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Methodology to create a unified hydrogeological map

December 2021

The project No.2018-1-0137 “EU-WATERRES: EU-integrated management system of cross-border groundwater resources and anthropogenic hazards” benefits from a € 2.447.761 grant from Iceland, Liechtenstein and Norway through the EEA and Norway Grants Fund for Regional Cooperation. The aim of the project is to promote coordinated management and integrated protection of transboundary groundwater by creating a geoinformation platform.

Technical information	
Document code:	WP4 - Reinforcement of the integrated use of data
Title of document:	Methodology to create a unified hydrogeological map
Reference activity:	Output 3. Methodology to create a unified hydrogeological map
Dissemination level:	Public
Version	1
Date	31.12.2021
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Document summary

The aim of the document is to create a unified terminology and instructions for the digital preparation of a unified hydrogeological map. A hydrogeological map legend to be used for transboundary groundwater mapping is presented. The hydrogeological map, developed in accordance with this instruction, should be used by institutions carrying out tasks related to the management and protection of water resources.

The report has been developed by seven project partners: Polish Geological Institute - National Research Institute, Latvian Environment, Geology and Meteorology Centre, University of Latvia, State Enterprise "Ukrainian Geological Company", Geological Survey of Estonia, Norwegian Water Resources and Energy Directorate and DC of NJSC "NADRA UKRAJYNY" "Zahidukrgeologiya". The project No.2018-1-0137 “EU-WATERRES: EU-integrated management system of cross-border groundwater resources and anthropogenic hazards” benefits from a € 2.447.761 grant from Iceland, Liechtenstein and Norway through the EEA and Norway Grants Fund for Regional Cooperation.
Scientific work published as part of an international project co-financed by the program of the Minister of Science and Higher Education entitled "PMW" in the years 2020-2023; agreement No. 5152 / RF-COOPERATION / 2020/2.

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Introduction

An integrated approach of hydrogeological mapping and a unified terminology is needed to improve the quality of international communication in the field of hydrogeology. EU-WATERRES project focuses on creating a common internet platform for the exchange of knowledge and data as well as GIS tools for modelling and creating digital hydrogeological maps. The resulting tools are dedicated for simulating the quality and quantity of transboundary groundwater.

The purpose of this report is to create a unified terminology and instructions for the digital preparation of a unified hydrogeological map. To fulfil the aim, the project partners from both pilot areas (Estonia-Latvia and Poland-Ukraine) evaluated their databases and existing hydrogeological maps and compared them to develop a unified legend and terminology for creating hydrogeological maps on transboundary areas.

This report presents a hydrogeological map legend to be used for transboundary groundwater mapping. The list of objects gives an overview of the parameters presented on the hydrogeological maps created within the framework of the EU-WATERRES project: hydrogeological parameters map, map of groundwater exploitation, and map of groundwater vulnerability and quality. The definition of all parameters is given along with the attributes of the objects mapped within the parameter. The attributes are given classifiers according to the conditions in the two pilot areas.

A cartographic presentation for the object in the unified hydrogeological map is given based on international guides. INSPIRE Data Specification and IAH-s guide on hydrogeological mapping are mostly used.

The hydrogeological map, developed in accordance with this instruction, should be used by institutions carrying out tasks related to the management and protection of water resources. The amount of information presented on the thematic and synthetic maps will interest investors, investment designers and insurers.

Glossary

Aquifer – (water bearing horizon) - a hydraulically continuous body of relatively permeable unconsolidated porous sediments or porous or fissured rocks containing groundwater. It is capable of yielding exploitable quantities of groundwater (IGRAC, n.d.);

Aquitard – groundwater-filled body of poorly permeable formations, through which still significant volumes of groundwater may move, although at low flow rates (IGRAC, n.d.);

Aquiclude – groundwater-filled bodies of poorly permeable formations, through which no or almost no flow of groundwater passes (IGRAC, n.d.);

Area of depression cone – zone of lowering the piezometric surface (groundwater table) caused by pumping or drainage of aquifers by intakes, mines, etc;

Artesian aquifer – An aquifer containing water between two relatively impermeable boundaries. The water level in a well tapping a confined aquifer stands above the top of the confined aquifer and can be higher or lower than the water table that may be present in the material above. The water level rises above the ground surface, yielding a flowing well (INSPIRE, 2014);

Available Groundwater Resources (AGR) – the multiannual average amount of the total supply of a defined groundwater body, reduced by the multiannual average amount of the flow required to achieve the ecological quality objectives set for surface waters, so as not to allow a significant deterioration of the ecological status of such waters and to avoid any significant damage to associated terrestrial ecosystems (Zasady, 2005);

Buried valleys – areas, where bedrock valleys are filled with younger sediments. Valleys are not necessarily appearing in topography. In the hydrogeological map, buried valleys are shown with a polygon layer showing valleys filled with various sediments;

Confined aquifer – fully saturated aquifer (i.e. pressure everywhere greater than atmospheric pressure) directly overlain by an impermeable or almost impermeable formation (confining bed). The confining bed prevents the aquifer from interacting directly with the atmosphere and with surface water bodies (except for surface water bodies that intersect the aquifer) (IGRAC, n.d.);

First Water Bearing Horizon (FWBH) – the first aquifer or group of aquifers from the surface having good hydraulic contact with each other (Instructions, 2004);

Groundwater body – distinct volume of groundwater within an aquifer or aquifers (INSPIRE, 2014);

Groundwater damming device – hydrotechnical device (dams, weirs, sills, gates - on rivers / streams) or other devices causing flow inhibition and damming of groundwater, i.e. raising of the groundwater table level;

Groundwater head – elevation to which groundwater will or does rise in a piezometer connected to a point in the groundwater domain. It is a time-dependent variable, varies from point to point within the groundwater domain, and indicates the potential energy of groundwater in any point considered (in meters of water column relative to a selected topographic reference level) (IGRAC, n.d.);

Groundwater intake – water supply well/group of wells, licenced water abstraction site;

Groundwater mineralization – the amount of total dissolved solids in groundwater (mg/l);

Groundwater monitoring points – bored or dug well or spring, which belongs to the national groundwater monitoring network, for monitoring groundwater chemistry and/or groundwater level;

Groundwater pollution site – artificial accumulation of pollutants (actual or potential) in groundwater. Pollution hotspots can be of various spatial nature: spot (drilling, petrol stations, warehouses), linear or strip (roads, pipelines), surface (landfills, sedimentation tanks, drainage and irrigation fields) and area (fertilization and chemicalisation of agriculture);

Groundwater Reservoir (GR) – complex of permeable aquifers of utility importance, the boundaries of which are determined by hydrogeological parameters or hydrodynamic conditions and the conditions of formation of groundwater resources (Dowgiałło et al. 2002);

Groundwater table – surface defined by the phreatic levels in an aquifer (i.e. surface of atmospheric pressure within an unconfined aquifer) (IGRAC, n.d.);

Groundwater vulnerability – Groundwater vulnerability is the potential of an aquifer to suffer loss or damage, and it is based on the concept that the natural environment provides protection to groundwater. The protection provided by different (hydro)geological conditions varies from one place to another. In the hydrogeological map, groundwater vulnerability is shown in polygon layer with different groundwater protection classes;

Hydrogeological unit – a part of the lithosphere with distinctive parameters for water storage and conduction (INSPIRE, 2014);

Hydroisohypses of the groundwater head – isolines for the equal level of groundwater head. In the hydrogeological map, the isolines for the equal level of the groundwater head in the main useful aquifer are shown;

Main Useful Aquifer (MUA) – the first usable aquifer or usable level from the ground surface, constituting the main source of supply with a predominant range and abundance in the area of a separate hydrogeological unit (Instructions, 2004);

Spring – a water body formed when the side of a hill, a valley bottom or other excavation intersects a flowing body of groundwater at or below the local water table, below which the subsurface material is saturated with water;

Subsurface Waters (SW) – waters of the aeration zone occurring above the groundwater table, also known as suspended waters: bound waters, capillary waters (some of them are soil waters), as well as free gravitational waters moving/flowing through the aeration zone to the groundwater table, to reach the free groundwater. The near-surface waters also include suspended groundwater levels and very shallow groundwater (low-thickness aeration zone) (Instructions, 2004);

Transboundary aquifer – an aquifer that spans two or more political entities, separated by political boundaries (IGRAC, n.d.);

Transboundary groundwater flow – groundwater flow over two or more political entities, separated by political boundaries;

Transmissivity – the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths;

Unconfined aquifer – an aquifer containing water that is not under pressure. The water level in a well is the same as the water table outside the well (INSPIRE, 2014);

Useful aquifer – a layer or set of aquifers showing good hydraulic contact, with the parameters of the quantity and quality of water qualifying for municipal use: thickness of aquifers over 5 m, water conductivity over 50 m2/24 hours, potential well over 5 m3/hour (Instructions, 2004);

Well – a bored, drilled, or driven shaft, or a dug hole whose depth is greater than the largest surface dimension.

1 Overview and analysis of international hydrogeological maps

1.1 International Hydrogeological Map of Europe in scale 1:1,500,000

International Hydrogeological Map of Europe, scale 1:1,500,000 (IHME1500), is a series of hydrogeological maps comprising 30 map sheets covering nearly whole Europe and parts of the Near East. National experts have compiled hydrogeological information delivered on a national level under the auspices of the International Association of Hydrogeologists (IAH) within the project supported by the Commission for the Geological Map of the World (CGWM). The scientific editorial work has been performed by the Federal Institute for Geosciences and Natural Resources (BGR) in cooperation with the United Nations Educational, Scientific and Cultural Organisation (UNESCO) (BGR - Projects - IHME1500 - International Hydrogeological Map of Europe 1:1,500,000 (bund.de)).

The idea of the international hydrogeology map of Europe was born in 1960 during the XXI International Geological Congress in Copenhagen. At that time, the IAH was assigned for the project of small scale European Hydrogeological Map, and with the support of UNESCO, an International Legend for Hydrogeological Maps was created. Based on this work, the first IHME was composed in 1970, and in 1974 the General Legend for the International Hydrogeological Map of Europe was developed.

The IHME1500 was based on the International Geological Map of Europe 1:1.500.000 (IGK1500). It used the same scale, topography and projection, and this is also where the lineation and attributes of aquifers partly derive from.

The aim of the development of IHME1500 was to create a tool that might be used not only for scientific purposes but also for large-scale planning as well as the basis for more detailed hydrogeological mapping. The IHME1500 does not contain the political division into countries or smaller administrative units and is focused on the hydrogeological setting of the continent.

The initial ambition of the experts responsible for the development of IHME1500 was to provide the quantitative data, e.g. specific capacity, well yield, conductivity and groundwater recharge. Due to the significant heterogeneity of data, this aim could not be reached. Nonetheless, selected topics have been presented on a regional scale. Their availability depends on their significance for the hydrogeological descriptions. Thus, the IHME1500 map sheets show the general hydrogeological information like lithology of the aquifer, type of aquifer (e.g. highly productive porous aquifer or low and moderately productive fissured aquifers), seawater intrusion, fractures (e.g. fault, overthrust, boundary of fractured belt with hydrogeological importance). Additionally, within the frames of 18 sheets, supplementary information, e.g. on the chemical composition of groundwater, climate, or geological features, have been published in the explanatory notes.

In 2008 a draft of the International Hydrogeological Map of Europe was printed as a Special Mosaic Map on the occasion of the International Year of Planet Earth (IYPE) and International Geological Congress in Oslo. This mosaic map was reduced to a scale of 1:5 000 000 and printed on only one sheet. It contained the simplified General Legend and showed the hydrogeological conditions of the geological units at and below the land surface. Although the significant reduction in the scale doesn’t allow to get to know the rich hydrogeological related information directly from the mosaic, this special edition of the IHME1500 shows the general hydrogeological conditions across the whole European continent (BGR - Projects - IHME1500 - International Hydrogeological Map of Europe 1:1,500,000 (bund.de)).

In 2013 the IHME1500 map sheets were completed and published. Additionally, with the help of Geographic Information System (GIS), some information from IHME1500 have been digitized and are available as spatial datasets in the shapefile format. The vector datasets are versioned, and their current version is "IHME1500 v1.2". The future updates of map content and addition of attributes will only concern the vector datasets (BGR - Projects - IHME1500 - International Hydrogeological Map of Europe 1:1,500,000 (bund.de)).

1.2 Groundwater Resources of the World

It is estimated that around 1.1 billion of the world's population do not have access to water, and over 2.7 billion experience water shortage for at least one month a year. The issue of the lack of water resources affects not only people but also ecosystems dependent on groundwater, which disappear from the surface of the planet very quickly. Agriculture is a branch of the economy that needs access to significant water resources. At the same time, it is a sector in which water losses due to ineffective irrigation systems and ill-considered use of resources are significant. The dramatic situation in the field of irreversible disappearing groundwater resources is influenced by climate change, causing droughts in some areas and floods in others.

The problem of the availability of groundwater resources is an important issue that requires an integrated approach, especially in cross-border areas where possible shortages may cause international conflicts. Decade after decade, this scenario is becoming more and more likely due to climate change, which makes groundwater resources irreversibly disappear in some parts of the world, and demand continues to increase due to the growing population.

The starting point for an integrated approach to the management of existing groundwater resources is the analysis of their availability. In other words, to know how much water we can safely use for economic and social purposes, we need to know how much water we have and how quickly the resources that we have exhausted will be recharged. The first step in this analysis is access to reliable data. For this reason, the World-wide Hydrogeological Mapping and Assessment Program (WHYMAP) was initiated in 1999. This is a joint program of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Commission for the Geological Map of the World (CGMW), the International Association of Hydrogeologists (IAH), the International Atomic Energy Agency (IAEA) and the German Federal Institute for Geosciences and Natural Resources (BGR). The main goal and ambition of the program is to exchange and provide accessible hydrogeological information to a wide audience (BGR - WHYMAP - Groundwater Resources of the World).

More detailed goals of the WHYMAP are (BGR - WHYMAP objectives):

1. summarise groundwater information on a global scale,
2. show groundwater data on maps and map applications,
   2.1. Groundwater resources Map of the World, scale 1:25 000 00
   2.2. Thematic special edition maps, scale 1:50 000 000
   2.3. Small scale maps for publications and presentations
   2.4. WHYMAP Viewer
3. provide map information for international discussion on water,
   3.1. World Water Assessment Programme (WWAP)
   3.2. World Water Development Reports (WWDR)
   3.3. World Water Forum
4. exchange information on groundwater with other research and development projects

The cooperation of the above-mentioned entities results in the gradual building of a geographic information system (WHYMAP GIS) in which data is not only collected and stored but also visualized. The result of the visualization is the development of the Groundwater Resources Map of the World in the scale 1: 25,000,000 and 1: 40,000,000, which was created based on the collected and published data.

Various colours on the map indicate areas of water reservoirs with different parameters influencing the possibilities of resource exploitation. There are three main types of reservoirs ():

- large and rather uniform reservoirs of ground waters, the occurrence of which is usually associated with large sedimentation reservoirs, creating favourable conditions for both the exploitation of resources and their restoration,
- groundwater reservoirs with a complex geological structure, the occurrence of which is usually associated with areas with a heterogeneous geological structure, such as fold or fault regions, which require additional recognition techniques to determine the location of high-performance zones in terms of exploitation,
- areas where the presence of aquifers is shallow and local - these are usually zones where water resources are associated with the weathered bedrock.

Within the three types of units distinguished above, up to five categories were additionally defined based on the recharge rates obtained by modelling, ranging from 300 mm to 2 mm per year. The areas with more intense (darker) colours are characterized by a high recharge rate, while the areas with less intensive colours (brighter) have lower values of the recharge potential. It is these (bright) areas that are considered to be the most sensitive and vulnerable to groundwater shortages due to intensive exploitation. The recharge rates were calculated based on data from 1961 to 1990 and are simulated with the global hydrological model WaterGAP, version 2.1f, provided by the University of Frankfurt am Main, Germany.

The areas of high natural value, the existence of which is related to wetlands, have not been neglected. These areas, over 500 ha, the continued existence of which depends on groundwater, have been defined on the basis of the database listing wetlands in line with the RAMSAR Convention (www.wetlands.org/rsis).

Due to the constantly growing number of people globally, an important aspect is also the location of large population centres (cities) where the exploitation of groundwater is more intensive. The map includes cities whose population, according to the United Nations Department of Economics and Social Affairs, exceeded 1 million inhabitants in 2005, and at least 25% of the total water consumption is supplied by groundwater.

Another important aspect included in the map is the quality of groundwater due to the possibility of using it for the purpose of supplying people with drinking water and for food production. Areas where groundwater salinity in the region exceeds 5 g/L, are marked with orange hatching. However, due to the readability of the map, the remaining aspects have been included in additional four insert maps at the 1: 120,000,000 scale. These maps include information on:

- Mean Annual Precipitation (based on data from the Global Precipitation and Climate Centre (GPCC) in Offenbach, Germany)
- River Basin and Mean Annual River Discharge (based on data from Global Runoff Data Centre (GRDC) in Koblenz, Germany)
- Population Density (based on Gridded Population of the World (GPW), Version 3 Center for International Earth Science Information Network (CIESIN), Columbia University; United Nations Food and Agriculture Programme (FAO) & Centro Internacional de Agricultura Tropical (CIAT) 2005)
- Groundwater Recharge per Capita (based on combined data of population density and amount of groundwater recharge modelled by Doell et al. [2006]).

1.3 Transboundary Aquifers of the World Map

Groundwater is an extremely valuable and, in many cases, non-renewable resource that is used by the population of the whole world. It is estimated that around the world, about 50% of the inhabitants consume water from underground sources for drinking on a daily basis. These resources are important from the point of view of the stability of the economy and agriculture and the existence of numerous natural ecosystems. Groundwater, like surface waters, does not know the concept of administrative borders and "flows" freely, crossing successive borders between countries. Often groundwater migration, especially forced by human activities such as exploitation, can be a potential source of international conflicts. For this reason, it is extremely important not only to identify transboundary aquifers but also to assess their resources, which allows to create a framework for sharing water use.

The most up-to-date map of Transboundary Aquifers of the World was prepared by the International Groundwater Resources Assessment Center (IGRAC) in 2015. Currently, the transboundary aquifers map provides an overview of the transboundary aquifers identified so far. It is the basis and inspiration for further research aiming at even better and more detailed identification of border areas with groundwater that has the potential to be an international source of drinking water for citizens. Map of transboundary aquifers was developed based on the results of work carried out by numerous teams of researchers from around the world who voluntarily submitted their results.

At present, 592 transboundary aquifers have been identified globally. For the purpose of preparation of the Map of Transboundary Aquifers of the World, a definition of a transboundary aquifer after the United Nations International Law Commission’s Draft Articles on the Law of Transboundary Aquifers (Draft Articles) had been used: “an aquifer or aquifer system, parts of which are situated in different States.”

As it was stated above, the Map is a product based on publicly available information gathered by national experts on a country level that has been merged to develop a delineation of transboundary aquifers. Subsequently, a series of regional consultations took place to update, improve, confirm and harmonize the information about the transboundary aquifers. The principle of creating the map was the most accurate cartographic representation of the received information while adapting it to the requirements of the scale of 1: 50 000 000. In case of the EU member states, Switzerland and Norway, the map shows not only transboundary groundwater layers but also transboundary groundwater bodies, the understanding of which is consistent with the provisions of the EU Framework Water Directive.

Due to the need to adjust the presented information to the map scale, smaller transboundary aquifers, the surface area of which does not exceed 6,000 km^2, have been marked with blue squares and green circles. For aquifers that boundaries have been verified and confirmed by all sharing countries, their boundaries are marked with a solid red line. On the map, however, you can find examples of aquifers that boundaries are marked with a dashed line due to the lack of confirmation of their boundaries by all countries sharing them. Lack of such confirmation is possible for two reasons (Transboundary Aquifers of the World. Edition 2015, 1: 50 000 000, TBAmap_2015.pdf (un-igrac.org)):

1. Limited amount of hydrogeological information regarding the layer/level,
2. Confirmation of the layer's boundaries by only one of the sharing countries or no data harmonization between the countries sharing the layer.

Sometimes, especially in case of larger transboundary aquifers, they are identified as overlapping layers. In this case, they have been marked on the map with orange polygons. In case of smaller layers, no such marking was made due to the map's readability.

For easy identification, all transboundary layers and groundwater bodies were given codes. For South and North America, these codes follow those of the Organization of American States (OAS), and in case of other regions, the codes were selected by IGRAC. In order to maintain the readability of the map, only the codes of the larger cross-border layers and reservoirs are marked (Transboundary Aquifers of the World. Edition 2015, 1: 50 000 000, TBAmap_2015.pdf (un-igrac.org).).

In addition to the main map in the scale of 1: 50 000 000, the study also includes three thematic maps in the scale of 1: 135 000 000. These maps show transboundary groundwater layers and reservoirs in relation to climatic zones, resources and supply of groundwater and population. Such an approach allows the assessment of the role of groundwater in the sustainable development of individual areas as well as their potential.

When developing the climate map, the simplified Köppen classification compiled by National Geographic was used. This map allows finding the relationship between the transboundary layers and reservoirs of groundwater and the climate.

The Groundwater Resources and Recharge map uses colours to show the differentiation of groundwater exploitation conditions. This map allows not only to assess the potential of groundwater use by the population but also to understand the simplified relationship between the occurrence of areas with favourable exploitation conditions and the geological structure of the region.

The population map shows the transboundary layers and bodies of groundwater against the population projected for 2015. This map allows for an estimate of how many people may have access to groundwater from transboundary layers and groundwater bodies.

1.4 Maps concerning groundwater resources in Norway and harmonisation with neighbouring countries

1.4.1 Hydrogeological maps and data in Norway

Groundwater monitoring and mapping have had and still has a low priority in Norway. The main reason for the very low attention to groundwater in Norway is probably that the authorities have not seen any public utility. Groundwater use within Norway is currently limited due to the country's abundant surface water resources, with most of the country supplied by piped network coverage. Groundwater abstraction is often limited to private borehole supplies. The number of aquifers in unconsolidated Quaternary deposits in Norway is large (many thousand). The exact number of aquifers is not known as many of them are very small, and most aquifers have never been mapped. Quaternary geology maps have been used to delineate aquifer outlines digitally. The resulting polygons have been merged and simplified as groundwater bodies (GWBs) for administrative purposes. Scotland, with the same quaternary geology as Norway, has chosen a different approach where both bedrock and sedimentary groundwater is delineated as waterbodies. These are divided into horizons, as required by the Water Framework Directive. Poland, Czechia, and other countries in the EU have chosen this approach for their mountainous areas. This could be an approach in a future waterbody delineation for Norway (https://www.eea.europa.eu/data-and-maps/data/wise-wfd-4).

Norway has five online free publicly available databases providing maps and data on groundwater. These five databases are hosted by three different agencies, the Norwegian Environment Agency, the Norwegian

Water Resources and Energy Directorate (NVE) and the Geological Survey of Norway (NGU). These three governmental directorates/institutions are reporting to three different ministries: the Ministry of Climate and Environment, the Ministry of Petroleum and Energy, and the Ministry of Trade, Industry and Fisheries. An overview of the databases and their functionality is given in Table 1.

Table 1 Overview of online free available maps and data on Norwegian groundwater.

Databases	Description
[1)]https://vannmiljo.miljodirektoratet.no/	Vannmiljø is the environmental authorities' professional system for registration and analysis of the condition of water. Vannmiljø thus plays a central role in the planning and implementation of all monitoring activity that follows the water regulations. However, data will be available for all types of case processing where information on condition and development in the aquatic environment quality is requested.
[2)]https://vann-nett.no/portal/	Vann-Nett contains maps shoving groundwater body location, quantitative and chemical status. Addition maps for pollutants will be added in winter 2021. Swedish data is available in the map interface. Reports can be downloaded to Excel.
[2)]https://nedlasting.nve.no/gis/	At this site, one can download vector data for groundwater, where the dataset contains waterbodyID, name, area, status, risk and administrative information.
[3)]http://geo.ngu.no/kart/granada_mobil/	GRANADA provides nationwide access to drilled groundwater wells, energy wells and natural springs of groundwater. In addition, a map layer showing proven groundwater potential and assumed groundwater potential is available. This map is based on quaternary geological maps.
[3)]http://geo.ngu.no/kart/nadag/	Geotechnical data, and other types of underground surveys, which provides a basis for assessing ground conditions.

[1)] the Norwegian Environment Agency

[2)] the Norwegian Water Resources and Energy Directorate (NVE)

[3)] the Geological Survey of Norway (NGU)

All five databases (Table 1) are based on INSPIRE, which makes cooperation on data sharing and map compilation easier nationally and internationally.

The hydrogeological state and evaluation of quantitative status are delivered by NVE, while the system Vannmiljø, administered by the Norwegian Environment Agency, delivers parameters for the chemical status. The classification is done in Vann-Nett where the colour coding follows the EU Water Framework Directive (WFD) guidelines. Groundwater vector data can be downloaded from NVE's downloading site in 2D with relational data as status and administrative information. Data from 3D modelling of groundwater aquifers have been done for different purposes at a very local scale, but these data are typically only available through reposts in pdf format (e.g., Hellestveit, 2018; Roseth et al., 2018).

Groundwater is only classified as either in good or poor condition in accordance with the WFD and the quality requirements in the Norwegian Regulations on water supply and drinking water (the drinking water regulations). The qualitative and quantitative condition of groundwater can, through water exchange between groundwater and surface water sources, have an important effect on the ecological condition of the surface water and can therefore play a vital role in the ecological assessment of water bodies. This is the information required by the WFD.

Figure 1 shows a screen shot from GRANADA (Table 1) showing assumed groundwater potential as derived from the Quaternary geological map where glacial and river deposits are characterised as having a proven significant groundwater potential (dark blue) while the moraines are characterised as having less groundwater potential (light blue). As of today, this map layer has not been used in the harmonization or water directive work.

Figure 1 Screen shot from GRANADA showing modelled groundwater potential

1.4.2 Hydrogeological maps and data Norway – Sweden

Norway shares eight IRBDs with Sweden. Västerhavet, Bottenviken, Bottenhavet, Torneälv on the Swedish side and Innlandet and Viken, Trøndelag, Nordland and Jan Mayen, Troms and Finnmark, on the Norwegian side. There is a Norwegian-Swedish strategy regarding practical issues but not a formal agreement between the two countries. There are currently no plans to adopt a formal strategy, but this will be taken into consideration. The informal strategy sets out agreed-upon methods for assessment of the water bodies and how information can be shared across the borders, especially at the regional level. Swedish groundwater data can be downloaded from the database VISS (https://viss.lansstyrelsen.se/). Figure 2 shows a screen shot from Vann-Nett showing a map of the Norwegian and Swedish groundwater bodies. There is a large gap in data structure between the Norwegian database, Vann-Nett, and the Swedish database VISS. Instead of a common database, APIs are created to give the possibility of mutual viewing of the data. Norway uses an ArcGIS Server and an MSSQL Server where all the data are located in the same database. Data is exchanged between Norway and Sweden on request. However, when displaying the Swedish and the Norwegian data together, the lack of harmonization becomes very visible (Figure 3). The data was initially harmonized but has since deviated. It was a strong focus on getting surface water ready for the 2016-reporting because of limited time and resources. Groundwater was therefore not prioritized for this reason and because of limited knowledge about groundwater. The objective is to get the Norwegian data harmonized to the Swedish data The largest transboundary groundwater body registered is crossing the national border between Magnor (Norway) and Charlottenberg (Sweden) and has an approximate size of 40 km^2. This is the only transborder groundwater body that has been mapped by georadar in Norway (Figure 4).

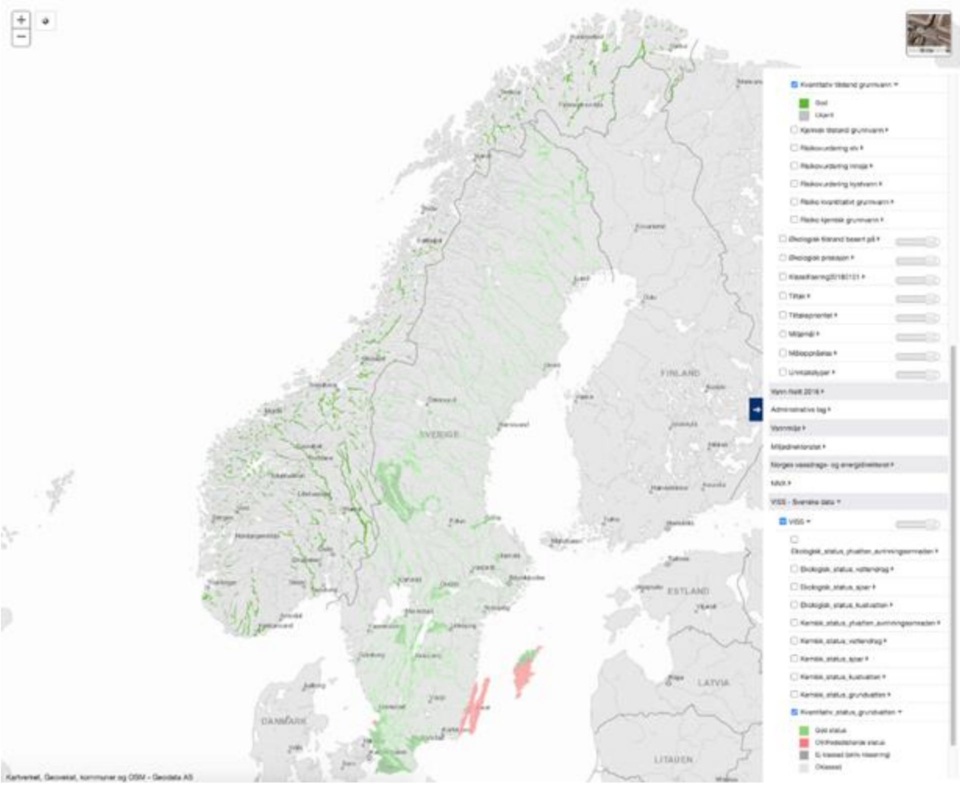


Figure 2 Screen shot from Vann-Nett showing a map of the Norwegian and Swedish groundwater bodies

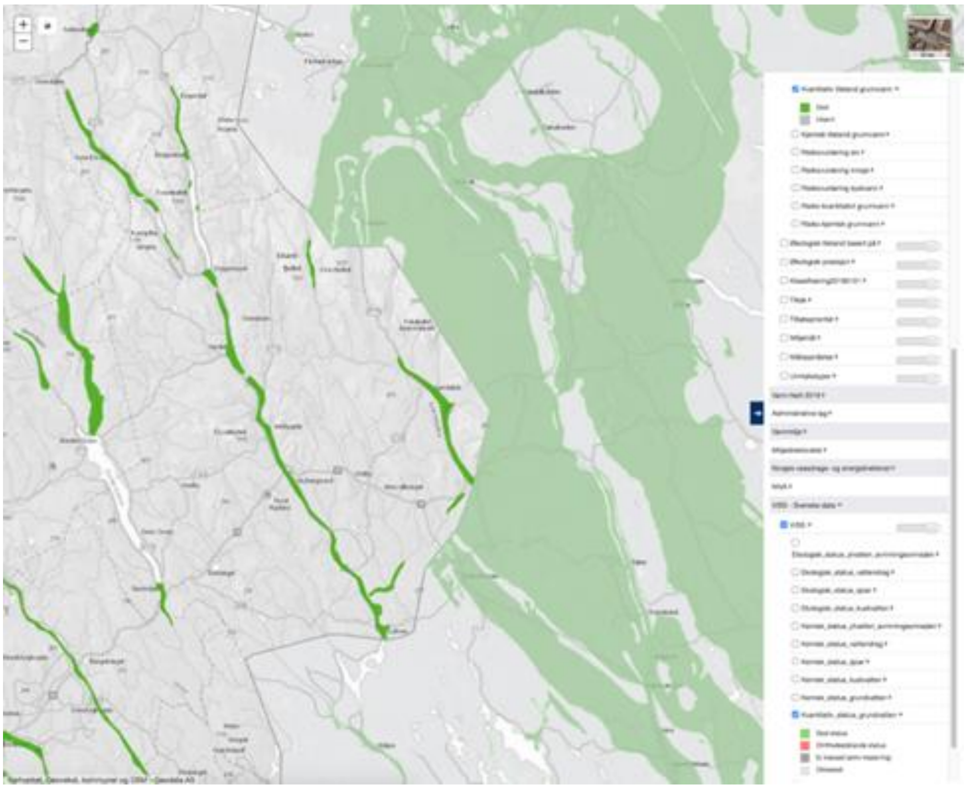


Figure 3 Screen shot from Vann-Nett showing an example on a total mismatch between the Norwegian and Swedish delineation of groundwater bodies

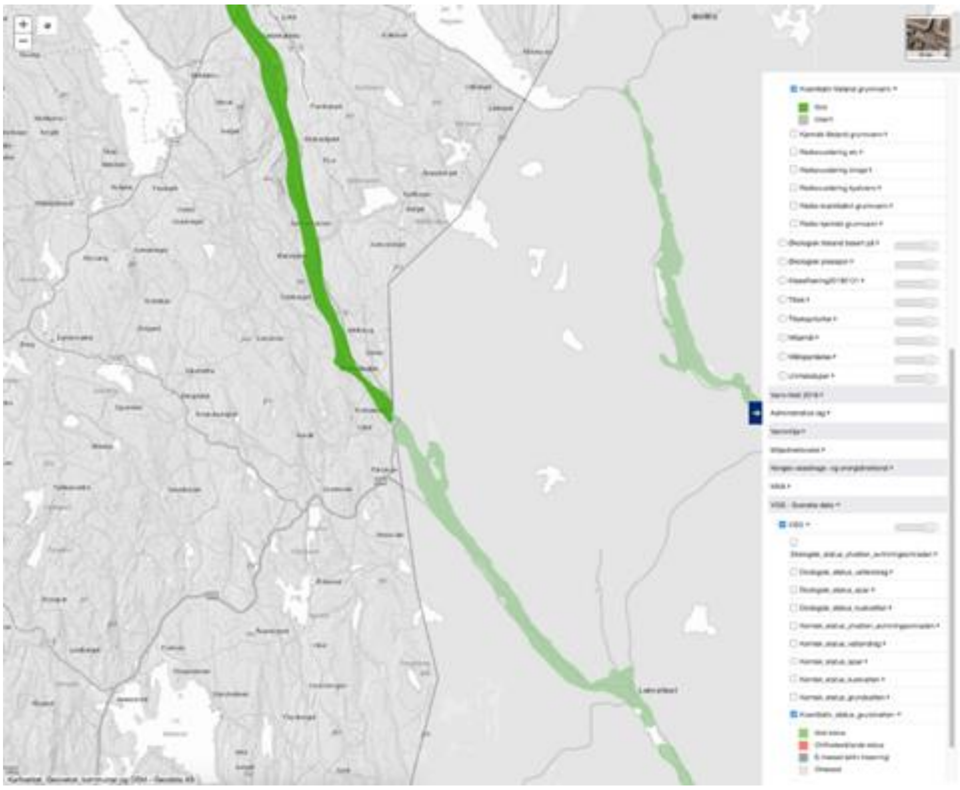


Figure 4 Screen shot from Vann-Nett showing an example on an almost match of groundwater bodies

The same data and maps as shown in Figures 1-3 can also be viewed from the EEA WISE map service.

1.4.3 Hydrogeological maps and data Norway – Finland

Norway shares four IRBDs (Troms and Finnmark, Norsk-Finsk, Torionjoen, Kemijoki) with Finland and the joint management is described in bilateral agreements accessible at http://www.vannportalen.no/vannregioner/norsk-finsk/om-norsk-finsk-vannregion/ (in Norwegian and English). In 2014, a formal agreement was adopted covering the majority of the sub-basins between Norway and Finland. The agreement was a result of the implementation of the WFD and covers the sub-basins Tana, Pasvik and Neiden, which cover substantial spatial areas and many watercourses and lakes in both countries. Two sub-basins, Kemijoki and Tornionjoki, which cover very small spatial areas in Norway, are not a part of the agreement.

Vann-Nett previously viewed Finnish groundwater data, which was provided through the cooperation between SYKE in Finland and NVE on waterbody geometry. A new URL will in the near future be obtained to the Finnish map service. The present delineated Norwegian groundwater bodies along the Finnish border are shown in Figure 5, and the Finnish groundwater bodies are shown in Figure 6 as a screen shot from the EEA WISE map service.

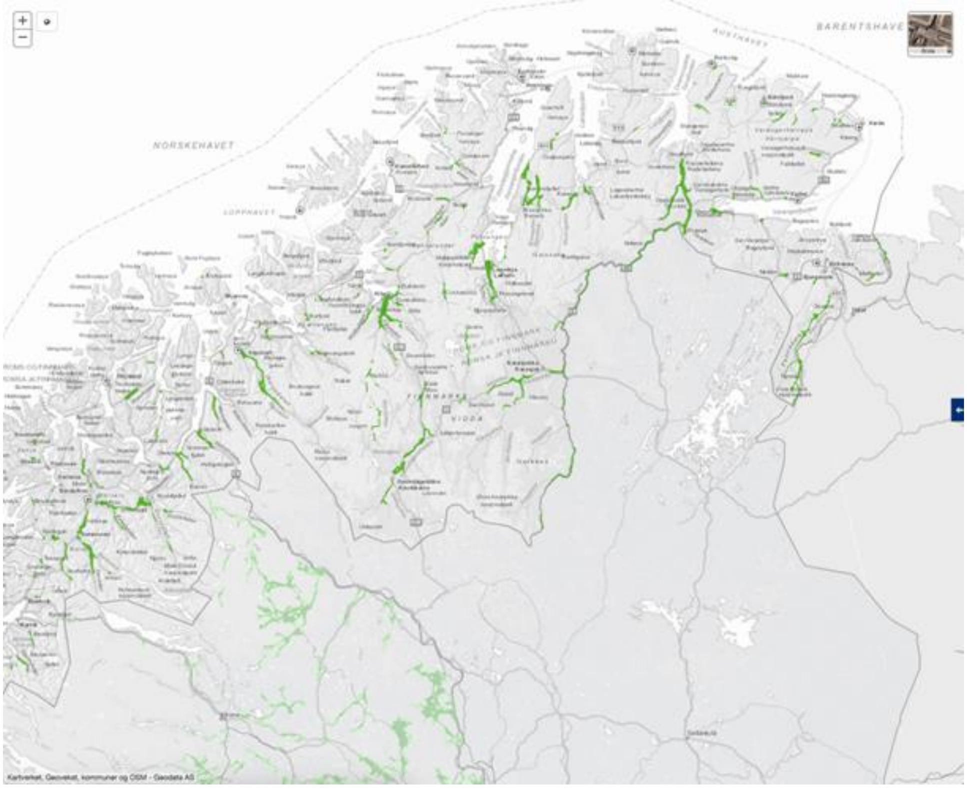


Figure 5 The present delineated Norwegian groundwater bodies along the Finnish border

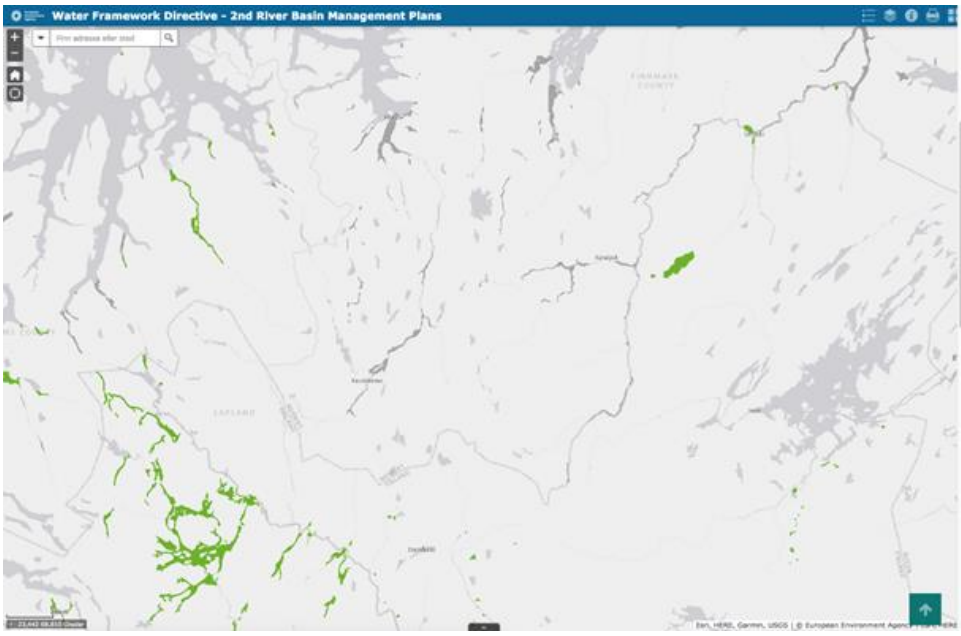


Figure 6 Norwegian and Finnish groundwater bodies from the 2016 WFD reporting

1.4.4 Hydrogeological maps and data Norway – Russia

According to the WFD, countries are obliged to try to obtain cooperation with countries outside the EEA/EU area when river basins are shared. At present, there is no cooperation on groundwater between Norway and Russia (Figure 7). However, there is a Joint Norwegian-Russian Commission on Environmental Protection.

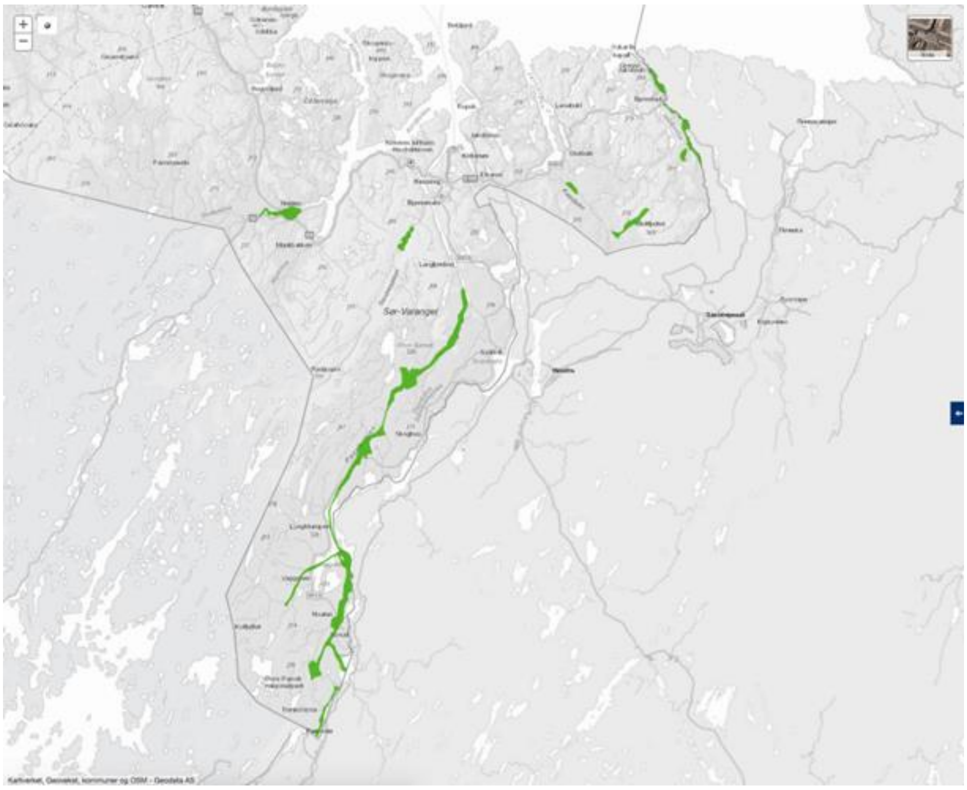


Figure 7 The present delineated Norwegian groundwater bodies along the Russian border

2 Principles of creating a hydrogeological map

The methodology and legend for creating a unified hydrogeological map are mainly based on instructions given by the International Association of Hydrogeologists' guide and standard legend on hydrogeological maps. This chapter, therefore, gives an overview of the principles of creating a hydrogeological map based on the guide by Struckmeier and Margat (1995).

For creating hydrogeological maps, it is crucial to define the map's objectives and the possible map users. In general, the preparation of a hydrogeological map consists of the following phases: initial (preparing, planning), fieldwork (data collecting) and interpretation (explaining, completing, and representing).

The initial phase of map preparation primarily comprises preparatory work, and it is essential in this phase to define the map concept and purpose. The map's content, scale, and representation need to be agreed on and consulted with potential users. The map legend is developed in the initial phase, and a suitable topographic base map is selected. Existing reports are studied for hydrogeological information and information on climate, hydrology, geology, land use, and water management. As an essential step, geological maps containing geological (lithological) units, structure and tectonics are studied. Additionally, satellite images are interpreted regarding topography, hydrogeological features, including karst vegetation, land use, geology, and tectonics.

During **the fieldwork phase**, the map authors should visit, assess, measure and plot springs, boreholes, wells, stream flow. Information from all water-related authorities should be collected. The map area is subdivided according to hydrogeology: areas of similar hydrogeological character are delineated, recharge and discharge areas are defined, all field observations are interpreted. If necessary, additional investigations will be outlined, including drilling, aquifer testing, geochemistry, geophysics.

It is essential to critically review, compare and correlate the data collected and retrieved elsewhere. All data and information derived from different sources should be checked, particularly data from boreholes and analyses. There are many possibilities for inaccurate descriptions, and lithological records may vary significantly. However, as lithology and structure broadly impact the groundwater flow, this information is particularly valuable for hydrogeological mapping.

After the fieldwork phase, correlation and pre-interpretation of the field data and additional data and information drawn from archives and databases, **the interpretation phase** for drafting the map begins. During the interpretation and map drafting phase, the author should transform the geological base map into a lithological base map (subdivide significant lithological units). The point data should be plotted precisely on the base map. An areal evaluation of data will be made by defining the map legend and regionalising the data. During this phase, representative cross-sections are drawn to cross important hydrogeological units and to include drillings and profiles in section lines. An explanatory text is written to define the map compilation procedure, present a synthesis of the mapped area's hydrogeology, and describe additional features not represented on the map.

The phase of interpretation and map drafting comprises mainly the interpretation of point and line data into areal information, whereby all data, information and observations are correlated and arranged with the aid of hydrogeological methods and models.

Hydrogeological maps are used to portray information on groundwater and the relevant rock bodies in relation to topography. Therefore, a hydrogeological map should require three fundamental properties:

1. Topographic base map

2. Hydrogeological data
3. Representational scheme and map legend

Therefore, a hydrogeological map includes an analysis and interpretation of existing data and analysis of areal information, e.g. topographical maps, hydrographical maps, meteorological and hydrological maps, geological maps, and satellite images.

The topographic map is a crucial element for hydrogeological mapping. Firstly, it offers a guide for locating on the surface and secondly, it can be used as a source of useful hydrogeological information, including river network, watersheds, and surface properties. A study on the river network on a topographical map includes delineating the watershed and describing different runoff regimes. The watershed or drainage basin of a stream is the surface within which water flows towards a stream. In most areas, the watershed boundaries roughly coincide with groundwater divides. In arid zones, however, the drainage network and watershed boundaries may be independent of the groundwater flow setting. The density and shape of a stream network and its relationship with the slope, lithology and geological structure contain a lot of helpful information for hydrogeological mapping.

For creating hydrogeological maps, a fundamental step is examining **the geological maps and reports** of the research area. The information provided by interpreting a geological map for hydrogeological mapping purposes allows the conversion of litho-stratigraphical units into hydrogeological units. The geological map provides information necessary to describe and understand the aquifer and groundwater flow systems, as well as the types and conditions of their boundaries controlled by geology and structure. The classification of underlying rocks after their hydrogeological character, i.e. their capacity to transmit and or store water, is usually essential in converting a geological into a hydrogeological map. For this, a description of lithological facies on a geological map is needed.

The distinction between unconsolidated and consolidated, permeable and impermeable rock bodies is made. The permeable rock bodies are then classified into three categories (porous, fissured, karstified), possibly complemented by intermediate classes. Prominent examples of such aquifers are:

1. gravel, sand (porous)
2. sandstone, marlstone, basalt (frequently fissured)
3. limestone, dolomite, gypsum (frequently karstified).

Hydrogeological units can also be classified based on permeability considerations often derived from a pure analogy between geology (lithological rock type) and hydrogeology (hydraulic conductivity K). However, hydraulic conductivity may vary widely, even in lithologically relatively uniform areas. The hydrogeological units are usually grouped into:

1. permeable formations ($K > 1*10^{-6}$ m/s), forming aquifers of relatively high permeability and productivity
2. semi-permeable formations (K between $1*10^{-6}$ and $1*10^{-9}$ m/s) forming less productive aquifers
3. impermeable formations (aquicludes) ($K < 1 . 10^{-9}$ m/s).

In unconsolidated porous sediments, more quantitative information about transmissivity (T) can be drawn from a geological map by considering the hydraulic conductivity assessed together with the saturated thickness. However, this requires knowledge of the depth dimension.

Structural information drawn from geological maps includes the geometry of the aquifers and the boundary conditions of aquifer systems which are often determined by the geological structures. A geological map shows the location of outcropping boundaries of rock units. Aquifer outcrops generally form recharge areas characterised by water table conditions. However, the boundaries of the rock unit may not necessarily coincide with the extent of the aquifer, particularly in platform areas or in areas of deep-lying water tables, where the unsaturated part of the aquifer is considerably thick.

For hydrogeological mapping, **meteorological and hydrological information** about the rainfall pattern, the long run of temperatures, particularly freezing periods, evaporation and aridity, is needed. This forms the background for understanding groundwater conditions in the map area and the interpretation of groundwater flow systems, their recharge and discharge.

An essential step in hydrogeological map preparation is additional data collection. **Fieldwork** for producing new hydrogeological data should be planned before going to the field by going through the data available in archives and on maps.

The content of the hydrogeological map should be complete and homogeneous data sets rather than focusing on single parameters and variables. Specific **hydrogeological data** are considered essential for all hydrogeological maps:

1. Observation point number or well number is necessary for systematic identification of the data.
2. Location (by coordinates) is necessary for the exact plotting and orientation of points for repeated observation.
3. Map sheet referenced to the regular coverage of topographic base maps at a relatively large scale (1:10 000 to 1:50 OOO), necessary to facilitate the numbering of observation points.
4. The altitude of the land surface is necessary for computing the elevation of the groundwater table.
5. Discharge of springs or baseflow of streams is necessary to estimate groundwater flow regimes' natural discharge conditions.
6. Depth to groundwater (static groundwater level) is necessary for computing the water table elevation to obtain indications of processes acting from the land surface
7. Elevation of the groundwater table is essential for the construction of groundwater table maps, which enable recognising the direction of groundwater flow, its gradient, and, together with topographical data, (surface water) recharge and discharge areas. A groundwater table map is one essential requirement, together with values for transmissivity, to assess the quantity of groundwater flow. Note that in areas of perennial river runoff, the river bed intersects the groundwater table and the land surface.
8. The total depth of a well indicates the relative position of an aquifer and, in connection with depth to groundwater, the level head characteristic (e.g. whether confined).
9. Salinity is a primary datum that indicates groundwater suitability.
10. Date informing about the time of observations of either own field investigations or previous observers
11. Source of data describing the reliability of the data.

3 Selection of the hydrogeological map types

3.1 Introduction

The development of pan-European transboundary hydrogeological maps and datasets is a contemporary challenge for scientific institutions and geological surveys. Issues of cross-border impact require access to consistent data with transnational coverage. The international harmonization of hydrogeological maps has a long history. The formulation of internationally unified mapping practices in the field of hydrogeology was the goal of several major projects - IHME1500 and WHYMAP. The precursors of these projects were the scientists from the International Association of Hydrogeologists (IAH) and the International Association of Hydrological Sciences (IAHS), who in the 1960s took the initiative to develop unified mapping procedures which required international coordination of methods for presenting hydrogeological information. In 1959, the IAH established the Hydrogeological Maps Commission, whose task was to prepare a standardized legend of the Hydrogeological Map of Europe in a scale of 1: 1 500 000. The draft of the legend of this map was published by UNESCO (Anon, 1963). The proposed legend and guidelines for cartographic presentation of hydrogeological conditions by individual countries were tested for a long time. The numerous additions and modifications to the 1963 legend were included in the second edition of the 1970 Hydrogeological Map Legend by the Institute of Geological Sciences (London), IAHS, IAH and UNESCO (Anon, 1970). On the other hand, the complete methodology of compiling the hydrogeological map of Europe in the 1: 1,500,000 scale was published in 1995 after the pilot study of selected sheets (Struckmeier & Margat, 1995). Hydrogeological maps are proposed to be divided into four categories depending on their basic content and main purpose as follows:

I. Groundwater Resource Map
II. Hydrogeological Parameters Map
III. Groundwater Systems Map
IV. Specialized Hydrogeological Maps, including derived maps, such as Vulnerability, Suitability and Protection maps.

Groundwater Resource Map

Groundwater Resource Map is a map of the potential of groundwater resources, presenting mainly information about the availability and suitability for the use of groundwater. The most frequently shown parameters are: exploitation and available groundwater resources provided for any unit and main groundwater reservoirs (aquifer layers and systems occurring in large sedimentation reservoirs, characterized by good conditions for the exploitation of groundwater and constituting strategic groundwater resources of high quality).

Hydrogeological Parameters Map

Parameter maps represent, with maximum accuracy, a specific set of data describing the conditions of occurrence of aquifers, their extent and hydrogeological characteristics. Common parameters displayed on such maps are - the depth to the aquifer, its thickness and water permeability, and the depth to the groundwater table.

Groundwater Systems Map

This type of map presents the hydrodynamic systems and boundary conditions of a specific area. These maps are particularly useful for hydrodynamic modeling as they greatly facilitate the understanding of groundwater flow systems and define the boundary conditions of the model, which is essential in the conceptual modeling phase. They require an advanced stage of data acquisition as they are based on an integrated approach to the analysis of the hydrogeological environment using auxiliary information such as morphological, structural, soil, hydrological and others. Common parameters displayed on these maps are - hydrodynamic zones of regional aquifers, types of boundaries of groundwater flow systems, flow directions and areas with a local, shallow aquifer. Therefore, such maps, apart from their usefulness in modeling, are the most effective tool for determining groundwater monitoring networks and water protection objectives.

Specialized Hydrogeological Maps

This type of map is the most diverse because it reflects the needs of a specific user. Generally, they can be grouped into maps that provide information about:

- suitability for the exploitation of groundwater;
- groundwater quality;
- groundwater sensitivity to pollution;
- protection of groundwater, indicating protection areas of groundwater reservoirs or individual intakes.

The compilation of the 1: 1 500 000 hydrogeological map of Europe was completed in 2013. Raster map formats are available from the BGR (Federal Institute for Geosciences and Natural Resources) website - www.bgr.de), where you can download scans of individual map sheets. Over the long period of almost 50 years of the implementation of the hydrogeological map of Europe, not only has there been huge progress in the methods of hydrogeological research but also there has been a paradigm shift in cartographic techniques. Geographic Information Systems (GIS) have completely replaced traditional cartography, and the available maps are now distributed as vector maps with attached databases. In addition, digital geological models (from 3D to 5D) are gaining popularity. The current challenge is pan-European harmonization of hydrogeological data according to a reference model. These activities are mainly coordinated by The Association of Geological Surveys of Europe (EuroGeoSurveys).

3.2 The method of selecting the types of hydrogeological maps representative for Polish-Ukrainian and Estonian-Latvian cross-border research areas

In order to select the types of hydrogeological maps appropriate to the scope of the information collected by the geological surveys of individual countries in the area of research, the following tasks were undertaken:

- Advice and support were obtained from a nominated 'expert group'.
- Relevant literature and achievements of international hydrogeological mapping projects were analyzed.
- A range of hydrogeological and other parameters for the monitoring and management of groundwater resources collected in the databases of individual EU-WATERRES partners was identified.
- The identified parameters were analyzed for data consistency in terms of spatial and temporal resolution between neighbouring countries.
- Unified requirements for the database structure were designed in terms of the type of vector layer (polyline/polygon/point), type of attributes (number/text), measurement units for numerical data and dictionaries (nomenclature) for text data.
- The database model for testing was prepared.

- The target database was grouped into categories based on the thematic classification of the parameters it contains, which are the basis for the selection of appropriate types of hydrogeological maps.
- The scope of the legend has been designed for individually selected types of hydrogeological maps.

In this way, three types of hydrogeological maps were selected, representative of the Polish-Ukrainian and Estonian-Latvian cross-border research areas:

I. Hydrogeological Parameters Map
II. Map of groundwater exploitation
III. Map of groundwater vulnerability and quality

3.3 Hydrogeological parameters map

The purpose of the Hydrogeological Parameters Map is to map the hydrogeological conditions most important for the parameterization of the aquifer constituting the main useful aquifer. Moreover, the presented data should be sufficient to the extent necessary to make a decision regarding the selection of optimal locations for the exploitation of groundwater.

Useful Aquifer (Słownik hydrogeologiczny, 2002) – a layer or set of aquifers showing good hydraulic connectivity, meeting certain quantitative and qualitative criteria, from which high-quality water can be taken permanently. A useful aquifer should have a thickness of more than 5m (more than 2 m), a potential well capacity of more than 5 m^3/hour (more than 2 m^3/hour), and a water conductivity of more than 50 m^2/day (more than 25 m^2/day). The values in parentheses refer to poor groundwater areas.

Main Useful Aquifer (MUA; Słownik hydrogeologiczny, 2002) – the first from the surface useful aquifer of regional importance.

Due to the fact that the Hydrogeological Parameters Map reflects the conditions of the occurrence of the useful aquifer, it was decided that the target parameters presented on this map should be based, e.g. on the useful aquifer separation criteria presented above. Thus, the parameters - thickness and water conductivity of the MUA were included in the target components of the Hydrogeological Parameters Map.

In addition to the above two parameters, special attention should be paid to the cartographic mapping of issues related to:

- Hydrodynamics.
- Vertical layout of the MUA.
- Protective cover (low permeable layer) over the MUA.
- Hydrogeological regionalization.

In the hydrodynamic aspect, information on the shape of the surface of the MUA water table, i.e. hydroisohypses and flow directions, deserves special attention in the context of shaping the legend of the Hydrogeological Parameters Map. A distinction is made between the hydroisohypses of the unconfined groundwater table and the hydroisohypses of the piezometric surface (hydraulic height) of an aquifer with a confined groundwater table.

The vertical distribution of the MUA is a good reflection of the depth to MUA level parameter, defined depending on the nature of the MUA water table as the depth from the ground surface to the unconfined confined groundwater table.

The presentation of information about the MUA protective cover, on the one hand, expands the view on the structure of the aquifer, and on the other - supports the information group on vulnerability and quality of MUA. The term "protective cover of the MUA" is meant as the poorly permeable layer of a specific thickness occurring above the MUA. In the scientific literature, this issue is also referred to as the degree of isolation of the MUA.

Traditionally, hydrogeological regionalization is a key component of the hydrogeological map. The separation of hydrogeological units is intended to indicate regions with similar hydrogeological conditions of the occurrence of the considered aquifer: its spatial development, lithology and stratigraphy of the aquifer, the nature of a groundwater table. Thus, the parameter - hydrogeological units in relation to MUA - was qualified as one of the target components of the Hydrogeological Parameters Map.

In conclusion, the following parameters were indicated as the mandatory elements of the Hydrogeological Parameters Map:

- Thickness of the MUA.
- MUA water conductivity.
- Hydroisohyps and flow directions.
- Depth up to MUA level.
- MUA insulation degree.
- MUA hydrogeological units.

3.4 Map of groundwater exploitation

The purpose of the Map of groundwater exploitation is to map the exploitation status of groundwater resources and possible changes in the hydrodynamic system as a result of anthropogenic impacts. This information is closely related to the time factor, so the Map of groundwater exploitation should always refer to the date or period when the variables were determined.

The selection of basic parameters for the presentation of information on the status of exploitation of groundwater resources was carried out on the basis of the analysis of commonly used categories in the assessment of groundwater resources:

- Static resources constituting the volume of groundwater stored (retained) in usable aquifers (Słownik hydrogeologiczny, 2002).
- Dynamic or renewable resources, which are the revenue part of the hydrogeological balance, are created by the infiltration of precipitation into aquifers (Słownik hydrogeologiczny, 2002).
- Available resources constituting the amount of groundwater that can be taken from usable aquifers under specific hydrogeological and environmental conditions (Słownik hydrogeologiczny, 2002). These resources are determined for the balance area without specifying the location and technical and economic conditions of the intakes.
- Exploitable resources, concerning the amount of water that can be taken from the intake under certain hydrogeological, environmental, technical and economic conditions (Słownik hydrogeologiczny, 2002).

The given categories of groundwater resources - available and operational - relate to the issue of rational groundwater abstraction. Maps containing these parameters are particularly useful in the preparation of planning documentation for the identification of impacts on changes in groundwater levels. The main group of recipients are also specialists of water management boards, who are trying to define the conditions for using the waters of the water region and development a water management plan, as well as geological administration employees approving hydrogeological documentation. Thus, the parameters - available groundwater resources broken down into individual balance areas and exploitation resources for individual intakes were classified as the target components of the Map of groundwater exploitation.

The second component of the Map of groundwater exploitation concerns the presentation of the extent of the area with a significant change in the position of the usable groundwater table of the aquifer as a result of anthropogenic impact. A significant change is most often understood as one that exceeds the value of the natural mean annual fluctuation amplitude of the groundwater table of the considered aquifer. In addition, the changes are bidirectional - lowering or raising.

The widely recognized anthropogenic impacts on the hydrodynamic system of groundwater are:

- Exploitation of groundwater intakes;
- Mining drainage;
- Agricultural and forest water drainage;
- Hydrotechnical damming of surface waters.

The most frequently used indicator of the extent of the area covered by anthropogenic lowering of the groundwater table is the depression cone. The extent of the depression cone is determined in accordance with possibly up-to-date source materials: hydrogeological documentation, numerical hydrodynamic model. Moreover, attention should be paid to the spatial scale of the depression cones presented on the map - local or regional, which depends on the target map scale. For example, in Poland, a frequently practised limitation on the 1: 50 000 scale hydrogeological map is the area of the depression cone of no less than 3 km^2.

Map of groundwater exploitation, apart from the resource aspect and the related issue of anthropogenic impacts, must show data on hydrogeological objects, such as boreholes, water intakes and sources. This information extends the view on the status of the exploration of groundwater resources. The scope of information is most often limited to providing the location of the object, basic drilling and lithostratigraphic data, as well as hydrogeological data.

In summary, the following parameters were indicated as the mandatory elements of Map of groundwater exploitation:

- Available groundwater resources broken down into balance areas.
- Exploitation resources of intakes.
- Areas with a significant change in the position of the groundwater table of the usable aquifer as a result of anthropogenic impact.
- Hydrogeological objects - boreholes, groundwater intakes and water sources.

3.5 Map of groundwater vulnerability and quality

The aim of Map of groundwater vulnerability and quality is a cartographic mapping of the chemical status and threats to groundwater quality, including an indication of their sensitivity to pollution. Consequently, Map of groundwater vulnerability and quality emphasizes the division into two groups of issues:

1. Groundwater quality and pollution hotspots.
2. Groundwater vulnerability to pollution.

In the first group of issues, against the background of the division of the research area into GWB units, groundwater quality classes will be defined at diagnostic and operational monitoring points, as well as the potential pollution hotspots for the main usable level and first groundwater level. The quantitative characteristics of the first group are supported by information on the mineralization of MUA waters in the form of isolines. The second group is emphasized by a colour separation of the degree of vulnerability of groundwater to pollution.

The concept of groundwater vulnerability to pollution is based on the assumption that the natural properties of the aquifer can provide a certain degree of protection for groundwater against anthropogenic impacts, especially in relation to the migration of pollutants from the ground surface to the aquifer. The term "groundwater vulnerability to pollution" was introduced by the French hydrogeologist J. Margat in the late 1960s. The popularity of this issue resulted in numerous methodological works on the method of assessing vulnerability (Aller et al., 1987; Duda et al., 2011; Krogulec, 2004; Robins et al., 1994). In addition, an idea was born to map the degree of vulnerability of groundwater to pollution as a function of hydrogeological conditions using maps. The idea quickly gained the interest of international organizations. At the meeting of the IAH Ground Water Protection Commission in 1987, the topic of groundwater vulnerability assessment and mapping on a global scale was launched. The work performed was finalized with the publication of a methodological guide for mapping groundwater resources and their vulnerability (Vrba & Zaporozec, 1994).

Since the beginning of the 1980s, a considerable number of groundwater natural vulnerability maps have been published worldwide, which mainly expressed groundwater specific vulnerability to pollution. The assessment indicators generally mapped on maps were characterized by a relative and dimensionless property. Most often, they were based on a ranking system assigning particular parameters a specific point weight. When using the definitions of groundwater natural vulnerability and groundwater specific vulnerability to pollution, attention should be paid to their definitive separateness. Groundwater natural vulnerability is understood as the protective property of the aquifer, resulting from the geological structure and hydrogeological conditions. On the other hand, the definition of groundwater specific vulnerability to pollution takes into account, apart from the natural vulnerability of the aquifer, also the type of pollution, its load and the nature of the pollution hotspot.

In this study, it is proposed to limit the issue of groundwater natural vulnerability due to the available input data. The main attributes used in the assessment will be the hydrogeological parameters of the aquifer and indicators of the recharge conditions. These indicators are derived from the thickness of the aeration zone or the depth to the groundwater table and the lithological nature of the cover through which pollutants migrate vertically from the ground surface.

Keeping in mind that the result of the groundwater natural vulnerability assessment is a relative value, the obtained maps will be useful for qualitative assessment in order to identify areas with a relatively greater or lesser vulnerability to pollutants migrating from the surface. In addition, on the basis of the groundwater natural vulnerability map database, it is possible, depending on the assumed scenarios of impact from selected types of pollution or land development methods, to assess the vulnerability of groundwater to pollution, i.e. to create risk scenarios.

Map of groundwater vulnerability and quality, in addition to providing information on the chemical status of groundwater, can be used, inter alia, to: solve problems related to the impact of anthropogenic pressure on the chemical status of groundwater, to prepare a groundwater pollution prevention program, to prepare a list of areas vulnerable to pollution, as well as water management plans. The main advantage of this map is its cross-border dimension. The experience so far has been limited to the creation of national maps of various scales only. The applied uniform and harmonized way of presenting the chemical status and groundwater vulnerability of transboundary aquifers made it possible to use this map for the analysis of transboundary impacts and the assessment of the effectiveness of the undertaken protective measures.

4 Hydrogeological map legend

4.1 Data gathering

4.1.1 Estonian-Latvian pilot area

The hydrogeological model (PUMA model) developed for the entire BAB, where the Latvian-Estonian pilot territory is part of the model territory, will be used to obtain most of the data for the Estonian-Latvian pilot area. After analysing the existing data for the pilot area, it was concluded that the PUMA hydrogeological model data characterises the current hydrogeological conditions of the Latvian-Estonian transboundary area. The PUMA model consists of 42 geological layers, 18 of which are distributed in the Latvian-Estonian pilot area. The PUMA model will be used to obtain data concerning the hydrogeological units, groundwater head and the depth and thickness of the aquifers and the overlying impermeable layer.

In addition to the existing PUMA model, a new hydrogeological model is being developed for the Estonian-Latvian pilot area within the framework of the EU-WATERRES project.

To comply with WFD requirements and coordinate water management, RBMP for each river basin in Estonia and Latvia are established for six years and are then updated. Data sets gathered for RMBP-s will be used to obtain information about groundwater bodies, pollution sites, springs, and monitoring wells.

The information on different input data sources for Estonian and Latvian research areas are given in Table 2 and Table 3.

Table 2 Input data for the Estonian part of the research area

GIS information layer	Source of data
Hydrogeological units of the main useful aquifer	PUMA model
Depth to the main useful aquifer	PUMA model
Hydroisohypses of the groundwater head of the main useful aquifer	New model created in EU-WATERRES
Thickness of the main useful aquifer	PUMA model
Transmissivity of the main useful aquifer	PUMA model
The thickness of the impermeable layer over main useful aquifer	PUMA model
Groundwater mineralization for main useful aquifer	National database “EELIS”
Groundwater bodies	RBMP
Springs	National database “EELIS”
Wells	National database “EELIS”
Intakes	National database “EELIS”
Areas of depression cones	New model created in EU-WATERRES

Groundwater pollution site	RBMP
Groundwater vulnerability	PUMA model, Groundwater Vulnerability map in scale 1:400 000;
Groundwater monitoring points	National database “EELIS”
Buried valleys	Geological Map in scale 1:400 000

Table 3 Input data for the Latvian part of the research area

GIS information layer	Source of data
Hydrogeological units of the main useful aquifer	PUMA model
Depth to the main useful aquifer	PUMA model
Hydroisohypses of the groundwater head of the main useful aquifer	New model created in EU-WATERRES
Thickness of the main useful aquifer	PUMA model
Transmissivity of the main useful aquifer	PUMA model
The thickness of the impermeable layer over main useful aquifer	PUMA model
Groundwater mineralization for main useful aquifer	National database “URBUMI”
Groundwater bodies	RBMP
Springs	National database “URBUMI”
Wells	National database “URBUMI”
Intakes	Latvian state statistical report forms "No.2-Water. Reports on the Use of Water Resources"
Areas of depression cones	New model created in EU-WATERRES
Groundwater pollution site	RBMP
Groundwater vulnerability	PUMA model + New model created in EU-WATERRES
Groundwater monitoring points	National database “URBUMI”
Buried valleys	Geological Map in scale 1:200 000

4.1.2 Polish-Ukrainian pilot area

The input data for the development of GIS information layers "Hydrogeological map" for the Polish-Ukrainian research area comes mainly from the databases of the Polish Geological Institute, Subsidiary enterprise " Zahidukrheolohiia" of Company "Nadra Ukraina" and "Ukrainian Geological Company".

For the Polish part of the research area, the information on input data sources broken down into individual information layers is presented in Table 4.

Table 4 Input data for the Polish part of the research area

GIS information layer	Source of data
Hydrogeological units of the main useful aquifer	GIS database „Hydrogeological map of Poland in scale 1:50 000”
Depth to the main useful aquifer	GIS database „Hydrogeological map of Poland in scale 1:50 000”
Hydroisohypses of the groundwater head of the main useful aquifer	GIS database „Hydrogeological map of Poland in scale 1:50 000”
Thickness of the main useful aquifer	GIS database „Hydrogeological map of Poland in scale 1:50 000”
Transmissivity of the main useful aquifer	GIS database „Hydrogeological map of Poland in scale 1:50 000”
Springs	Central Hydrogeological Data Bank; GIS database „Hydrogeological map of Poland in scale 1:50 000”
The insulation degree of main useful aquifer	GIS database „Hydrogeological map of Poland in scale 1:50 000”
Boreholes	Central Hydrogeological Data Bank
Intakes	Database on registered consumption from groundwater intakes; Central Hydrogeological Data Bank
Groundwater damming devices	GIS database „Hydrogeological map of Poland in scale 1:50 000” – first aquifer – occurrence and hydrodynamics
Areas of depression cones	GIS database „Hydrogeological map of Poland in scale 1:50 000” Regional documentations
Groundwater bodies	Groundwater Bodies database
Groundwater pollution site – wastewater treatment plants	Chief Environmental Protection Inspection Provincial Inspectorate of Environmental Protection in Lublin, Provincial Inspectorate of Environmental Protection in Rzeszów
Groundwater pollution site – waste landfills	Chief Environmental Protection Inspection Provincial Inspectorate of Environmental Protection in Lublin, Provincial Inspectorate of Environmental Protection in Rzeszów
Vulnerability to groundwater pollution	GIS database „Hydrogeological map of Poland in scale 1:50 000” – first aquifer – sensitivity to pollution and water quality
Groundwater monitoring points	Groundwater Monitoring database**;** **Hydrogeological Yearbook**

For the Ukrainian part of the research area, the information on input data sources broken down into individual information layers is presented in Table 5.

Table 5 Input data for the Ukrainian part of the research area

GIS information layer	Source of data
Hydrogeological units of the main useful aquifer	Database of SE “Zahidukrheolohiia”; Hydrogeological maps of scale 1:200000 of stocks of SE “Zahidukrheolohiia”; Archive SE „Ukrainian Geological Company”
Depth to the main useful aquifer	Database of SE “Zahidukrheolohiia”; SE "Heokaptazhminvod"; Archive SE „Ukrainian Geological Company”
Hydroisohypses of the groundwater head of the main useful aquifer	Database of SE “Zahidukrheolohiia”; SE "Heokaptazhminvod"; Hydrogeological maps of scale 1:200000 of stocks of SE “Zahidukrheolohiia”; Archive SE „Ukrainian Geological Company”
Thickness of the main useful aquifer	Database of SE “Zahidukrheolohiia”; SE "Heokaptazhminvod"; Hydrogeological maps of scale 1:200000 of stocks of SE “Zahidukrheolohiia”; Archive SE „Ukrainian Geological Company”
Transmissivity of the main useful aquifer	Database of SE “Zahidukrheolohiia”; SE "Heokaptazhminvod"; Hydrogeological maps of scale 1:200000 of stocks of SE “Zahidukrheolohiia”; Archive SE „Ukrainian Geological Company”
Springs	Database of SE “Zahidukrheolohiia”; Archive SE „Ukrainian Geological Company”
The insulation degree of main useful aquifer	Database of SE “Zahidukrheolohiia”; SE "Heokaptazhminvod"; Archive SE „Ukrainian Geological Company”
Boreholes	Database of SE “Zahidukrheolohiia”; SE "Heokaptazhminvod"; Archive SE „Ukrainian Geological Company”
Intakes	Databases of SE “Zahidukrheolohiia”; State Research and Production Enterprise “Geoinform of Ukraine”; Database on registered consumption of groundwater intakes; Archive SE „Ukrainian Geological Company”
Groundwater damming devices	Data of the State Agency of Water Resources; Data from the Volyn Region Water Agency
Areas of depression cones	Regional documentation of SE “Zahidukrheolohiia”; Regional documentation of the SE „Ukrainian Geological Company”;
Groundwater bodies	Database of SE “Zahidukrheolohiia”;

	Archive SE „Ukrainian Geological Company”
Groundwater pollution site – wastewater treatment plants	Department of Ecology and Natural Resources of Lviv Regional State Administration; Department of Ecology and Natural Resources of Volyn Regional State Administration; Ecological Inspectorate of the Volyn Region; Ecological Inspectorate of the Lviv Region
Groundwater pollution site – waste landfills	Register of waste disposal sites (Department of Ecology and Natural Resources of Volyn Regional State Administration); Ecological Inspectorate of the Volyn Region; Department of Ecology and Natural Resources of Lviv Regional State Administration; Ecological Inspectorate of the Lviv Region
Vulnerability to groundwater pollution	Database of SE “Zahidukrheolohiia”; Archive SE „Ukrainian Geological Company”
Groundwater monitoring points	State Research and Production Enterprise “Geoinform of Ukraine”; State groundwater Cadastre (Volyn region); Database of the regional groundwater monitoring of Ukraine

4.2 List of objects

4.2.1 Hydrogeological units of the main useful aquifer

Definition: An aquifer is a hydraulically continuous body of relatively permeable unconsolidated porous sediments or porous or fissured rocks containing groundwater. A useful aquifer is defined as an aquifer or group of aquifers showing good hydraulic connectivity, with the parameters of the quantity and quality of water qualifying for municipal use.
Criteria for identification of the useful aquifer:

- Transmissivity > 50 m^2/d,
- total thickness M≥5m (with an average state of retention),
- shows a continuity of occurrence (with the accuracy of hydrogeological schematization appropriate for a map in the scale of 1: 50,000) in the area A> 20 km^2 (in conditions of good identification and clear spatial differentiation of hydrogeological conditions, A > 5 km^2 is allowed);
- enable the execution of a drilled well with a recharge of over 5m^3/h.

Layer GIS type: polygons.

Attributes:

- Lithology of aquifer (lithological index)
- Aquifer types (terrigenous/fractured)
- Stratigraphy of dominating sediments (stratigraphic index)
- Type of groundwater level (confined/unconfined)

Table 6 Hydrogeological unit classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Aquifer	• Text	• Quaternary aquifer / Devonian Plavinas-Ogre aquifer system / Devonian Aruküla-Amata aquifer system
• Lithology of aquifer	• Text	• sandstone with siltstone interlayers / dolomite with dolomitic marl
• Aquifer type	• Text	• Terrigenous / Fractured / Fractured-cavernous
• Stratigraphy of dominating sediments	• Text	• Q / Dpl-og / Dar-am / Dpl-og and Dar-am

Table 7 Hydrogeological unit classifiers for the Polish-Ukrainian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Aquifer	• Text	• Quaternary alluvial aquifer / Quaternary fluvio-glacial aquifer / Miocene aquifer / Upper Cretaceous aquifer / Cretaceous-Paleogen aquifer system
• Lithology of aquifer	• Text	• Flow in a porous medium: ○ sand, ○ gravel Flow in a fractured, fractured-cavernous medium: ○ chalkstone, ○ gaize ○ limestone, ○ marl, ○ opoka, ○ chalk, ○ dolomites, ○ gypsum, ○ sandstone
• Aquifer type	• Text	• Terrigenous / Fractured / Fractured-cavernous
• Stratigraphy of dominating sediments	• Text	• Qa Qfg Q/K2 Q/Pg Pg N1/Pg N1 K2 Pg/K2 Q/Pg/K2
• Type of groundwater level	• Text	• confined / unconfined

4.2.2 Depth to the main useful aquifer

Definition: The depth to main useful aquifer (MUA) is defined depending on the nature of the MUA water table as the depth from the ground surface to:

- MUA unconfined groundwater table,
- MUA confined groundwater table (that is, to impermeable / semi-permeable deposits limiting the MUA from the top).

Layer GIS type: polygons.

Attributes:

- Depth of the top of the MUA

Table 8 Depth to the main useful aquifer classifiers for the Estonian-Latvian pilot area

Intervals of polygons of the depth to aquifer*
• < 5 m • 5-10 • 10-20 • 20-40 • > 40

*Intervals of the polygons will be confirmed after collecting the data

Table 9 Depth to the main useful aquifer classifiers for the Polish-Ukrainian pilot area

Intervals of polygons of the depth to aquifer
• 0 - 2 m absence MUA • 2 - 5 m • 5 - 15 m • 15 – 50 m • > 50 m

4.2.3 Hydroisohypses of the groundwater head of the main useful aquifer

Definition: Contour lines for connecting equal level groundwater head points of the main useful aquifer.

Layer GIS type: polyline.

Attributes:

- Value of the hydroisohypses

Table 10 Hydroisohypses of the groundwater head classifiers for the Estonian-Latvian pilot area

Intervals of isolines of the water head*
10 m

*Intervals of the isolines will be confirmed after collecting the data

Table 11 Hydroisohypses of the groundwater head classifiers for the Polish-Ukrainian pilot area

Intervals of isolines of the water head
10 m

4.2.4 Thickness of the main useful aquifer

Definition: Thickness of the main useful aquifer, measured between its top and bottom.

Layer GIS type: polygons/isolines.

Attributes:

- Thickness of the MUA

Table 12 Thickness of the main useful aquifer classifiers for the Estonian-Latvian pilot area

Intervals of isolines of the thickness of the aquifer*
10 m

*Intervals of the isolines will be confirmed after collecting the data

Table 13 Thickness of the main useful aquifer classifiers for the Polish-Ukrainian pilot area

Intervals of polygons of the thickness of the aquifer
• 0–2 m absence MUA • 2–5 m • 5–10 m • 10–20 m • 20–40 m • > 40 m

4.2.5 Transmissivity of the main useful aquifer

Definition: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths.
polygons.

Layer GIS type: areas

Attributes:

- Transmissivity of the MUA

Table 14 Transmissivity classifiers for the Estonian-Latvian pilot area

Intervals of areas of the transmissivity*
50 m^2/d

*Intervals of the areas will be confirmed after collecting the data

Table 15 Transmissivity classifiers for the Polish-Ukrainian pilot area

Intervals of polygons of transmissivity of the aquifer
• 0–2 m^2/d absence MUA • 2–100 m2/d • 100–200 m^2/d • 200–500 m^2/d • > 500 m^2/d

4.2.6a The thickness of the impermeable layer over main useful aquifer

Definition: Isolines for the thickness of the impermeable layer over main useful aquifer.

Layer GIS type: isolines.

Attributes:

- Intervals of the thickness of the impermeable layer
- Stratigraphy of dominating sediments
-

Table 16 Thickness of the impermeable layer classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Intervals of the thickness of the impermeable layer	• Number	• <5m 5–10 10–20 20–40 40*
• Stratigraphy of dominating sediments	• Text	• Type of Quaternary sediments

*Intervals of the isolines will be confirmed after collecting the data

4.2.6b The insulation degree of main useful aquifer

Definition: The insulation degree of main useful aquifer - a qualitative index, which is established on the basis of the total thickness of low-permeable layers (k = 10-6-10-9 m/s) and practically impermeable (k < 10-9 m/s) located above the main useful aquifer.

Layer GIS type: polygons.

Attributes:

- Insulation degree of the MUA

Table 17 Insulation degree classifiers for Poland-Ukraine pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Intervals of polygons of the insulation degree of MUA	• Text	• a - no insulation / b - partial insulation / c - total insulation / ab - diversified the insulation degree with the dominance of class a and sub-class b / ba - diversified the insulation degree with the dominance of class b and sub-class a / bc - diversified the insulation degree with the dominance of class b and sub-class c / cb - diversified the insulation degree with the dominance of class c and sub-class b

4.2.7 Groundwater mineralization for main useful aquifer

Definition: Values of the mineralization in groundwater in the main useful aquifer, displayed by isolines.

Layer GIS type: isolines.

Attributes:

- Intervals of isolines of mineralization

Table 18 Groundwater mineralization classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Intervals of isolines of mineralization	• Number	• 0,5 g/l / 1,0 g/l*

*Intervals of the isolines will be confirmed after collecting the data

4.2.8 Groundwater bodies

Definition: According to the definition given in the Water Framework Directive, groundwater bodies include groundwater that occur in aquifers with porosity and permeability, enabling a significant uptake in water supply to the population or flow with an intensity significant for shaping the desired state of surface water and terrestrial ecosystems.

Layer GIS type: polygons.

Attributes:

- EU code of GWB;
- National code of GWB;
- Area of GBW;
- River basin
- Water region;
- Regional Water Management Authority;

- Main river;
- Number of the MUA;
- Stratigraphy of the MUA;
- Dominant chemical type of MUA water;
- The threat of anthropopressure;
- Type of anthropopressure;
- Area of groundwater dependent ecosystems;
- Area of protected areas;
- Diffuse pollution areas;
- Assessment of the quantitative status of GWB;
- Assessment of the chemical status of the GWB;
- Overall assessment of the state of the GWB;
- Year of the most recent GWB assessment;
- Risk assessment of failure to achieve environmental goals.

Table 19 Groundwater bodies classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• EU code of GWB	• Text	• EU code of GWB
• National code of GWB	• Text	• National code of GWB
• Area of GWB	• Number	• Area in km^2
• River basin	• Text	• Name of the river basin
• Main river	• Text	• Name of the main River Basin
• Stratigraphy of the MUA	• Text	• Q+Dar-am / Q+Dpl-og /Dar-am and Dpl-og
• Dominant chemical type of MUA waters	• Text	• Natural type (HCO3-Ca) / A type deviating from the natural (HCO3-SO4-Cl-Ca)
• Threat of pressures	• Text	• Yes / No
• WFD pressure types	• Text	• Point / Diffuse / Anthropogenic pressure – Other / Anthropogenic pressure – Unknown / Anthropogenic pressure – Historical pollution
• Area of groundwater dependent ecosystems	• Number	• Area in ha
• Area of protected areas	• Number	• Area in ha
• Diffuse pollution areas	• Text	• Areas prone to nitrate pollution from agriculture / urban areas
• Assessment of the quantitative status of GBW	• Text	• Good / Poor
• Assessment of the chemical status of the GBW	• Text	• Good / Poor
• Overall assessment of the state of the GBW	• Text	• Good / Poor
• Year of the most recent GBW assessment	• Number	• Year of the last assessment
• Risk assessment of failure to achieve environmental goals	• Text	• Endangered / not endangered

Table 20 Groundwater bodies classifiers for the Polish-Ukrainian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• EU code of GWB	• Text	• EU code of GWB
• National code of GWB	• Text	• National code of GWB
• Area of GWB	• Number	• Area in km^2
• River basin	• Text	• Name of the river basin
• Water region	• Text	• Name of the water region
• Regional Water Management Authority	• Text	• Name of the RWMA
• Main river	• Text	• Name of the main River Basin
• Number of the MUA	• Number	• Number
• Stratigraphy of the MUA	• Text	• Q / Ng / Pg / K
• Dominant chemical type of MUA waters	• Text	• Natural type (HCO3-Ca) / A type deviating from the natural (HCO3-SO4-Cl-Ca)
• Threat of anthropopression	• Text	• Yes / No
• Type of anthropopression	• Text	• Depression cones / mines / cities / mining drainage / salt water ingressions
• Area of groundwater dependent ecosystems	• Number	• Area in ha
• Area of protected areas	• Number	• Area in ha
• Diffuse pollution areas	• Text	• Areas prone to nitrate pollution from agriculture / urban areas
• Assessment of the quantitative status of GBW	• Text	• Good / Poor
• Assessment of the chemical status of the GBW	• Text	• Good / Poor
• Overall assessment of the state of the GBW	• Text	• Good / Poor
• Year of the most recent GBW assessment	• Number	• Year of the last assessment
• Risk assessment of failure to achieve environmental goals	• Text	• Endangered / not endangered

4.2.9 Springs

Definition: Natural, concentrated outflow of groundwater on the ground surface.

Layer GIS type: point.

Attributes:

- Terrain elevation;
- Stratigraphy of the captured aquifer;
- Flow rate.
- Name
- Link to national database

Table 21 Springs classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Terrain elevation	• Number	• Elevation in m a.s.l.
• Stratigraphy of the captured aquifer	• Text	• Q / Dpl-og / Dar-am / Dar-am and Dpl-og
• Flow rate	• Number	• Flow rate in l/s
• Name	• Text	• Name of spring
• Link to national database	• Text	• Link

Table 22 Springs classifiers for the Poland-Ukraine pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Terrain elevation • Stratigraphy of the captured aquifer • Flow rate	• Number • Text • Number	• Elevation in m a.s.l. • Q / Ng / Pg / K / J • Flow rate in l/s

4.2.10 Wells/ Boreholes

Definition: A borehole made to determine the hydrogeological conditions, groundwater exploitation, observation, etc.
In Estonian-Latvian pilot area, the wells with abstraction data for 2014-2019 (WP3 output reference).

Layer GIS type: point.

Attributes:

- National number of wells/borehole;
- Type of wells/borehole;
- Water type;
- Terrain elevation;
- Year when the borehole was made;
- Year of the liquidation of the borehole;
- Borehole depth;
- Stratigraphy bottom of the layer;
- The depth of the screen from…;
- The depth of the screen to…;
- Stratigraphy of the aquifer;
- The depth of the drilled groundwater level;
- The depth of the static groundwater level (b.g.l);
- Groundwater level (a.s.l).

Table 23 Wells/boreholes classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• National number of well • Type of borehole • Terrain elevation • Year when the borehole was made • Borehole depth • The depth of the screen from… • The depth of the screen to…. • Stratigraphy of the aquifer • The depth of the static groundwater level • Groundwater level	• Number • Text • Number • Number • Number • Number • Number • Text • Number • Number	• National number of well • Exploitation well / research well • Elevation in m a.s.l. • Year when the borehole was made • Depth in m b.g.l • Depth in m b.g.l • Depth in m b.g.l • Q / Dar-am / Dpl-og / Dar-am and Dpl-og • Depth in m b.g.l • Elevation in m a.s.l

Table 24 Wells/boreholes classifiers for the Poland-Ukraine pilot area

Attribute	Type of attribute	Unit or Dictionaries
• National number of borehole	• Number	• National number of borehole
• Type of borehole	• Text	• Exploitation borehole / research borehole
• Water type	• Text	• Ordinary / medicinal / mineral / thermal groundwater
• Terrain elevation	• Number	• Elevation in m a.s.l.
• Year when the borehole was made	• Number	• Year when the borehole was made
• Year of the liquidation of the borehole	• Number	• Year of the liquidation of the borehole
• Borehole depth	• Number	• Depth in m b.g.l
• Stratigraphy bottom of the layer	• Text	• Q / Ng / Pg / K / J
• The depth of the screen from…	• Number	• Depth in m b.g.l
• The depth of the screen to….	• Number	• Depth in m b.g.l
• Stratigraphy of the aquifer	• Text	• Q / Ng / Pg / K / J
• The depth of the drilled groundwater level	• Number	• Depth in m b.g.l
• The depth of the static groundwater level	• Number	• Depth in m b.g.l

4.2.11 Intakes

Definition: Groundwater intake - a set of devices used to abstract groundwater from one point, many points or from a certain area, supplying a specific user or for a specific purpose.
For the Estonian-Latvian pilot area, this parameter shows fields with approved water resources. In Latvia, the water resources are approved for abstractions over 100 m^3/d; in Estonia, over 500 m^3/d.
Intakes with approved exploitation resources of groundwater above 10 m^3 h will be presented on the Polish-Ukrainian pilot area.

Layer GIS type: point.

Attributes:

- National number of intake;
- Name of intake;
- Role of the intake;
- Stratigraphy of the aquifer;
- Exploitation resources;
- Capture zone/Protection zone
- Depression magnitude range for authorized resource;

Table 25 Intakes classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• National number of intake	• Number	• National number of intake
• Name of intake	• Text	• Name
• Role of the intake	• Text	• Communal (collective supply) / industrial / individual
• Stratigraphy of the aquifer	• Text	• Q / Dar-am / Dpl-og / Dar-am and Dpl-og
• Exploitation resources	• Number	• Resource volume in m^3/d
• Capture zone/Protection zone	• Number	• Extent in km

Table 26 Intakes classifiers for the Polish-Ukrainian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• National number of intake • Role of the intake • Stratigraphy of the aquifer • Exploitation resources • Depression magnitude range for authorized resources	• Number • Text • Text • Number • Number	• National number of intake • Communal (collective supply) / industrial / individual • Q / Ng / Pg / K / J • Resource volume in m^3/h • Size of depression in m b.g.l

4.2.12 Areas of depression cones

Definition: Zone of lowering the piezometric surface (groundwater table) caused by pumping or drainage of aquifers by intakes, mines, etc. Depression of regional importance, with an area of more than 50 km^2 or smaller ones with a mirror depression of more than 50 m.

Layer GIS type: polygons.

Attributes:

- Type of lowering the groundwater level;
- Drainage facility;
- Stratigraphy of the drained aquifer;
- Depression cone surface.

Table 27 Areas of depression cones classifiers for Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Type of lowering the groundwater level; • Drainage facility; • Stratigraphy of the drained aquifer; • Depression cone surface.	• Text • Text • Text • Number	• Cone from the exploitation of groundwater / Cone from mining drainage / decrease from melioration / decrease from land drainage • Name of the facility: water intake, mining plant, etc. • Q / Dar-am / Dpl-og / Dar-am and Dpl-og • Area in km^2

Table 28 Areas of depression cones classifiers for Poland-Ukraine pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Type of lowering the groundwater level; • Drainage facility; • Stratigraphy of the drained aquifer; • Depression cone surface.	• Text • Text • Text • Number	• Cone from the exploitation of groundwater / Cone from mining drainage / decrease from melioration / decrease from land drainage • Name of the facility: water intake, mining plant, etc. • Q / Ng / Pg / K / J • Area in km^2

4.2.13 Groundwater damming devices

Definition: Groundwater damming device, it is understood as a hydrotechnical device (dams, weirs, sills, gates - on rivers / streams) or other devices causing flow inhibition and damming of groundwater, i.e. raising of the groundwater table level.

Layer GIS type: point.

Attributes:

- Name of the river, lake on which the hydrotechnical device exists;
- Type of hydrotechnical device or other groundwater damming device.

Table 29 Groundwater damming devices classifiers for Poland-Ukraine pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Name of the river, lake on which the hydrotechnical device exists	• Text	• Name of the lake, river, or reservoir
• Type of hydrotechnical device or groundwater damming device	• Text	• Dams, weirs, sills, gates or other

4.2.14 Groundwater pollution site

Definition: Groundwater pollution site - artificial accumulation of pollutants (actual or potential) in groundwater. Pollution hotspots can be of various spatial nature: spot (drilling, petrol stations, warehouses), linear or strip (roads, pipelines), surface (landfills, sedimentation tanks, drainage and irrigation fields) and area (fertilization and chemicalisation of agriculture).
This work focuses on the pollution hotspots that are the most important for the research area, which are: wastewater treatment plants and waste landfills, including mining heaps.

Groundwater pollution site – wastewater treatment plants

Layer GIS type: point.

Attributes:

- Type of wastewater treatment plant;
- Capacity of the wastewater treatment plant;
- Type of wastewater;
- Wastewater receiver.

Table 30 Wastewater treatment plants classifiers for Poland-Ukraine pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Type of wastewater treatment plant;	• Text	• Mechanical / biological / chemical / biological-chemical / mechanical-biological / mechanical-chemical / mechanical-biological-chemical
• Capacity of the wastewater treatment plant;	• Number	• Maximum amount of sewage in m^3/day
• Type of wastewater;	• Text	• Municipal / industrial / municipal-industrial / agricultural / other / no data available
• Wastewater receiver.	• Text	• Name of the river, watercourse, drainage (filtration fields)

Groundwater pollution site – waste landfills

Layer GIS type: point.

Attributes:

- Landfill area;
- Waste storage method;
- Technical security;
- The origin of the stored waste;
- Type of waste deposited - hazard;
- The condition of the landfill;
- Year of the landfill closure;
- Groundwater monitoring;
- Known contamination of groundwater.

Table 31 Waste landfills classifiers for Poland-Ukraine pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Landfill area;	• Number	• Area in hectares
• Waste storage method;	• Text	• Above-level / sub-level / mixed / no data available
• Technical security;	• Text	• Leachate drainage / landfill bottom insulation / no data available
• The origin of the stored waste;	• Text	• Municipal / industrial / municipal-industrial / mining / no data available
• Type of waste deposited - hazard;	• Text	• Dangerous / non-hazardous / no data available
• The condition of the landfill;	• Text	• Open / not used / during liquidation / liquidated / closed without reclamation / closed during reclamation / closed reclaimed / closed-self-reclamation
• Year of the landfill closure;	• Number	• Closing year
• Groundwater monitoring;	• Text	• Yes / no / no data
• Known contamination of groundwater.	• Text	• Yes / no / no data

Groundwater pollution site

For both the Estonian and Latvian side of the transboundary area, spatial data prepared for RBMP (Pressure types in WFD Reporting Guidance 2022) will be used for this parameter and attribute table modified according to the attributes required for this parameter.

Layer GIS type: point

Attributes:
- Pressure type

Table 32 Groundwater pollution site classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Pressure type	• Text	• Pressure type from WFD Reporting Guidance

4.2.15 Groundwater vulnerability

Definition: Groundwater vulnerability is based on the concept that the natural environment provides protection to groundwater. The protection provided by different (hydro)geological conditions varies from one place to another.

Layer GIS type: polygons.

Attributes:
- Vulnerability class
- Aquifer type

Table 33 Groundwater vulnerability classifiers

Attribute	Type of attribute	Unit or Dictionaries
• Vulnerability class	• Text	• Very low/ Low / Average / High / Very high*
• Aquifer type	• Text	• Type of aquifer

*The number of vulnerability classes will be decided after the harmonization of methodologies

4.2.16 Groundwater monitoring points

Definition: a station with appropriate devices for measuring and sampling groundwater for repeated hydrogeological observations carried out over a longer period.

Layer GIS type: point.

Attributes:
- National number of point;

- WFD code
- Type of point;
- Type of groundwater level;
- Terrain elevation;
- Year of starting observations;
- Type of monitoring;
- Depth of observation well;
- The depth of the screen from;
- The depth of the screen to;
- Stratigraphy of the aquifer;
- The depth of the drilled groundwater level;
- The depth of the stabilized groundwater table.

Table 34 Groundwater monitoring points classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
National number of point;	Number	National number of point
WFD code	Number	International code (WFD)
Type of point;	Text	Piezometer / drilled well
Type of groundwater table;	Text	Confined / unconfined
Terrain elevation;	Number	Elevation in m a.s.l.
Year of starting observations;	Number	Year of starting observation
Type of monitoring;	Text	Quantitative / Chemical / Complex
Depth of observation well;	Number	Depth in m b.g.l
The depth of the screen from;	Number	Depth in m b.g.l
The depth of the screen to;	Number	Depth in m b.g.l
Stratigraphy of the aquifer;	Text	Q / Q / Dar-am / Dpl-og / Dar-am and Dpl-og
The depth of the stabilized groundwater level;	Number	Depth in m b.g.l
Groundwater level.	Number	Elevation in m a.s.l

Table 35 Groundwater monitoring points classifiers for the Polish-Ukrainian pilot area

Attribute	Type of attribute	Unit or Dictionaries
National number of point;	Number	National number of point
Type of point;	Text	Piezometer / drilled well
Type of groundwater table;	Text	Confined / unconfined
Terrain elevation;	Number	Elevation in m a.s.l.
Year of starting observations;	Number	Year of starting observation
Type of monitoring;	Text	Quantitative / Chemical / Complex
Depth of observation well;	Number	Depth in m b.g.l
Stratigraphy bottom of the layer;	Text	Q / Ng / Pg / K / J
The depth of the screen from;	Number	Depth in m b.g.l
The depth of the screen to;	Number	Depth in m b.g.l
Stratigraphy of the aquifer;	Text	Q / Ng / Pg / K / J
The depth of the drilled groundwater level;	Number	Depth in m b.g.l
The depth of the stabilized groundwater level.	Number	Depth in m b.g.l

4.2.17 Buried valleys

Definition: Area layer showing valleys filled with different sediments.

Attributes:

- Name

Table 36 Buried valleys classifiers for the Estonian-Latvian pilot area

Attribute	Type of attribute	Unit or Dictionaries
• Name	• Text	• Name of the buried valley

4.3 Cartographic presentation

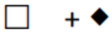
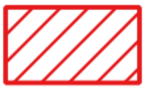
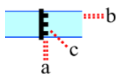
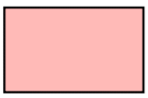
The cartographic work for hydrogeological maps consists of portraying the topographic and thematic information of the map by using a system of cartographic elements: points, polylines and areas. The graphic elements have variation by changing their density/tone, colour, orientation, size etc (Struckmeier and Margat, 1995).

Table 37 shows the cartographic presentation of the parameters on the unified hydrogeological map based on IAH-s guide and a standard legend for hydrogeological mapping (Struckmeier & Margat, 1995), and the guidelines given by INSPIRE Data specification on Geology – Technical Guidelines (https://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_DataSpecification_GE_v3.0.pdf).

Table 37 Cartographic presentation of the parameters for the unified hydrogeological map

Parameter	Object	Geometry type	Symbol	Description of the Symbol	International guide
Hydrogeological units of the main useful aquifer	Fractured	Area		RGB(255;173;178)	INSPIRE GE.Aquifer.MediaType
	Porous	Area		RGB(140;255;255)	INSPIRE GE.Aquifer.MediaType
	Karstic	Area		RGB(204;224;188)	INSPIRE GE.Aquifer.MediaType
	Compound	Area		RGB(255;211;127)	INSPIRE GE.Aquifer.MediaType
	Karstic and fractured	Area		RGB(191;191;255)	INSPIRE GE.Aquifer.MediaType

	Porous and fractured	Area		RGB(155;255;153)	INSPIRE GE.Aquifer.MediaType
	Aquiclude - unconsolidated	Area		RGB(237;212;153)	INSPIRE GE. Aquiclude.Constitution OfAquiclude
	Aquiclude - Consolidated (rock)	Area		RGB(217;178;140)	INSPIRE GE. Aquiclude.Constitution OfAquiclude
	Aquitard	Area		RGB(140;180;226)	INSPIRE GE.Aquitard. ConstitutionOfAquitard
Depth to the main useful aquifer	Intervals of the main useful aquifer depth	Area	Pattern fill	To be defined in the Output "Coherent spatial database for the EU-Waterres platform"	
	Intervals of the main useful aquifer depth	Polyline		Line width: 1 px Line style: solid RGB(0;0;0)	
Hydroisohypses of the groundwater head of the main useful aquifer	Isolines of the hydroisohypses			Line width: 1 px Line style: solid RGB(128;0;140)	Struckmeier & Margat (1995) 1.1 contours of the potentiometric surface
Thickness of the main useful aquifer	Intervals of the main useful aquifer thickness	Area	Pattern fill	To be defined in the Output "Coherent spatial database for the EU-Waterres platform"	
	Intervals of the main useful aquifer thickness	Polyline		Line width: 1 px Line style: solid RGB(0;0;0)	
Transmissivity of the main useful aquifer	Intervals of the main useful aquifer transmissivity	Area	Pattern fill	To be defined in the Output "Coherent spatial database for the EU-Waterres platform"	
	Intervals of the main useful aquifer transmissivity	Polyline		Line width: 1 px Line style: solid RGB(0;0;0)	
The thickness of the impermeable layer over main useful aquifer	Intervals of the impermeable layer thickness	Area	Pattern fill	To be defined in the Output "Coherent spatial database for the	

				EU-Waterres platform”	
	Intervals of the impermeable layer thickness	Polyline		Line width: 1 px Line style: solid RGB(0;0;0)	
The insulation degree of main useful aquifer	Intervals of the insulation degree of main useful aquifer	Area	Pattern fill	To be defined in the Output “Coherent spatial database for the EU-Waterres platform”	
Groundwater mineralization for main useful aquifer	Intervals of the main useful aquifer mineralization	Polyline		Line width: 1,5 px Line style: solid RGB(198;108;0)	Struckmeier & Margat (1995) 2.2 isolines of equal groundwater salinity
Groundwater bodies		Polyline		Line width: 1 px Line style: solid RGB(0;0;0)	INSPIRE GE.GroundWaterBody
Springs		Point		ESRI Caves 2/249/14 RGB(90;0;90)	Struckmeier & Margat (1995) 1.10 perennial karst spring
Wells/ Boreholes		Point		RGB(0;0;0)	INSPIRE 165-w2
Intakes		Point		RGB(0;0;0)	INSPIRE 163-w2 + 174-w2
Areas of depression cones		Area		RGB(255;0;0)	
Groundwater damming devices		Point		Line width: a- 2 px; b,c -1,5 px Line style: solid	Technical standards for creating cartographic thematic studies in the field of 1: 10,000 scale hydrographic maps
Groundwater pollution site		Point			EU Waterres Output2: Integrated groundwater observation network in Latvian-Estonian transboundary area
Groundwater vulnerability	Very high	Area		RGB(255;141;137)	Duda R., Witczak S., Żurek A., 2011. Mapa wrażliwości wód podziemnych Polski na zanieczyszczenie. 1:500 000: Metodyka i objaśnienia tekstowe. AGH, Kraków
	High	Area		RGB(255;186;183)	Duda R., Witczak S., Żurek A., 2011. Mapa wrażliwości wód podziemnych Polski na zanieczyszczenie. 1:500 000: Metodyka i objaśnienia tekstowe.

					AGH, Kraków
	Medium	Area		RGB(255;255;172)	Duda R., Witczak S., Żurek A., 2011. Mapa wrażliwości wód podziemnych Polski na zanieczyszczenie. 1:500 000: Metodyka i objaśnienia tekstowe. AGH, Kraków
	Low	Area		RGB(198;232;171)	Duda R., Witczak S., Żurek A., 2011. Mapa wrażliwości wód podziemnych Polski na zanieczyszczenie. 1:500 000: Metodyka i objaśnienia tekstowe. AGH, Kraków
	Very low	Area		RGB(245;210;137)	Duda R., Witczak S., Żurek A., 2011. Mapa wrażliwości wód podziemnych Polski na zanieczyszczenie. 1:500 000: Metodyka i objaśnienia tekstowe. AGH, Kraków
Groundwater monitoring points	Quantity	Point			INSPIRE 162-w2 + 178-w
	Quality	Point			INSPIRE 181w
	Complex	Point	Point	To be defined in the Output "Coherent spatial database for the EU-Waterres platform"	
Buried valleys		Area		RGB(0;0;0)	

References

Aller L., Bennett T., Lehr J.H., Petty R.J., Hackett G., 1987 – DRASTIC: A standardized system for evaluating groundwater pollution potential using hydrogeologic settings. Doc. EPA/600/2-87/035. United States Environmental Protection Agency (USEPA), Washington, 622 p.

Anon A., 1963 – International legend for hydrogeological maps. UNESCO Document NS/NR/20., Paris, 32 p.

Anon A., 1970 – International legend for hydrogeological maps. UNE3SCO/IASHIIAH/Institute of Geol. Sciences, London, 101 p.

BGR - Projects - IHME1500 - International Hydrogeological Map of Europe 1:1,500,000 (bund.de)

BGR - WHYMAP - Groundwater Resources of the World

BGR - WHYMAP objectives

Dowgiałło, J. Kleczkowski, A. S., Macioszczyk, T., Różkowski, A., 2002 – Słownik hydrogeologiczny (Hydrogeological Dictionary). Polish Geological Institute. Warsaw.

Draft articles on the Law of Transboundary Aquifers, 2008.

Duda R., Witczak S., Żurek A., 2011. Mapa wrażliwości wód podziemnych Polski na zanieczyszczenie. 1:500 000: Metodyka i objaśnienia tekstowe. AGH, Kraków, 138 p.

Hellestveit, M. S., 2018. 3D-modellering av grunnvannstrømning og varmetransport i akviferen i Melhus sentrum. En kvartær- og hydrogeologisk tolkning, med vurdering av uttakskapasitet (3D modeling of groundwater flow and heat transport in the aquifer in the center of Melhus. A Quaternary and hydrogeological interpretation, with assessment of extraction capacity). Phd thesis, NTNU, pp. 154.

IGRAC, (n.d.). Groundwater Glossary. International Groundwater Resources Assessment Centre (IGRAC). https://www.un-igrac.org/groundwater-glossary

INSPIRE, (2014). INSPIRE Maintenance and Implementation Group (MIG) (2014): INSPIRE glossary. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-10109-glossary

Instructions, (2004). Instructions for sharing, updating, verifying and developing the Hydrogeological Map of Poland (2004)

Krogulec E., 2004 – Assessment of groundwater vulnerability to pollution in the river valley on the basis of hydrodynamics. Publ. of Warsaw Univ., Geology, 178 p.

Robins N., Adams B., Foster S., Palmer R., 1994 – Groundwater vulnerability mapping: the British perspective. Hydrogeologie, 3: 35–42.

Roseth, R., Kværner, J., Rognan, Y., Reinemo, J., Mæland, T., 2018. Overvåking av grunnvann påvirket av jordbruk Haslemoen, Rimstadmoen, Horpestad og Lærdal (Groundwater monitoring affected by agriculture Haslemoen, Rimstadmoen, Horpestad and Lærdal). NIBIO RAPPORT, VOL. 4, No. 117, 2018, pp. 34.

Słownik hydrogeologiczny, 2002. Państwowy Instytut Veologiczny, Warszawa. (E:\Słownik\hasla do internetu.vp (mos.gov.pl)).

Struckmeier W., Margat J., 1995 – Hydrogeological maps: a guide and a standard legend. International Association of Hydrogeologists, Hannover, p. 178.

Technical standards for creating cartographic thematic studies in the field of 1: 50,000 scale hydrographic maps Poland (2005)

Transboundary Aquifers of the World. Edition 2015, 1 : 50 000 000, TBAmap_2015.pdf (un-igrac.org)

Vrba J. & Zaporozec A. (eds), 1994 – Guidebook on mapping groundwater vulnerability. IAH InternContribution to Hydrogeology,v.16, Hannover, Heise Verlag, 131 p.

www.wetlands.org/rsis

Zasady, (2005). Zasady rejonizacji hydrogeologicznych warunków występowania pierwszego poziomu wodonośnego (Principles of hydrogeological zoning of the occurrence of the first aquifer), PIG-PIB, 2005