented with boundary conditions for the modelling area, covering the Polish-Lithuanian cross-border zone. Discussions also aimed at the issues related to the transboundary spatial extent of model layers. It was decided that the numerical model will be developed in Groundwater Vistas software, operating in the Microsoft Windows environment. In terms of the organization of the calculation process, GW Vistas is an interface on the ModFlow group calculation modules. During the meeting in Sidorówka experiences referring to already existing numerical models, developed in Poland and in Lithuania were compared.

Task 4.2 of WP4 (*Integrated evaluation and harmonization of the hydrogeological data set for modelling purposes*) was conducted since January 2019. Participants of the project prepared and provided: geological, hydrogeological and other data useful for groundwater modelling purposes. In this stage of the project cooperating parties of the project made attempts aimed at adjusting data (that are partly available in analog form or in .pdf files) to the requirements of GIS environment. The raw data were processed to the common projection in the GIS environment. The jointly agreed geographic coordinate system used is PUWG-1992. System WGS-84 was used to share data between the cooperating parties.

Task 4.3 "Unification and harmonization towards a hydrogeological dataset and the model parameters and layers for the multi-aquifer system" aimed to collect the rest of necessary data and prepare the GIS layers for modelling purposes. Some layers were merged on the contact surface and gaps of data were filled with necessary information. As the result of this work, harmonized GIS data, that presented schematic hydrogeological conditions for the study cross-border area were obtained.

8.1 Unification and harmonization of data

Task 4.3 "Unification and harmonization towards a hydrogeological dataset and the model parameters and layers for the multi-aquifer system" included following activities:

- Determination of the number, occurrence and spatial extent of model layers, especially within the cross-border area,
- Development of model layers in GIS,
- Merging the model layers at the border, filling the gaps of data,
- Distribution of the hydrogeological parameters (layer thickness, hydraulic conductivity coefficient k, transmissivity T) in model layers.

Partners of the consortium from the Lithuanian Geological Survey and the Polish Geological Institute-National Research Institute prepared model layers in GIS environment in .shp files of ArcGIS software.

In the framework of task 4.3, the hydrogeological dataset with data on thickness, depth of the top and the bottom of model layers of the multi-aquifer system and the hydraulic parameters of the layers were unified and harmonized. Moreover, the spatial extent of each model layer was distinguished

and determined. The geometry of transboundary watercourses and ordinates of the surface water table in rivers were unified in this approach.
The team of WP4 worked on import of the prepared GIS layers into the modeling software (Groundwater Vistas). Developed and merged model layers allowed to obtain schematization of hydrogeological conditions for the transboundary area. Some gaps of data on the contact surface within the cross-border area between Poland and Lithuania were filled and GIS layers were merged in these parts.

9 DEVELOPING THE TEMPLATE

9.1 Data collection structure

A joint data set was developed in the GIS environment, using the ArcGIS software for the management of the archive hydrogeological data and results of field works. For modelling purposes, the following raw data of the Polish Geological Institute-National Research Institute and the Lithuanian Geological Survey were collected:

- litho-stratigraphic profiles of hydrogeological objects (hydrogeological boreholes, piezometers and drilling wells),
- data related to hydrogeological parameters of aquifers (hydraulic conductivities k values from the pumping tests, accessible in the Central Hydrogeological Data Base of the PIG-PIB),
- layers of the Geological Map of Poland 1:50 000 (of Quaternary sediments),
- layers of the Hydrogeological Map of Poland 1:50 000,
- hydrometeorological data,
- Digital Model Terrain layers,
- other various data essential for the project needs.

All the data mentioned above were processed, transformed and adopted to the GIS layers, which were imported in the modelling software in the framework of the task number 4.4 “Set-up of a hydrodynamic model for Polish-Lithuanian cross-border area”. The ArcGIS environment was used for the management of the field works data, as well as to archive geological and hydrogeological data. The structure of resulting data set is illustrated in the scheme on Fig. 16.

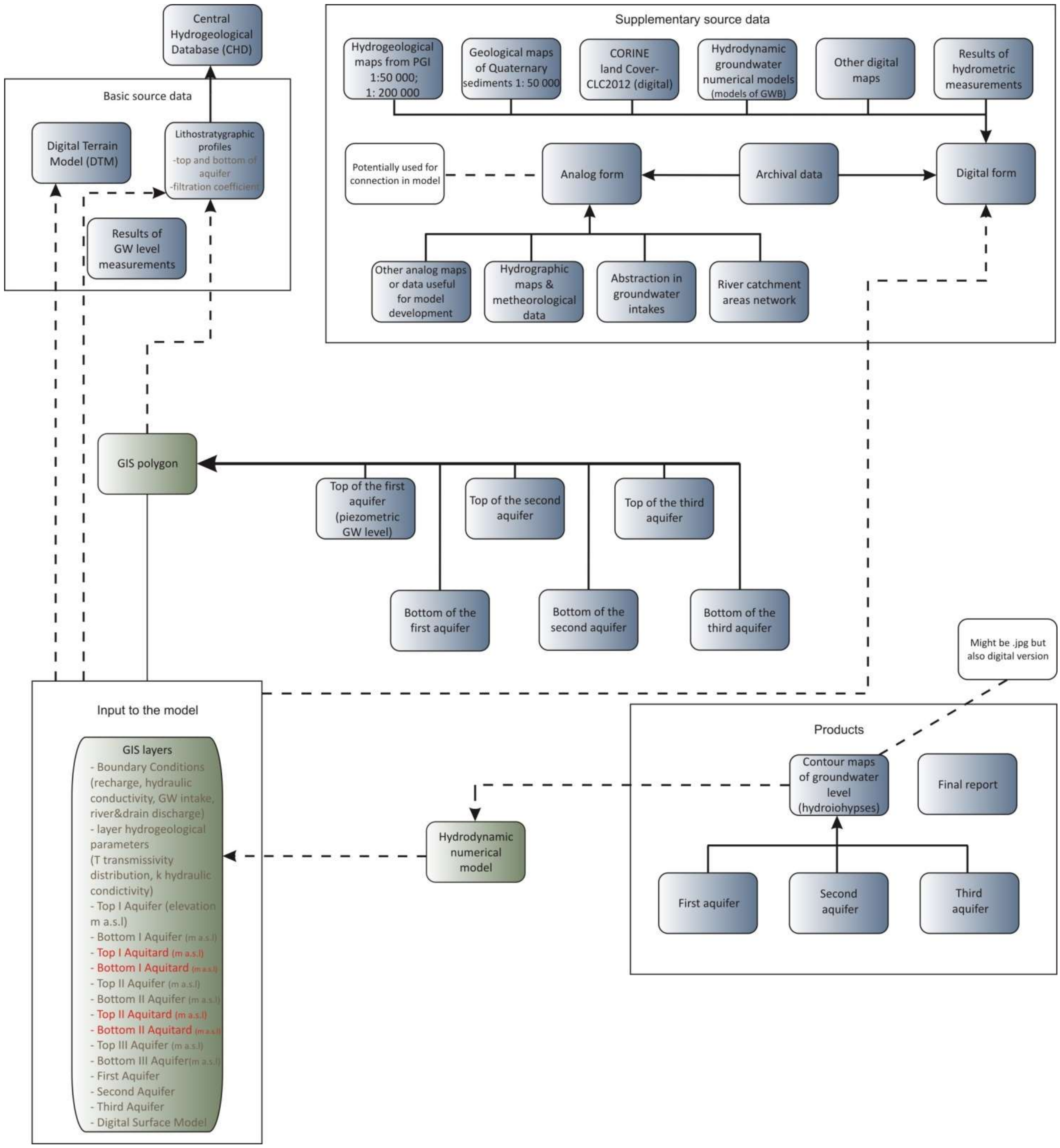

Fig. 16. Scheme of data set of the Polish Geological Institute – National Research Institute usable for numerical modelling within the Polish-Lithuanian cross-border area (Lewandowski P., Gidziński T., 2019)

10 HARMONIZATION OF DATA TOWARDS MULTI-AQUIFER STRUCTURE

In the task 4.2 “Integrated evaluation and harmonization of the hydrogeological data set for modelling purposes” were mentioned different examples, that were identified in the contact surface of GIS layers, that were developed and provided by both parties of the project consortium form the Polish Geological Institute – National Research Institute (PIG-PIB) and from the Lithuanian Geological Survey (LGT). The data and GIS layers were unified, harmonized and merged in the task 4.3 “Unification and harmonization towards a hydrogeological dataset and the model parameters and layers for the multi-aquifer system”. Beneficial in the process of preparation of cross-border GIS layers was access to the new hydrogeological data from the border territory of the riparian country. The GIS layers were unified and harmonized, using accessible, reliable data from profiles of existing geological boreholes, hydrogeological wells and piezometers.

In a case where we identified differences in the thickness of aquifers on the GIS layers contact surface, a decision was made to use average values of the thickness to merge the model layers. Thickness of individual layer, aquifer hydraulic properties and parameters of aquitards change and differ in some parts of the modelling area. The GIS layers were harmonized and merged in the parts mentioned above, using reliable data from profiles of existing hydrogeological objects. Sharing data from the territory of another country was a unique opportunity to fill or verify hydrogeological information in the cross-border scale. Close to the border line, where accuracy of data provided by each party is not sufficient, data were reprocessed using GIS tools e.g. interpolation.

In June 2020, groundwater tables were measured in selected, representative piezometers and hydrogeological boreholes within the Polish part of the modelling area. Moreover, this includes data from automatic data loggers, that were installed in selected piezometers.

The principal calibration criterion in task 4.4 “*Set-up of a hydrodynamic model for Polish-Lithuanian cross-border area*” was to minimize the difference between the groundwater table heads measured in the field and calculated in selected observation wells by the groundwater flow simulations. Some selected layers of the model or their parts were modified based on simulation results (e.g. based on the solution of an inverse task).

11 SCOPE OF TASK 4.4

Task 4.4 of the TRANSFLUX project was "*set-up of a hydrodynamic model for Polish-Lithuanian cross-border area*".

In the task 4.4 following activities were distinguished:

- Set-up of the cross-border numerical groundwater flow model,
- Calibration and verification of the numerical model, model simulations,
- Determination of the transboundary groundwater flow directions in the cross-border area,
- Groundwater contour (level elevation, hydroizohypses) maps for model layers (aquifers) were presented in enclosures: 1, 2 and 3,
- Assessment of the volume of groundwater that flows through the state border between Poland and Lithuania in each model layer (- in each, individual aquifer).

As the final result of the numerical model simulations, we obtained groundwater contour maps for each aquifer, that were distinguished in the model structure.

11.1 Groundwater numerical model

Hydrogeological information compiled and analyzed during the first stages of the project was then used to develop a numerical hydrodynamic model for Quaternary aquifers within the cross-border area. For the purpose of the model, the study area was discretized to 500 m by 500 m model cells, the model boundaries were defined, and the boundary conditions were determined. The crucial part of the project, which focused on the numerical model development was preceded by gathering and processing of available geological, hydrogeological and other data useful for groundwater modelling purposes. Data was prepared in GIS layers, that represent first, second and third aquifer, which are composed of Quaternary sediments.

Groundwater Vistas software, operating in the Microsoft Windows environment was selected for model development. GW Vistas is an interface of the MODFLOW group calculation modules. The program is used to solve the filtration equation using the finite difference method. The main function of GW Vistas is the use of a graphical interface to enter input data, control calculation process, analyze results and communicate with other applications used in hydrogeological tasks.

The calculation algorithm is based on the approximate, numerical solution of the system of equilibrium flows resulting from the general differential equation describing the movement of groundwater in three-dimensional space in a porous environment:

$$\frac{\delta}{\delta_x}(k_{xx}\frac{\delta_h}{\delta_x})+\frac{\delta}{\delta_y}(k_{yy}\frac{\delta_h}{\delta_y})+(k_{zz}\frac{\delta_h}{\delta_z})-W=S_S\frac{\delta_h}{\delta_t} \quad (1)$$

k_{xx}, k_{yy}, k_{zz}, - hydraulic conductivity along the x, y, z axis $[LT^{1}]$

h - hydrostatic pressure [L]

W - recharge $[T^{1}]$

S_S – storage coefficient *$[L^{-1}]$*

t - time [T]

The Groundwater Vistas program implements a fully spatial model of groundwater flow. As such, it presupposes a strict sequence of layers. Numerical calculations are subject of the solution of a different equation in which the hydraulic heights are unknown. In order to achieve a properly calibrated model, groundwater levels in the modeled aquifer are necessary.

The structure of the conceptual model was accomplished taking into account the following criteria:

- The distinguished aquifers had to be of common occurrence in the area,
- Aquifers were aggregated, if they have good hydraulic connection,
- By aggregating of aquifers, the hydrogeological parameters of the sediments of aquifers and their water permeability were taken into account,
- The developed conceptual model refers to the division of the regional hydrogeological system. Three main aquifers in the Quaternary formation were distinguished,
- Distinguished separating layers of semi-permeable and low-permeable sediments had to be of considerable thickness and continuous extent in the regional scale.

11.2 Model boundaries and grid discretization

To carry out modelling investigations the study area was discretized, the model boundaries were defined, and the boundary conditions were determined. The model boundary conditions were defined mainly as a no flow (2nd type) boundary, and as a 3rd type boundary along rivers and creeks. Only small parts of model borders were defined as 1st type (constant head) boundary condition. The groundwater recharge and well pumping rates were defined as the 2nd type boundary conditions. The square of model cell is 500 m by 500 m. On the base of the hydrogeological conditions within study area were distinguished three productive aquifers of Quaternary age. The first aquifer from the ground surface is unconfined and locally confined, composed of sands and gravels of Holocene and Pleistocene age. The second aquifer is the main usable aquifer in study area.

The hydrogeological scheme was supplemented by the following assumptions:

- Bottom of the third aquifer is non permeable;
- Flow field is steady-state;
- Vertical groundwater flow is neglected;
- Aquifer is hydraulically connected to the rivers and lakes;
- The distribution of spatial model parameters and the heterogeneity of the aquifers were taken into account by differentiation of the parameters in the discretization grid,
- it is assumed isotropicity of the aquifer in individual calculation block.

In software for numerical modelling the properties of aquitards were presented as parameter of “leakance”.

The steady-state groundwater flow in numerical model has been solved using the finite difference method for the rectangular regular mesh with the constant spatial step 500 m by 500 m. The applied calculation procedure required input of individual aquifer top and bottom elevations and permeability values for each node of the finite difference mesh. For the unconfined parts of the aquifer its top is equivalent to the calculated elevation of groundwater table. The aquifer top and bottom elevations were input by the import of the files generated in the ArcGIS for the Polish and Lithuanian models, using the interpolation procedure.

11.3 Model Calibration

Numerical model always constitutes the simplification of the real hydrogeological conditions. This is why model simulations results include certain error, which results from the never full knowledge of the investigated hydrogeological system and necessary simplification made during the construction of the model.

Factors limiting the model reliability:

- Insufficient number of piezometers and observation wells with the possibility to measure groundwater heads in the investigated area,
- Mosaic distribution of the permeability values,
- Differences in archive hydrogeological data (parameters) provided by project partners,
- Small number of reliable data from hydrogeological database in low populated cross-border areas.

The principle calibration criterion was to minimize the difference between the groundwater table elevations measured in the field and calculated in selected observation wells by the groundwater flow simulations.

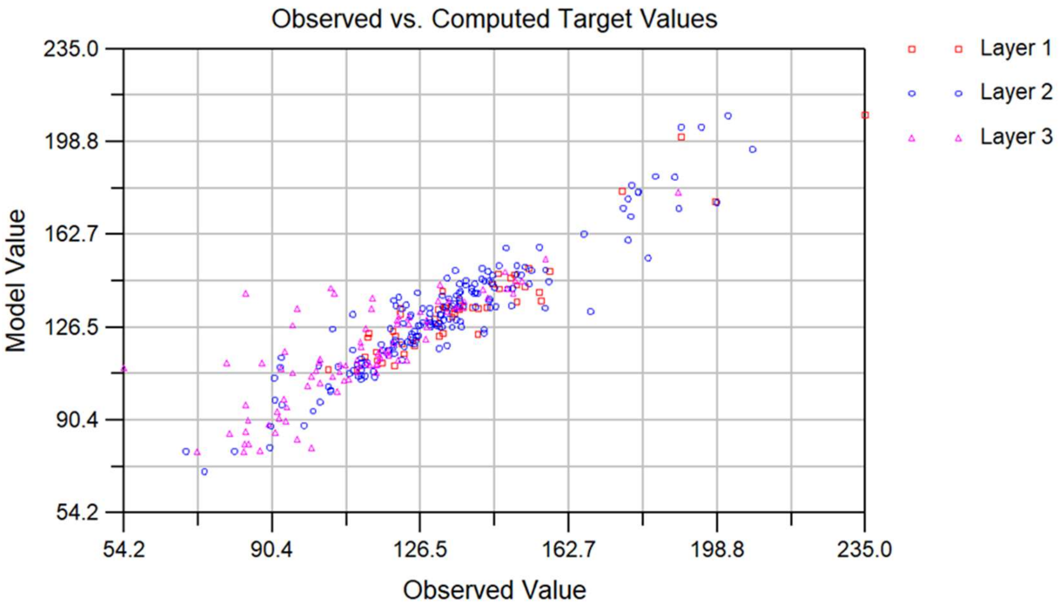

Fig. 17. Model calibration results

Table 1. Assessment of groundwater volume, which crosses state border between Poland and Lithuania, based on results of hydrodynamic modelling

Number of aquifer with accordance to the model layers	Groundwater flow from Poland to Lithuania [m^3/24h]	Groundwater flow from Lithuania to Poland [m^3/24h]
I First aquifer	2764,85	4880,48
II Second aquifer	37242,01	31795,44
III Third aquifer	9193,26	9033,68

Table 2. Groundwater flows between aquifers in the hydrodynamic numerical model

Direction of groundwater flow	Groundwater flow in numerical model within Poland [m^3/24h]	Groundwater flow in numerical model within Lithuania [m^3/24h]
Groundwater flow from first to second aquifer	78808,32	127065,7
Groundwater flow from second to first aquifer	73203,03	126311,2
Groundwater flow from second to third aquifer	53726,98	169921,3
Groundwater flow from third to second aquifer	53569,66	196374,3

12 CONCLUSIONS

This report summarizes the results of the set-up of the cross-border numerical groundwater flow model, that covers multi-aquifer system of Quaternary sediments within the Polish-Lithuanian cross-border area. In the framework of aforementioned task, we calibrated and verified the numerical hydrodynamic model and interpreted the model simulations. As the result, transboundary groundwater flow directions in the cross-border area were established. This report presents groundwater contours, elevation of groundwater level or hydro-isohypses in the form of maps for each model layer, that corresponds with distinguished Quaternary aquifers (Figures 13-15 and detailed maps in the Appendix). Moreover, the volume of groundwater that flows in each, individual aquifer (related to each model layer) through the state border between Poland and Lithuania was evaluated.

13 RECOMMENDATIONS FOR USE OF THE MODEL RESULTS IN GROUNDWATER MANAGEMENT

The results of the WP4 project made it possible to achieve the assumed goals, i.e. to define the directions of groundwater filtration in the Polish-Lithuanian border zone, and to estimate the volume of groundwater that flows across the border between Poland and Lithuania. The research results can be used for the purpose of verifying and updating the ideas on the scope of the existing groundwater monitoring and for their further development, in order to create a coherent system of cross-border monitoring networks. The research results can also be used in the activities of the inter-state Polish Lithuanian Commission on Transboundary Waters and the working groups operating within its structure, including Working Group No. 3 For the Protection of Border Waters Against Pollution.

The numerical model can be further developed in a new project to obtain information on groundwater safe yield (groundwater disposable resources) and water management plans in cross-border areas of river basins.

The new project using the results of the WP4 RESOURCE GeoERA research may also be focused on the consideration of different scenarios of both climate changes and their impact on changes in groundwater dynamics, as well as changes in water resources, in conjunction with projected changes in the surface water environment.

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APPENDIX: CROSS-BORDER ISOHYPSE MAPS OF GROUNDWATER HEADS FOR THE 3 AQUIFERS IN THE STUDY REGION

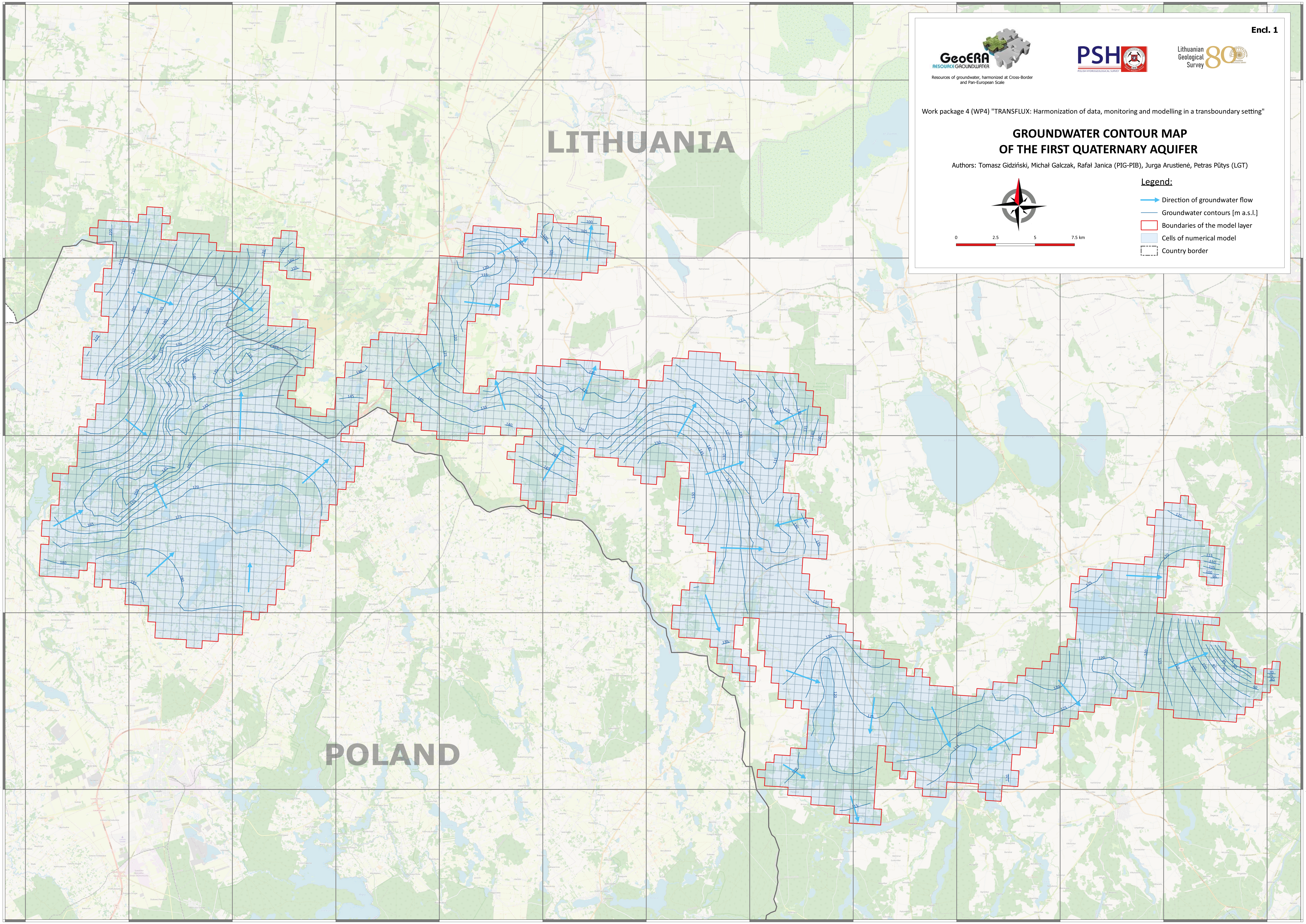
Encl. 1

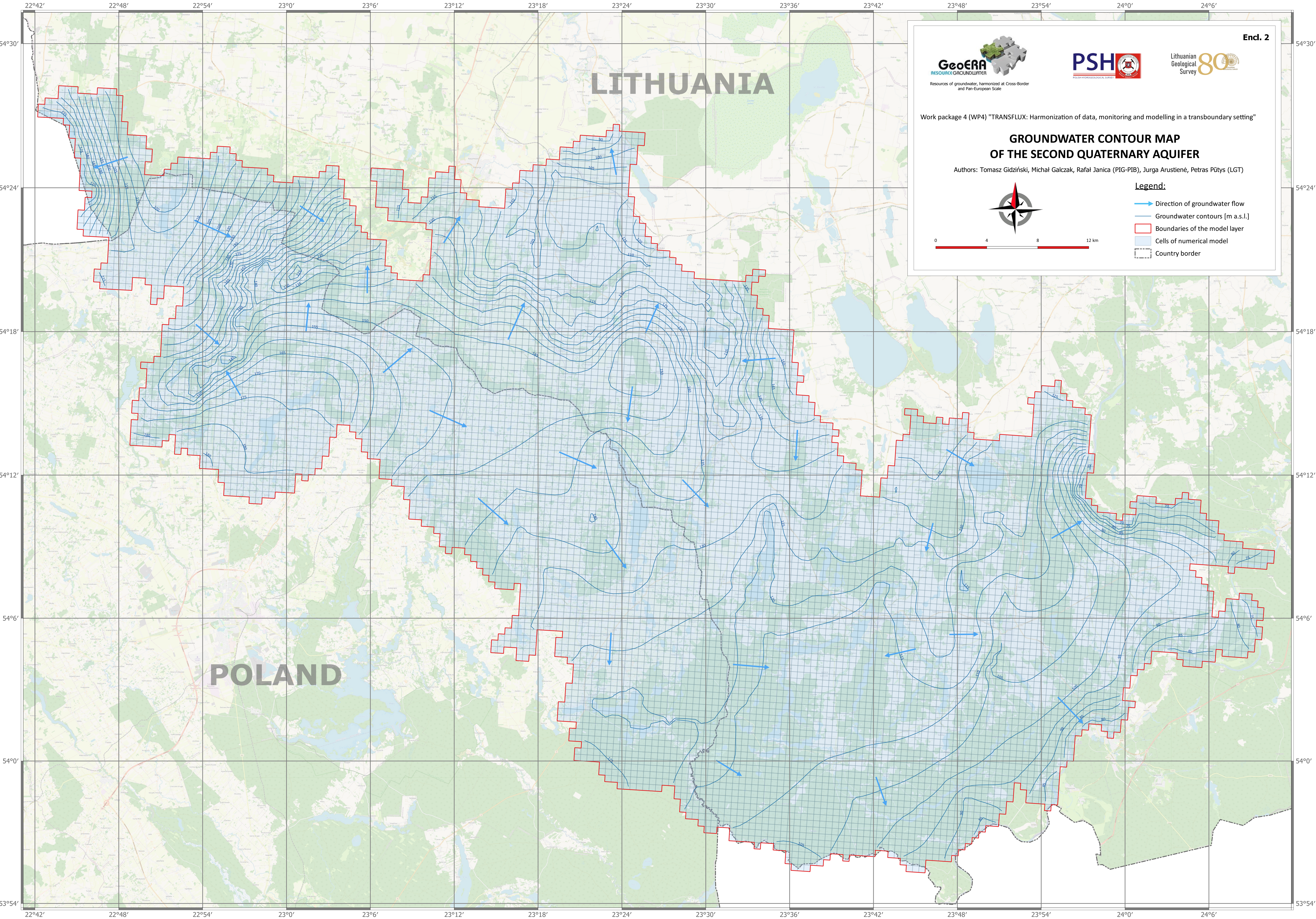
Resources of groundwater, harmonized at Cross-Border and Pan-European Scale

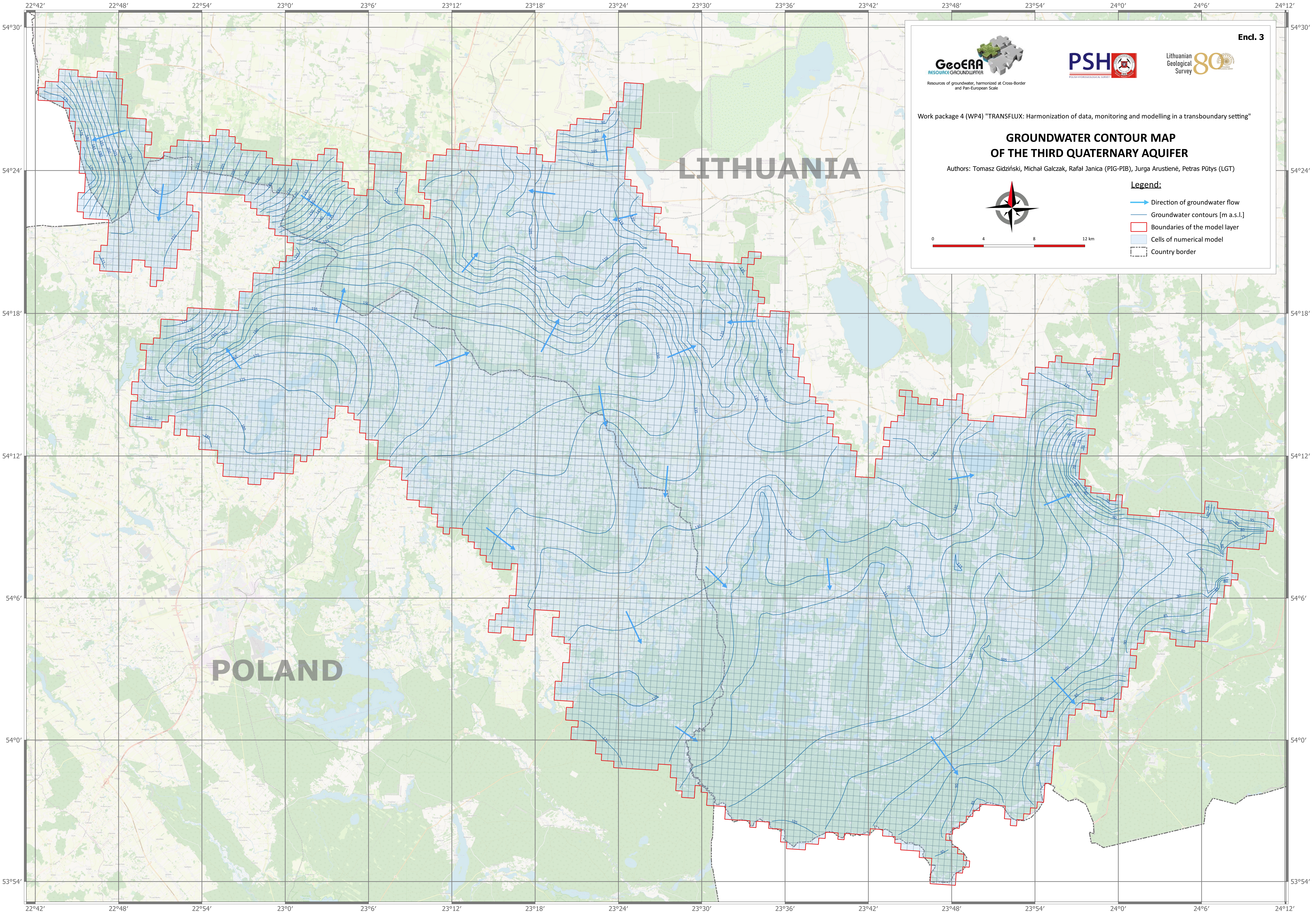
Work package 4 (WP4) "TRANSFLUX: Harmonization of data, monitoring and modelling in a transboundary setting"

GROUNDWATER CONTOUR MAP OF THE FIRST QUATERNARY AQUIFER

Authors: Tomasz Gidziński, Michał Galczak, Rafał Janica (PIG-PIB), Jurga Arustienė, Petras Pūtys (LGT)




Encl. 2
Resources of groundwater, harmonized at Cross-Border and Pan-European Scale
Work package 4 (WP4) "TRANSFLUX: Harmonization of data, monitoring and modelling in a transboundary setting"
GROUNDWATER CONTOUR MAP
OF THE SECOND QUATERNARY AQUIFER
Authors: Tomasz Gidziński, Michał Galczak, Rafał Janica (PIG-PIB), Jurga Arustienė, Petras Pūtys (LGT)
Legend:
Direction of groundwater flow
Groundwater contours [m a.s.l.]
Boundaries of the model layer
Cells of numerical model
Country border
0
4
8
12 km
LITHUANIA
POLAND
22°42′
22°48′
22°54′
23°0′
23°6′
23°12′
23°18′
23°24′
23°30′
23°36′
23°42′
23°48′
23°54′
24°0′
24°6′
54°30′
54°24′
54°18′
54°12′
54°6′
54°0′
53°54′


Encl. 3
GeoERA RESOURCE GROUNDWATER
Resources of groundwater, harmonized at Cross-Border and Pan-European Scale
PSH
POLISH HYDROGEOLOGICAL SURVEY
Lithuanian Geological Survey
Work package 4 (WP4) "TRANSFLUX: Harmonization of data, monitoring and modelling in a transboundary setting"
GROUNDWATER CONTOUR MAP
OF THE THIRD QUATERNARY AQUIFER
Authors: Tomasz Gidziński, Michał Galczak, Rafał Janica (PIG-PIB), Jurga Arustienė, Petras Pūtys (LGT)
Legend:
Direction of groundwater flow
Groundwater contours [m a.s.l.]
Boundaries of the model layer
Cells of numerical model
Country border
0
4
8
12 km
LITHUANIA
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22°42′
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53°54′