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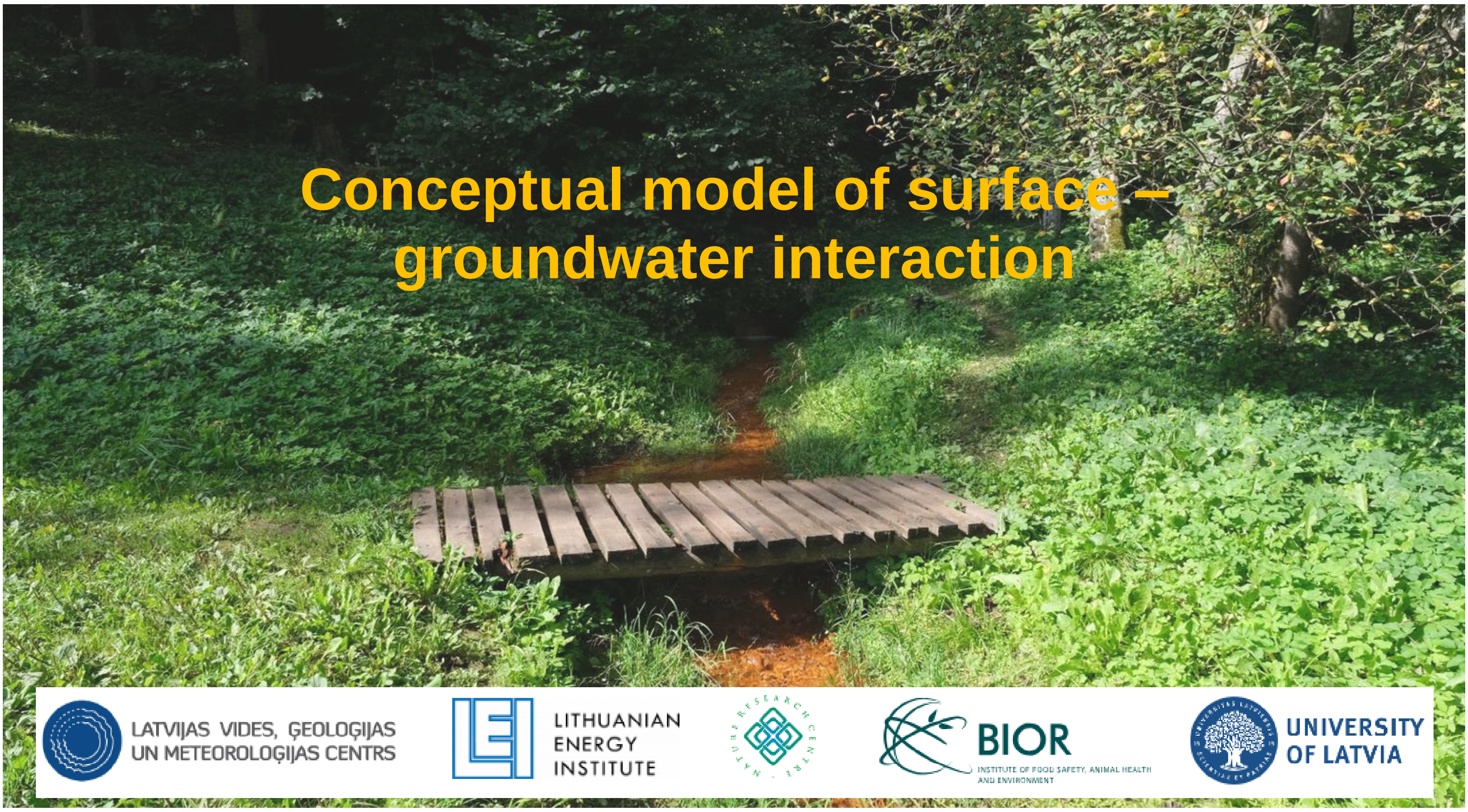
Conceptual model of surface – groundwater interaction



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List of used abbreviations

a.s.l.	above sea level
Bream/RoachW%	roach and bream percentage by weight in a gill net with a mesh size 20-35 mm
Chl-a	chlorophyll-a
EQR	ecological quality ratio
GAAEs	Groundwater associated aquatic ecosystems
GDEs	Groundwater dependent ecosystems
MS	meteorological station
PerchW%	percentage of perch by weight in gill nets with mesh size of 20-35 mm
RoachWavg	roach average weight (g) in a catch using nets with a mesh size of 20-35 mm
RBD	river basin district
Wavg	average weight

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I INTRODUCTION

Dynamic interactions between ground- and surface water are widely known, but the role of groundwater contribution and catchment characteristics is still too poorly understood and documented due to the spatiotemporal complexity (Terasmaa et al., 2020). Groundwater dependent ecosystems (GDEs) are ecosystems whose current composition, structure and function rely on groundwater supply. Ilzu/Ilge lake is one of such ecosystems, more precisely groundwater associated aquatic ecosystem (GAAE).

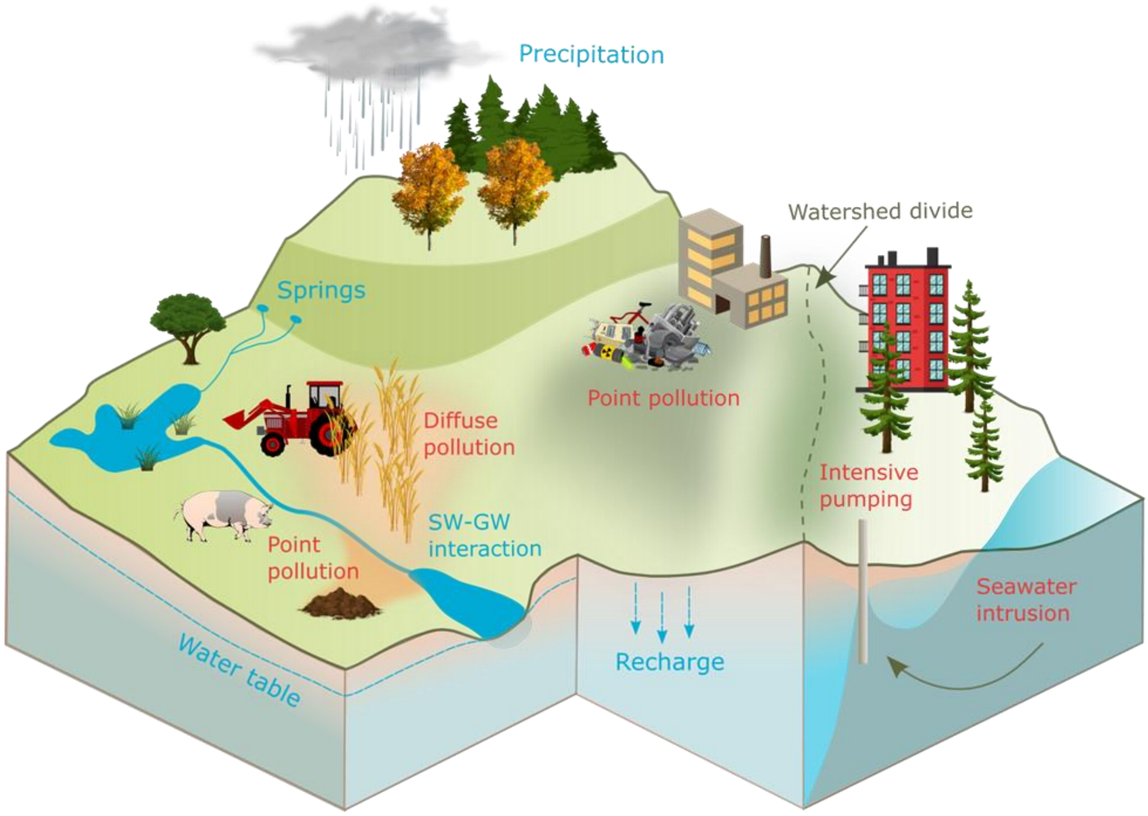

Figure 1.1. Elements of hydrogeological conceptual model (blue text – natural processes, red text – human influences)

A conceptual hydrogeological model is a descriptive and graphical representation of the structure and processes occurring in a hydrogeological system. The model is a set of hypotheses as to how the real hydrogeological system behaves, how it is related to the environment, and how it responds to external factors (Fig. 1.1) (EU-WATERRES…, 2021). A hydrogeological conceptual model usually describes and quantifies the relevant geological characteristics, flow conditions, hydrogeochemical and hydrobiological processes, anthropogenic activities (groundwater pumping, polluting activities), and their interactions (Fig. 1.1). The degree of detail is based on the given problems and questions. Conceptual models can be applied under circumstances, from detailed assessments to a simplified scheme of interacting processes for communication purposes with stakeholders. Development of a conceptual model is one of the basic steps for the management of groundwater bodies (European Commission, 2010).

Main points during conceptual model setup (European Commission, 2010) are as follows. First, the identification of the question we want to answer with the model or aim, then followed by agreement on the degree of detail and complexity of such a model. When initial vertical and horizontal boundaries have been identified (mainly surface and subsurface catchments) we can move to the next parametrization and quantification steps. The most important part of the development of a conceptual model is iterative evaluation and updates according to the new information. It is suggested to start with a very simplified version of the conceptual understanding already in the very beginning and then add details.

II ILZU (GARAIS)/ILGE LAKE CATCHMENT CHARACTERISTICS

2.1. Topography (morphology, surface waters, surface water catchment)

The Ilzu (Garais) / Ilge Lake belongs to the Mēmele/Nemunelis River Basin that is one of two big sub-basins of the Lielupe River Basin.

The upper reach of Lielupe RBD is located in the north of Lithuania (Fig. 2.1.). The largest part of this area consists of Mūša-Nemunėlis Plain where the average height fluctuates from 40 to 60 m above sea level (a.s.l.) and of Zemgale Plain with fluctuation of 30-50 m a.s.l.

In Latvia, the largest part of the Lielupe River basin is situated in the Middle Latvian Lowland, and the elevation downstream from Jelgava city is normally less than 10 m a.s.l. Exceptions are the Eastern Kurzeme Upland in the most western part of Lielupe RBD and the Augšzeme Upland in the southeastern part, where elevations reach up to 150 m a.s.l. The Ilzu (Garais)/Ilge Lake locates here, in the Augšzeme Upland (Fig. 2.1).

According to the “Watershed model for the Lake Garais/Ilge” report, the catchment area of the lake is 8.72 km^2, 5.04 km^2 of which is located in Latvia and 3.68 km^2 in Lithuania.

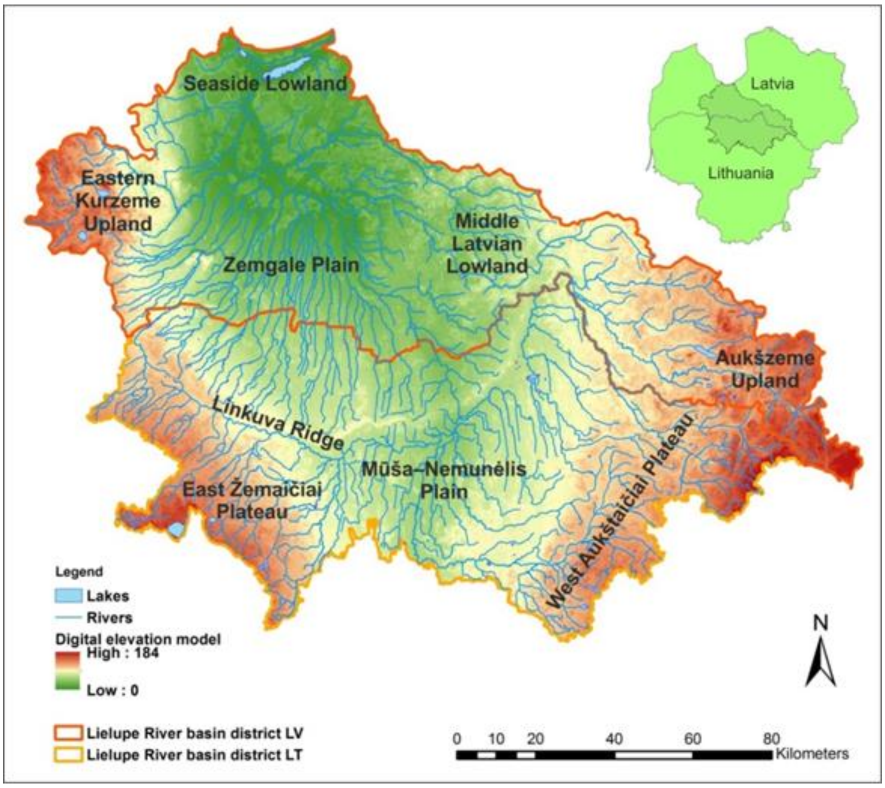

Figure 2.1. Topography and hydrography of Lielupe RBD (ECOFLOW Project, 2017)

2.2. Climate, hydrology and hydrography

Climate in the Eastern part of the Lielupe River basin can be characterized as a transitional between mild Western European and continental Eastern European climate. The Baltic Sea has an impact on the climate here, however from west to east, the sea has less and less influence on climatic conditions.

According to Zilani meteorological station (hereinafter MS) data, the annual air temperature in the vicinity of Ilzu/Ilge Lake is +6.6 °C, annual amount of precipitation – 670 mm (climate normal data for the period 1991-2020).

Average air temperature in February (the coldest month of the year) is -4.3 °C, while average air temperature in July (the warmest month of the year) reaches 16.8 °C.

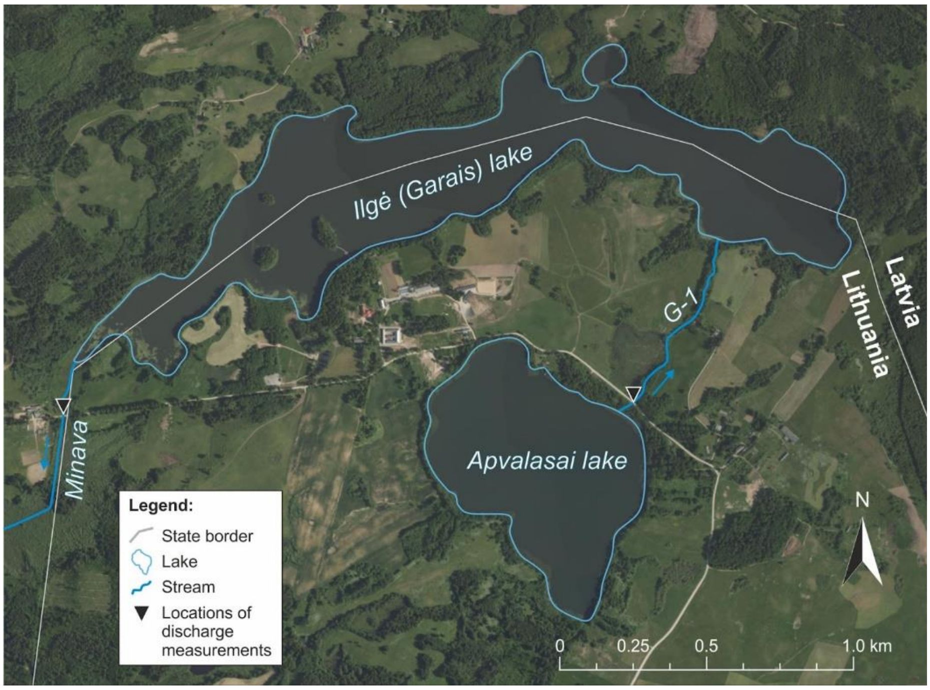

Figure 2.2. Ilzu (Garais) / Ilge Lake catchment area.

The hydrological regime in the basin is characterized by the spring flood, summer and winter low flow periods, and autumn/winter rainfall floods. 42% of water mass rivers and lakes have their origin from snow melting, about 55% from rainfall, and the rest – from groundwater.

Ilzu (Garais)/Ilge Lake is a drainage lake with a small inflow from the drainage channel in Latvian territory and a creek connecting Ilzu (Garais)/Ilge and Apvalasai lakes on Lithuanian side (Fig. 2.2). Small Minava River outflows to Lithuanian territory. Specific water discharge in a lake basin is about 7 L/sec*km^2.

2.3. Land use

The land cover/land use analysis is primarily based on CORINE Land Cover data (Fig. 2.3). The main types of land use in the catchment area of Ilzu (Garais)/Ilge Lake are forest lands (broad-leaf forests, mixed tree forests and transitional forests/shrubberies) and surface areas of two lakes, which together comprise about 53.8% of the total catchment area. Agricultural lands with significant areas of natural vegetation make up 37.2% of the total area. Of the remaining 9%, pastures make up 6.6% and non-irrigated arable lands – 2.4% of the total catchment area.

Land use	Area, ha	Area, %
Pastures	58.1	6.6
Non-irrigated arable land	20.6	2.4
Mixed forest	210.1	24.1
Broad-leaved forest	24.3	2.8
Transitional woodlands shrub	103.4	11.9
Water body	131.0	15.0
Agriculture lands with significant areas of natural vegetation	324.1	37.2
Total	**871.6**	**100**

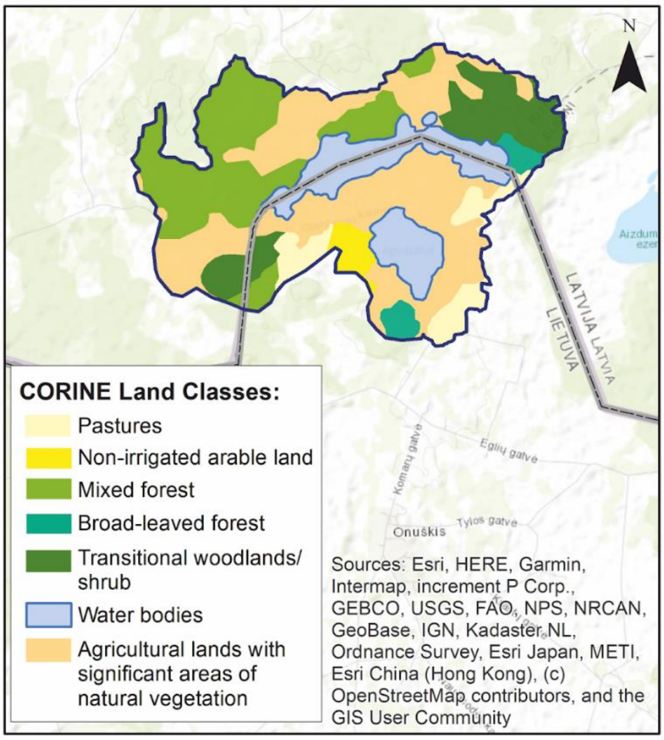

Figure 2.3. Land use types in the catchment of Ilzu (Garais)/Ilge Lake.

In the Lithuanian part of the project territory, agricultural land covers 67.2% of the project area, of which 20.9% are pastures and non-irrigated arable land, and 46.3% are agricultural lands with large areas of natural vegetation. The rest of the territory is forest land (9.8%) and water body surface (23.0%) (Fig. 2.4).

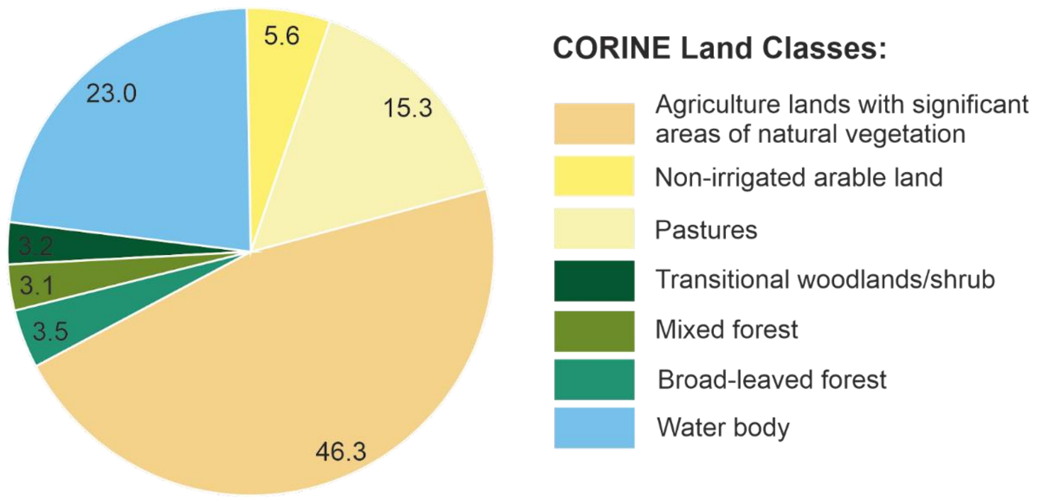

Figure 2.4. Main land use types in the Lithuanian part of Ilzu (Garais)/Ilge Lake catchment.

In Latvia, 59.9% of the territory is forest land. Agricultural land comprises 30.5% of the territory, with large areas of natural vegetation. The rest of the territory is the surface area of Ilzu (Garais)/Ilge Lake (9.2%) and pastures, which make up a small part of the area – only 0.4% (Fig. 2.5).

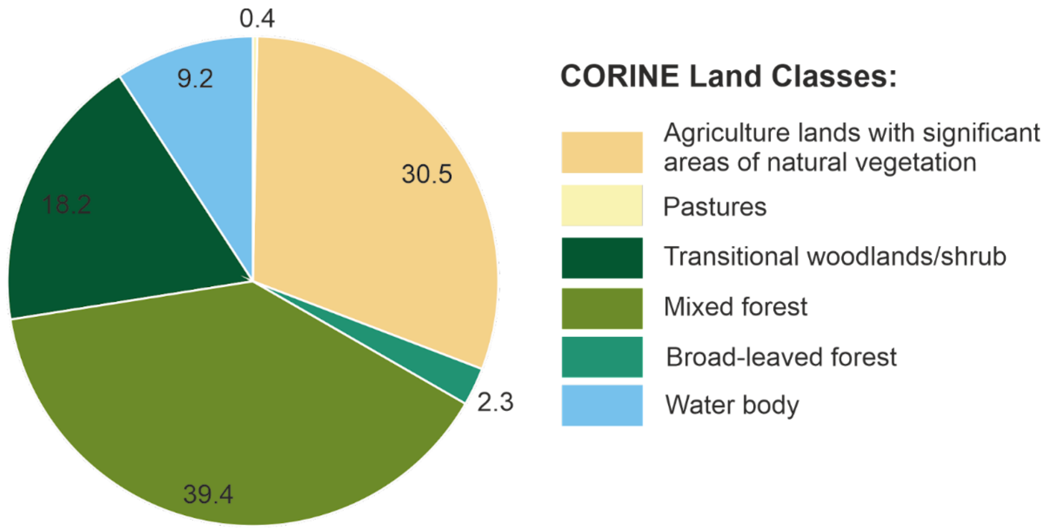

Figure 2.5. Main land use types in the Latvian part of Ilzu (Garais)/Ilge Lake catchment.

According to the collected data, agricultural areas (pastures and non-irrigated arable land), which can significantly affect water quality, makes up less than 20% (only 10%, if not included area of Ilzu (Garais)/Ilge Lake itself) of the catchment area. Agricultural pressure is more intensive in the Lithuanian part of the catchment area.

2.4. Bathymetry

The bathymetry and morphometrics are among the most important lake characterization indicators that provide necessary information on the status of a water body and its development in relation to its place and changes in the hydrological regime. The morphometric parameters of the lake are influenced by the location, origin, natural conditions, other water bodies, and watercourses of the lake catchment area, as well as the anthropogenic impact (Tundisi and Matsumara-Tundisi, 2012). Bathymetric mapping provides results on a waterbody dimension.

Ilzu (Garais)/Ilge Lake has a maximum depth of 3.6 m and an average depth of 2.4 m. In most parts of the lake, the depth is more than 0.5 m. Lake's water volume at water level 97.3 m (a.s.l.) is 2 105 318 m^3.

Using a bathymetric map, it is possible to determine the morphometry of a water body, which can be used to correctly classify a waterbody. The classification of the lakes is needed to understand their potential for use. Ilzu (Garais)/Ilge Lake has a notched and complex shoreline and an elongated form (Fig. 2.6). Water depths are important in several physical and biological processes that occur in the lake. The depth of the lake influences its water quality, and economic exploitation potential (fishing, recreation, shipping, water abstraction for agricultural use, drinking). The bathymetric maps of the lakes reveal that lake morphometric parameters vary according to natural conditions, terrain, and human economic activity (Dumpis, 2020).

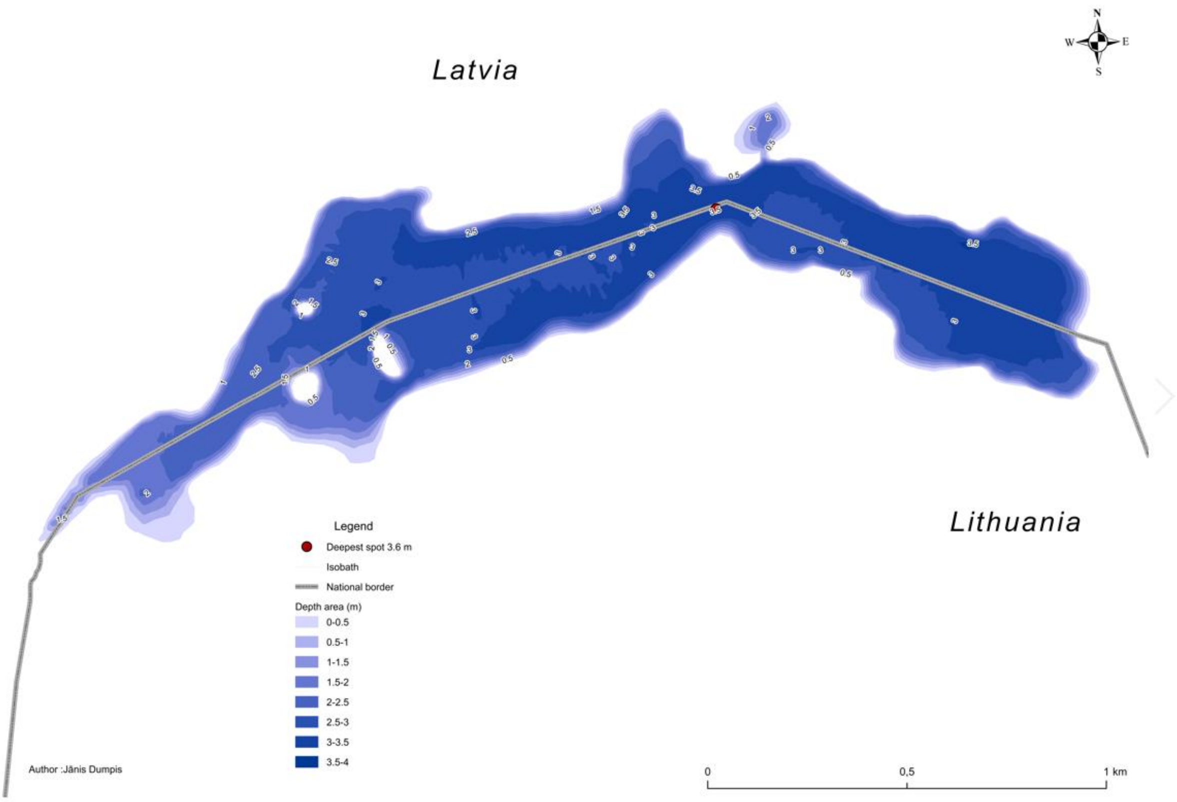

Figure 2.6. Bathymetric map of Ilzu (Garais) / Ilge Lake

III HYDROGEOLOGICAL CONDITIONS OF ILZU (GARAIS)/ILGE LAKE

3.1. Geomorphology, geology and hydrogeology

Geomorphologically, the Ilzu (Garais)/Ilge Lake (hereinafter – the lake) is located in the southern part of the Sēlija moraine hillside of the Augšzeme highland, on the border of Latvia and Lithuania. Sēlija moraine hillside is an interlining hillside, which was formed in the contact zone of the ice mass of two glacier tongues approximately 14’000 years ago (Latvijas daba, 1998). The territory of the catchment area of the lake is characterized by hilly relief, the highest point of which is Kapu Hill (145 m a.s.l.). In the rest of the territory, the altitude ranges from 97 m to 120 m a.s.l., and in only a small part of the territory vary between 120 m and 145 m a.s.l.

The following description of the area is based on geological and hydrogeological mapping at 1:200’000 scale (Meirons u.c., 2002), PUMA and LAMO model data, information on existing wells from the LEGMC database “WELLS”, as well as other available information sources (Prols and Dēliņa, 1997; Dēliņa, 2007; Lithuanian Geological Survey (no date); B - solutions, 2019).

In the catchment area of the Ilzu (Garais)/Ilge Lake and its immediate surroundings, the pre-Quaternary surface, as shown in Figure 3.1, is mainly formed by the terrigenous sediments of the Gauja-Amata stage – sandstones with aleurolite and clay interlayers. In the southwest part of the territory, in a small area on the pre-Quaternary surface, the carbonate sediments of the Pļaviņas stage are also revealed – dolomites with interlayers of marl and dolomite marl.

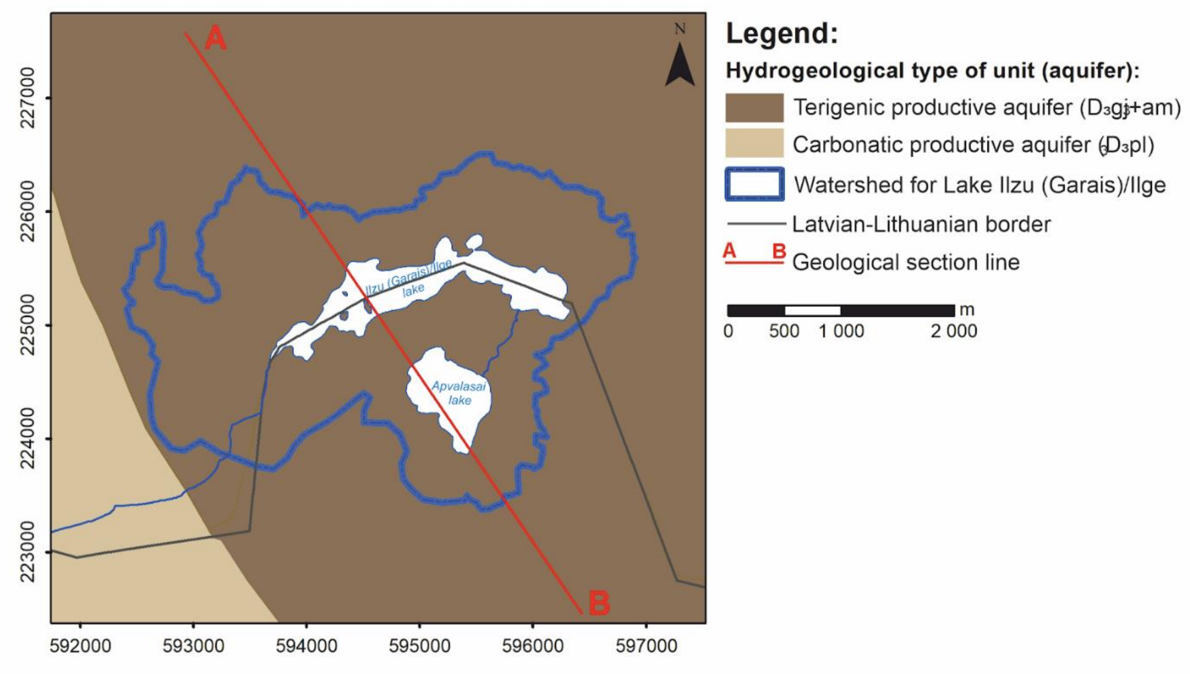

Figure 3.1. Prevalence of pre-Quaternary sediments in the vicinity of the Ilzu (Garais)/Ilge Lake

The Quaternary sediment cover in the area consists mainly of glacial sediments of the last glaciation (gQ_3*ltv*) – moraine sand and loam, as well as fluvioglacial (fQ_3*ltv*) sediments (sand and gravel) found in the largest area of the territory. Outside the catchment area of the lake, limnoglacial (lgQ_3*ltv*) sand sediments and bog peat (bQ_4) sediments, which have formed after the last glaciation in the relief depressions, are also present (Fig. 3.2).

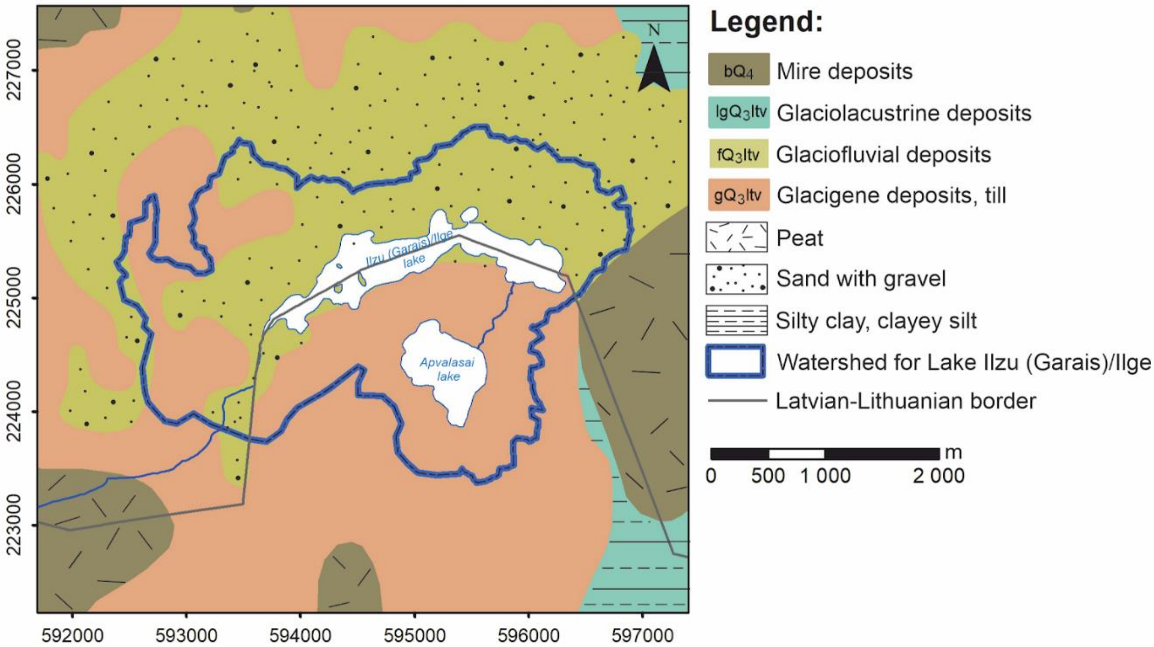

Figure 3.2. Prevalence of Quaternary sediments in the vicinity of the Ilzu (Garais)/Ilge Lake

The catchment area of the Ilzu (Garais)/Ilge Lake and the adjacent area is part of the Baltic Artesian Basin, which contains diverse aquifers of different ages. The aquifers of the pre-Quaternary sediments are separated from each other by both local and regional aquitards – impermeable layers. The main regional aquitards are the Narva regional aquitard and the Silurian-Ordovician aquitard layers. They divide the entire sediment cover into three practically isolated parts: the active, slowed down and stagnant (difficult) water exchange zones. Water overflow between these layers is possible only in small areas through cracks and fractures. Taking into account the hydrogeological conditions of the study area and the depth of the lake, it was considered that only the active water exchange zone with the Narva regional aquitard at the base is relevant within the framework of this study.

The active water exchange zone (up to the Narva regional aquitard) reaches 210 – 250 m in thickness and consists of Quaternary and pre-Quaternary sediments, which form an alternation of aquifers and aquitards (Fig. 3.3).

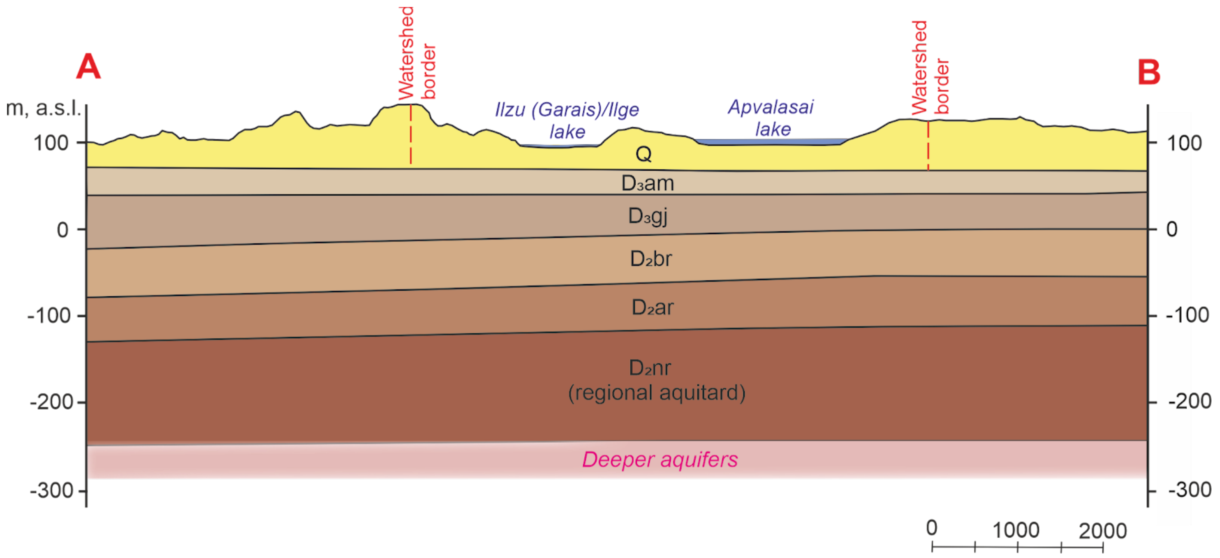

Figure 3.3. Schematic geological section along line A-B

The thickness of **the Quaternary sediments** in and around the catchment area of the lake varies mainly around 30-50 m, but in the southwest part of the area it decreases to 20 m, and in some elevations the thickness increases up to 70-80 m. Shallow groundwaters in the area are sporadic, associated with either sand and sand-gravel sediments above the moraine layer or with sand lenses in the moraine sediments. The thickness of aquiferous sediments usually ranges from 4 m to 10 m, and only some sections can reach a thickness of 20 m. Therefore, their use for water supply is limited and they can mainly be used only by the individual sector (dug wells) with limited resources. Depending on the terrain, the groundwater level can vary in different areas – in depressions it is 0.5-2.0 m below the ground surface, but in some hilly areas it can be as much as 10-20 m below the ground surface. Shallow groundwaters are vulnerable to surface pollution. Compared to confined groundwaters, shallow groundwaters have a lower amount of dissolved salts (mineralization) and hardness, but often has an increased concentration of organic matter and associated water colour.

The replenishment of shallow groundwaters resources is mainly due to the infiltration of atmospheric precipitation. Its intensity depends on the amount of precipitation, surface runoff, the thickness of the aeration zone, sediment filtration properties, as well as other factors. Part of shallow groundwaters infiltrates into the deeper layers, replenishing the resources of the confined aquifers, while part drains into local depressions, river and stream valleys, lakes and drainage ditches. The regional shallow groundwaters flow in the study area is directed to the lake (Fig.3.4).

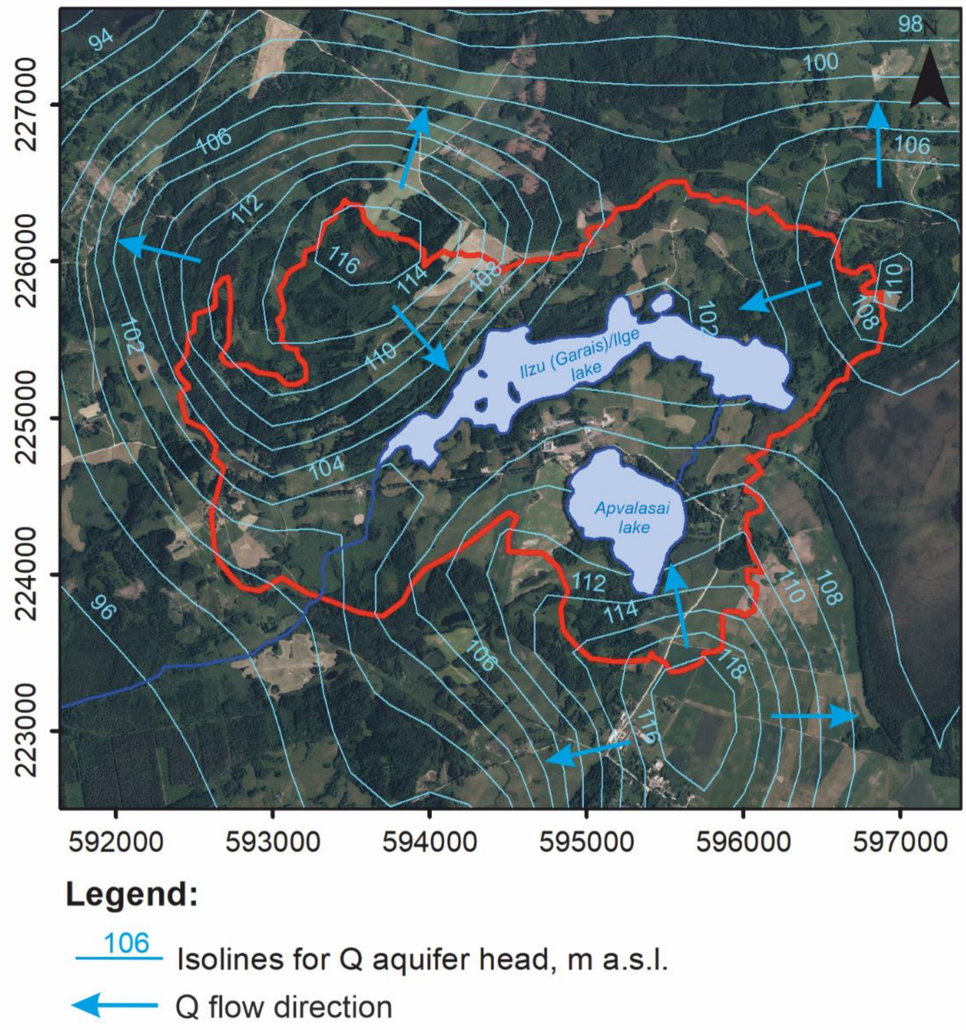

Figure 3.4. Regional shallow groundwater flow at the vicinity of the Ilzu (Garais)/Ilge Lake

In **the pre-Quaternary sediment** section, several aquifers and aquifer systems are distributed in the active water exchange zone: Pļaviņas (D_3*pl*) aquifer and hydraulically connected Arukilas-Amata (D_2*ar*-D_3*am*) aquifer system, which includes Amata (D_3*am*), Gauja (D_3*gj*), Burtnieki (D_2*br*) and Arukila (D_2*ar*) aquifers. The pre-Quaternary Devonian sediments are more saturated with groundwater and, unlike shallow groundwaters, there are fewer seasonal and annual fluctuations in the groundwater levels (the deeper the aquifers, the smaller the amplitude of the fluctuations). The regional flow of groundwater in these sediments is directed to the northwest – to the discharge area in the Gulf of Riga, the flow gradient is around 0.001 (Fig. 3.5).

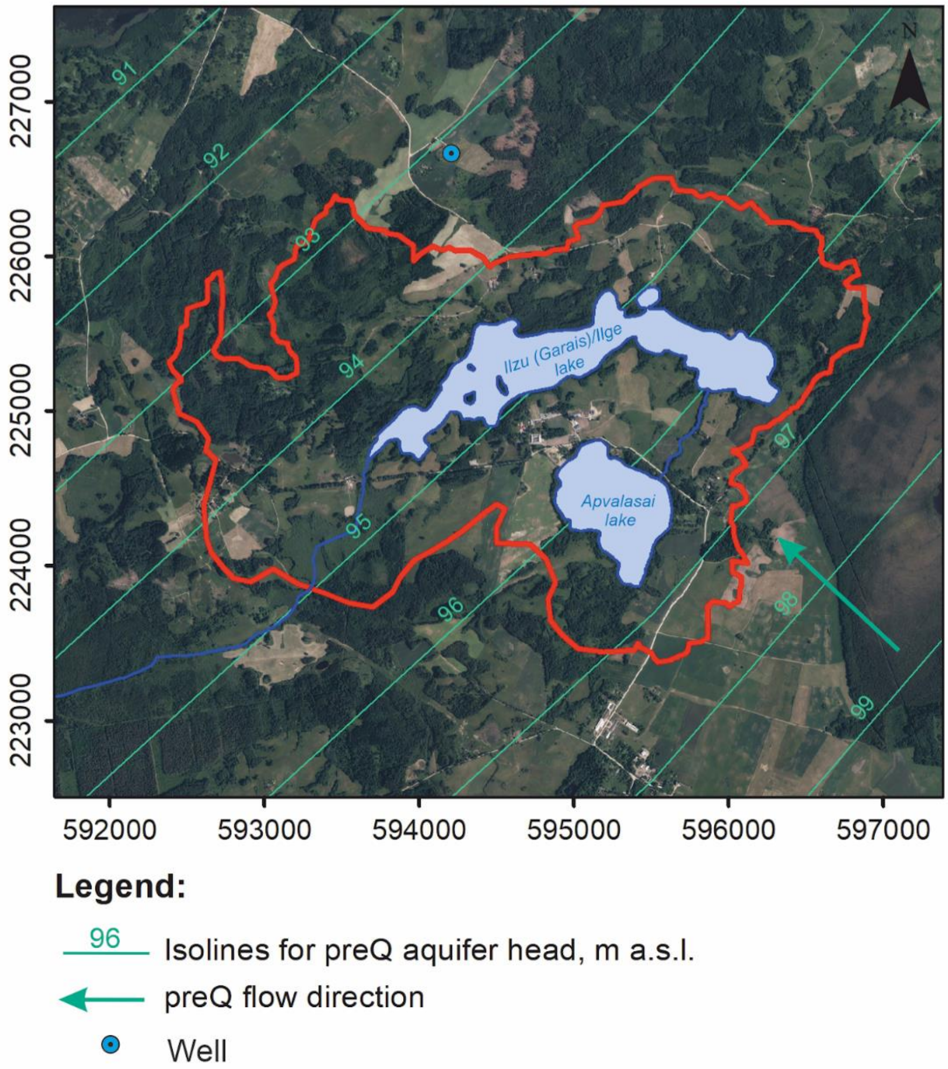

Figure 3.5. Regional confined groundwater flow ate the vicinity of the Ilzu (Garais)/Ilge Lake

The Pļaviņas (D_3*pl*) aquifer is not distributed in the catchment area of the lake and is identified only in the southwest part of the observed area with a small thickness (approx. 2-7 m). The saturation of the aquifer in the area is unknown, but it is likely to be limited due to the small thickness of the aquifer.

The Gauja-Amata (D_3*gj+am*) aquifer is distributed throughout all of the study area, mainly below the Quaternary sediments and only in the southwest part of the territory it is embedded under the Pļaviņas aquifer. The total thickness of this aquifer in the area is about 60-80 m (effective thickness is about 45-50%). The static levels of the Gauja-Amata aquifer vary over a wide range and, depending on the surrounding terrain, may be close to or above the ground surface, and may be at a depth of 10 m to 23 m below the ground surface. The aquifer contains bicarbonate calcium-magnesium type freshwater with mineralization 0.2-0.4 g/L, total iron content is 1-2 mg/L on average. This aquifer is widely used in the area. Well flow rates vary from 1 L/s to 4 L/s, specific flow rates are 0.3-1 L/s/m.

In the lower part of the active water exchange zone, at a depth of about 110-140 m (average about 125 m), **the Arukila-Burtnieki (D_2*ar+br*) aquifer** is formed, which is formed by a 100-110 m thick layer of terrigenous sediments – sandstones, siltstones and clay. In the catchment area of the Ilzu (Garais)/Ilge Lake and its immediate surroundings, the waters of this aquifer are not used due to the significant depth of it. In addition, there is not enough information on the water quality of this aquifer. Regional studies indicate that the mineralization of the Arukila-Burtnieki aquifer increases with its depth and in the lower part of the aquifer it can reach 0.8-1.0 mg/L and even slightly more.

Despite the fact that the catchment area of the Ilzu (Garais)/Ilge Lake include five aquifers, it should be noted that only shallow groundwaters of the Quaternary aquifer has a direct hydraulic connection with the lake and it is the most important aquifer for the assessment of the lake (Fig. 5.1). On the contrary, deeper groundwater of confined aquifers are not hydraulically connected to the lake (Fig.3.5), thus their contribution to the lake water budget is negligible. During periods when the shallow groundwaters levels are elevated as a result of prolonged high infiltration, the lake may replenish from the shallow groundwaters and its water level fluctuations due to external factors (sudden periods of drought) will be smaller. The natural resources of shallow groundwaters are supplemented by precipitation infiltration, the amount of which depends mainly on the depth of the layer and the lithological composition of the aeration zone. The total annual precipitation in the study area exceeds evaporation and infiltration is seasonal (it is cyclical in nature and may vary from year to year, and there may be longer periods of change). On average, 15-20% of precipitation can infiltrate in shallow groundwaters.

It should be noted that no official wells or boreholes using the Quaternary aquifer (shallow groundwaters) have been registered in the area. Outside the catchment area of the lake, approximately 1.1 km from it, there is one groundwater supply well, installed in the Gauja aquifer and which possibly is used with a small abstraction rate (up to 10 m^3/d). There is no official information on the amount of water abstracted from this well.

3.2. Estimation of groundwater contribution to lakes water balance

A rough estimation of groundwater contribution to the lake balance can be performed by long term reanalysis datasets. One of the state of the art dataset of global reanalysis timeseries is ERA5-Land that is created by European Centre for Medium-Range Weather Forecasts or ECMWF (https://www.ecmwf.int/) and provided by Copernicus Climate Data Store (https://cds.climate.copernicus.eu/). This dataset has a relatively high resolution compared to former reanalysis datasets with a resolution of 0.1° in regular latitude/longitude grid, that translates to ~9 km in projected grid. The data are available either in hourly or monthly time steps. The focus of this dataset is to provide not only meteorological variables, but also land surface-related variables, including hydrological. The ERA5-Land dataset includes such important hydrological parameters as total precipitation, runoff (including surface runoff and sub-surface runoff), evaporation, temperature, and others. It must be noted that values of the dataset represent average values for grid cells.

While the grid size of the ERA5-Land is relatively small, it is still large compared to the Ilzu (Garais)/Ilge Lake watershed (Fig. 3.6). As a result, a single cell was selected for the analysis of Ilzu (Garais)/Ilge Lake hydrology with coordinates of 56.2 North and 25.5 East. The watershed, however, lies on the south-eastern corner of the cell, while the cell represents average values across the whole cell. As a result, some degree of inconsistency might be present in the analysis, while the general trends and overall values are usable for estimation needs.

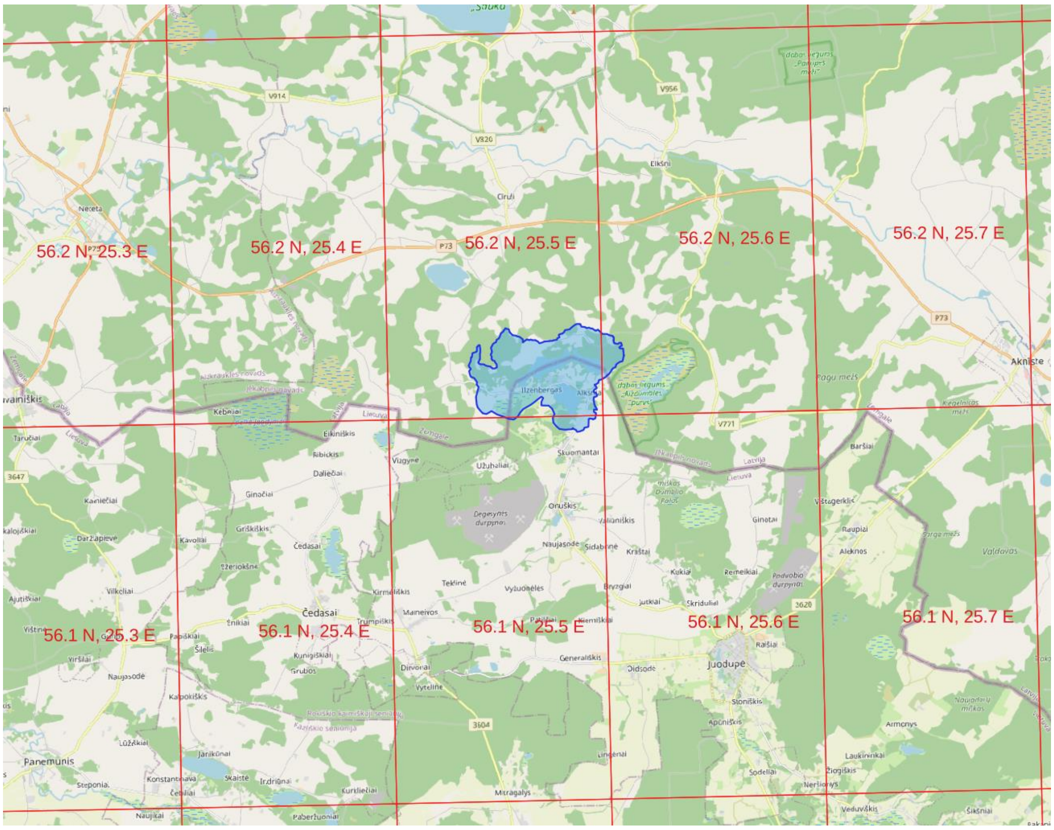

Figure 3.6. ERA5-Land grid with coordinates (WGS84) near Ilzu (Garais)/Ilge Lake (blue polygon – Ilzu (Garais)/Ilge Lake watershed).

The selected time period for the analysis spans from January 1981 up to December 2018 having 37 full years in total. This period covers both dry years as well as wet years with the year 2018 being an exceptionally dry year in the Baltic region. The overview yearly values of total precipitation, total evaporation and sub-surface runoff for the selected time period is presented in Figure 3.7. Distinct years can be identified, such as years 1996, 2003 and 2006 which are characterized by very low sub-surface runoffs, while the year 2018 is characterized as very dry year also in the vicinity of Ilzu (Garais)/Ilge Lake.

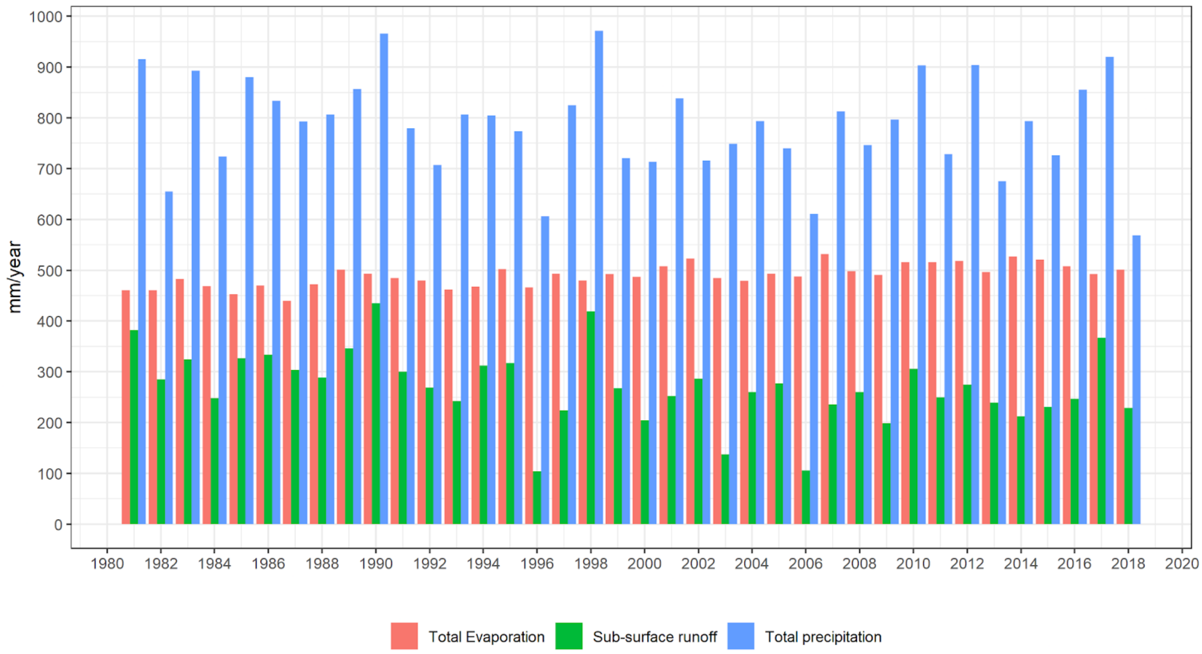

Figure 3.7. Yearly values of three selected hydrological variables from the EAR5-Land dataset for a period of years 1981-2018

The long-term average precipitation for the Ilzu (Garais)/Ilge Lake vicinity according to the ERA5-Land dataset is 787.1 mm/year, while total evaporation accounts for 489.5 mm/year. Sub-surface runoff greatly exceeds surface runoff, having a long-term average rate of 271 mm/year as opposed to surface runoff of 39.8 mm/year. These results indicate that in the vicinity of Ilzu (Garais)/Ilge Lake approximately 34.4 % of total precipitation infiltrates the ground contributing to the shallow groundwater resources. As identified in the chapter 3.1, there is almost no hydraulic connection with deeper located confined aquifers (D_3*gj+am*), therefore it is presumed that the only groundwater input is shallow groundwater recharged within the watershed area. Considering the total area of the watershed (8.72 km^3) and average sub-surface runoff or shallow groundwater recharge rate (271 mm/year), the average groundwater contribution to the Ilzu (Garais)/Ilge Lake watershed is 2’363’675 m^3/year according to the ERA5-Land dataset.

IV QUALITY OF ILZU (GARAIS)/ILGE LAKE ECOSYSTEM

Lakes receive nutrient (nitrogen and phosphorus compounds) and other pollutant loads from catchment via river inflow, surface runoff and groundwater inflow. Due to their long renewal time lakes are sensitive to increased nutrient loads. High nutrient loads are causing eutrophication process and are a significant driver for increase of primary productivity, e.g., biomass of algae and higher vegetation and an indirect driver for changes in community composition in lakes (Carvalho et al., 2006). The impact of nutrient loads in a particular lake or lake type can be dependent on a number of 'sensitivity' factors such as water colour, water exchange time, hydromorphological modifications, lake morphometry, climate etc. In general, deep lakes are more tolerant to eutrophication and its effects are more predictable. In shallow lakes, ecological thresholds in response to changes in nutrient loads are much more difficult to predict due to the feedback effects of macrophytes and fish on lake community structure (Fig. 4.1; Carvalho et al., 2006; Scheffer & Nes, 2007).

Phytoplankton is considered to be the first ecosystem component responding to changing nutrient loads. Species composition, abundance, biomass, concentration of *chl-a* as well as phytoplankton bloom frequency and intensity are used as indicators of eutrophication process. Phytoplankton blooms are usually dominated by potentially toxic cyanobacteria. Increased phytoplankton growth leads to increased water turbidity and reduced light availability for growth of macrophytes (Carvalho et al., 2006).

In Ilzu (Garais)/Ilge Lake, the predominant phytoplankton groups in May 2021 samples were Bacillariophyta which formed 59% of sample biomass, Chrysophyta (24%) and Chlorophyta (11%). The predominant phytoplankton groups in August 2021 samples were Bacillariophyta (68%), Cyanophyta (22%) and Chrysophyta (7%). According to monitoring results at monitoring station "Garais ezers (Rites pag.), middle part", phytoplankton blooms were not observed and Cyanophyta formed ~22% of total biomass in the August sample. *Chl-a* concentrations varied from 11.9 μg/L in May to 35 μg/L in August. *Chl-a* concentrations indicate moderate to poor ecological status.

Macrophyte species composition in the Ilzu (Garais)/Ilge Lake characterizes a typical turbid lake. The taxonomic richness is low (18 species) where emergent species dominate (61%). Dominating species are *Phragmites australis, Equisetum fluviatile* and *Typha latifolia.* Floating-leaved species *Nuphar lutea* and *Potamogeton natans* also occurred frequently. High turbidity reduces development of submerged macrophytes in the lake and therefore their species diversity is low (3 species) and stands are very sparse. The colonization depth of submerged macrophytes is 1.5 m.

In lakes with high macrophyte species diversity (Fig. 4.2.) vegetation absorbs nutrients and reduces turbidity. And reversely, water transparency is a key physico-chemical factor controlling the distribution and abundance of submerged macrophytes in lakes.

The greatest total **zooplankton** abundance in Ilzu (Garais)/Ilge Lake was observed in May, both in the surface layer (1560 ind/L) and throughout the water column (626 ind/L). It gradually decreased in August (surface 516 ind/L, column 383 ind/L) and was even lower in October (surface 132 ind/L, column 279 ind/L).

Rotifers were dominant only in spring while later in August and October cladocerans and copepods were more abundant. All together 10 rotifer and 31 small crustacean species were found both in zooplankton and littoral zone. Of those in zooplankton samples there were 10 rotifer and 18 small crustaceans species (12 Cladocera and 6 Copepoda). The dominant and most frequent species among zooplankton were *Daphnia cucullata* (common in Latvia, known from eutrophic lakes and ponds with high fish predation pressure, planktonic species), *Bosmina (Eubosmina) coregoni thersites* (known from this region of Latvia before, characteristics for mesotrophic-eutrophic lakes), *Chydorus sphaericus* (very common, widely distributed and highly adaptive species from different kind and trophy gradient water bodies), *Eudiaptomus graciloides* (common, widely distributed species), *Mesocyclops leuckarti* (common, inhabiting large variety of water bodies) and *Thermocyclops oithonoides* (widely distributed species which abundance increases with the trophy increase). In the littoral part dominant was *Ceriodaphnia pulchella* and *Eucyclops macrurus* (both are widely distributed). As to rotifers *Keratella cochlearis, K. quadrata*, *Polyarthra* sp. and *Kellicottia* sp. were among most abundant species in the plankton and are known as widely distributed and common species (Bledzki and Rybak, 2016). Moreover, three first species apart from Kellicottia sp. are known to show positive correlation with total phosphorus (Ceirans, 2007). Cyclopoida nauplii were more present in the upper water layer and less common throughout the water column. Of large species *Cyclops vicinus* and *Leptodora kindti* were found, both in the upper water layer and in the water column. As suggested by Zettler and Carter (1986), reduced transparency in turbid waters may favour large zooplankton species protecting from fish predators seeking visually.

Benthic invertebrates are an important group to maintain the ecological functioning of an ecosystem. In general, the diversity of macroinvertebrates indicates the well-being of an ecosystem. Dissolved oxygen is the main factor affecting the distribution of benthic invertebrates in different depths. Lakes at turbid state might have oxygen deficiency limiting the composition and distribution of the macroinvertebrates (Carvalho et al. 2006). The macroinvertebrate community composition of the Lake Ilzu (Garais)/Ilge are characteristic for a eutrophic lake. In total, 51 benthic invertebrate taxa were found in Ilzu (Garais)/Ilge Lake. The most diverse taxa were Gastropoda (snails) with 13 species. The littoral communities are dominated by chironomids. Also, saprophytophagous species *Asellus aquaticus* is common at the littoral zone. The pollution tolerant group Oligochaeta was not abundant at the sampling stations since it dominates the profundal zone. The sensitive taxa EPT (Ephemeroptera, Plecoptera, Trichoptera) were presented by a few species. From aquatic Insecta the most diverse groups were Trichoptera (caddisflies) and Odonata (dragonflies); Hirudinea (leeches) were represented by 5 species.

The most common functional feeding groups at all three sampling sites were: i) grazers and scrapers; ii) gatherers/collectors; iii) predators and active filter feeders.

Higher species diversity was found at sampling site No 3, and LLMMI (Latvian Lake Macroinvertebrate Multimetric Index (Skuja, Ozoliņš, 2017)) showed good ecological quality at that site, whereas at sampling sites No 1 and No 2 species diversity was lower and ecological quality corresponded to moderate class. According to spring season data, the lake could be assessed as being in moderate ecological state.

Fish species. Typically, in a lake, which is not directly affected by large rivers, which significantly (up to 2 times) increases the number of fish species, 12 species are common: belica *Leucaspius delineatus*, bleak *Alburnus alburnus*, bream *Abramis brama*, crucian carp *Carassius carassius*, perch *Perca fluviatilis*, pike *Esox lucius*, roach *Rutilus rutilus*, rudd *Scardinius erythrophthalmus*, ruffe *Gymnocephalus cernua*, spined loach *Cobitis taenia*, tench *Tinca tinca* and white bream *Blicca bjoerkna*. Water clarity (degree of eutrophication) in Latvian conditions does not affect the occurrence of these species. The number of species decreases with increasing water browning/acidity. Fewer species are common also in closed and shallow lakes.

The Ilzu (Garais)/Ilge Lake can be considered as an atypical lake, because neither we nor Lithuanians caught the beak (white bream). It may be present, but the population is too small for us to catch it.

Table 4.1. Ilzu (Garais)/Ilge Lake quality according to the fish indices*.

Metric	***Wpue (kg)***	***Bream/RoachW%***	***PerchW%***	***RoachWavg (g)***
Value	2.1	84	15	78
EQR	0.63	0.12	0.25	0.31

*Institute BIOR data

EQR calculated using a combination of all four metrics is 0.35. That means lake has a poor/bad ecological status based on Latvian Lake Fish Index. Secchi depth (26.08.2021) was also low – 0.9 m indicating poor quality.

Formally, eutrophication should be accompanied by an increase in fish biomass (should be characterized by catches in the net Wpue), an increase in the proportion of bream/roach (Bream/RoachW%) and a decrease in the proportion of perch (PerchW%). The average weight of roaches (RoachWavg) could also decrease. However, the catches of nets as passive fishing gear can vary significantly from fishing act to fishing act. In addition to the different activity of fish species, other factors also affect the results. For example, Wpue in turbid water is usually higher than in clear water therefore the fish have poorer visibility of the net. Lighter and darker lighting has a similar effect (sun or clouds, as well as date, how far from the longest day of the year). In a shallow lake, where the net occupies the entire layer of water, it is harder for fish to avoid it than in deeper lake.

In the lake in turbid state, fish promote phytoplankton growth by recycling nutrients, stirring-up sediments as well as by controlling the development of zooplankton that could otherwise help clear the water of phytoplankton. Wind activity also can disturb upper sediment layers in shallow lakes with little or no vegetation. In this situation, light limitation and disturbance of the sediments make it difficult for submerged plants to settle. In lakes where submerged plants are abundant, they can greatly reduce turbidity by a suit of mechanisms resulting in control of excessive phytoplankton development and prevention of wave resuspension of sediments (Scheffer & Nes, 2007).

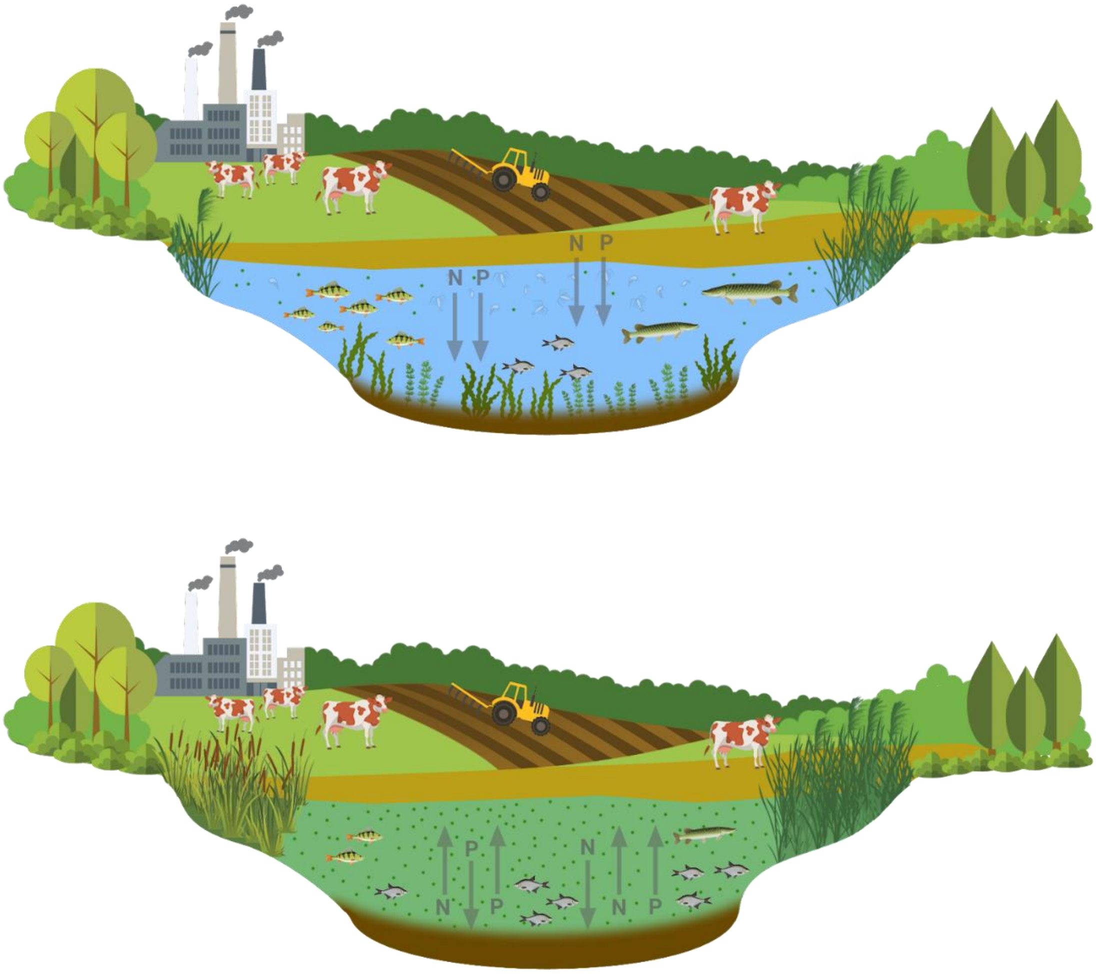

Figure 4.1. Possible alternative stable states of shallow lakes. Upper panel shows a lake in a clear water stage, and the lower panel shows a lake in a turbid state.

Lake Ilzu (Garais)/Ilge is a shallow, oligohumic lake with a high water hardness (lake type L5 according to the Latvian lake typology). Observations during the field campaigns suggest that Ilzu (Garais)/Ilge Lake is a hypereutrophic lake in a turbid state (Fig.4.3.). In contrast, the shallow part of Lielais Kumpinišķu Lake represents a shallow, eutrophic lake in a clear-water stage (Fig. 4.2.).

In 2021, total nitrogen concentration in Ilzu (Garais)/Ilge Lake varied from 0.61 mg/L to 3.1 mg/L, being lowest in summer and highest in winter. Total phosphorus content was in range 0.019 – 0.063 mg/L. Secchi depth from July until October was below 1 m.

Figure 4.2. Shallow lake in clearwater stage (L. Lielais Kumpinišķu; photo: I.Kokorīte).

Figure 4.3. Shallow lake in turbid water stage (L.Ilzu (Garais)/Ilge; photo:L.Grīnberga).

V CONCEPTUAL MODEL FOR ILZU (GARAIS)/ILGE LAKE

Based on the gathered information, a conceptual model was developed for Lake Ilzu (Garais)/Ilge, which helps to assess the connection of groundwater with the surface water body – the lake, – and assess the impact of groundwater on the ecological status of the lake. However, given that no hydrogeological research has been carried out in the area within this project, and existing materials (mainly regional-level data) were used as a basis for the conceptual model (Figs. 5.1. and 5.2.), it should be noted that the current conceptual model provides initial understanding of the situation.

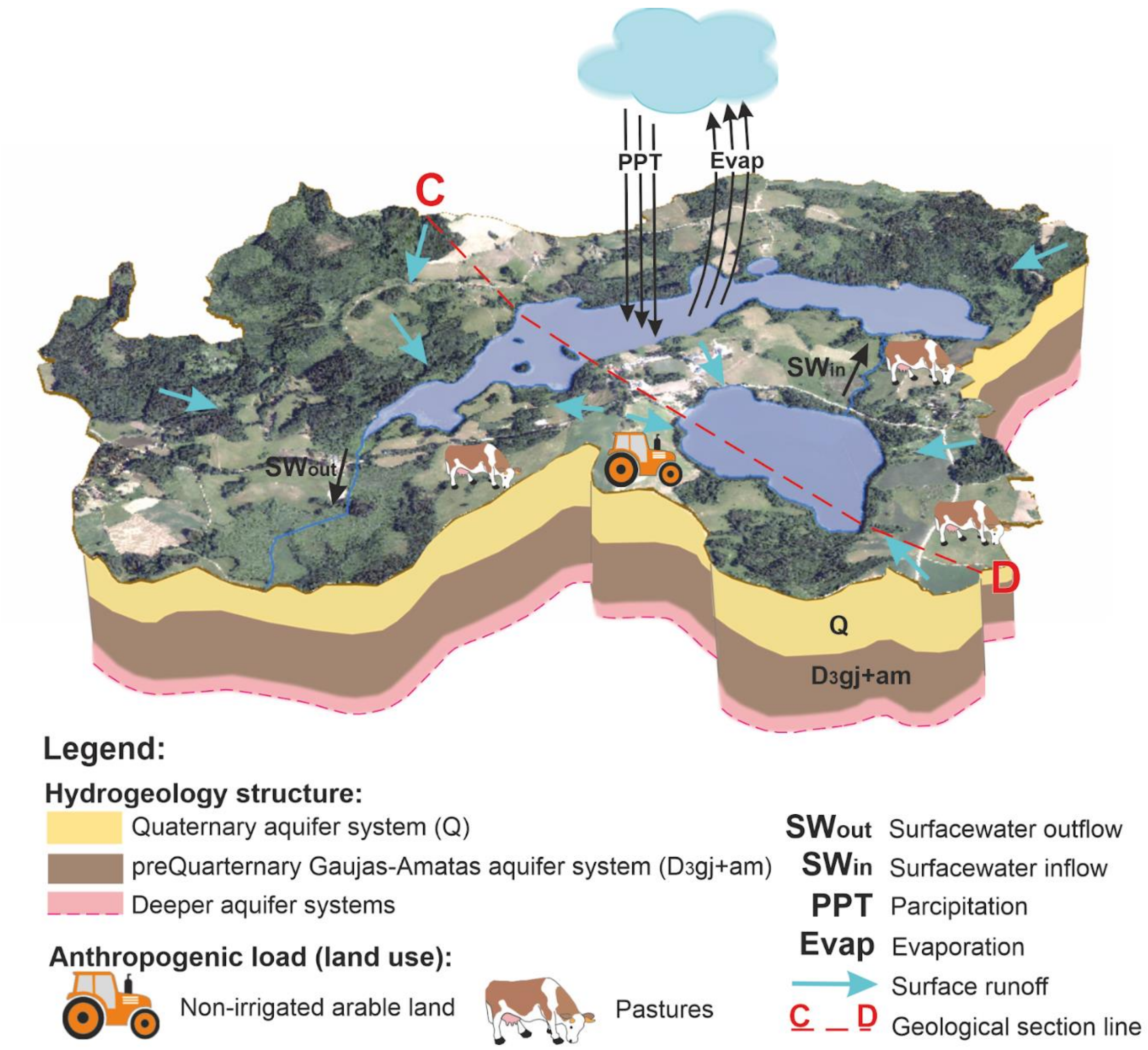

Figure 5.1. Conceptual model for Ilzu (Garais)/Ilge lake

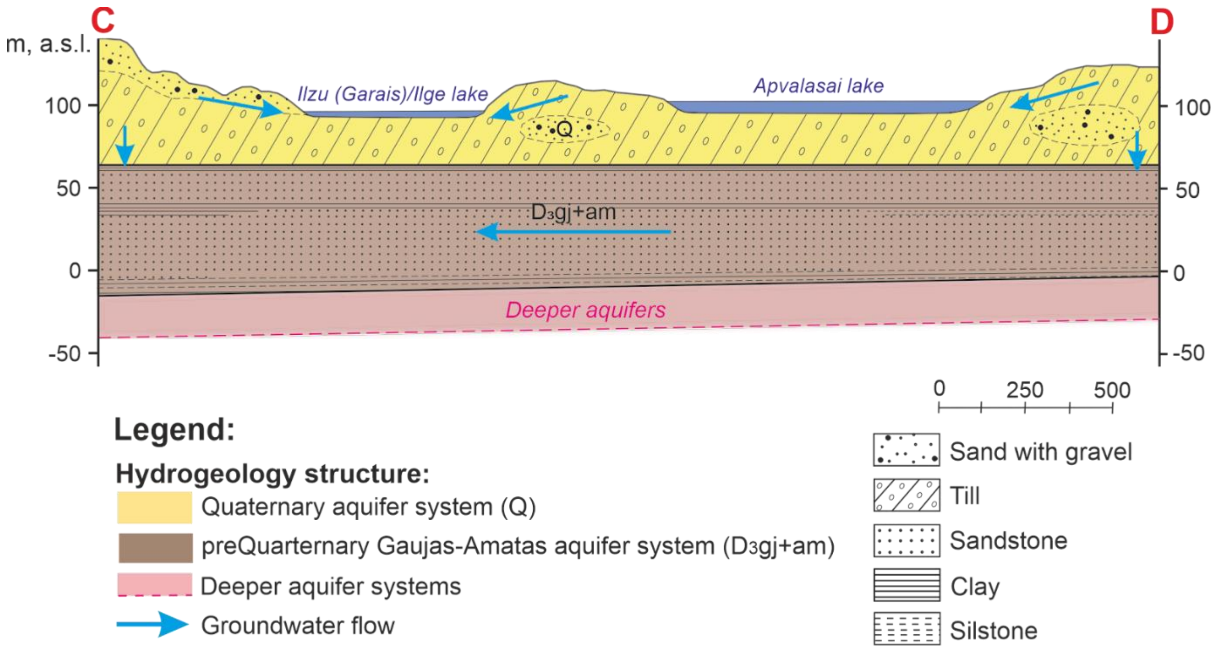

Figure 5.2. Schematic geological section along line C-D

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