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Program of cross-border groundwater monitoring for Polish-Ukrainian and Estonian-Latvian transboundary areas

June 2022

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.

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Document summary

This report is an attempt to establish joint monitoring and assessment programs for transboundary groundwater reservoirs for two pilot areas - the Polish-Ukrainian and Estonian-Latvian border areas. The recommendations were developed taking into account the guidelines of national legislation and the requirements of the EU law and the 1992 UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes. The report focuses mainly on how to harmonize the monitoring results and use comparable evaluation methods and data management systems as well as uniform reporting procedures. The program aims to assist national authorities responsible for groundwater monitoring in the implementation of the cross-border monitoring. In addition, the key target group are institutions responsible for the management of transboundary groundwater reservoirs at the national and international levels as well as organizations responsible for environmental issues in terms of transboundary impacts.

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Preface

This transboundary groundwater monitoring program is a continuation of the work carried out in an earlier stage of the project *"EU-WATERRES: EU-integrated management system of cross-border groundwater resources and anthropogenic hazards"*, in the framework of the study: "Integrated groundwater observation network between neighboring countries for 2 transboundary aquifers”. The implementation of this action was completed in December 2021. The development of a transboundary groundwater monitoring program for two pilot areas - Polish-Ukrainian and Estonian-Latvian is the first attempt to integrate international approaches to the issue, taking into account both the recommendations of European Union law and guidelines of national legislation.

The basic requirement under the 1992 UNECE Convention on the protection and use of transboundary watercourses and international lakes is the establishment of joint programs for monitoring and assessing the status of transboundary waters, including groundwater. These assessments are necessary for the integrated management of water resources in transboundary basins shared by two or more countries. A common decision base that requires harmonized and comparable evaluation methods and data management systems, and uniform reporting procedures is needed.

The specificity of transboundary groundwater monitoring is tracking the effects of interconnections of the transboundary hydrogeological system in natural and anthropogenically changed conditions in order to prevent the development of adverse transboundary impacts. The main tasks of cross-border monitoring include the provision of information on: a) the direction and intensity of the transboundary groundwater flow; b) compliance with the conditions for sustainable abstraction of common groundwater resources; c) cross-border migration of pollutants.

This program has been developed for the purpose of assessing the state of transboundary groundwater reservoirs on the basis of internationally harmonized principles. The presented recommendations concern the establishment of a common scope and frequency of measurements and tests as well as reference methodologies, conditions for ensuring the quality of measurements and tests for individual indicators.

Work on the report was coordinated by Latvian Environment, Geology and Meteorology Centre as part of work package 3 - Developing of methodology of harmonized monitoring of groundwater in 2 pilot areas. The guidelines were developed by working groups representing the national entities responsible for groundwater monitoring in 4 countries:

- Estonia **-** Geological Survey of Estonia (*Group Leader Andres Marandi*);
- Latvia - Latvian Environment, Geology and Meteorology Centre (*Group Leader Jekaterina Demidko*);
- Ukraine – Zahidukrgeologiya (*Group Leader: Dmytro Panov*) and Ukrainian Geological Company (*Group Leader: Volodymyr Klos*);
- Poland - Polish Geological Institute (*Group Leader: Tomasz Gidziński*).

T. Solovey

June 2022,
Tatiana Solovey,
Coordinator EU-WATERRES
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Abbreviations

CIS – Common Implementation Strategy

DPSIR – Driver, Pressure, State, Impact, and Response

EEA - European Environment Agency

EC – European Commission

EU – European Union

GIS - Geographic Information system

GWB – Groundwater body

IGRAC - International Groundwater Resources Assessment Centre

NGO - Non-governmental organization

NVZ – Nitrate vulnerable zone

PFAS - Perfluoroalkyl and Polyfluoroalkyl Substances

RBMP – River Basin Management Plan

TBA – Transboundary aquifer

UNECE – United Nations Economic Commission for Europe

WFD – Water Framework Directive (2000/60/EC)

Introduction

Obtained information on groundwater, based on well-organized groundwater monitoring programs, is a key prerequisite for accurately assessing the state of groundwater resources and the extent of water problems. These assessments are essential to prepare appropriate policy measures at local, national and cross-border levels. In addition, the integrated management of groundwater resources in a transboundary area shared by two or more countries requires comparable information. A common decision-making framework is needed, which requires harmonized and comparable assessment methods and data management systems, as well as common reporting procedures.

Monitoring is undoubtedly a key aspect to support decision-making processes and successfully implement transboundary aquifer management strategies. Before the implementation of this project, the cross-border aspect of none of the territories under review (Poland-Ukraine and Latvia-Estonia) was not looked at in detail and the monitoring observations carried out in the border area were not coordinated between the countries.

The transboundary monitoring program is a continuation of the work carried out at an earlier stage of the project *"EU-WATERRES: EU-integrated management system of cross-border groundwater resources and anthropogenic hazards"*, as part of the study: *"Integrated groundwater observation network between neighbouring countries for 2 transboundary aquifers"*. The development of a transboundary groundwater monitoring program for the Polish-Ukrainian area is the first attempt to approach the issue in such a comprehensive manner, taking into account both the recommendations of European Union law and the guidelines of national legislation. The activities carried out earlier in the scope of expanding the groundwater monitoring observation network covered the border area only on one side of the border and were not carried out in a coordinated manner in cooperation by experts from Poland and Ukraine.

The recommendations of solutions and the proposals presented in the research program constitute an original approach to the subject matter in question regarding the expansion of the research monitoring network and the development of groundwater monitoring studies in the region of the Polish-Ukrainian border. It should be emphasized that more detailed guidelines in the scope described above require further, ongoing exchange of information and data, e.g. on the impacts (including anthropogenic pressures) of a transboundary nature, the amount of groundwater abstraction, data on the geological structure and hydrogeological conditions in the transboundary context, as part of the continuation of Polish-Ukrainian international cooperation.

On the other hand, the development of a cross-border groundwater monitoring program in the Latvian-Estonian zone is the first attempt to coordinate monitoring activities in the border area, taking into account the current groundwater monitoring principles and recommendations of EU law, as well as the guidelines of national legislation. The recommendations on the improvement of the cross-border underground water observation network and the developed monitoring strategy, which were laid out in the prepared report, also started the future close international cooperation between Latvia and Estonia.

1. Legal bases for transboundary groundwater monitoring

1.1 Strategy organization and functioning of cross-border groundwater monitoring

Groundwater accounts for almost 98% of the world's freshwater resources and its importance will only grow with the increasing urbanization and climate change. Especially challenging task is to manage shared groundwater resources, namely transboundary aquifers, which crosses one or more international political borders and have significant cross-border flows. The first task is to delineate vertical and horizontal boundaries of TBAs, that is often based on limited data and borders should be revised iteratively when new data are gathered. Later, the knowledge must be translated to conceptual models that should support the design of cross-border groundwater monitoring networks and indicate locations and frequencies for gathering the necessary data. Finally, this process can underpin science-based policy implementation and integrated water resources management (IWRM). To maintain a healthy groundwater environment various and complex attempts have to be made: structural (e.g., construction of a monitoring network, artificial recharge ponds, remediation measures, and development of information and decision systems), institutional (reforms, delegated tasks), or political and regulatory. The response can also come from different actors such as government, NGOs, academia, individuals, and local communities.

In this document the emphasis will be made on managing sedimentary aquifer systems that are common in EU-WATERRES project's two pilot areas - Polish-Ukrainian and Estonian-Latvian transboundary aquifers. The identification of TBAs and development of conceptual models has been carried out in previous steps (see EU-WATERRES previous outputs https://eu-waterres.eu/news-resources/resources/). While this document builds on previous TBAs assessment outcomes to design targeted cross-border groundwater monitoring strategies for pilots for current status assessment of shared groundwater resources, as well as suitable to provide necessary data for modeling of various future scenarios (e.g. increased groundwater consumption or reduced groundwater recharge as a result of climate change).

1.1.1. Fundamentals for planning the cross-border groundwater monitoring based on conceptual understanding

Groundwater resources are more prone to quick changes and less vulnerable (mostly) to anthropogenic pressure in contrast to surface water. However, negative trends of groundwater quantity (available resources) and quality (chemical composition) are also slow processes that can occur below large land areas. Such negative changes cannot be easily observed by one measurement or survey and timely identification requires more elaborated monitoring networks and data interpretation. *The major aim of transboundary groundwater monitoring is to control the impacts of groundwater abstraction (quantitative status) and contaminant pressure (qualitative status) that can have a cross-border nature.*

Cross-border groundwater monitoring networks must be designed in a way to provide necessary data for objective evaluation of groundwater issues, such as application of the DPSIR framework. DPSIR is a widely used tool to provide and communicate knowledge on the state and causal factors regarding environmental issues. The five components in the framework are related by logical relations: drivers that generate pressure; pressures influence/modify state; states provoke or cause impacts; impacts stimulate or ask for responses; and responses modify or substitute drivers, eliminate/reduce/prevent pressures, restore/influence states, and compensate or mitigate impacts.

Groundwater status is determined by natural (geology, climate) and human activities (abstraction, pollution) and many of the pressures and the underlying driving forces are common to all or some of the issues. For instance, agricultural activity is a significant force in terms of ecosystems ecological quality, nutrient enrichment, hazardous substances (mostly pesticides) and water quantity. Table 1 summarizes how indicators vary according to quantitative and qualitative pressures on groundwater.

Table 1. DPSIR framework for analyzing qualitative and quantitative pressures on water (adapted from Pandey and Shrestha, 2016 with emphasis on groundwater issues)

DPSIR components	General indicators	Indicators for quantity issues	Indicators for quality issues
Drivers	• Geology • Natural vulnerability • Climate • Agriculture • Aquaculture • Industry • Energy • Population • Tourism	• Industry • Energy • Agriculture • Aquaculture • Population • Tourism • Climate	• Industry • Agriculture - livestock density and fertilizer/ pesticide usage • Population - wastewater treatment • Historical pollution (brown fields etc.)
Pressures	• Point source pollution • Diffuse source pollution • Water abstraction • Physical intrusions • Climate change	• Total abstraction • Sectoral water use: household, industry, agriculture etc. • Climate change.	• Discharge from point source (type) • Atmospheric deposition • Loads to coastal water • Nitrogen balance
State	• Water quantity • Surface water status • Ecological status • Chemical • Physical • Biological	• Available groundwater resources	• Pollutants in groundwater (e.g.nitrogen, phosphorus) • Pollutants in connected and associated ecosystems (like lakes, rivers, wetlands and marine waters) where groundwater discharge
Impacts	• Loss of habitats/ species • health problems • Droughts/ floods • Salinizatio • Loss or reduction of ecosystem services (e.g. water purification) • Eutrophication	• Declining groundwater levels • Freshwater shortage • Modification of stream flows (dependent ecosystems) • Saltwater intrusion	• Exceedance of standards (threshold values) for drinking water and bathing water • Large scale aquifer pollution that reduce its usage possibilities without pretreatment • Secchi depth in lakes (associated aquatic ecosystems) • Low oxygen in bottom layers of marine waters • Harmful phytoplankton in coastal waters
Responses	• Water use restrictions • Artificial recharge	• Groundwater usage permits and control based on resources	• Measures to reduce nonpoint sources (agriculture)

	• Alternative supplies/ aquifers • Subsidized water prices • Improved information • Demand-side management • Voluntary agreements • Regional cooperation • Wastewater treatment	assessment (e.g. by hydrodynamic model) • Timely and active control mechanisms set by national law • Charging price for water • Increasing water use efficiency • Reducing water leakages	• Voluntary good agricultural praxis • Wastewater treatment (households and industry) and control • Restrictions to apply fertilizers in vulnerable areas and certain time periods • Citizen education through campaigns and citizen science tools (e.g. voluntary spring monitoring)

Subsurface environmental problems can be grouped into two large parts: changes in groundwater quantity and quality. It is important to highlight that the cause-and-effect relationship between urban development and subsurface environment can have direct and indirect links that can be extremely challenging to identify, interpret or quantify (see Figure 1). For instance, the changes in groundwater quantity such as decreased groundwater level can lead to subsequent groundwater quality issues such as salinization of freshwater aquifers. The response (R) component in the center (Figure 1) indicates that responses to subsurface environmental problems are directed either to driving forces, pressure, state or impacts, or to a combination of these components.

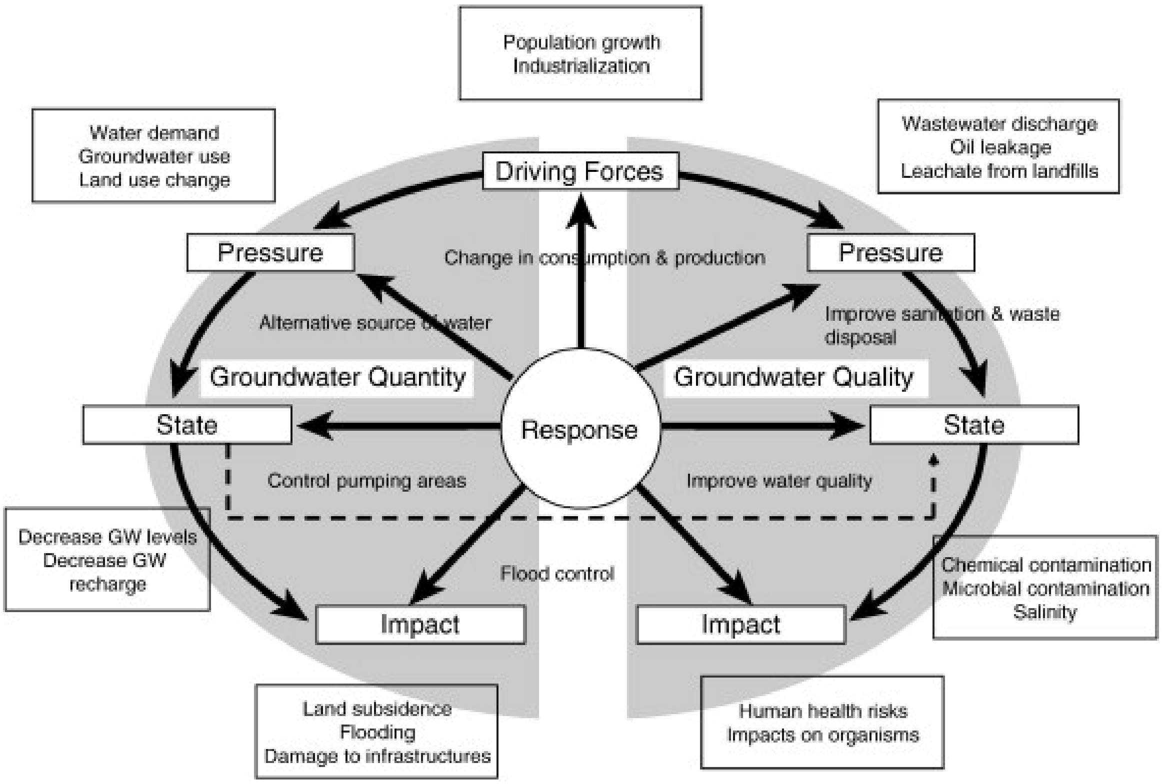


Figure 1. DPSIR Framework for Subsurface Environment Problems (Jago-on et al, 2009)

Transboundary groundwater monitoring networks must cover at least hotspots, but for evaluation needs the network should include the whole potential pollutant path - recharge (intrusion), transport and discharge areas. This path is a component of conceptual understanding for TBAs or conceptual models. Sustainable groundwater management should include not only the recognition of the current state, but preventive measures and forecasts (e.g. migration of historical pollution or climate change impacts). For this reason, so-called “baseline” groundwater stations can be established typically containing long and continuous groundwater level and chemical composition observations with no anthropogenic pressures.

Table 2. Generic set of indicators used for evaluation groundwater status (adapted from Pandey and Shrestha, 2016 with emphasis on transboundary groundwater issues)

Components	Indicators
Drivers	• Population growth (density and growth rate) • Migration or urbanization • Tourism • Economic growth (industrial and agricultural development) • Climate change
Pressures	• Increase in water demand • Inadequate surface water supply • Increase in groundwater abstraction • Land use changes • Occupational shift • Wastewater discharge • Leachate from landfill sites (historical legacy)
States	• Well statistics • Groundwater abstraction (volume or quantity) • Chemical and microbial contamination • Groundwater level • Groundwater recharge • Legal framework and institutions
Impacts	• Deterioration of groundwater quality (exceeded thresholds) • Decline in groundwater level • Land subsidence • Human health risk • Decline in production capacity of wells • Modification of stream flows • Saltwater intrusion • Poor quality of dependent ecosystems and reduced ecosystem services
Responses	• Groundwater monitoring (quality, level) • Alternative water resources • Change in consumption and production • Improved sanitation and waste disposal • Control in pumping areas, permits • Increasing water use efficiency and connection to centralized water supply • Application of advance technology • Environmental standards and guidelines • Transboundary cooperation and regular, international knowledge exchange

A comprehensive summary table to assess status of transboundary groundwater resources is presented in Table 2. The relevant DPSIR indicators can be easily identified through literature review. Each indicator can be discussed and interpreted in terms of spatial and temporal trends, their ranges, and interlinks with other indicators and data availability and limitations. It is especially important to take into consideration all archive materials and indirect information (stakeholders surveys) when developing a joint knowledge base. Such information can suggest where certain historical pressures could be located and with what possible types of contaminants you have to deal with. All in all, that will save time and money in the long term.

1.1.2. Requirements for transboundary groundwater monitoring

The evaluation of groundwater quantitative and qualitative status requires usage of various data types that can be direct and indirect groundwater descriptors. In Table 3, the column "time-dependent data" accounts for what is usually considered groundwater monitoring. Therefore, groundwater monitoring comprises the collection, analysis and storage of a wide range of data on a regular basis according to the monitoring objectives. The type and volume of required dataset can vary considerably based on the management issue (e.g. general status assessment, control of seawater intrusion or climate change forecasts). Inevitably, groundwater monitoring depends upon available financial resources, institutional capacity and political aspects.

Table 3. Types of data required for groundwater management (modified after GW MATE, 2006)

Data type	Baseline data (from national archives/databases)	Time-dependent data (from monitoring networks)
Groundwater occurrence and aquifer properties	• water well records (hydrogeological logs, instantaneous groundwater levels and quality) • well and aquifer pumping tests	• groundwater level monitoring • groundwater quality monitoring
Groundwater use	• water wellfields (using > 100 m^3/d) or small abstractions (>10 m^3/d) • water-use inventories • population registers and forecasts • consumption for irrigation	• water well/wellfields abstraction monitoring (direct or indirect) • well groundwater level variations
Supporting information	• climatic data • land-use inventories (national or international) • geological maps/sections • natural vulnerability mapping	• riverflow gauging • meteorological observations • satellite land-use surveys • climate forecasts and scenarios

There are two main types of wells that form the basis for groundwater monitoring. First, **abstraction wells** usually provide a wide coverage dataset of productive aquifers and water quality being used for water supply. However, data collected from operational water wells are normally more difficult to interpret, because groundwater levels are affected by the drawdown-recovery cycle and pumped-sample quality reflects the variable mixing of groundwater from a wide range of aquifer depths and residence times. Such wells do not provide information about static groundwater levels that are necessary to assess natural conditions and e.g. climate change impacts. Near-natural groundwater levels can be obtained if pumping is stopped for a specific time period prior to the groundwater level measurement, a hydrogeological understanding of the site is needed to determine the needed time period to account for groundwater level recovery.

Second type are **observation wells** - these are dedicated monitoring stations installed with the aim to detect potential changes in groundwater flow and quality, have well known site descriptions (geology, aquifers parameters), usually have valuable long term continuous observations and sometimes are installed nearby at different depths (nested piezometers or well clusters) and in very deep (brines) or impacted aquifers (seawater intrusion affected). Observation wells typically are installed in key locations according to their monitoring task. However, such wells are usually much less in numbers if compared to abstraction wells and their spatial coverage might be limited.

Often, the coverage of monitoring points in the existing groundwater monitoring networks is scarce in the peripheral areas and the installation of new wells is a long and costly process, or even economically unreasonable (if very deep aquifers should be monitored). **Springs** are natural groundwater outflows that can fill gaps in monitoring networks in specific cases. Monitoring springs can be a cost-effective solution that eases water sampling, moreover, their water can provide information on a significantly larger catchment area than monitoring wells. Watersheds should be estimated for monitoring springs to improve their representativeness. However, spring sites cannot be selected like monitoring wells due to their natural (un)availability, so selecting the best springs requires a thorough preliminary assessment.

A good conceptual understanding of the recharge area is a prerequisite for the selection of suitable monitoring springs, therefore prescreening of a variety of geochemical indicators at an early stage is strongly advised (such as field parameters, major ions, biogenic and trace elements, water stable isotopes). Some springs must be sampled more than once to assess seasonal variability if they represent unconfined aquifers (could be assessed based on geochemical screening results). It is advised to use statistical approaches (e.g. multivariate statistics) in combination with watershed delineation and assessment (such as verification of watersheds using discharges vs precipitation analysis, or land use assessment to identify the conditions that spring represents) to select springs most suitable for filling gaps in transboundary groundwater monitoring network. Even though groundwater levels cannot be measured in springs, they can be equipped with manual or automatic discharge measurer - v-notch weir, to observe water quantity and resource changes over time.

Monitoring networks and systems are often classified into three groups (see Table 4), and are specifically designed and operated to:

- detect general changes in groundwater flow and trends in groundwater quality, and bridge gaps in scientific understanding of the groundwater resource base (*Primary Systems*).
- assess and control the impact of specific risks to groundwater (*Secondary and Tertiary Systems*).

Table 4. Classification of groundwater monitoring systems by function
(modified after GW MATE, 2006)

System	Basic function	Well/ spring locations
Primary (Reference Monitoring)	General groundwater status assessment: • trends resulting from land-use change and climatic variation • processes such as recharge, flow and diffuse contamination	• in uniform areas with respect to hydrogeology and land use according to monitoring program developed based on regional conceptual model (groundwater body scale)
Secondary (Protection Monitoring)	Protection against potential impacts of following: • strategic groundwater resource • wellfields for public water supply • archaeological sites against rising water table • groundwater-dependent ecosystems	• around areas/ facilities/ features requiring protection to monitoring program developed based on local conceptual model
Tertiary (Pollution Containment)	Early warning of groundwater impacts from: • intensive agricultural land use • industrial sites • solid waste landfills • land reclamation areas • quarries and mines	• immediately down and up-hydraulic gradient from hazard according to monitoring program developed based on local conceptual model

1.1.3. Organization of cost-effective transboundary groundwater monitoring

The two requirements for effective groundwater (also transboundary) monitoring network are:

1. *It should be driven by a specific objective* - monitoring for its own sake often leads to inefficient use of manpower and budgets.
2. *The data collected should be systematically stored* for future use (and exchange with neighboring countries) and data from archives must be digitized.

Development and maintenance of groundwater monitoring is expensive. The main components of expenditure are network installation, sampling (instruments, personal, logistics) and analytical costs. Moreover, data processing and storage should also be accounted for. However, groundwater monitoring is an integral part of sustainable resource management and avoids loss of valuable water supply sources and dependent ecosystems, the introduction of costly treatment or the need for expensive aquifer remediation.

Table 5. Rules for development of effective transboundary groundwater monitoring through smart network design, system implementation and data interpretation (modified after GW MATE, 2006)

Network design	• objectives must be defined and program adapted accordingly • groundwater flow system must be understood • sampling locations and monitoring parameters must be selected by monitoring objectives (based on conceptual understanding)
System implementation	• appropriately-constructed observation and abstraction wells must be used • field equipment and laboratory facilities must be appropriate to objectives • a complete operational protocol and data handling system must be established • groundwater and surface water monitoring should be integrated where applicable • locations of areas of interest (drinking water protected areas, nitrate vulnerable areas or locations of groundwater dependent ecosystems) should be taken into account where possible
Data interpretation	• data quality must be regularly checked through internal and external controls • decision makers should be provided with interpreted management-relevant datasets • program should be periodically evaluated and reviewed • statistical approaches (e.g. multivariate statistics) should be used to ease the overall assessment of the annual results

The effectiveness of groundwater monitoring (network and programme) can be increased by implementation of some basic success rules summarized in Table 5. Addition rules that could improve the design and functioning of transboundary groundwater monitoring summarized from cooperation experiences are:

- When planning and designing groundwater monitoring programmes it is important to select monitoring stations (where possible) that are easily accessible and plan the joint sampling of nearby stations to reduce travel costs and contribute to greener design principles (reduce CO_2 emissions).
- The balance between costs of three major parts in the water monitoring programme (sampling, laboratory analysis and data evaluation) should be achieved. If one of the three parts is inadequately funded, then investments in two other parts are wasted. For example, often samples are collected and analyzed in the laboratory, but results are not properly evaluated on a regular basis. Monitoring only for the purpose of monitoring is not useful: a conceptual hydrogeological model should be developed for each groundwater monitoring station, defining the purposes of the monitoring, justifying parameters to be monitored.
- Parameters to be monitored by national groundwater monitoring networks should be related to the type of (potential) pressure. Targeted monitoring is cost-effective (both

money and time) and provides relevant, site specific data for future assessment needs (analysis). Wise planning of monitoring is necessary to consider knowledge on the current situation and planned land/ resource use intentions (potential impacts).

- Groundwater monitoring, weather stations and surface water monitoring stations should be at the same or close-by locations, so the preference is given to sites where these conditions can be met.
- Collection of water samples is time consuming and expensive, thus the number of measured parameters could be increased providing extra useful information at nearly the same costs. For example, ion chromatography can determine multiple parameters on a single sample run without extra expenses, but often only a short list of parameters is reported and stored in national databases according to monitoring programs. The communication between experts working on development of monitoring programs, further data analysis and laboratories performing the sample analysis should be improved.

1.1.4. Quantitative groundwater monitoring and its challenges

Assessment of quantitative status of groundwater can be achieved by collection of direct and indirect data:

- Direct monitoring of groundwater abstraction in individual operation water supply wells by means of meters. The readings (for abstraction amounts >10m^3/d) are typically made by the water user and submitted to regulatory institutions. After this can be summarized and compared with calculated groundwater resources in the area, e.g. by using hydrodynamic modeling and balance estimation.
- Measuring spring discharge can improve the understanding of the functioning of an aquifer and the availability of groundwater resources, including sustaining groundwater dependent ecosystems. The amount of water discharged from a spring is expected to vary seasonally, thus, in order to get a detailed overview of the dynamics of groundwater flow, it is necessary to carry out measurements in all seasons. The measurements can be made manually or automatically by water management authorities, but also can be obtained through citizen science and engagement of the public (like a voluntary spring monitoring campaign by Interreg WaterAct project). Long term spring discharge measurements are a crucial source for assessing climate change impacts.
- Indirect groundwater abstraction data can be obtained from collection of indicative data - e.g. estimation of water used for irrigation through hours of pump operation (obtained from energy consumption) multiplied by average pumping rate. The use of remote sensing data - satellite or airborne sensors can also support the assessment, but typically for large areas with quasi-continuous cover at low cost per km^2. Finally, at regional levels the groundwater abstraction (or at least trends) can be estimated from demographic changes and random checks on per capita water use.

Manual or automatic groundwater level observations that provide information on the changes of groundwater levels and their trends due to natural or anthropogenic impacts, and are vital to carry out time series analysis or develop hydrodynamic models to calculate aquifer budget.

Operation of a monitoring network requires human resources and logistical investments, together with clear, documented procedures to assure the continuous generation of good quality dataset. Lack of these resources is often a constraint in maintaining the necessary level of data collection and quality control. Delegation of monitoring responsibility to the local level with self-monitoring by water users can help to overcome this problem, but it is important to keep the controlling function and provide clear and easy to understand guidelines (e.g. via financed training).

Groundwater level data storage is an important component of groundwater quantitative monitoring and should be used not only to verify and interpret results annually, but already at an early stage, e.g in field conditions. The flow of data from the field stations to the database should be assured, and qualified personnel be available to review data collected. Often groundwater levels have been monitored for decades resulting in an extensive number of time series and quality control of the data is an essential first step prior to any further application. The presence of various errors, such as outliers, shift and drift require evaluation of each time series and the most common sources of error due to the actual measurement processes are related to the measurement instruments, the conversion from pressure to heads, time lag effects and defects of observation wells. Data processing errors (e.g., typing errors, duplicates) generally account for a large proportion of errors in databases.

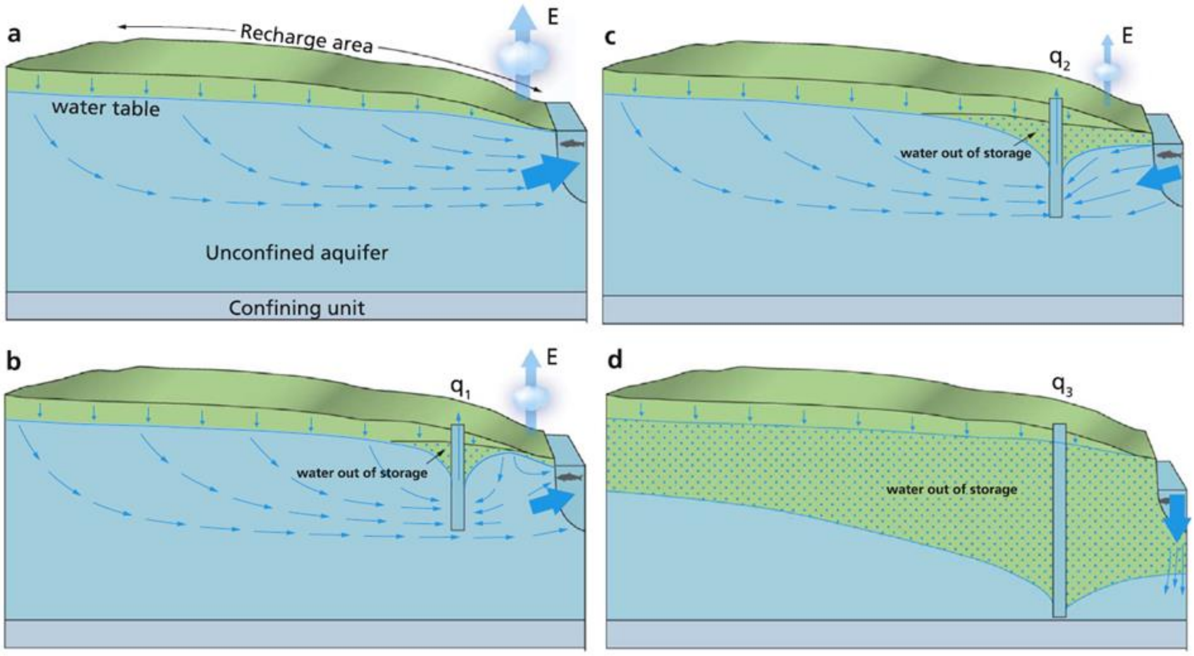


Figure 2. The impact on groundwater abstraction on surface water bodies according to the pumping rate (modified from Bierkens and Wada, 2019)

Groundwater abstractions have an impact on *groundwater dependent ecosystems* through lowered groundwater levels and decreased discharge to streamflows, lakes, wetlands, springs. However, the impact of groundwater abstraction is strongly related to pumping rate, groundwater recharge rate and the storativity of the aquifer.

In natural conditions groundwater flows from recharge area to the discharge zone that can be either river, lake, spring, or a sea (Figure 2, a). When groundwater pumping starts to take place, some water that originally contributed to the surface water body is taken out from the system, causing lowered groundwater levels next to the abstraction site and slightly decreasing water level in surface bodies, although surface water balance still benefits from groundwater discharge (Figure 2, b). At higher pumping rate the groundwater system is affected to such a high degree that the surface water body is losing its water to groundwater to meet the pumping demand in the abstraction site (Figure 2, c). In such conditions the surface water body loses its water input from groundwater that might affect water chemistry, temperature, and other parameters, including surface water level. Decreased groundwater levels result in a thicker aeration zone, causing more soil to be exposed to oxygen that can yield other negative effects.

If the groundwater pumping rate is extremely high (or aquifer water storage properties are poor), groundwater can be lowered to a such low level that the surface water body becomes disconnected from groundwater meaning that the soil under the lake (or any other water body) is not fully saturated (Figure 2, d). In these extreme situations surface water is freely infiltrating the groundwater at its maximum rate and the surface water body can lose a significant amount of water resources, leading to distinctively lowered surface water levels.

Groundwater level can have an impact on water chemistry and ecosystem quality too. For example, a shallow groundwater table typically is dominated by nutrient poor alkaline rich groundwater that promotes low productive fen ecosystems with rare species. However, lowering of water table can cause drastic changes to soil water chemistry – oxidation of iron and sulphide can yield sulphuric acid, whereas increased dominance of rainwater in the soil zone can cause reduction of pH and, subsequently, cause mobility of potentially toxic metals. Furthermore, lowered groundwater level leads to oxygen increase that induces mineralization of organic matter which increases nutrient availability, in particular nitrogen. This example raises the importance of necessity to assess anthropogenic impact on groundwater levels.

The assessment of the groundwater abstraction impact on groundwater dependent ecosystems is a challenging task. There are many obstacles that make it difficult to do the assessment. A common problem is the availability of data to prove that groundwater level has decreased due to groundwater abstraction. Therefore, the quantitative groundwater monitoring network should take into account the location of key groundwater dependent ecosystems.

1.1.5. Groundwater quality monitoring and its challenges

The process of well pumping and sample handling can cause major sample modification through air entry, degassing and volatile losses (potentially introducing more significant errors than actual sample analysis), which need to be addressed through appropriate sampling procedures summarized in Table 6. It is especially important to gather and store the information of when the sample was collected, how and when analyzed. This can allow detection of sampling and laboratory issues before further interpretation of results.

Table 6. Summary of sampling procedures and precautions necessary to reliably obtain results for specific groups of groundwater quality parameters (modified after GW MATE, 2006)

Determinand group	Sampling procedure	Prefered materials	Storage time/ temperature	Operational difficulty/ costs
Major Ions (Cl, SO_4, Na, K)	• 0.45 µm filter only • no acidification	any	7 days/4 ˚C	minimal
N Species (NO_3, NH_4, NO2)	• sealed 0.45 µm filter	any	1 day/4 ˚C	moderate/ low
Carbonate Equilibria (pH, HCO_3, Ca, Mg)	• unfiltered well-sealed sample • on-site analysis (pH, HCO_3) (Ca/Mg at base laboratory on acidified sample)	any	1 hour (150 days)	moderate
Oxygen status (pE(EH), DO, T)	• on site in measuring cell • avoid aeration • unfiltered	any	0.1 hour	high/ moderate
Trace Metals (Fe, Mn, As, Cu, Zn, Pb, Cr, Cd, etc.)	• sealed 0.45 µm filter • acidify (pH <2) • avoid aeration through • splashing/head space	plastic	150 days	moderate
Microbiological (TC, FC, FS)	• sterile conditions • unfiltered sample	dark glass	6 hours/ 4 ˚C	moderate/ low

	- on-site analysis preferred			
Organics (TOC, VOC, HC, ClHC, etc.)	- unfiltered sample - avoid volatilization - (direct absorption in cartridges preferred)	dark glass or teflon	1–7 days (indefinite for cartridges)	high

Taking samples from wells via pumping or from springs is the most commonly practiced groundwater sampling method. When a new monitoring station is established it is advised to take a wide range of geochemical descriptors and potential pollutants in order to carry out screening. This will allow us to identify baseline conditions and verify if the station represents certain conditions e.g. particular land type and pressures.

On the long-term basis the analyzed set of parameters can be decreased if no pollutants have been observed or their occurrence is water is unlikely (e.g. nitrates in strongly reducing aquifer conditions). However, according to the pressure analysis fuller analytical checks should be undertaken periodically and immediately after any significant change is detected, including indirect indications (e.g. changes in land use type, increased abstraction). Detailed monitoring of water quality should be continued for at least 3–4 years to consider a site as a good reference site. Then the sampling frequency and number of parameters can be decreased based on locally identified pressures. Major compounds for ionic charge balance calculation (typical data quality assessment) should be measured in all water samples. If any problems are identified it will allow us to understand the ongoing hydro-geo-chemical processes. The “major compounds” typically include seven basic parameters that form most of the water composition in % (cations Ca, Mg, Na, K and anions HCO_3, Cl, SO_4). Depending on the site specifics (conceptual model that include description of prevailing deposits and dominant pressures) other parameters can be included into ionic charge balance calculations based on the conceptual understanding, e.g. Fe and Mg if the waters are strongly reducing and typically have large amounts of such elements; F and Sr in areas with gypsum presence; NO_3 and NH_4 ions if the area is known to have large agricultural pressure etc. The mismatching ionic charge balance can indicate which type of ions (cation or anions) should be included into the equation or which type of ions (unknown natural peculiarities or potential pollution signatures) should be searched for in the sample in the next sampling campaign.

1.1.6. Groundwater monitoring as early warning system

Timely detection of any negative trends in groundwater quality and quantity is fundamental to avoid future harmful effects on human well-being and dependent nature as well as need for large investments in surveys, remediation and reallocation of abstraction wells. Groundwater monitoring network must be designed in a way to relate to the three-dimensional spatial variation of groundwater flow and quality (see example in Figure 3). It must be done based on conceptual understanding of the site, thus the conceptual models have to be developed. Only then it will be possible to obtain samples representative of the quality of the more recent recharge (replenishment) of the aquifer of interest.

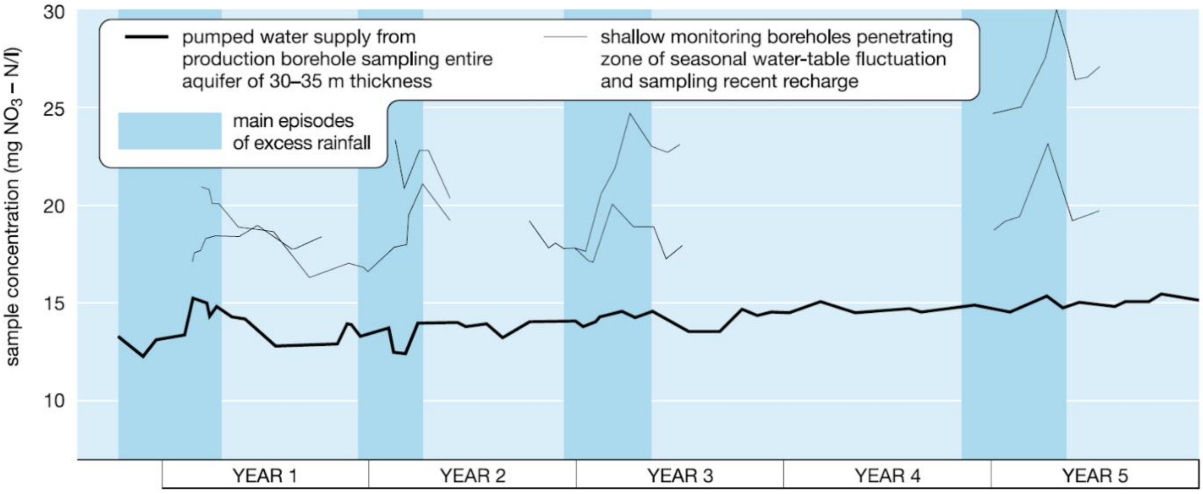


Figure 3. Detection of groundwater quality trends in aquifer replenishment in the vicinity of a public-supply water well (from GW MATE, 2006)

One specific sample can be different from the average quality of groundwater in aquifer systems as a result of the very large storage volumes and long residence times of many groundwater systems. Other factors, like examples in Figure 4, can also cause marked vertical variation in groundwater quality and will require a similar monitoring approach.

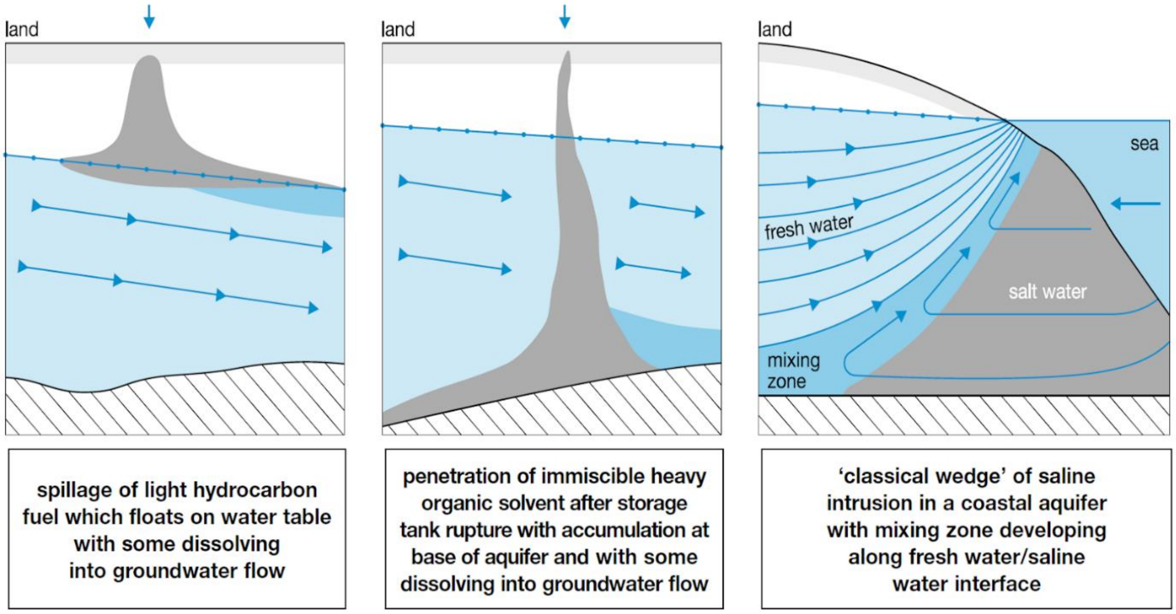


Figure 4. Processes causing major vertical variations in groundwater quality within an aquifer-system which need to be detected through monitoring (from GW MATE, 2006)

The rapid growth of urban and industrial waste disposal to the ground and the widespread intensification of agricultural cultivation requires major expansion of focused groundwater quality monitoring, using sampling piezometers designed and installed for a specific needs or pressure assessment (Figure 5) with the following types of objectives:

- to facilitate the early warning of the onset of groundwater pollution from a given activity and allow the timely introduction of any necessary control measures,
- to provide advance warning of the arrival of polluted water at an important groundwater supply source and thus make provision for treatment or other mitigation,
- to identify any contamination reaching an aquifer from a potential major pollution source and thus take early remedial action,
- to establish evidence to determine legal liability for groundwater pollution incidents.

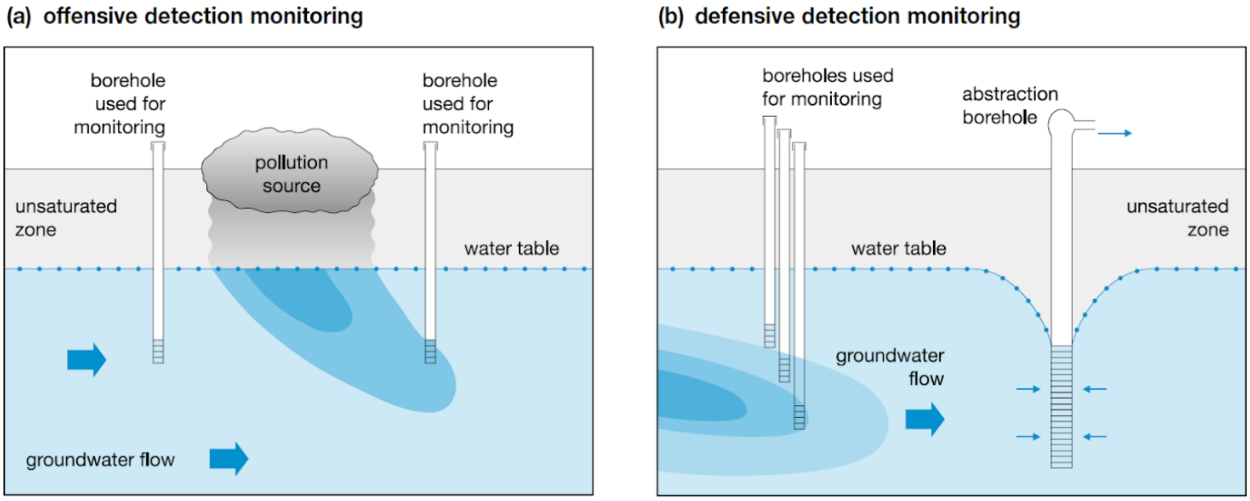


Figure 5. Schematic representation of groundwater quality monitoring network design for specific management objectives (from GW MATE, 2006)

The complexity of groundwater flow and quality regimes is often such that hydrogeological expertise is required in many applications - both to design monitoring networks and to interpret their results. Moreover, when multidisciplinarity is considered such as the links between ecosystems and groundwater, it is essential to design networks in joint discussions between managing authorities, scientists and policy makers, sometimes also end users as water suppliers or municipalities.

Established state groundwater monitoring networks (e.g. in Estonia and Latvia) have been designed to serve different purposes (e.g. to detect regional trends in groundwater quality or quantity, assess impacts of diffuse pollution) and provide valuable long-term datasets. Currently the locations of groundwater monitoring networks and dependent ecosystems overlap and id do, the amount of wells and springs monitored is not enough. The locations of wells cannot be moved, and current monitoring frequency must not be interrupted. However, an effort should be made to improve groundwater monitoring networks by establishment of new wells and selection of new springs for national monitoring needs considering locations of protected areas (like drinking water protected areas, dependent ecosystems and nitrate vulnerable zones). A conceptual hydrogeological model should be developed for each monitoring station serving as a tool for planning future monitoring programs, evaluating the results, accumulation of knowledge and institutional memory.

1.2 Legal bases for the assessment of groundwater status in Poland

The legal bases regulating the Community water management conducted in the Member States of the EU, including the guidelines for the monitoring of groundwater and the assessment of groundwater status, are set out in Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 (WFD) establishing a framework for Community action in the field of water policy. Activities resulting from the implementation of the provisions of WFD have been implemented into national legislation in the form of the amended Act of July 20, 2017, Water Law (Journal of Laws 2021, item 624, as amended) and relevant Regulations.

1.2.1. European Union Legislation on State Assessment

According to the information provided in the introductory part of this chapter, WFD of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy was recognized as the basic legal act of the

European Union in the field of water management in the Member States. In accordance with the provisions of the Directive:

"In its resolutions of 25 February 1992 and 20 February 1995, the Council asked for a groundwater action program and for the amendment of Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain hazardous substances, as part of an overall policy to protect freshwater".

The above position was confirmed in the report "Environment in the EEA Annual Report of November 10, 1995 regarding the need to take measures to protect the waters of the European Community in terms of both quantity and quality.

The purpose of the Directive according to Article 1 is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. Objectives relating to groundwater aim to:

a) prevent further deterioration and protect and enhance the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems;
b) promote sustainable water use based on a long-term protection of available water resources;
c) enhance protection and improve the aquatic environment, inter alia, through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances;
d) ensure the progressive reduction of pollution of groundwater and prevent its further pollution, and
e) contribute to mitigating the effects of floods and droughts.

The implementation of the above-mentioned priorities will allow for:

- the provision of the sufficient supply of good quality surface water and groundwater as needed for sustainable, balanced and equitable water use,
- a significant reduction in pollution of groundwater,
- the protection of territorial and marine waters, and
- achieving the objectives of relevant international agreements, including those which aim to prevent and eliminate pollution of the marine environment, by Community action under Article 16(3) to cease or phase out discharges, emissions and losses of priority hazardous substances, with the ultimate aim of achieving concentrations in the marine environment near background values for naturally occurring substances and close to zero for man-made synthetic substances.

This groundwater monitoring program covers the Polish-Ukrainian cross-border area. Ukraine is not a member of the European Union, however, striving to integrate already at this stage, it takes steps to adapt to the implementation of selected solutions, applicable in this area in the Community. Conducting effective and efficient actions in the field of groundwater protection, the confirmation of which may be the results of monitoring observations, requires jointly agreed work and research. In Poland, the assessment of groundwater status is carried out for areas designated as GWBs. In the case of a cross-border area, appropriate steps should be taken to maintain or improve the quantitative and chemical status of waters, including groundwater in the cross-border areas. The recommendations included in Annex V to WFD regarding the scope, form and frequency of monitoring the quantitative and chemical status of groundwater are of a rather general nature. With regard to quantitative status monitoring, it is recommended "*that the number* *of observation points and the frequency of measurements taken were sufficient to reliably characterize changes in the level of the groundwater table and to assess the quantitative status of all groundwater bodies". "The frequency of monitoring should be sufficient to assess the quantitative status of each body or group of bodies of groundwater, taking into account the short and long term variability in the body's recharge."*

"For bodies of groundwater where groundwater flow exceeds the boundary of a Member State, frequency shall be sufficient for measuring to estimate the direction and volume of groundwater flow across the boundary of a Member State." The above provision also only generally defines the rules for the number and location of observation points for the monitoring of the quantitative status of groundwater.

The scope of chemical tests necessary to assess the chemical status of GWBs according to WFD includes the electrical conductivity of water (specific electrolytic conductivity of water) and the concentration of pollutants.

"The groundwater monitoring network is established in accordance with the requirements of Articles 7 and 8. The monitoring network is designed to allow a consistent and comprehensive picture of the groundwater chemical status within each river basin to be obtained and to enable the detection of long-term anthropogenic trends in increasing pollution levels. On the basis of the characterization and impact assessment performed in accordance with Article 5 and Annex II, Member States shall establish, for each period to which the river basin management plan applies, a surveillance monitoring program. The results of this program are used to establish the operational monitoring program for the remaining periods of the river basin management plan."

The above provision applies to the assessment of the chemical status of river basins, i.e. in case of the EU-WATERRES research project it also applies to international activities that should be undertaken for cooperation aimed at obtaining a characterization of the chemical status of groundwater in international river basin districts. The implementation of the discussed objectives requires good cooperation between states located in a given international basin. For the results of physicochemical groundwater tests carried out as part of monitoring according to the guidelines of the river basin management plans, the levels of confidence and accuracy of the results should be determined.

"On the basis of the characterization and impact assessment performed in accordance with Article 5 and Annex II, Member States shall establish, for each period to which the river basin management plan applies, a surveillance monitoring program. The results of this program are used to establish the operational monitoring program for the remaining periods of the river basin management plan."

On the basis of the results of the diagnostic monitoring, the status of groundwater (good or poor) is determined at individual observation points from which water samples were taken for testing, and the final assessment of the chemical status of groundwater bodies is determined, in accordance with the applicable methodology for assessing the state of groundwater. Individual Member States of the EU have quite a lot of freedom in defining and selecting standards and criteria (including, for example, the applied quality classes, as is the case in Poland), which are classified as good or poor chemical status of groundwater.

The following goals were set for diagnostic monitoring in the WFD:

- supplementing and checking the impact assessment procedure;
- to provide information for the assessment of long-term trends resulting both from changes in natural conditions and from anthropogenic activities.

The surveillance monitoring should cover groundwater bodies identified as at risk on the basis of the characterization performed, in accordance with Annex II, and groundwater bodies crossing the border of a Member State. The analysis of the results of diagnostic monitoring in conjunction with the results of the pressure analysis provides the basis for determining GWB, which are at risk of failing to achieve a good condition for conducting research in them as part of operational monitoring. The following parameters and indicators were considered the obligatory scope of determinations according to the guidelines of the WFD: dissolved oxygen in water, pH value, specific electrolytic conductivity value, nitrates and ammonium nitrogen. In the case of groundwater bodies identified as significantly endangered by failure to achieve good status, the range of monitored parameters should additionally include indicative substances for the impacts influencing the status of the discussed UGBs. Diagnostic monitoring should be performed *"at least once in the period covered by the river basin management plan"*.

Pursuant to the guidelines of the WFD, in the periods between the implementation of diagnostic monitoring programs, operational monitoring tests should be performed at least once a year, with a frequency sufficient to detect the impact of individual impacts. It is conducted in order to:

- establish the chemical status of all GWBs or groups of GWBs identified as at risk;
- establish the presence of any anthropogenic-induced long-term upward trend in the concentration of any pollutant.

The operational monitoring results from individual monitoring points are aggregated for the water body as a whole. For the parameters for which environmental quality standards have been established in the Community legislation, the average value of the operational monitoring results is calculated at each observation point, in a given body of groundwater or in the group of GWBs. The calculated average values make it possible to establish compliance with the good chemical status of groundwater for individual GWB.

According to the WFD, operational monitoring of groundwater is carried out for all water bodies which, on the basis of both the impact assessment carried out in accordance with Annex II and the diagnostic monitoring, have been identified as being at risk of failing to achieve the objectives established under Article 4. *"Selection of monitoring sites shall also reflect the results of an assessment of the representativeness of the monitoring data carried out on site for the quality of the water body or group of bodies of groundwater concerned."*

With reference to the guidelines of the WFD, the scope of groundwater monitoring for the cross-border area between Poland and Ukraine should include both measuring the level of the groundwater table in observation wells, measuring the efficiency of sources, as well as testing the parameters and physical and chemical indicators of water. However, not all observation points have to fulfil all of the above-mentioned functions, because the scope and frequency of monitoring observations should be selected appropriately to the assumed goals, set for the implementation of monitoring observations.

Another legal act of the EU, the provisions of which refer to groundwater, is Directive 2006/118/EC of 12 December 2006 on the protection of groundwater against pollution and deterioration of its condition, the so-called The Groundwater Directive.

As defined in the introductory part of the discussed document:

"Groundwater is a valuable natural resource that as such should be protected from deterioration and chemical contamination. This is particularly important for groundwater-dependent ecosystems and when groundwater is used to provide human drinking water."

There is a provision in the Directive that directly relates to cross-border issues:

"In order to ensure consistent protection of groundwater, Member States should coordinate monitoring activities, the setting of threshold values and the identification of relevant hazardous substances where a body of groundwater is located within several Member States." In reference to the information already included in the earlier part of this chapter, in the profile of Poland's border with neighbouring countries, no transboundary groundwater bodies have been designated so far, therefore it is extremely important to undertake concerted actions regarding groundwater as part of international works.

Another (17) provision of Directive 2006/118/EC relates to the monitoring of groundwater:

"Reliable and comparable groundwater monitoring methods are an important tool for assessing groundwater quality and for selecting the most appropriate measures. Article 8 (3) and Article 20 of WFD provide for the adoption of standard methods for the analysis and monitoring of the status of waters and, where necessary, guidelines for implementation, including monitoring." The above guidelines also emphasize the need for international cooperation and the implementation of solutions enabling the results of monitoring observations to be obtained in an appropriate, comparable standard.

Pursuant to Decision 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 establishing the Sixth Community Environment Action Program, efforts should be made to achieve *"water quality levels which do not have a significant impact on human health and the environment, and do not pose risks to human health and the environment".* These guidelines should also apply in a cross-border context. The indication in force for EU countries may also refer to other units that will be jointly assessed, including, for example, aquifers with transboundary dispersal.

Point 3, Article 2, specifying the obligations of the states belonging to the EU, indicates that:

"For groundwater bodies within the territory of two or more Member States and bodies of groundwater where groundwater flow crosses a Member State border, Member States shall ensure the coordinated setting of threshold values by the Member States concerned, in accordance with Article 3 (4) of WFD".

Clause 2a defines that in order to confirm the good chemical status of the GWB "adequate monitoring demonstrating that the conditions set out in point 2.3.2 of Annex V to WFD are met" is essential.

In point 3, article 4 of the Directive, it was confirmed that the Member States are obliged to: "selection of groundwater monitoring stations meeting the requirements of Annex V, section 2.4 to (WFD) as to its design to provide a consistent and comprehensive picture of groundwater chemical status and representative monitoring data."

According to the guidelines of Directive 2006/118/EC, groundwater monitoring surveys are aimed at assessing trends for the purposes of including in river basin management plans.

In Annex I to the Groundwater Directive, for the assessment of the chemical status of groundwater, nitrates and active ingredients of pesticides, including relevant metabolites, as indicators of pollution are included. Quality standards have been defined for them in accordance with Article 4, corresponding to the standards listed in Annex V to WFD and established in accordance with Article 17 of the Directive. Part B of Annex II to Directive 2006/118/EC provides the minimum list of pollutants and indicators of pollution for which Member States are required to consider threshold values in accordance with Article 3. The list includes the following indicators and parameters: arsenic, cadmium, lead, mercury, ammonium ions, chloride ions, sulphate ions, man-made substances: trichlorethylene, tetrachlorethylene and specific electrolytic conductivity.

As a result of updating Annex II, nitrites and phosphates (phosphorus) have been added to the indicators for which threshold values should be established.

Another piece of EU law applicable to groundwater is Council Directive 91/676/EEC of 12 December 1991 on the protection of waters against pollution caused by nitrates from agricultural sources (so called “Nitrates Directive”). The aim of the directive was to reduce and prevent water pollution caused by nitrogen inputs from agricultural sources. The requirements of Directive 91/676/EEC required European Union countries to designate sensitive zones in all known areas where waters (including groundwater) are at risk of nitrate pollution or where there is a high probability of such a threat. Vulnerable zones were distinguished by the presence of waters in which the nitrate concentration exceeds 50 mg / l, or water where such concentrations are likely to occur unless appropriate remedial measures are taken. Annex I to the Nitrates Directive sets out the criteria for designating NVZs. The action programs included in the Nitrates Directive were one of the main actions in the WFD (Annex VI) and acted as a mechanism to support the reversal of the nitrate pollution trend in line with the Groundwater Directive. The approach presented in the Nitrates Directive in the scope of monitoring concentrations of nitrates of agricultural origin in groundwater in areas designated by NVZs was implemented until 2016. The boundaries of the NVZs were updated on the basis of the results of groundwater surveys every 4 years. In this scope, the monitoring covered areas which together constitute approximately 5% of the territory of Poland. According to the guidelines of the Nitrates Directive, groundwater testing in areas where the nitrate content of groundwater in at least one sample exceeds 25 mg/l was found, groundwater testing in the range of concentrations of the substances in question should be carried out at least once every four years, while at other groundwater monitoring points once every eight years.

With the amendment of the Water Law Act in 2017, from 2018 the entire territory of Poland was covered by the obligation to protect waters against pollution with nitrates of agricultural origin. The activities undertaken are aimed at counteracting the pollution of groundwater with nitrates from agricultural activities. The results of the chemical monitoring of groundwater Chief Inspectorate for Environmental Protection (CIEP) allow for the assessment of the effectiveness of the above-mentioned procedure.

1.2.2. Methodological guidance documents and reports

The basic document regulating cooperation in scope of water, including groundwater, between Poland and Ukraine is the Agreement between the Government of the Republic of Poland and the Government of Ukraine on cooperation in the field of water management in border waters, drawn up in Kiev on October 10, 1996.

The organization of the groundwater monitoring network in transboundary areas may also take into account the recommendations and guidelines of the following recommendations and methodological guides:

- Guidance document N^o 3. Analysis of Pressures and Impacts. European Communities, 2003, Common Implementation Strategy for the WFD (2000/60/EC);
- Guidance document N^o 7. Monitoring under the WFD, European Communities, 2003, Common Implementation Strategy for the WFD (2000/60/EC);
- Guidance Document N^o 15. Guidance on Groundwater Monitoring. European Communities, 2007, Common Implementation Strategy for the WFD (2000/60/EC);
- Guidance document N^o 16. Guidance on Groundwater in Drinking Water Protected Areas, European Communities, 2006, Common Implementation Strategy for the WFD (2000/60/EC);

- Guidance document N° 17. Guidance on preventing or limiting direct and indirect inputs in the context of the groundwater directive 2006/118/EC, European Communities, 2007, Common Implementation Strategy for the WFD (2000/60/EC);
- Guidance document N° 18. Guidance on groundwater status and trend assessment, European Communities, 2009, Common Implementation Strategy for the WFD (2000/60/EC);
- Guidance document N° 21. Guidance for reporting under the WFD, European Communities, 2009, Common Implementation Strategy for the WFD (2000/60/EC);
- Guidance document N° 26. Guidance on risk assessment and the use of conceptual models for groundwater, 2010, Common Implementation Strategy for the WFD (2000/60/EC);
- State of the art monitoring and assessment of groundwater. UN/ECE Task Force on Monitoring and Assessment;
- Technical report on groundwater quality trend and trend reversal assessment. Procedures applied by Member States for the first RBMP cycle. European Communities, 2019;
- Guidelines on Monitoring and Assessment of Transboundary Groundwaters. UNECE Task Force on Monitoring & Assessment;
- Guidelines for Monitoring Strategies in Transboundary Aquifers: Goals, Methods and Tools. The Case of the DRIN project (ALB-MTN). (UNESCO, 2020).

As was the case with the WFD guidelines and the so-called of the Groundwater Directive, EU Member States have a great deal of discretion in interpreting the recommendations, best practices and guidance documents. The provisions of the documents in question are often characterized by a high level of generality and the lack of an unambiguous, unified interpretation of EU regulations. As a result, the approach to the above-mentioned groundwater legislation shows some interpretation differences across the EU.

1.2.3. Groundwater law in Poland (state assessment regulations)

The main act of national law in the field of water management in Poland is the Act of 20 July 2017 - Water Law (Journal of Laws of 2017, item 1566, as amended). The Act implements the guidelines of WFD. The last amendment to the Water Law Act took place on April 20, 2022 (Journal of Laws 2022, item 855). Pursuant to the Act, the tasks of the state hydrogeological survey are carried out by the Polish Geological Institute - National Research Institute.

Article 53.1 of the Act, point 4, states that *"groundwater monitoring and data interpretation should take into account the fact that the flow conditions and the chemical composition of groundwater vary vertically and horizontally".*

Article 110 contains a provision that *"as part of the state environmental monitoring, monitoring is carried out to assess the effectiveness of the action program".*

The guidelines for the monitoring of groundwater and the assessment of groundwater condition have been developed in the form of Regulations of the Minister of Infrastructure and the Minister of Maritime Economy and Inland Navigation. These are:

- Regulation of the Minister of Infrastructure of 13 July 2021 *on the forms and methods of monitoring surface water bodies and groundwater bodies* (Journal of Laws 2021 item 1576);
- Regulation of the Minister of Maritime Economy and Inland Navigation of October 11, 2019 *on the criteria and method of assessing the state of groundwater bodies* (Journal of Laws of 2019, item 2148).

In paragraph 1, point 2 of the Regulation of the Minister of Infrastructure of 13 July 2021 *on the forms and methods of monitoring surface water bodies and groundwater bodies*, the forms and methods of groundwater monitoring are specified in the following scope:

- types of monitoring and goals of their establishment;
- criteria for selecting water bodies for monitoring;
- criteria for determining measurement and control points;
- scope and frequency of monitoring;
- reference methodologies and conditions for ensuring the quality of monitoring.

According to the provisions of paragraph 12 of the Regulation (Journal of Laws of 2021, item 1576), monitoring of groundwater bodies is carried out in a way that allows:

a) assessment of the status of groundwater bodies;
b) detection of significant and sustained trends in increasing concentrations of pollutants due to anthropogenic impacts;
c) determining the impact of the status of groundwater bodies on protected areas included in the lists of protected areas referred to in Article 317 paragraph 4 point 1 and point 4 of the Act.

In case of transboundary groundwater tests, their results should enable the assessment of the state of the border fragments of GWBs, and in case of finding poor chemical or quantitative status, they may be the basis for determining the poor state of a fragment or the entire GWB and, possibly, considering the need for separation of new subparts or poor GWB.

Paragraph 13 of the Regulation defines that the monitoring of GWBs is carried out in the form of measurements or tests:

a) chemical status,
b) quantitative status.

In § 14, the following types of monitoring of groundwater bodies have been distinguished:

a) chemical state monitoring,
b) quantitative state monitoring,
c) investigative monitoring.

Paragraph 15 defines the following types of chemical monitoring of GWBs:

a) diagnostic monitoring of the chemical status of groundwater bodies, established on the basis of the characteristics of GWBs and the assessment of the impact of anthropogenic pressure;
b) operational monitoring of the chemical status of GWBs, established on the basis of the characteristics of GWBs and the assessment of the impact of anthropogenic pressure and diagnostic monitoring.

Diagnostic monitoring of the chemical status of groundwater bodies is carried out in order to:

- supplementing and checking the procedure of anthropogenic impact assessment;
- provide information for the assessment of long-term trends resulting from both changes in natural conditions as well as anthropogenic impacts.

Diagnostic monitoring of the chemical status of GWBs is carried out at least once during the 6-year update cycle of the river basin management plan.

The operational monitoring of the chemical state is aimed at:

- assessment of the chemical status of groundwater bodies deemed at risk of failure to meet their environmental objectives, referred to in Article 59 of the Act;
- finding the presence of significant and sustained trends in increasing concentrations of pollutants caused by anthropogenic impacts.

The base year from which significant and sustained trends in the increase in the concentration of pollutants referred to in paragraph 2 point 2 are determined is 2007 or 2008, depending on the availability of monitoring data as part of diagnostic or operational monitoring, and when calculating these trends starting levels, which represent average concentrations measured in the base year, will be taken into account.

The operational monitoring of the chemical status of groundwater bodies is carried out at least once a year, with the exception of the year in which diagnostic monitoring of the chemical status of GWBs is carried out.

"Paragraph 21.1 of the Regulation defines that the monitoring of the quantitative status of groundwater bodies is established in order to assess the quantitative status of groundwater bodies, including the determination of the reserves of available groundwater resources and the analysis of the groundwater table level for each groundwater body. The scope of this monitoring of the state includes measurements of the groundwater table level and determination of available groundwater resources and the average long-term actual groundwater abstraction. It is carried out in the field of measurements of the level of the groundwater table with a frequency sufficient to assess the quantitative status of groundwater bodies, taking into account short-term and long-term variability in the supply of groundwater bodies".

§ 22.1 of the Regulation stipulates that investigative monitoring of GWBs or their parts should be carried out in order to:

1) explanation of the reasons for the failure to meet the environmental objectives set for a given GWB, unless the reasons can be explained on the basis of data and information obtained as a result of measurements or tests carried out as part of the monitoring of the quantitative status of groundwater bodies or the monitoring of the chemical status of groundwater bodies;
2) identify the type, concentrations and extent of the pollution, if the body of groundwater has been contaminated or there are grounds to conclude that such a pollution risk exists;
3) identification of the extent of a significant decrease in the groundwater level causing the risk of non-compliance with the environmental objectives for the given groundwater body.

The development of the investigative monitoring network justifies the need for a detailed diagnosis of the type and extent of transboundary impacts, with particular emphasis on anthropogenic pressures on groundwater.

The regulation also defines that *"the scope and frequency of research monitoring of groundwater bodies shall be adapted to the reasons for its conduct and local conditions, so that its results provide information on the actions necessary to achieve environmental objectives or on specific remedial measures against the effects of pollution."*

The Regulation of the Minister of Maritime Economy and Inland Navigation of 11 October 2019 *on the criteria and method of assessing the status of groundwater bodies* (Journal of Laws of 2019, item 2148) specifies the criteria and method of assessing groundwater bodies, including:

1) classification of physicochemical parameters;
2) definitions of groundwater quantitative status and chemical status classification;
3) the method of interpreting the results of tests of physicochemical parameters;
4) method of presentation of the groundwater status;

5) frequency of groundwater status assessment;
6) threshold values, which are environmental quality standards expressed as the concentration of a given pollutant, group of substances or substances expressed as an index, which should not be exceeded for the protection of the environment and human health, hereinafter referred to as "threshold values".

In the classification of physicochemical parameters of groundwater status, five groundwater quality classes have been distinguished:

1) class I includes waters of very good quality, in which the values of physicochemical parameters:
    a) they are shaped only as a result of natural processes in groundwater and fall within the hydrogeochemical background,
    b) do not indicate the impact of human activities;
2) class II - good quality waters in which:
    a) the values of some physicochemical parameters are increased as a result of natural processes occurring in groundwater,
    b) the values of physicochemical parameters do not indicate the influence of human activity, or the influence is very weak;
3) class III - water of satisfactory quality, in which the values of physicochemical parameters are increased as a result of:
    a) natural processes in groundwater or
    b) weak influence of human activity;
4) class IV - water of unsatisfactory quality, in which the values of physicochemical parameters:
    a) are elevated as a result of natural processes in groundwater,
    b) show the clear impact of human activities;
5) class V - poor quality waters, in which the values of physicochemical parameters indicate a significant influence of human activity.

The classification of the physicochemical parameters of groundwater status is carried out on the basis of the limit values of the physicochemical parameters of groundwater status, which are set out in the Annex to the Regulation. Based on the classification of the chemical state of GWB, the following are determined:

1) good chemical status;
2) poor chemical status.

Quality classes I-III were classified as good chemical status, and the remaining classes qualify the tested waters to poor chemical status. The threshold values are the limit values of the physicochemical parameters of the groundwater status specified in the Annex to the Regulation for groundwater quality class III.

Point 3 of the Regulation states that *when assessing the chemical status of groundwater at the measuring point, it is allowed to exceed the limit values of the physicochemical parameters of groundwater status when it is caused by natural processes, provided that the exceeding of these values does not apply to the physicochemical parameters set out in the Annex to of the Regulation with the symbol "H", and is within the limits adopted for the next, lower groundwater quality class.*

1.3. Transboundary groundwater monitoring issues in the national law of Ukraine

In accordance with the second part of Article 21 of the Water Code of Ukraine, the Cabinet of Ministers of Ukraine approved the Procedure of state water monitoring, which came into force on January 1, 2019. The procedure complies with WFD and will help to obtain more information on the water condition in Ukraine.

This Procedure defines the basic requirements for the organization of state water monitoring, interaction of central executive bodies in the process of its implementation and providing state authorities and local governments with information for decision-making on water state.

State water monitoring is carried out in order to collect, process, store, summarize and analyse information on water bodies condition, forecast its changes and develop scientifically sound recommendations for decision-making in the field of water use, protection and reproduction of water resources.

The objects of state water monitoring are:

- uniform body of surface waters (surface water bodies or their parts), including coastal waters and zones (territories), which are subject to protection;
- uniform body of groundwater (GWBs or parts thereof), including areas (territories) that are subject to protection;
- sea waters within the territorial sea and the exclusive maritime economic zone of Ukraine, including zones (territories) subject to protection.

Depending on the goals and objectives of state water monitoring, the following procedures are established:

- procedure for diagnostic monitoring of surface and groundwater massifs;
- procedure of operational monitoring of surface and groundwater massifs;
- procedure of research monitoring of surface water massifs;
- sea water monitoring procedure.

Diagnostic, operational and research monitoring is carried out according to the basin principle.

The subjects of state water monitoring are the Ministry of Environmental Protection and Natural Resources, the State Water Agency, the State Service for Geology and Subsoil (Geological Survey) and the State Service of Ukraine for Emergencies. The Geological Survey is responsible for conducting state monitoring of GWBs. Its Enterprises measure the static level in the wells of the monitoring network and take water samples to assess their natural chemical composition. The definitions include 22 parameters, including concentrations of heavy metals and pesticides.

Groundwater monitoring in Ukraine is carried out at two levels:

- Regional - in the state regional geological enterprises on the territory of activity where the information which is transferred to the state level is processed.
- State - in State Research and Production Enterprise "Geoinform of Ukraine", which generalizes information at the regional level, stores it, analyses and processes it.

There are no regulatory requirements for groundwater monitoring of border areas within Ukraine, the requirements are determined by the terms of international agreements. Ukraine has concluded bilateral agreements with the neighbouring Republic of Moldova, the Republic of Poland, Hungary, Romania, the Slovak Republic, and the Republic of Belarus.

To resolve the issues arising from these Agreements, each Contracting Party shall appoint a Commissioner of the Government and his deputies for cooperation in border waters. In addition, bilateral Commissions for Border Waters are being set up. The activities of these Commissions are regulated by the Statute.

The main purpose of transboundary groundwater monitoring is to prevent negative transboundary impacts. When organizing a transboundary groundwater monitoring network, a monitoring strategy is being agreed upon between neighbouring countries. The main provisions are set out in bilateral agreements, which ensure coordination of the development of relevant documents, and the exchange of data and results. Article 112 of the Water Code of Ukraine states that if an international treaty in which Ukraine participates establishes norms other than those provided for by the water legislation of Ukraine, the norms of the international treaty shall apply.

To fulfil Ukraine's international obligations, joint water monitoring programs may be developed with border states. The implementation of groundwater monitoring in the border area of Ukraine-Poland in the framework of the EU-WATERRES project in its content meets the requirements of groundwater monitoring of Ukraine at the regional level.

Nowadays in Ukraine work of the defining of GWBs is at the stage of coordination and approval. As part of the implementation of the provisions of the WFD in 2022, Ukraine will move to the stage of diagnostic monitoring, and in 2 years - to the operational.

As Poland has significant practice in implementing the requirements of the European Directives (WFD, Groundwater Directive, Nitrate Directive) in the field of protection and management of water resources, the transfer of experience in cooperation is very important. This will allow Ukraine to implement a common approach with Poland based on EU legislation when developing its regulations.

1.4. Transboundary groundwater monitoring issues in the national law of Latvia

Since 2004, when Latvia became a member state of the EU, groundwater management has mainly carried out in compliance with EU legislation and the implementation of the WFD and the requirements of subordinate legislation (subordinate Directives, EC guidance documents). The requirements of the WFD are adopted and incorporated into national legislation. Also, the Directive 2006/118/EC (so-called Groundwater Directive) on the protection of groundwater against pollution and deterioration was adopted in 2006.

Before Latvia was bound by the WFD, transboundary groundwater management issues were mainly addressed on the basis of the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention, 1992). In 1992, Latvia signed the UNECE Water Convention and it was ratified in national legislation in 1996. The Water Convention requires Parties to prevent, control and reduce transboundary impact, use transboundary waters in a reasonable and equitable way and ensure their sustainable management. Parties bordering the same transboundary waters have to cooperate by entering into specific agreements and establishing joint bodies.

According to groundwater monitoring, the main instrument for integrated groundwater management implementation in Latvia is the WFD, which sets requirements for groundwater management, including the development of monitoring. WFD also imposes requirements on transboundary groundwater management and monitoring. The establishment of high-quality long-term monitoring programs is essential to achieve the WFD goals.

The main national legal act regulating the management and protection of water resources (including – groundwaters) is the Water Management Law (2002), as well as the Cabinet

Regulations issued on the basis of this law. These regulations mainly cover groundwater management at the national level and the transboundary groundwater management issues are very limited in national legislation. The Water Management Law contains general requirements for the joint management and development of plans for international river basin districts, but does not set specific requirements for a transboundary groundwater management plan and strategy. Requirements for groundwater monitoring at the national level, including transboundary groundwater monitoring, are specified in Cabinet Regulation No. 92.

Cabinet Regulation No.92 (adopted on February 17, 2004) "Requirements for the Monitoring of Surface Water, Groundwater and Protected Areas and the Development of Monitoring Programs" issued on the basis of the Water Management Law stipulate activities such as establishing monitoring network, which allows the evaluation of the direction, rate and changes in the chemical quality of transboundary groundwater flow, as well as the determination of the cause of changes; as well as performing monitoring in GWBs crossing the state border of Latvia, which allow the determination of the risk of transboundary impact and the evaluation of transboundary impact.

While national laws and regulations contain general guidelines for the management and monitoring of transboundary groundwater, specific actions and plans, including the implementation of monitoring, are set out in bilateral agreements between countries with which groundwater resources are shared. Latvia has signed such agreements with Estonia and Lithuania (in 2003 and 2016, respectively). However, cooperation on transboundary groundwater monitoring was only included in the agreement with Lithuania.

The EU-WATERRES project is a very important platform to promote cooperation between Latvia and Estonia to improve the common transboundary groundwater management, including the establishment of a transboundary groundwater monitoring program.

1.5. Transboundary groundwater monitoring issues in the national law of Estonia

Transboundary water management was included in Estonian legislation in 1992 when the country signed the Water Convention (Water Convention, 1992). After 2004, when Estonia had joined the EU, the principles of WFD were incorporated into national legislation. The implementation of WFD started with the process of delineation of groundwater bodies in 2000 in Estonia. In 2004, the first version of GWBs were confirmed. The WFD methodology for the assessment of Estonian GWBs and the determination of threshold values was developed in 2013 (supplemented by the GSE in 2019), and based on it, the status of GWBs (currently there are 31) is assessed every six years (2014 and 2020). This has also had a direct impact on decisions on the national groundwater monitoring plan.

Monitoring of transboundary waters is regulated by the Water Act (Riigikogu, 2019). According to the Water Act of Estonia, all watersheds which reach across the national borders are considered as transboundary water bodies, the management of such water bodies will take place according to the international agreements and the responsible institution of transboundary water management is the Ministry of Environment.

Until recent water management plans, Koiva river basin was the only transboundary water basin according to the river basin in Estonia. In the new river basin management plans (2021-2027), which are under construction at the moment, the possibility to consider all river basins as transboundary ones, is given.

Estonia and Latvia have an agreement signed between the Ministry of Environment of the Republic of Latvia and the Ministry of the Environment of the Republic of Estonia on co-operation in protection and sustainable use of transboundary watercourses (signed on 24 October 2003)

Despite the existence of the bilateral agreement, the actual cooperation between countries and water specialists is sporadic and highly dependent on the successful applications of projects funded by local or regional funds, e.g. INTERREG. The lack of funding for mutual cooperation is mentioned as one obstacle in the Water Convention 2017 and 2021 year reports of both countries.

2. Methodology of the assessment of groundwater state GWB

2.1. Principles of interpretation and presentation of the results of the assessment of groundwater state GWB in Norway

2.1.1. Principles of interpretation of groundwater state

The EEA uses the DPSIR framework as the foundation for the principles of interpretation of groundwater state. The DPSIR structure gives a flexible framework that can be used to assist decision makers in the many steps of a decision process. This framework was initially developed by the Organisation for Economic Co-operation and Development, OECD in 1994. The DPSIR framework has been widely used for many applications to relate human activities to the state of the environment e.g., in management of wetlands, marine systems, agro-environments, sustainable development, air pollution, climate change, biodiversity, invasive species, water resources, and river basins.

In December 2006, The European Commission approved the new Groundwater Directive, and in that connection, a flyer published describing how to use the DPSIR framework for groundwater (EC, 2008). When working after the DPSIR framework principles the first step is to collect data and information on all the different elements in the DPSIR chain (Figure 6). The Driving forces can originate and act globally, regionally, or locally. Drivers are often defined as socio-economic sectors that fulfil human needs for food, water, shelter, health, security, and culture. Human activities, that apply pressure include for example land use changes, resource consumption, release of substances, and physical damage. Pressures depend on the kind and level of technology involved in source activities and can vary across geographic regions and spatial scales. The pressures exerted by society may lead to unintentional or intentional changes in the State of the ecosystem. Usually, these changes are unwanted and are seen as negative (damage or degradation). The pressures may directly impact the ecosystem, such as harvesting or drainage, or may indirectly cause changes in ecosystem conditions. The status is usually quantified by physical variables – such as temperature, groundwater level, and chemical variables.

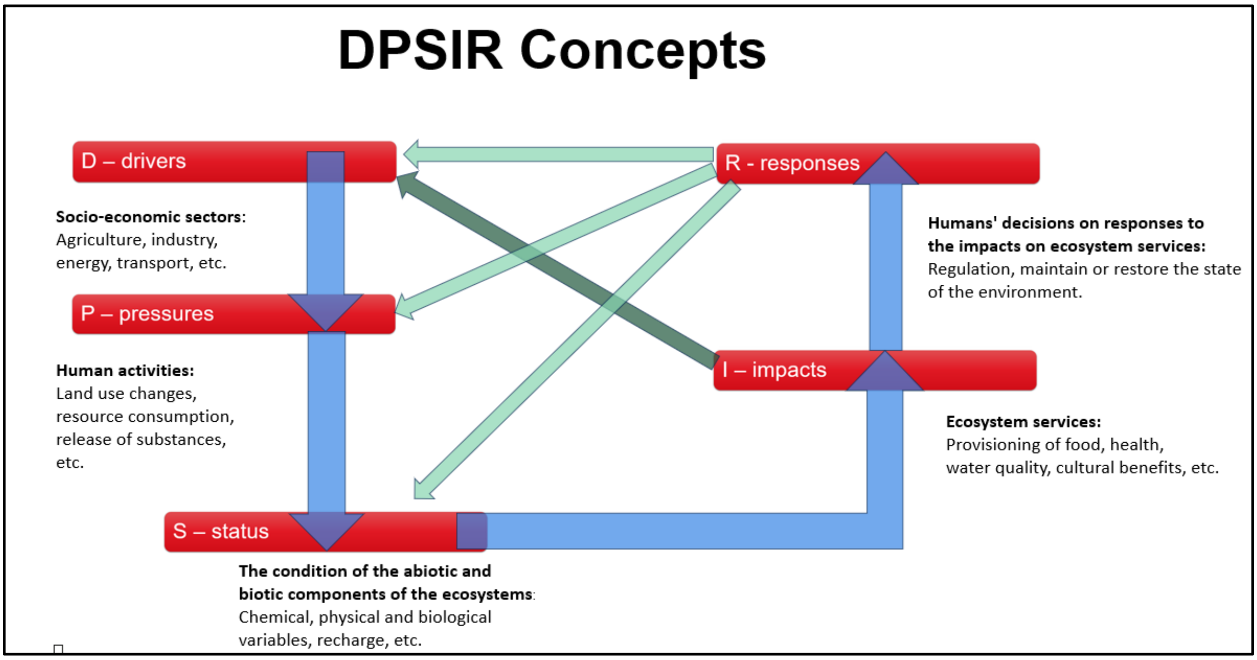


Figure 6. The "DPSIR" principle. Drivers (D) and related pressures (P) affecting groundwater. The status (S) and impacts (I) concerns both the groundwater resource and the associated and dependent aquatic and terrestrial ecosystems. The responses (R) are the action programmes of relevant EU legislations (primarily the programme of measures of the Water Framework Directive) (EC, 2008)

Changes in the quality and functioning of the ecosystem have an Impact on the welfare or well-being of humans through the provision of the ecosystem services. Ecosystem goods and services are ecosystem functions or processes that directly or indirectly benefit human social or economic drivers or have the potential to do so in the future. Ecosystem processes benefit humans through supplying food, water, health, and cultural (e.g., recreation). Humans make decisions in Response to the impacts on ecosystem services or their perceived value. Responses are actions taken by groups or individuals in society and government to prevent, compensate, or adapt to changes in the state of the environment by seeking to a) Control drivers or pressures through regulation, prevention, or mitigation b) Directly maintain or restore the state of the environment or c) Deliberately "do nothing", but then based on the data collected from the different elements in the DPSIR can. The benefit of the DPSIR Framework is that it is essentially human-centric, making it appealing to the public and decision-makers. It is a causal framework for describing the interactions between society and the environment, the human impact on the environment and vice versa because of the interdependence of the components. The characterisation of groundwater bodies relies on system understanding, in particular on the knowledge of drivers (D), pressures (P), status (S), impacts (I) and responses (R) and constitutes the backbone of river basin management planning and reporting to the European Commission.

To meet the provisions of the WFD the Norwegian Ministry of Environment (NEA), the national authority for the implementation of the WFD, analysed drivers and pressures towards Norwegian groundwater bodies. Based on this a selection of potential urban, industrial, or agricultural influenced groundwater sites was selected for monitoring (Figure 7). A cooperation agreement on mapping and monitoring of these sites was then established between NEA, NVE (The Norwegian Water Resources and Energy Directorate), NIBIO (The Norwegian Institute of Bioeconomy Research) and NGU (The geological survey of Norway).

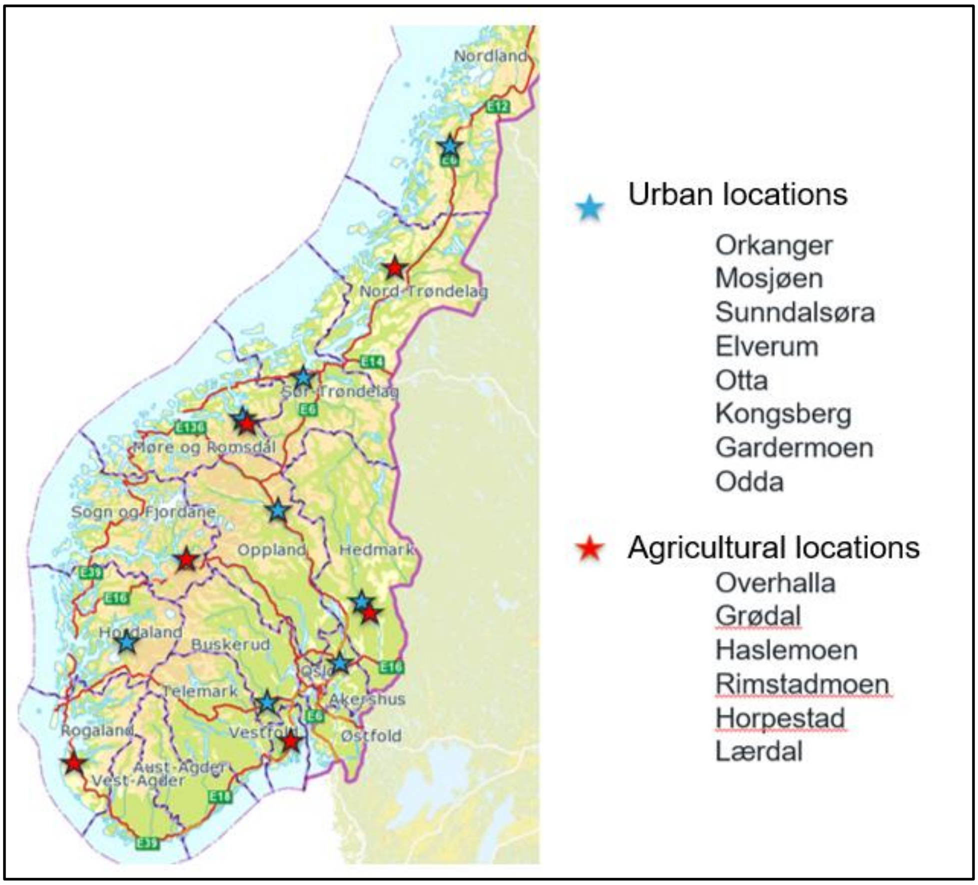


Figure 7. Groundwater monitoring stations establish in areas with pressures (https://www.ngu.no/)

All monitored groundwater locations in urban/industrial areas are characterized as in good condition, except one airport location where PFAS are found. In the agricultural areas the groundwater chemistry reflects the impact from the local form of agricultural operation, in addition to climatic and hydrogeological conditions. Increased content of nitrate was found at all the agricultural monitoring stations. In addition, have a total of 15 different pesticides and metabolites been identified.

Good chemical status of groundwater is defined in the Norwegian framework for water management, usually referred to as “Vannforskriften” or the Water Regulation (KLD, 2006) Annex V, chapter 2.3.2. The Water Regulations (Annex IX) gives threshold values for some substances from human activities which, based on the actual load situation has led to, or may pose, a potential danger to groundwater quality (Table 7). Threshold value is a fixed concentration of substances in the groundwater that defines the boundary between good and bad chemical state (environmental goal). The Committee of Directorates for water management (https://www.vannportalen.no/organisering2/nasjonal-vannforvaltning/direktoratene-og-direktoratsgruppen/oversikt-over-etatene-i-direktoratsgruppa-med-kontaktpersoner/) published in 2018 a guide on classification of environmental condition in coastal waters, groundwater, lakes, and rivers (Committee of Directorates for water management, 2018).

Table 7. Priority substances listed with associated threshold values and turning point values for groundwater (Annex IX in the Norwegian Water Regulation)

Parameter	Threshold value	Turning point value
Nitrate, mg/l	50	37.5
Pesticides µg/l	0.1	0.075
Pesticides, total, µg/l	0.5	0.4
Chloride, mg/l	200	150
Sulphate, mg/l	100	75
Ammonium, mg/N	0.5	0.4
Arsenic, µg/l	10	7.5
Cadmium, µg/l	5	3.75
Lead, µg/l	10	7.5
Mercury, µg/l	0.5	0.4
Sum of trichloroethene and tetrachloroethene, µg/l	10	7.75

2.1.2 Presentation of the results of the assessment of groundwater state

Norway has five online and open publicly available databases providing maps and data on groundwater (Männik et al., 2021). These five databases are hosted by 3 different agencies, the Norwegian Environment Agency, the Norwegian Water Resources and Energy Directorate (NVE) and the Geological survey of Norway (NGU). The Norwegian data base Vann-Nett (https://vann-nett.no/portal/) contains maps displaying groundwater body location, quantitative and chemical status. Swedish data is available through the Vann-Nett map interface. Reports can be downloaded to Excel free of charge. Groundwater status is shown in three colours: green, red, and grey as shown in Figure 8 and 9. All GWBs in Norway are considered to have good quantitative status as the groundwater level in the GWB is such that the long-term average abstraction does not exceed the available groundwater resource.

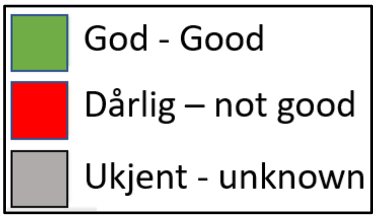


Figure 8. Collours used in Norwegian data bases to indicate groundwater status

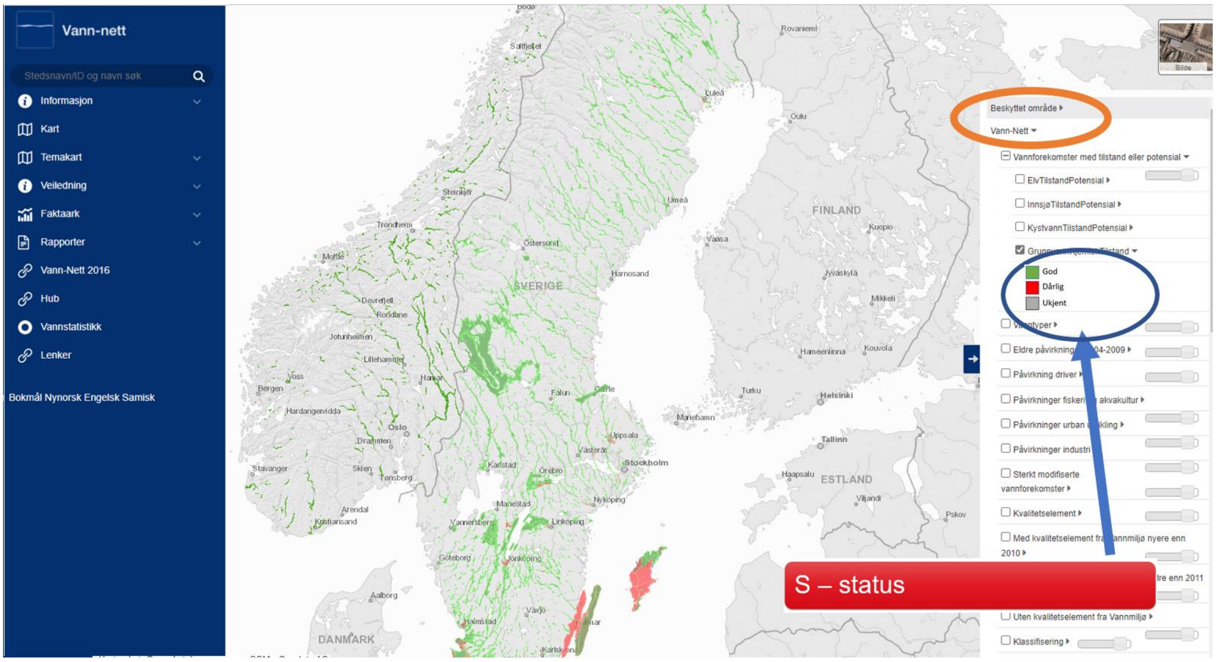
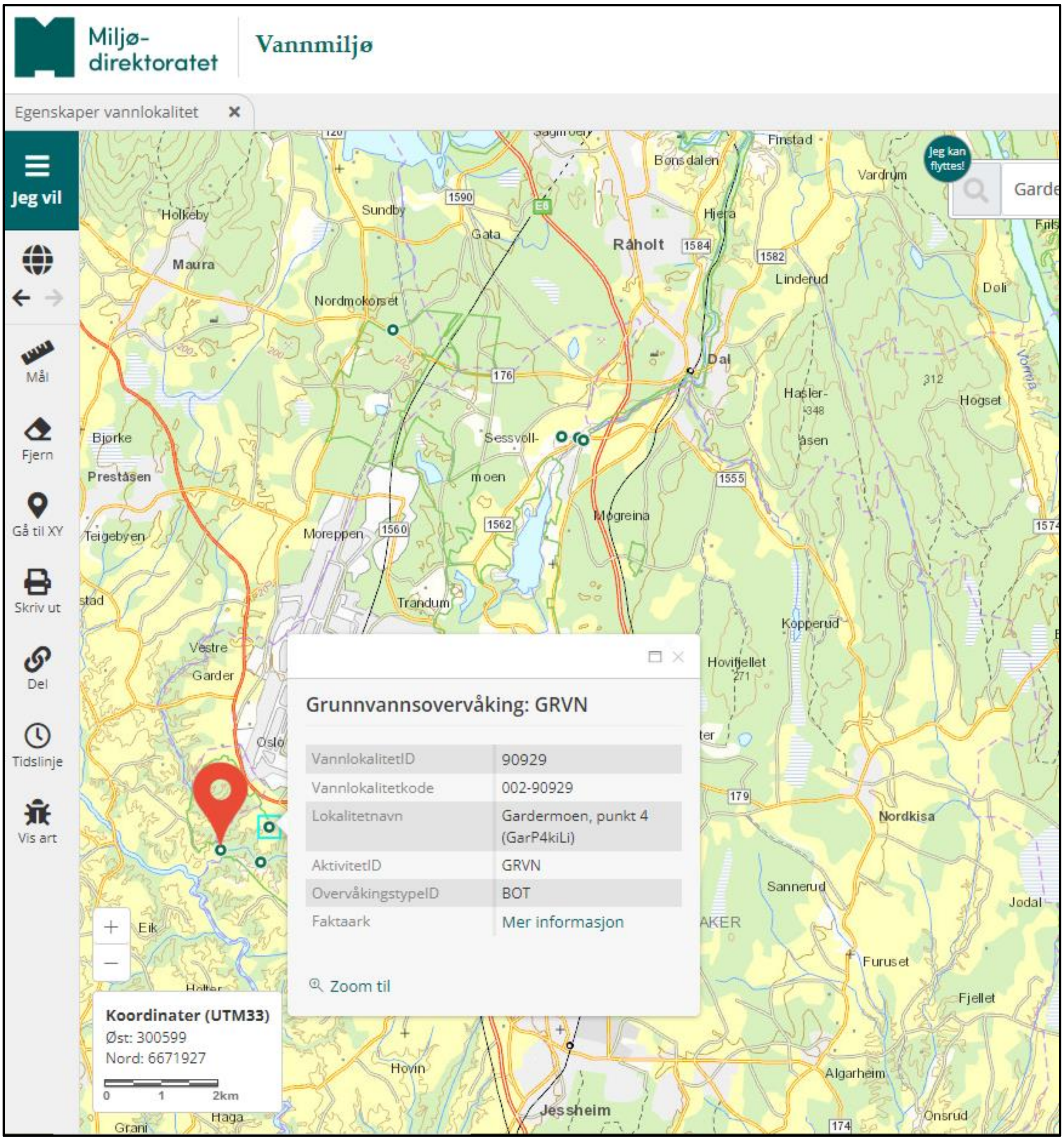


Figure 9. The Norwegian groundwater data base showing groundwater body location, quantitative, and chemical status

Vannmiljø (https://vannmiljo.miljodirektoratet.no/) is the environmental authorities' professional system for registration, coordination, and analysis of the water condition. Vannmiljø thus plays a central role in the planning and implementation of all monitoring activity that follows from 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. Figure 10 shows a screen shot from Vannmiljø with monitoring wells indicated by green circles. Information on the type of monitoring, the water locations ID and code is shown by choosing a circle. More information about the groundwater location can be obtained from the fact sheet link (Figure 10: “Mer informajon”- https://vannmiljofaktaark.miljodirektoratet.no/Home/Details/90929). A screen shot of the upper part of the fact sheet for the groundwater location Gardermoen location 4, chosen in Figure 10, is shown in Figure 11. The fact sheet for the groundwater location provides monitoring data from each year of monitoring and the status of the GWB regarding each measured parameter in colour codes as given in Figure 8.

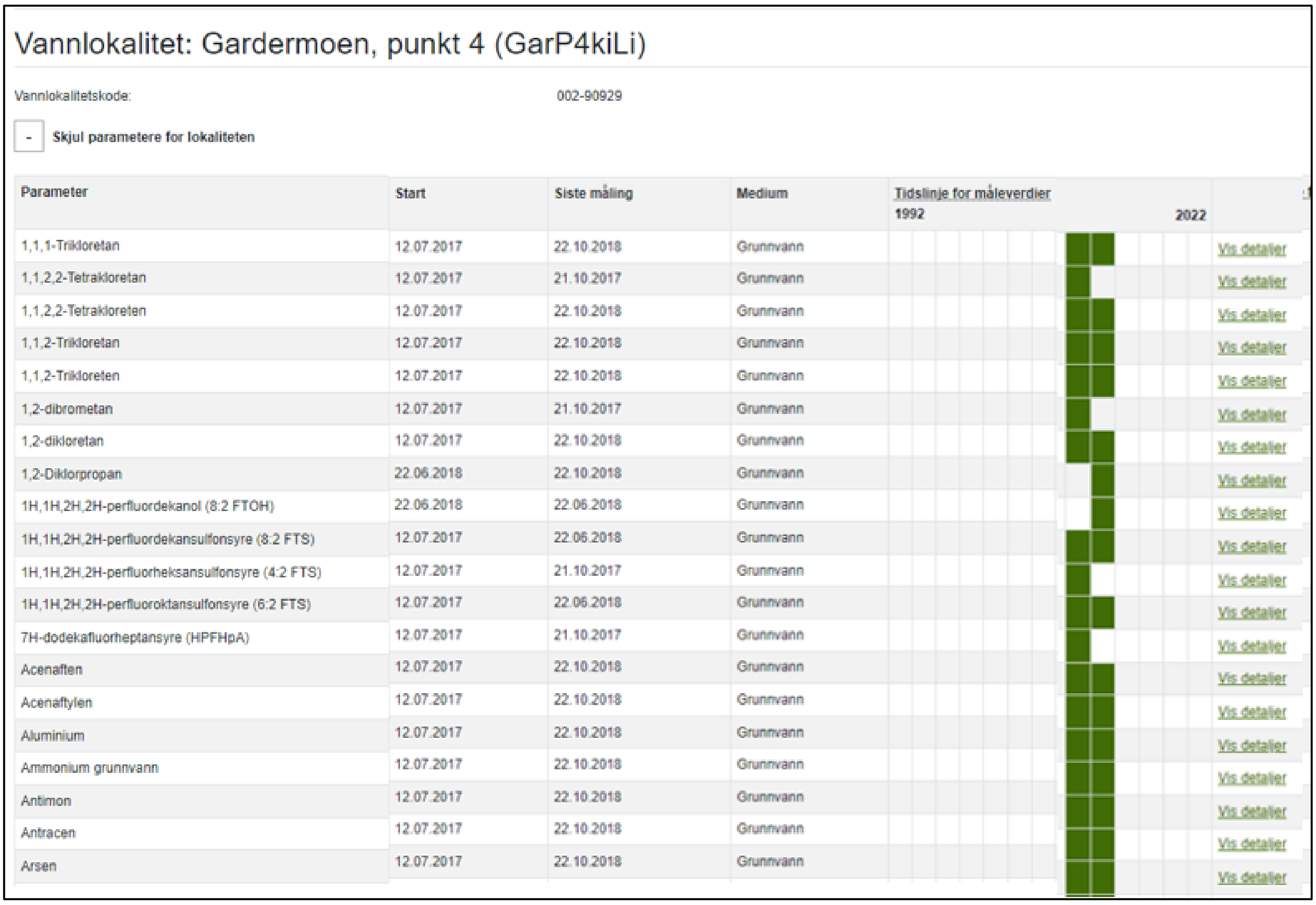


Grunnvannsovervåking: GRVN

VannlokalitetID	90929
Vannlokalitetkode	002-90929
Lokalitetnavn	Gardermoen, punkt 4 (GarP4kiLi)
AktivitetID	GRVN
OvervåkingstypeID	BOT
Faktaark	Mer informasjon

Koordinater (UTM33)
Øst: 300599
Nord: 6671927

Figure 10. Screen shot from the data base Vannmiljø. Monitoring wells are indicated by green circles. Information on the type of monitoring, the water locations ID and code is shown by choosing a circle (More information about the groundwater location can be obtained from the given fact sheet link “Mer informajon”- which in this case links to https://vannmiljofaktaark.miljodirektoratet.no/Home/Details/90929)



Vannlokalitet: Gardermoen, punkt 4 (GarP4kiLi)

Vannlokalitetskode: 002-90929

\- Skjul parametere for lokaliteten

Parameter	Start	Siste måling	Medium	Tidslinje for måleverdier 1992 2022	
1,1,1-Trikloretan	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
1,1,2,2-Tetrakloretan	12.07.2017	21.10.2017	Grunnvann	🟩	Vis detaljer
1,1,2,2-Tetrakloreten	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
1,1,2-Trikloretan	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
1,1,2-Trikloreten	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
1,2-dibrometan	12.07.2017	21.10.2017	Grunnvann	🟩	Vis detaljer
1,2-dikloretan	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
1,2-Diklorpropan	22.06.2018	22.10.2018	Grunnvann	🟩	Vis detaljer
1H,1H,2H,2H-perfluordekanol (8:2 FTOH)	22.06.2018	22.06.2018	Grunnvann	🟩	Vis detaljer
1H,1H,2H,2H-perfluordekansulfonsyre (8:2 FTS)	12.07.2017	22.06.2018	Grunnvann	🟩🟩	Vis detaljer
1H,1H,2H,2H-perfluorheksansulfonsyre (4:2 FTS)	12.07.2017	21.10.2017	Grunnvann	🟩	Vis detaljer
1H,1H,2H,2H-perfluoroktansulfonsyre (6:2 FTS)	12.07.2017	22.06.2018	Grunnvann	🟩🟩	Vis detaljer
7H-dodekafluorheptansyre (HPFHpA)	12.07.2017	21.10.2017	Grunnvann	🟩	Vis detaljer
Acenaften	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
Acenaftylen	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
Aluminium	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
Ammonium grunnvann	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
Antimon	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
Antracen	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer
Arsen	12.07.2017	22.10.2018	Grunnvann	🟩🟩	Vis detaljer

Figure 11. Fact sheet for groundwater body Gardermoen location 4. All parameters have status good or unknown (https://vannmiljofaktaark.miljodirektoratet.no/Home/Details/90929)

2.2. Methodology of the assessment of groundwater state GWB in Latvia

In accordance with the WFD, all GWBs must achieve good status by 2026. The environmental objectives for each GWB must be set by all Member States and the process must be monitored during the River Basin Management cycles. At the end of each cycle (6-year period), the status of all GWBs must be assessed to see the progress.

To assess the status of GWBs, by all Member States assessment methodology must be developed. Methodological CIS Guidance Document No.18 “Guidance on groundwater status and trend assessment” is developed (Guidance document No.18, 2009). The GWB status assessment can be classified as the risk assessment on how human activities can endanger the achievement of environmental objectives. The assessment is supported by conceptual understanding, which is a base of the selection of environmental quality standards and monitoring principles (Annex III of the Groundwater Directive).

CIS Guidance Document No.18 proposes a tiered approach with 9 assessment tests for the chemical and quantitative status assessment of GWBs (Guidance document No.18, 2009). Each relevant test must be carried out separately and the results must be combined to provide an overall GWB’s chemical and quantitative status. The worst-case result test defines the overall status of GWB (Figure 12).

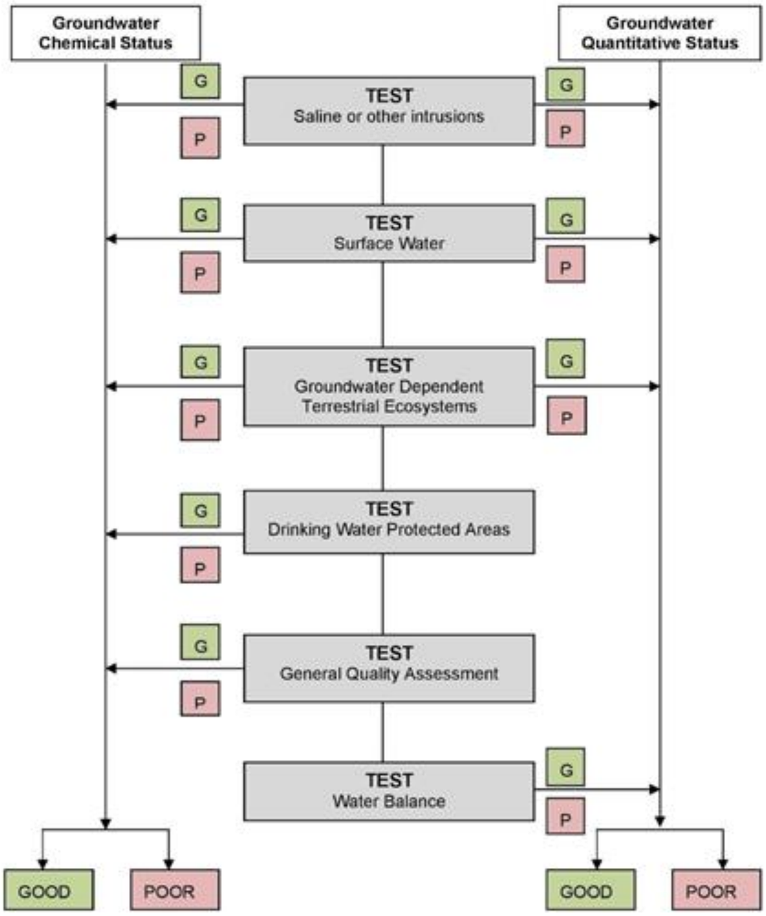


Figure 12. Overall procedure of tests for assessing groundwater status (European Commission, 2009)

Chemical status assessment

In accordance with Article 17 of the WFD, criteria for the assessment of good groundwater chemical status, as well as criteria for the identification of significant and sustained upward trends and the identification of starting points for trend reversals, must be adopted. The Groundwater Directive 2006/118/EC on its part already provides certain quality criteria for nitrates and pesticides and technical regulations for all the above tasks. The WFD also defines that all Member States of transboundary GWBs must jointly coordinate their activities concerning monitoring, threshold values determination, as well as the development of programs of measures.

The WFD states that the good chemical status of GWB is achieved if it meets all the conditions set out in Table 2.3.2 of Annex V. Point 2.4.5 of Annex V also states that the average values at each monitoring point must be calculated when assessing the chemical status of GWB, and, following Article 17, these values must be used to prove compliance with good groundwater chemical status. Following the requirements of Point 1 of Annex III to the Groundwater Directive, the chemical status assessment must be carried out only for those GWBs identified as having significant anthropogenic pressures or risks, and only for those pollutants, groups of pollutants, or indicators, which would characterize it as that. GWBs that are not at risk (no significant anthropogenic pressure has been identified) are automatically classified as in good status. Additional characterization is also mandatory for all transboundary GWBs (Annex II, point 2.3 of the WFD).

The following criteria must be used to assess the chemical status of GWBs in accordance with Chapter 2.3 of Annex V to the WFD, as well as based on the recommendations of CIS Guidance

Documents No.18 (Guidance document No.18, 2009):

- **groundwater quality standards** referred to in Annex I of Directive 2006/118/EC for nitrates and pesticides, the values of which may be reduced if the Member State itself considers it will prevent achieving the objectives of the WFD; in both Estonia and Latvia, these groundwater quality standard have already been adopted (Table 8):

Table 8. Groundwater quality standards adopted in Estonia and Latvia
(Marandi et al., 2020; LEGMC, 2021)

Pollutant	Quality standards
Nitrates	50 mg/l
Active substances in pesticides, including their relevant metabolites, degradation and reaction products(1)	0.1 µg/l 0.5 µg/l (total)(2)
(1) "Pesticides" means plant protection products and biocidal products as defined in Article 2 of Directive 91/414/EEC and in Article 2 of Directive 98/8/EC, respectively (2) "Total" means the sum of all individual pesticides detected and quantified in the monitoring procedure, including their relevant metabolites, degradation and reaction products.	

- **threshold values** set by the Member States following Article 3 of the Groundwater Directive only for those GWBs in which the risk of failure to achieve good chemical status has been identified. Threshold values must be set for parameters that pose a risk or are recognized as indicators of risk. Recommended parameters (but not mandatory) are given in Annex II - As, Cd, Pb, Hg, NH_4^+, Cl^-, SO_4^{2-}, NO_2^-, phosphorus (total) or phosphates, trichloroethene, tetrachloroethene, and electrical conductivity (as intrusion indicator); in Estonia and Latvia, threshold values are determined individually for each GWB.

In accordance with the recommendations given by the CIS Guidance Document No.18 (Guidance document No.18, 2009), several tests (Figure 12) must be developed to assess the chemical status of GWB. Each relevant test must be performed individually and the results of each test must be combined to obtain an overall assessment of the chemical status of the GWB.

The assessment of the chemical status of GWB is a two-step procedure. **In the first step**, the compliance of the chemical status of GWB with the environmental quality standards and/or threshold values must be assessed - if no exceedances are detected at any of the monitoring points, the GWB is considered to be in good chemical status. If exceedances are observed, **the second step** must be taken - a detailed assessment of the chemical status of the GWB using appropriate tests (Figure 12) must be taken to assess compliance with the required environmental conditions. According to CIS Guidance Document No.18, the prevalence of pollutants is significant if it occurs in 20% or more of the area or volume of a groundwater body (Guidance document No.18, 2009).

Quantitative status assessment

The definition of good quantitative status of the GWB is set out in the Annex V 2.1.2 of the Water Framework Directive - good groundwater quantitative status is achieved when the available groundwater resources of the GWB are not exceeded by the long-term annual average groundwater abstraction (the quantitative status of the GWB can be described as the extent to which the GWB is affected by the direct or indirect groundwater abstraction) (Guidance document No.18, 2009).

To determine the quantitative status of the GWB, several tests (Figure 12) must be taken that considers the impacts of anthropogenically induced long-term alterations in groundwater levels and/or flow. Each test must assess whether the GWB is meeting the relevant environmental objectives. Not all environmental objectives apply to every GWB - only relevant tests should be applied as necessary. An overlap between the chemical status assessment for certain elements of the quantitative status assessment exists, in particular relating saline or other intrusions (Guidance document No.18, 2009).

An assessment of quantitative status is required for all GWBs, however, where there is a high degree of confidence that the GWB is currently not at risk of failing quantitative status objectives it is reasonable to assume that the GWB is in good quantitative status, based on the assessment of pressures and impacts (no significant groundwater abstraction pressure or any other groundwater levels altering impacts have been identified) (Guidance document No.18, 2009).

2.2.1. Methodology of the GWB status assessment in Latvia

Chemical status assessment

The methodology of the chemical status assessment of GWBs in Latvia was developed in 2021 for the need of the 3rd cycle RBMPs (LEGMC, 2021). The assessment procedure of the chemical status in Latvia was developed for all GWBs based on the requirements set out in previously mentioned CIS Guidance Document No.18 (Guidance document No.18, 2009). Chemical status assessment procedures of GWBs were developed only for general quality assessment and saline or other intrusions tests, dividing them into separate subtests: the general quality assessment test was divided into three separate tests, considering previously identified pressures in each GWB, but saline or other intrusions test was divided into seawater intrusion test and saline water intrusion test (LEGMC, 2021). The overall quality assessment test is performed for all GWBs, regardless of the pressures identified in them (it can be considered as the background check), while the other tests were selected for each GWB individually, depending on the anthropogenic pressure identified and its impact on groundwater quality:

- **diffuse pressure assessment test** was developed for GWBs with significant diffuse pressure;
- **point pressure assessment test** was developed for GWBs with significant point pressure;
- **seawater intrusion assessment test** was developed for GWBs bordering the sea and exposed to the ground surface with significant abstraction pressure that may cause seawater intrusion;
- **saline water intrusion assessment test** was developed for GWBs located above, below or adjacent to high mineralization areas with significant groundwater abstraction pressure that may activate freshwater mixing with high mineralization waters.

For each test individual parameters and quality criteria were used: the overall quality assessment test (for GWBs with no significant anthropogenically induced pressures) the parameters and quality criteria listed in Annex I of the WFD - nitrates and pesticides - were used. For other tests, taking into account the previously identified anthropogenically induced pressures within each GWB, only those parameters that pose a risk or were recognized as risk indicators were assessed using previously delineated threshold values (LEGMC, 2021).

For the synthetic parameters, following the widely used BRIDGE methodology (Müller et al., 2006), the limit values were set as ½ from environmental quality standards (according to Cabinet Regulation No.118 of March 12, 2003 “Regulations on Surface water and Groundwater quality” (hereinafter - Cabinet Regulation No.118)). Full environmental quality criteria were used as the limit value for parameters such as permanganate index, total nitrogen, and nitrites, which occur in nature but for which threshold value could not be determined due to limited data set. It should be noted that if the general quality assessment test overlapped with the diffuse pressure assessment test, the strictest quality criteria were used for the assessment of nitrates and pesticides. The list of parameters used for each assessment test is given in Table 9, but the limit values of additional parameters are given in Table 10.

Table 9. Parameters used to assess the chemical status of groundwater bodies according to each assessment test (LEGMC, 2021)

Assessment test and its subtest		Parameters
General quality assessment	**Without significant pressure**	nitrates (NO_3^-), pesticides (in total), pesticides (separately)
	With significant diffuse pressure	nitrites (NO_2^-), nitrates (NO_3^-), ammonium (NH_4^+), pesticides
	With significant point pressure	nitrites (NO_2^-), nitrates (NO_3^-), ammonium (NH_4^+), chlorides (Cl^-), sulfates (SO_4^{2-}), total phosphorus (P_{tot}), total nitrogen (N_{tot}), cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), nickel (Ni), permanganate index (CODMn), sum of benzene, toluene, ethylbenzene and xylenes (BTEX), trichlorethylene (TCE), tetrachlorethylene (PCE)
Saline or other intrusions	**Seawater intrusion**	chlorides (Cl^-)
	Saline water intrusion	chlorides (Cl^-), sulfates (SO_4^{2-})
Remarks: black color - GWB-specific threshold values were applied (except in general quality assessment test for GWBs without significant pressures where groundwater quality standards set by the Groundwater Directive were applied); **blue color** - quality standards specified in the Cabinet Regulation No.118 were applied; **red color** - ½ from quality standards specified in the Cabinet Regulation No.118 were applied		

Table 10. Limit values of additional parameters (to groundwater quality standards and threshold values) used to assess the chemical status of groundwater bodies (LEGMC, 2021)

Parameter	Unit of measure-ment	Environmental quality standard according to Cabinet Regulation No.118	The limit value used in chemical status assessment of GWBs	Pressure type
Nitrites (NO_3^-)	mg/l	0.5	0.5	Point/diffuse
Total nitrogen (N_{tot})	mg/l	3	3	Point
Permanganate index (CODMn)	mg/l	5	5	Point
Sum of benzene, toluene, ethylbenzene and xylenes (BTEX)	µg/l	10	5	Point
Trichlorethylene (TCE)	µg/l	10	5	Point
Tetrachlorethylene (PCE)	µg/l	10	5	Point
Pesticides (total)	µg/l	0.50	0.25	Diffuse

Aldrin, dieldrin, heptachlor and heptachlor epoxide (separately)	µg/l	0.030	0.015	Diffuse
Other pesticides (separately)	µg/l	0.10	0.05	Diffuse

The assessment was performed individually for each GWB, using appropriate tests with identified pressure parameters or groups of parameters, as well as the established groundwater quality standards and/or threshold values. To assess the compliance of GWB with good or poor chemical status, the results of groundwater monitoring for the period from 2014 to 2019 were compiled, calculating the average concentrations of previously identified parameters for each GWB at each monitoring point. Samples with ionic balance discrepancies (deviations greater than ±10%) as well as extremely high and/or low values (outliers) were excluded from the data set. For parameters whose concentrations were below the limit of quantitation (LoQ), they were replaced with values that are ½ of this LoQ value. In turn, only quantified concentrations were used to calculate average concentrations of pesticides (values lower than LoQ value were excluded from the dataset), following the recommendations of the CIS Guidance Document No.18 (LEGMC, 2021).

If no exceedances were identified at any of the monitoring points and tests performed, the GWB was considered to be in good chemical status (high or medium confidence). If at least in one of the tests exceedances were identified at least at one of the monitoring points, an in-depth data analysis was performed and the significance of the detected exceedance at the level of GWB was initially assessed (examining whether the prevalence of pollutants represented more than 20% of the total area of the GWB) (LEGMC, 2021).

Using the Thiessen polygon method, the area (as a percentage) of the total GWB area was calculated for each monitoring station, which represents the prevalence or significance of the detected exceedance. The areas determined by groundwater monitoring stations were summarized if the exceedances were marked in several monitoring wells, which represent different monitoring stations (Figure 13). It should be noted that the area occupied by the exceedances was calculated for the group of pollutants that characterize the specific pressure type, not for each parameter separately (LEGMC, 2021).

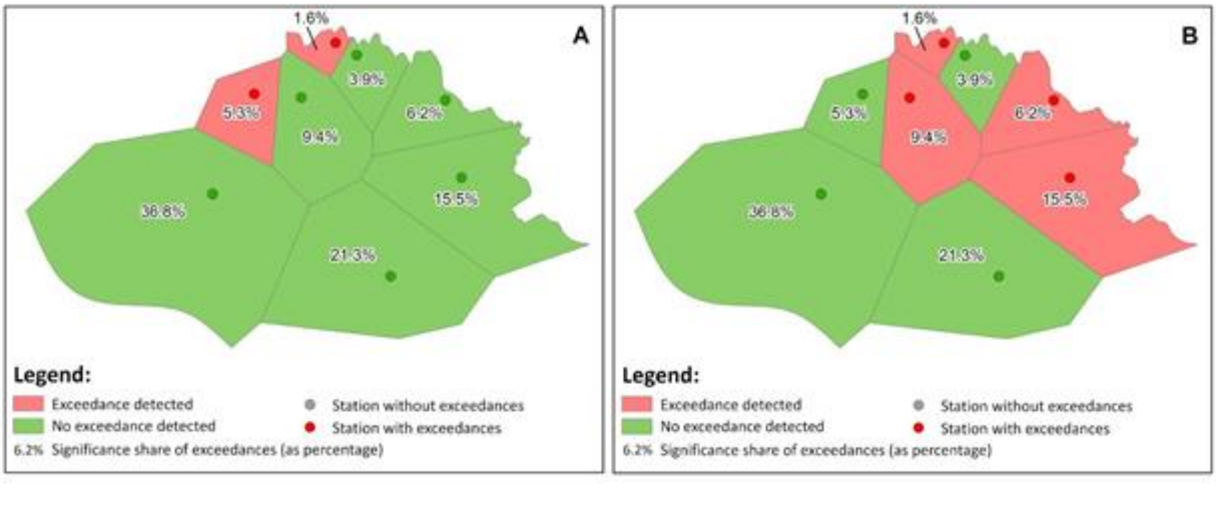


Figure 13. A - exceedances identified at two monitoring stations, representing 6.9% of the total area of GWB; B - exceedances identified at four stations, representing 32.7% of the total area of GWB (LEGMC, 2021)

If the identified exceedances of the pollutant threshold values did not exceed 20% of the total area of the GWB, then GWB was considered to be in good chemical status (with high or medium confidence). If the identified exceedances represented more than 20% of the total GWB area, an additional assessment and trend analysis was performed for each monitoring point with the identified exceedance. GWB was considered to be in good chemical status (high or medium confidence) if no statistically significant upward trend was identified at any of these monitoring points or the identified exceedances did not pose a significant risk to the chemical status of the GWB, and good status (with medium confidence) if trends could not be assessed due to lack of data. Otherwise, GWB was considered to be in poor status (with high confidence) if it could not be proved that the identified exceedances did not pose a significant risk to the overall chemical status of GWB, or were representative only of local effects, or of groundwater natural status/quality (LEGMC, 2021). The test procedure is given in Figure 14.

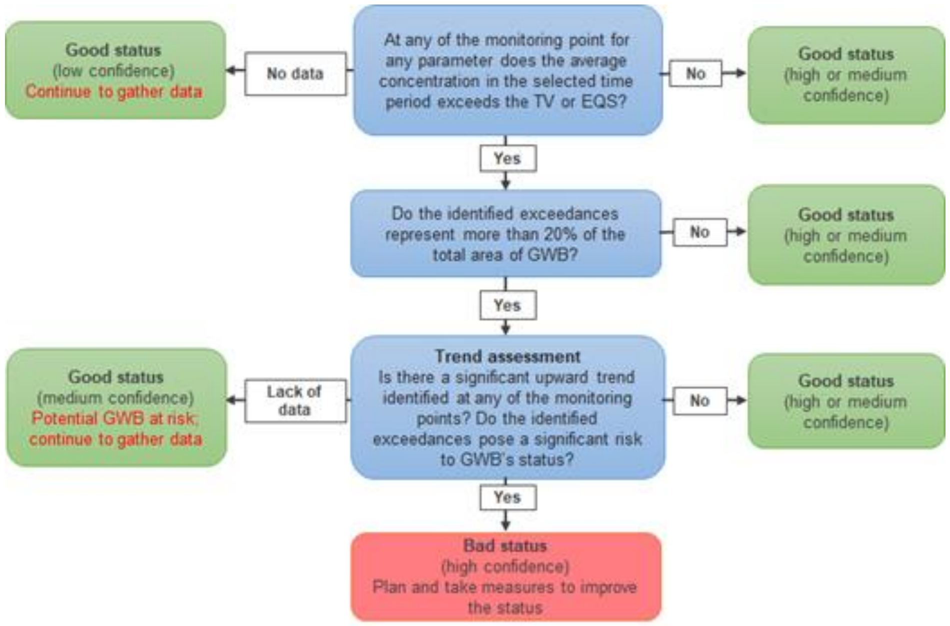


Figure 14. Schematic procedure for tests used to assess the chemical status of GWB

(LEGMC, 2021)

Each test was performed individually and the results of each test were summarized to obtain an overall chemical status of the GWB: the worst result of all the chemical status assessment tests performed was considered to be the final chemical status of GWB. The level of confidence of the results of the chemical status assessment was based on the monitoring network coverage (number of monitoring points), the number of collected groundwater samples, as well as the identified exceedances (LEGMC, 2021).

At the time of development of the 3rd cycle RBMPs the work was underway for identifying and assessing the quality of groundwater-associated aquatic ecosystems (GAAEs) and groundwater-dependent terrestrial ecosystems (GDTEs) at the national level, therefore within the framework of this management cycle chemical status assessment tests for surface waters and groundwater-dependent terrestrial ecosystems tests were not developed for the assessment of the chemical status of GWBs.

Quantitative status assessment

Assessment of the quantitative status must be carried out for all GWBs, but in cases where there is a high probability that GWB is not at risk of not achieving a good quantitative status, the GWB can be assessed as being in good quantitative status. Accordingly, in Latvia, the in-depth assessment of the quantitative status was performed only for GWBs for which a significant groundwater abstraction pressure has been identified (LEGMC, 2021).

For GWBs where no significant groundwater abstraction pressure was previously identified, the quantitative status was assessed as good (average confidence). Additional criteria were also set: if in none of the groundwater well fields of the respective GWB no depletion of groundwater resources was detected in the respective period (2014-2019), as well as no exceedances of the calculated maximum groundwater level reduction were observed, then GWB was assessed with good quantitative status (with an average level of confidence). For other GWBs where exceedances were observed and groundwater abstraction pressures were identified, an in-depth quantitative status assessment was performed by performing groundwater balance, as well as seawater and/or saline intrusion tests (according to the characteristics of each GWB) (LEGMC, 2021).

In the groundwater balance test, primarily the average groundwater abstraction (m^3/d) for the period from 2015 to 2019 was compared with the total approved (calculated) groundwater resources (m3/d) in groundwater well fields, expressed as a ratio (%). GWB was assessed being in good quantitative status (average confidence) if this ratio did not exceed the 75% threshold value (the 75% threshold value was adapted for the assessment of groundwater balance from Guidance Document No.18 (Guidance document No.18, 2009), where this threshold value is used in trend assessment as a starting point for irreversible deterioration in quality). In case of exceeding this threshold value, additional data analysis were performed - long-term data on changes in groundwater levels in State Monitoring Network monitoring wells were collected and assessed whether statistically significant downward trends are observed. GWB was considered to be in good quantitative status (high confidence) if no statistically significant downward trends were observed in any of the monitoring wells. If a statistically significant downward trend was identified in one or more monitoring wells, it was assessed whether the identified monitoring wells represented more than 20% of the total GWB area (according to the Thiessen polygon method). If the 20% threshold was not exceeded, GWB was considered to be in good quantitative status (high confidence). If the 20% threshold was exceeded, GWB was considered to be in poor quantitative status (high confidence) (LEGMC, 2021). The schematic procedure of the groundwater balance assessment test is given in Figure 15.

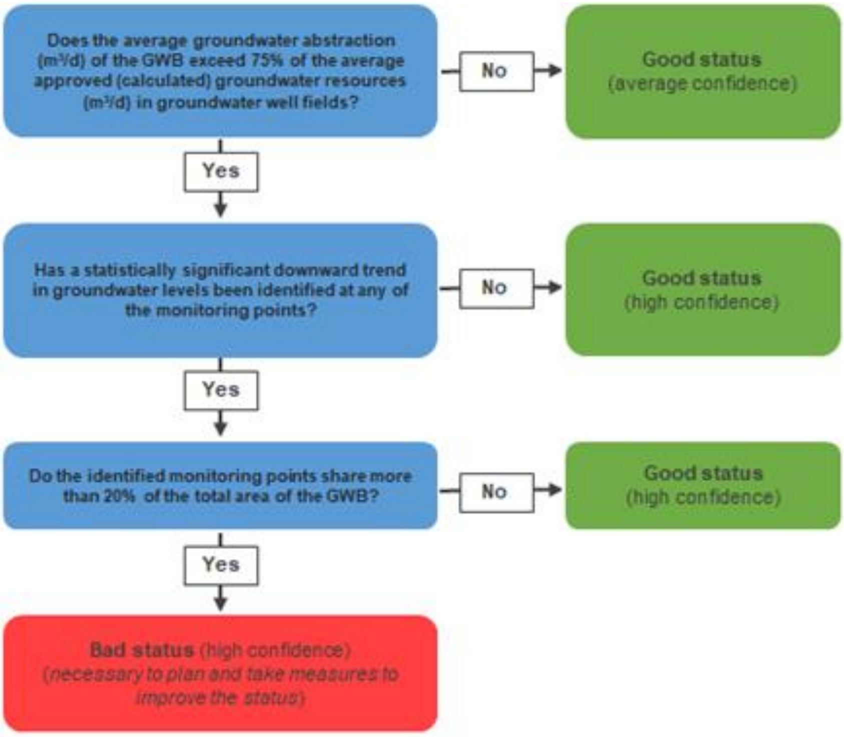


Figure 15. Schematic procedure of groundwater balance test (LEGMC, 2021)

It should be noted that in the groundwater balance test, none of the GWBs reached the step of assessing trends in groundwater levels, as the 75% threshold value for approved (calculated) groundwater resources was not exceeded. In the future, it is necessary to develop a detailed methodology for the assessment of trends in groundwater levels and to intensify the arrangement of groundwater level measurement data series, because, with current knowledge and available data quality, the assessment is heavily based on expert judgment in each case (LEGMC, 2021).

Saline or other intrusion test was also performed only for GWBs for which significant groundwater abstraction pressure was previously identified. As a starting point for both tests, the results of the respective tests from the chemical status assessment were used - if the poor chemical status of GWB was not identified in the corresponding test during the chemical status assessment, then GWB was assigned with a good quantitative status (average confidence) in the relevant quantitative test (Figure 16).

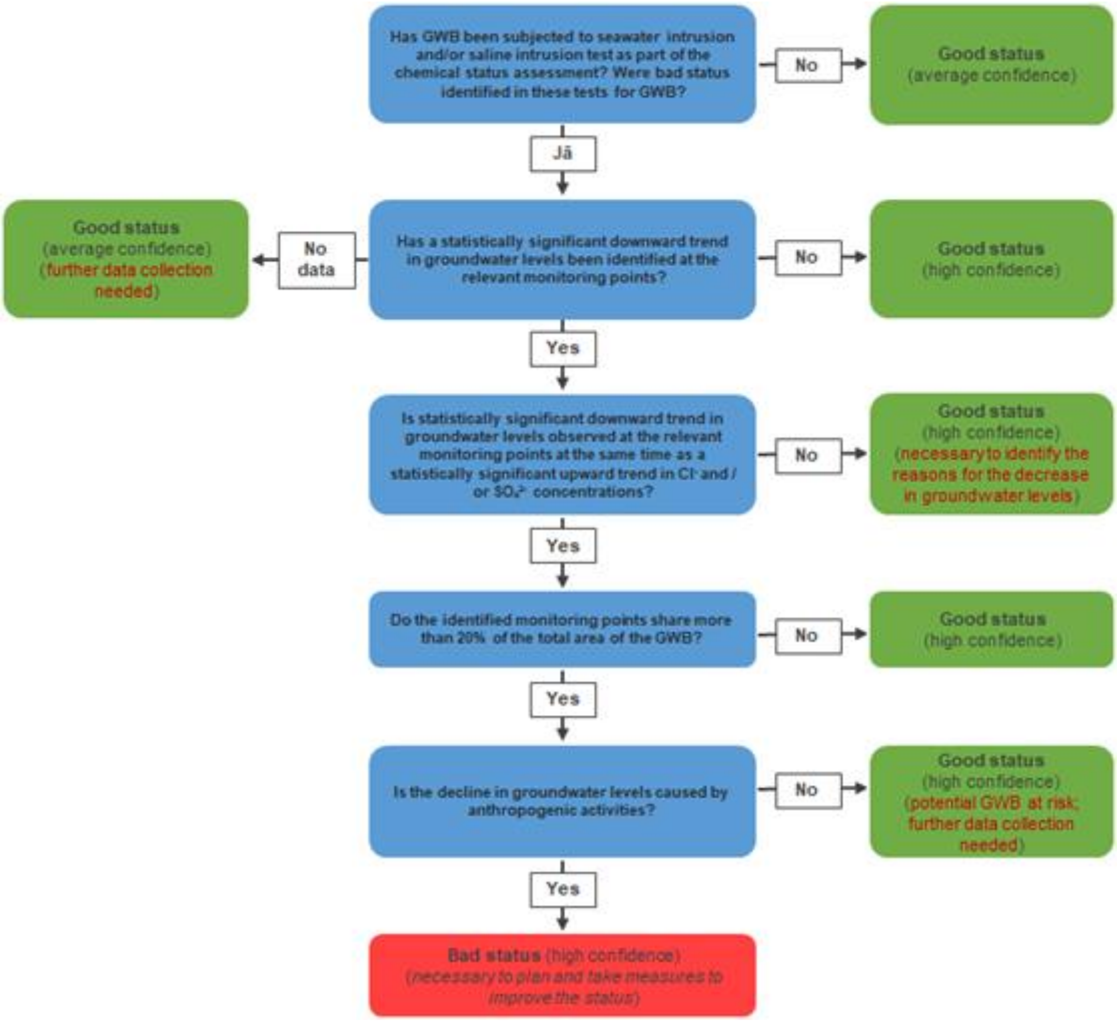


Figure 16. Schematic procedure of saline or other intrusion tests (LEGMC, 2021)

In case poor chemical status was identified for GWB in saline or other intrusion tests as part of the GWB chemical status assessment, an in-depth saline or other intrusion test was performed on GWB by analyzing trends in groundwater levels, identifying statistically significant downward trends. If no such trends were identified, GWB was considered to be in good quantitative status (high confidence). If it was not possible to assess trends in groundwater levels due to a lack of data, GWB was also considered to be in good quantitative status but with an average level of confidence (Figure 16).

If statistically significant downward trends in groundwater levels were identified at one of the relevant monitoring points, then based on the results of the chemical status assessment in the relevant test, it was determined whether they are observed simultaneously with statistically significant upward trends in Cl^- and/or SO_4^{2-} concentrations. If no such overlap was identified, GWB was considered to be in good quantitative status (high confidence), but with the side-note of the need to clarify the reasons for the decrease in groundwater levels in the future (Figure 16).

If an overlap between the two processes was observed, it was further identified whether such monitoring points share more than 20% of the total area of the GWB (according to the Thiessen polygon method). If the 20% threshold was not exceeded, GWB was considered to be in a good quantitative status (high confidence) (Figure 16).

If the 20% threshold was exceeded, it was additionally assessed whether the decrease in groundwater levels was due to local anthropogenic impacts. If no link was identified, GWB was considered to be in a good quantitative status (high confidence), but GWB could be potentially at risk. If anthropogenic effects were identified, then GWB was considered to be in poor quantitative status (high confidence) (Figure 16).

It should be noted that in saline or other intrusion tests, the step of assessing trends in groundwater levels was reached only for GWBs at risk. The long-term groundwater level data series were used in the trend assessment, calculating the average value of groundwater levels each year to assess the development of the overall groundwater level situation (respectively: an increase or decrease in groundwater levels). In the end, based on the mathematical results of the regression analysis, the results were used only from those monitoring wells where statistically significant trends (upward or downward) were observed. In the future, it is necessary to develop a detailed methodology for assessing trends in groundwater levels and to focus more on arranging data series for groundwater level measurements, because, with current knowledge and the quality of available data, the assessment is heavily based on expert judgment in each case (LEGMC, 2021).

The tests were performed individually and the results of each individual test were summarized to obtain an overall assessment of the quantitative status of GWB. The worst result from each test was considered to be the total quantitative status of GWB (LEGMC, 2021).

At the time of development of the 3rd cycle RBMPs the work was underway for identifying and assessing the quality of groundwater-associated aquatic ecosystems (GAAEs) and groundwater-dependent terrestrial ecosystems (GDTEs) at the national level, therefore within the framework of this management cycle quantitative status assessment tests for surface waters and groundwater-dependent terrestrial ecosystems tests were not developed for the assessment of the quantitative status of GWBs.

2.3. Methodology of the GWB status assessment in Estonia

Chemical status assessment

Chemical status assessment in Estonia is a two-step procedure. During the first step, exceedances of groundwater quality standards, threshold values, and/or limit values were identified at all monitoring points. If the relevant quality standards were not exceeded at any monitoring point, the chemical status of the GWB was considered to be good and the remaining chemical status assessment tests were not performed for that particular GWB. However, if groundwater quality standard, threshold value, and/or the limit value were exceeded in one (or more) cases, further chemical status assessment tests were performed (Marandi et al., 2020).

The chemical status assessment of GWBs used groundwater quality data collected during the national groundwater monitoring, company self-monitoring, nitrate vulnerable zone groundwater monitoring, and the data from hazardous substances survey in 2018, but only from monitoring points included in the national groundwater monitoring network, which ensures the consistency of the time series of the monitoring data and the uniformity and comparability of the data over the different assessment periods. The monitoring data were compiled and the annual average concentrations of the relevant pollutants for the whole reference period (2014-2019) were calculated at all monitoring points in the GWB. For pollutants whose concentrations were below the limit of quantitation (LoQ), they were replaced with values that are ½ of this LoQ value. In turn, only quantified concentrations were used to calculate average concentrations of pesticides (values lower than LoQ value were excluded from the dataset), following the recommendations of the CIS Guidance Document No.18 (Marandi et al., 2020).

According to the regulation of the Minister of the Environment No.48 (adopted on 01.10.2019), the quality indicators used to determine the chemical status class of GWBs are groundwater quality standards (as presented in Table 11), threshold values, as well as electrical conductivity, pH, dissolved oxygen content, chemical oxygen demand (COD), ammonium (NH_4^+), chlorides (Cl^-), sulfates (SO_4^{2-}); as well as hazardous substances, including concentrations of arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), trichloroethylene (TCE), tetrachlorethylene (PCE) and other synthetic substances (Marandi et al., 2020).

In addition to groundwater quality standards and threshold values, in case of Estonia, for GWB to be in good chemical status it must comply with the quality indicators listed in § 7(1) of the regulation of the Minister of the Environment No.48 (adopted on 01.10.2019) (Marandi et al., 2020):

- the concentration of chloride (Cl^-) and sulphate (SO_4^{2-}) ions as well as the concentration of total dissolved solids (TDS) measured by electrical conductivity do not show an upward trend indicating anthropogenic pollution or saline intrusion;
- the pH is in the range of 6-9;
- the dissolved oxygen (O_2) content does not show a downward trend due to human activity or the chemical oxygen demand (COD) contect is ≤5 mg/lO_2 or, if the value of the quality indicator is exceeded, the natural origin of the dissolved oxygen in the groundwater has been proven;
- the content of ammonium (NH_4^+) ions in naturally aerobic groundwater does not exceed 0.5 mg/l or does not exceed 1.5 mg/l in naturally anaerobic aquatic environment, or, if the value of a quality indicator is exceeded, the natural origin of ammonium (NH_4^+) ions in groundwater should been proven;
- hazardous substances, including arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), trichlorethylene (TCE), tetrachlorethylene (PCE) and synthetic substances should be absent in groundwater, or their concentration does not exceed the groundwater quality limit values for hazardous substances, or the natural origin of these hazardous substances in groundwater should been established;
- the concentration of pollutants should not impede the achievement of the environmental objectives set for the surface waters associated with the GWB and should not cause significant damage to the ecological or chemical status of the surface waters or to terrestrial ecosystems directly dependent on that GWB.

In Estonia, GWB is considered to be with aerobic groundwater if it includes the first aquifer from the ground surface, and for the GWBs the quality limit of ammonium (NH_4^+) ions is set as 0.5 mg/l (Marandi et al., 2020).

The groundwater quality standards for hazardous substances are expressed through environmental quality standards and threshold values. The environmental quality standard indicates the concentration of a hazardous substance in groundwater at a value equal to or less than the quality of groundwater in the area. The threshold value indicates the concentration of a hazardous substance in groundwater above which groundwater is considered to be contaminated and measures must be taken to eliminate the pollution and improve the quality of the groundwater, except in the case of natural pollution. In the case of hazardous substances (Table 11), the threshold values provided in the regulation of the Minister of the Environment No.39 (adopted on 04.09.2019) were used in assessing the chemical status of GWBs in agreement with the contracting authority (Marandi et al., 2020).

Table 11. Groundwater quality threshold values for hazardous substances

Hazardous substance		Threshold value (µg/l)
Arsenic (As)		100
Cadmium (Cd)		10
Mercury (Hg)		2
Lead (Pb)		200
Chlorinated Aliphatic Hydrocarbons (CAHs)	Trichlorethylene (TCE)	70
	Tetrachlorethylene (PCE)	70

If during the first stage of the assessment (*the background check*) it is identified that the average values of the parameters during the period 2014-2019 have not been exceeding the respective environmental quality standards and/or threshold values at any monitoring point, the chemical status of GWB is considered to be good and no other chemical status assessment tests were performed. If any exceedances are identified, the chemical status assessment was continued with other chemical status tests, which, among other things, assessed the variability of pollutant concentrations affecting groundwater status during the assessment period (2014-2019) and variability from baseline levels (Marandi et al., 2020).

The baseline level is the average pollutant concentration in the GWB measured in the course of groundwater monitoring in 2007–2009 (Riigikogu, 2019). The values of the baseline levels of the chemical parameters used in the groundwater chemical status assessment tests have been calculated based on data collected by the Estonian Geological Survey during the work of groundwater bodies (Marandi et al., 2019). If there was no data on the pollutant at the monitoring points before, the first annual average concentration measured during the assessment period has been taken as the baseline (Marandi et al., 2020).

The chemical status tests and the reporting of the results shall assess whether there is a statistically significant upward trend in the concentrations of pollutants in groundwater during the assessment period (steady upward trend). The Water Act defines that “*a significant or sustained increase in the pollutant content of groundwater indicates a statistically reliable and environmentally significant increase in the pollutant content in an endangered groundwater body*”. In the event of an increase in the pollutant concentration, a threshold for reducing the pollutant concentration of groundwater must be established (indicating that the pollutant concentration of the endangered GWB has increased by 75% of the pollutant threshold value), to stop the increase in pollutant content or reduce the pollutant content (Riigikogu, 2019).

A significant increase in the pollutant concentration is an increase in the average annual pollutant concentration in an endangered GWB for more than 20% of the baseline level for two consecutive years (Riigikogu, 2019). An environmentally significant increase in pollutant concentration could not be implemented in the assessment according to this definition. For example, a 20% increase in chloride (Cl^-) ions concentration is not environmentally significant if the initial chloride level is only 3 mg/l. An increase in the concentration of the indicator will become important if it starts to approach the threshold value of the GWB. In agreement with the contracting authority, it was found that environmentally significant growth needs to be redefined in legislation, and in this case, only the criterion of a sustainable growth trend is used to assess trends. One option in the future is to consider an increase above the pollutant reduction threshold (75% of the threshold value) as an environmentally significant increase. The use of a pollutant reduction threshold as an additional criterion was necessary to screen for large percentage fluctuations caused by low baseline levels and natural groundwater chemistry variability (Marandi et al., 2020).

A steady increase in the pollutant content of groundwater is defined in the Water Act as an increase in the average annual pollutant content in an endangered GWB for six consecutive years compared to the baseline level (Riigikogu, 2019). As recommended by the European Commission's Groundwater Assessment Guidelines (Guidance document No.18, 2009), only an increase in pollutant concentration with statistical reliability of a linear growth trend of more than 95% (p-value < 0.05) was considered a sustainable growth trend in the status assessment. In the assessment, the pollutants for which threshold values have been set for the GWB were considered. The monitoring of pesticides has been too insufficient to observe trends. Different pesticides have been identified from different observation wells and thus it is not yet possible to monitor statistically reliable growth trends during this assessment period. The significant growth trend found in the monitoring wells is marked with a black dot in the figure of the assessment result of each groundwater body. Different pesticides have been identified from different observation wells and thus it is not yet possible to monitor statistically reliable growth trends during this assessment period (Marandi et al., 2020).

The **general quality assessment** test partly overlaps with the collection of background information on the chemical composition of the GWB - *the background check*. If the groundwater quality standards, threshold, and/or limit values were exceeded, the status assessment was continued with the next steps (Figure 17).

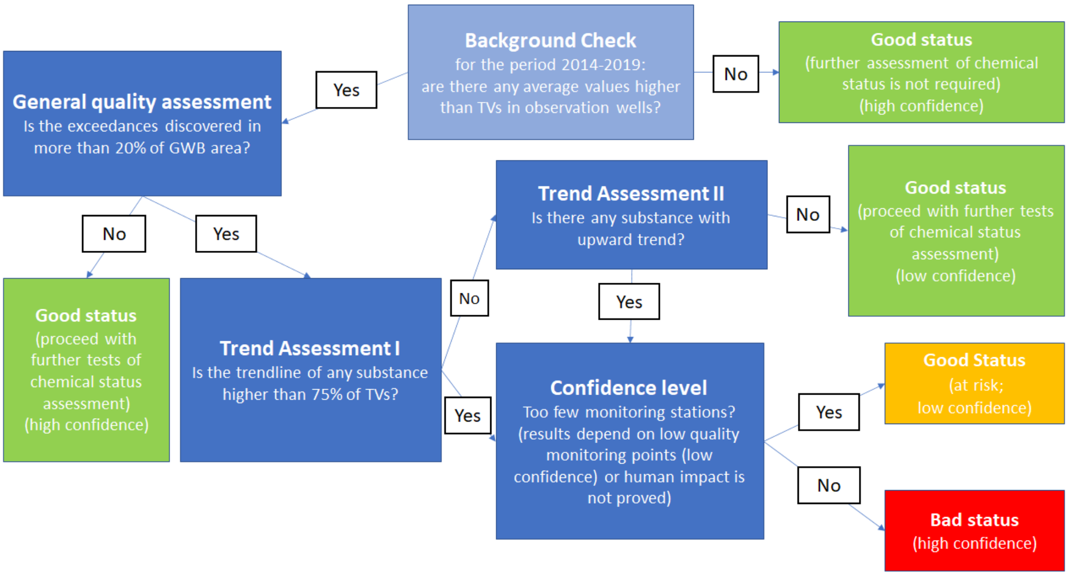


Figure 17. Flow diagram of the background check and the general quality assessment test (Marandi et al., 2020)

First, the share of monitoring points in the GWB where groundwater quality standards, threshold values, and/or limit values were exceeded for the average concentration of pollutants in the period of 2014-2019 was assessed. According to CIS Guidance Documents No.18, the spread of pollutants is significant if it occurs in 20% or more of the area or volume of a GWB (Guidance document No.18, 2009). To assess this extent, a spatial analysis of the location of the monitoring points was used, during which the impact ranges on the monitoring points of the Thiessen polygons were determined by the surface generation method. As a result of the application of the Thiessen polygons, the GWB was subdivided into smaller and larger units, which characterize the scope of impact of a certain monitoring point (Figure 18).

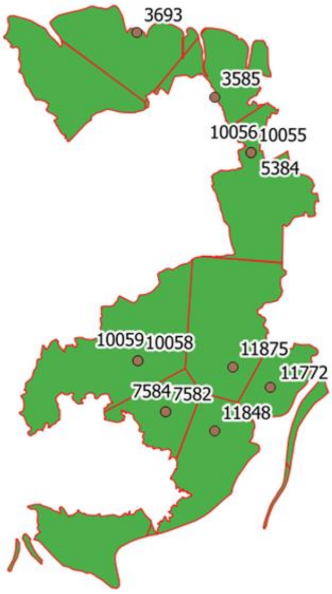


Figure 18. The example of the use of the Thiessen polygon method to define the share of the importance of each monitoring point in GWB Nr.13 (Marandi et al., 2020)

If the share of the monitoring points with exceedances of groundwater quality standards, threshold values and/or limit values was less than 20% of the GWB area, the GWB was considered to be in good status, according to the general quality assessment test and the assessment was continued with the following status assessment tests. However, if the share of these monitoring points reached more than 20% of the GWB area, the trend assessment (aggregated data by whotrend le GWB) for relevant pollutants was carried out (Figure 17, Trend Assessment I). If during this assessment the linear trend line exceeded 75% of the threshold or limit value established for any relevant pollutant, the GWB was considered to be in poor status. However, attention was also paid to the reliability of the monitoring network (Figure 17, Confidence Level), which means that it was assessed whether there were an insufficient number of monitoring points, and if pollutant concentrations and growth trends were affected by poor quality monitoring points and/or human impact was identified (Marandi et al., 2020).

In a situation where the trend lines of aggregated data by GWB of the pollutants in question in all monitoring points did not exceed 75% of the threshold and/or limit value, the next step was to perform the trend assessment of these pollutants in each monitoring point. If a statistically significant upward trend was identified at least at one monitoring point, the GWB was considered to be in poor status (high confidence) based on a reliable monitoring network and analytical data. If the monitoring data were affected by insufficient or poor quality monitoring points and no human impact was detected, the GWB was considered to be in good status, but at risk. The confidence level of this result was low, as in the next observation period it has to be determined whether the high concentrations of pollutants in monitoring points are local or pose a threat to the whole GWB. Therefore, also, in this case, the status assessment was based on the quality of the specific monitoring point and the corresponding monitoring data, and the configuration of the monitoring network on the GWB level (Marandi et al., 2020).

A test to identify the risk of **saline or other intrusions** and to assess its impact on the chemical status of GWB was performed only in GWBs where threshold values have been established for chloride (Cl^-) and sulfate (SO_4^{2-}) ions, characterizing intrusion processes. The first step was to determine whether a statistically significant upward trend in the annual average chloride (Cl^-) and sulfate (SO_4^{2-}) ion concentrations (aggregated data by whole GWB) have been identified and whether these concentrations have exceeded the established threshold values (by single monitoring point) (Figure 19). If there were no statistically significant upward trends identified (in the aggregated data by whole GWB) and the average concentrations in the individual monitoring points were lower than the threshold values, the GWB was considered to be in good chemical status, according to this test (Marandi et al., 2020).

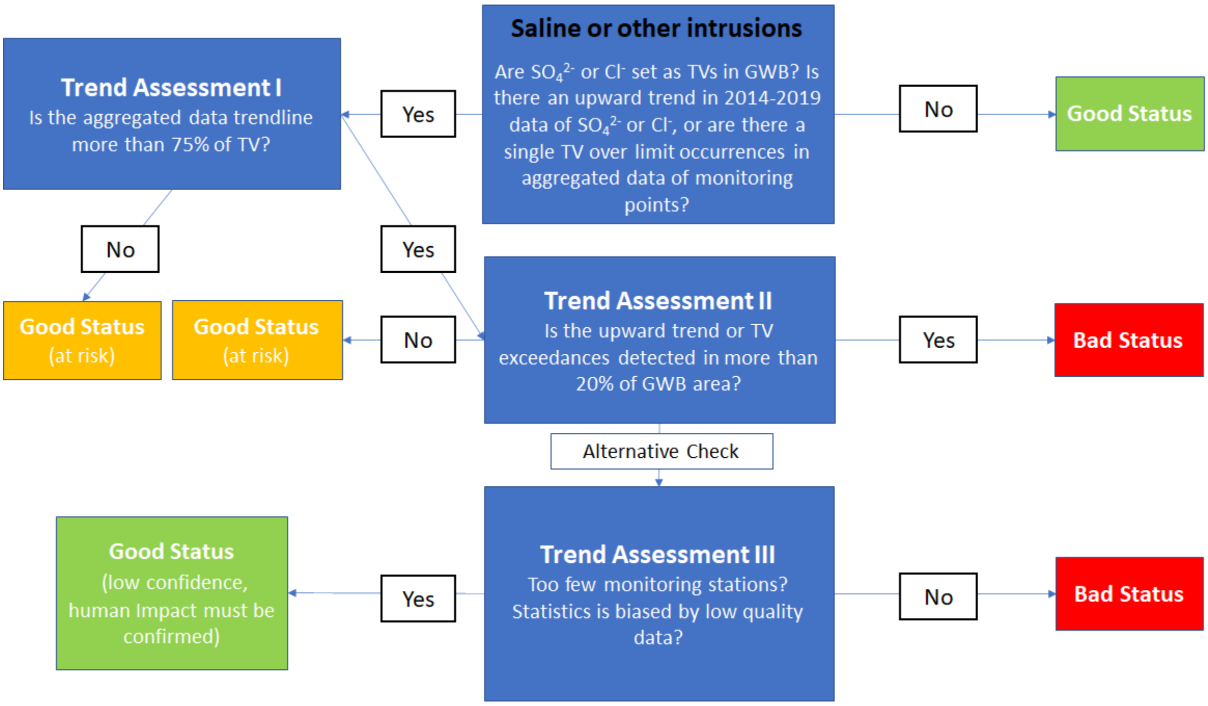


Figure 19. Flow diagram of the saline or other intrusions test (Marandi et al., 2020)

If there was a statistically significant upward trend identified based on chloride (Cl^-) and sulfate (SO_4^{2-}) ions concentrations in the aggregated data by whole GWB, verification was made whether the trend line exceeds 75% of the threshold value (Figure 19, Trend Assessment I). If the trend line remained below the 75% mark of the threshold value, the GWB was considered to be in good status, but at risk. However, if the upward trend of chloride (Cl^-) and sulfate (SO_4^{2-}) ions exceeded the 75% mark of the threshold value and/or there were monitoring wells with the average concentration above the threshold value, the assessment proceeded with the trend assessment in single monitoring point (Figure 19, Trend Assessment II).

The further assessment did determine whether the monitoring point or points, where the threshold value was exceeded, characterizes an area larger or smaller than 20% of the whole GWB area. In the case of monitoring points with an impact area of less than 20% of the whole GWB area, the GWB was considered to be in good status, but at risk (If the concentration of chloride (Cl^-) and sulfate (SO_4^{2-}) ions will continue to increase). Otherwise, the GWB was considered to be in poor status based on this test (Marandi et al., 2020).

In Estonia, there are several GWBs potentially affected by intrusion processes, where the number of monitoring points is insufficient and, as a result, the share of one monitoring point in the assessment is very high (for example, GWBs on islands). To avoid situations where, based on the data of one monitoring point, the GWB qualifies as being in poor status, the peculiarities of the monitoring network were alternatively studied (Figure 19, Alternative Check). If a monitoring point with high chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentration and with a significant share of GWB area did not show an upward trend in the annual average concentrations and the high concentrations was of natural origin, the GWB was considered to be in good status according to this test (Marandi et al., 2020).

The purpose of the **surface water** test was to assess whether the chemical quality characteristics of groundwater may cause unfavorable status for surface water bodies. The connections of groundwater-associated surface water bodies with GWBs were outlined in the 2015 study of the Institute of Ecology of Tallinn University (TU) (Terasmaa et al., 2015). In the absence of surface water bodies associated with groundwater, the GWB was considered to be in good status (Figure 20).

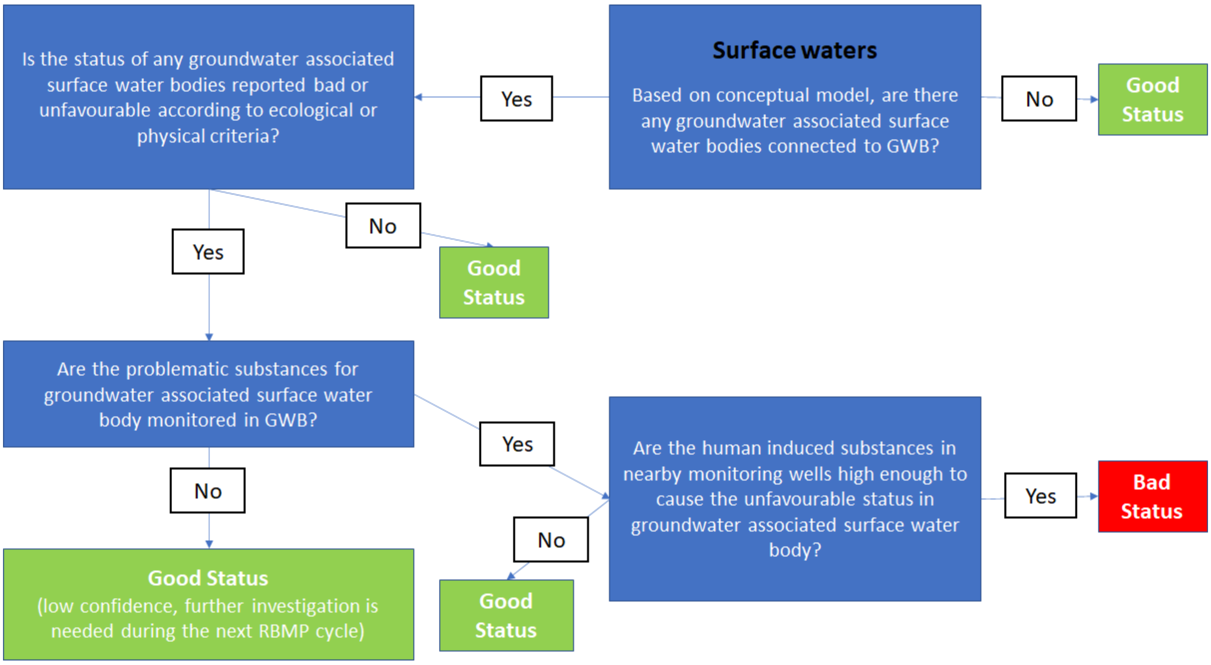


Figure 20. Flow diagram of the surface waters test (Marandi et al., 2020)

Surface water bodies (watercourses and lakes) that have been identified as significantly dependent on groundwater in the development of conceptual models of GWBs were identified. Following that the status of these surface water bodies (based on the results of an assessment carried out during the preparation of RBMPs) were linked to the associated GWBs (Marandi et al., 2020).

If groundwater-associated surface water bodies were identified in the GWB, the next step was the assessment of the status of these surface water bodies (Figure 20). In the course of RBMPs, surface water bodies were assessed for their ecological and chemical status, based on which they have been assigned an integrated status. In those groundwater-dependent surface water bodies where the chemical status was assessed as poor, it was examined whether the pollutants causing poor status have been determined in the groundwater monitoring points. If the groundwater monitoring contained data on these pollutants, the spatial location of groundwater monitoring points and groundwater-associated surface water bodies and their catchment areas, as well as the proportion of the surface water body supplied by the groundwater was further analyzed. Where available monitoring data allowed, the analysis of the test resulted in a status assessment and reliability on the GWB (Marandi et al., 2020).

Among the quality elements of the ecological status of surface water bodies, the nutrients (mainly P_{tot} and N_{tot}) and river basin-specific life quality elements (mainly Ba and Hg) were taken into account in this test. In those surface water bodies where the quality elements of Physico-chemical quality indicators and river basin specific pollutants caused unfavorable status (worse than good), the monitoring data of the GWB was considered whether the pollutant content in the nearest national monitoring well is so high due to human impact that it could cause the unfavorable status of surface waters (Marandi et al., 2020).

Groundwater dependent terrestrial ecosystems (GDTEs) test (Figure 21) was developed to assess whether the groundwater chemical quality may cause the disadvantage of such ecosystems. List of potential GDTEs in Estonia were identified in 2015 (Terasmaa et al., 2015) and results were used to identify any GDTEs connected to the GWB. In the absence of GDTEs associated with a GWB (e.g., deep GWBs), the GWB was considered to be in good status (Figure 21).

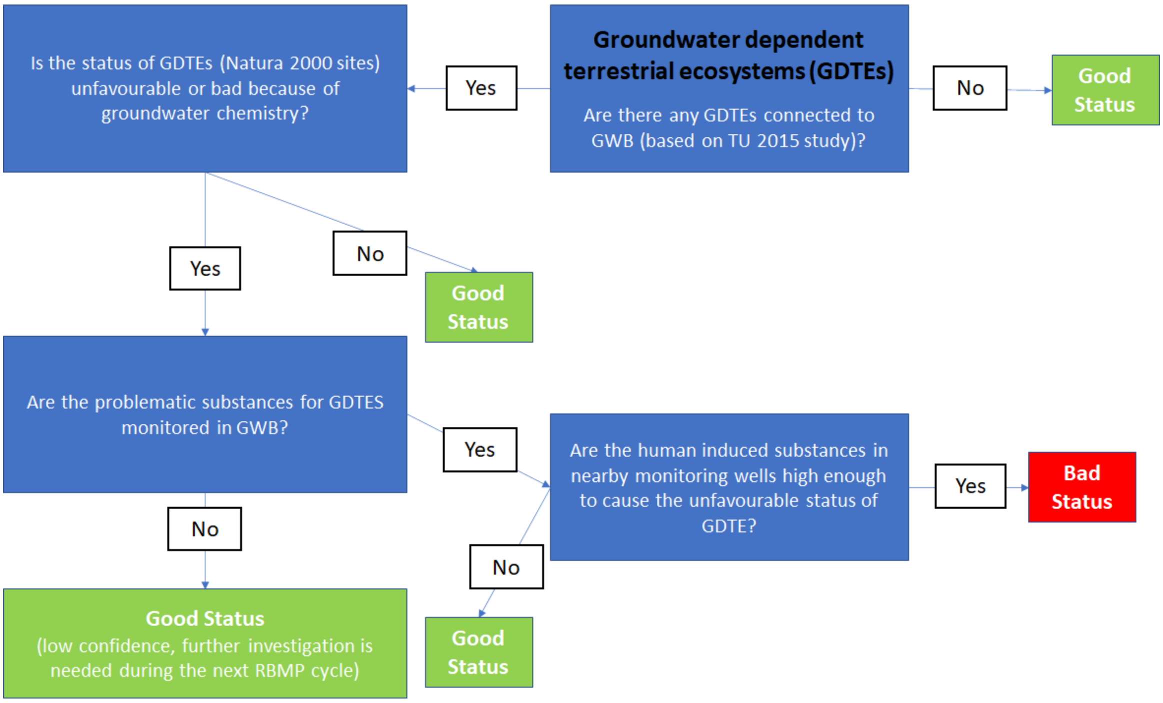


Figure 21. Flow diagram of the groundwater-dependent terrestrial ecosystems test (Marandi et al., 2020)

As a next step, it was clarified whether the deterioration of the ecosystem has been caused by changes in groundwater chemistry, but in the absence of such monitoring data, it was usually not possible to make a further assessment. However, the Natura 2000 assessment results for unsatisfactory GDTEs and the factors causing their disadvantage were reviewed. If necessary, further monitoring recommendations were provided for the next assessment period. Due to human activities, the status of GDTEs is more likely to be affected by the decrease in groundwater levels due to groundwater abstraction, rather than due to changes in the chemical composition of groundwater (Marandi et al., 2020).

In the course of the **drinking water protected areas** test, it was assessed whether there are significant upward trends of pollutants due to human impact in large drinking water intakes (groundwater well fields), which would have forced the water companies to close groundwater intakes, change groundwater intake locations or apply more efficient groundwater treatment methods; the test does not assess whether the groundwater quality meets the quality requirements for drinking water (Marandi et al., 2020).

Groundwater intakes (groundwater well fields) with an abstraction rate greater than 500 m^3/d were included in this test. Another important criterion was whether the problems with drinking water quality have been referred to the Groundwater Commission in the period 2014-2019 (Figure 22). If groundwater abstractions of this magnitude did not occur within the GWB and the problems related to drinking water had not been reported to the Groundwater Commission, the chemical status of the GWB was considered to be good. In the event of quality problems, it was determined whether the GWB is in poor or at-risk status based on the results of general quality assessment and saline or other intrusions tests; if the results of these tests confirmed it, GWB was also considered to be in poor status in this test. However, if the results of those two tests showed that poor or at-risk status was indicated by a quality indicator that has not been addressed in previously mentioned tests, the behavior of this content in the nearest groundwater monitoring point was investigated. If there was an upward trend in the pollutant in the nearest monitoring wells identified (Figure 22, Trend Assessment I), it was assessed concerning the 75% mark of the threshold value. If this value was exceeded, the GWB was considered to be in poor status (high confidence), otherwise, it was considered to be in good status (in the latter case, this was probably a local groundwater intake-specific problem, the cause of which should be determined by research) (Marandi et al., 2020).

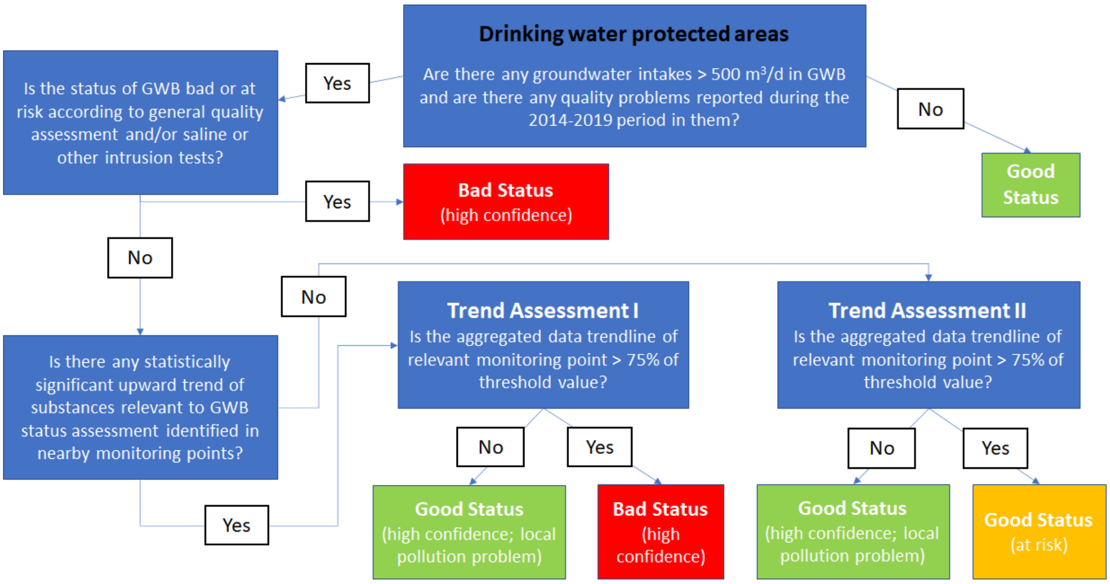


Figure 22. Flow diagram of the drinking water protected areas test (Marandi et al., 2020)

If there was no upward trend of the pollutant in the monitoring wells closest to the problematic groundwater intake identified (Figure 22, Trend Assessment II) and the trend line of the pollutant remained below the 75% mark of the threshold value, then the chemical status of the GWB was considered to be good (the presence of the pollutant is related to groundwater intake and it does not affect the GWB more broadly). If the pollutant trend line value was above the 75% mark of the threshold value, the GWB was considered to be in good chemical status, but at risk (Marandi et al., 2020).

Quantitative status assessment

The quantitative status assessment is based on the calculation of the natural balance of the GWB and on the evaluation of how the disturbances caused by human activity would affect that (Marandi et at., 2020). The level of disturbances is defined via the available groundwater resource in the WFD: *"Available groundwater resources' means the long-term annual average rate of overall recharge of the body of groundwater less the long-term annual rate of flow required to achieve the ecological quality objectives for associated surface waters specified under Article 4, to avoid any significant diminution in the ecological status of such waters and to avoid any* *significant damage to associated terrestrial ecosystems".*

Therefore the first test in GWB quantitative status assessment was water balance test (Figure 23), where the natural groundwater resources (natural balance) was assessed against the approved (calculated) groundwater resources and the groundwater abstraction (total abstraction and abstraction in groundwater well fields) (Marandi et at., 2020).

The first step of the test was to determine whether the natural groundwater resources of the GWB is less or greater than approved (calculated) groundwater resources in groundwater well fields. In the case when approved (calculated) groundwater resources were greater than the natural groundwater resources of the GWB, groundwater abstraction from major (greater than 500 m^3/d) groundwater intakes (groundwater well fields) was compared with the natural groundwater resources of the GWB (Figure 23).

If the groundwater abstraction in groundwater well fields was greater than the natural groundwater resources of the GWB, the GWB was considered to be in poor status (high confidence). If the groundwater abstraction in groundwater well fields was lower than the natural groundwater resources of the GWB, the test was continued with the overall (total) groundwater abstraction from the GWB (Figure 23).

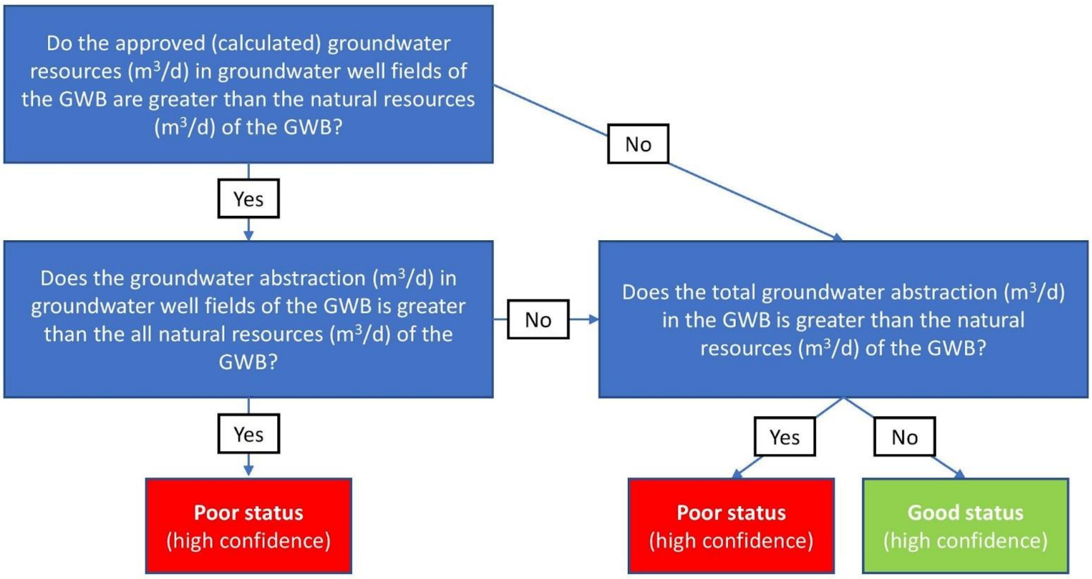


Figure 23. The flow diagram of the water balance test

In the assessment of overall (total) groundwater abstraction, the quantities of groundwater natural resources of the GWB and total groundwater abstraction in the GWB were compared. If the overall (total) groundwater abstraction was less than the natural groundwater resources of the GWB, the GWB was considered to be in good status (high confidence). Otherwise, the GWB was considered to be in poor status (high confidence). Further tests were evaluating more local resources to assess whether the groundwater abstraction can affect saline or other intrusions (Figure 24), surface waters (groundwater associated aquatic ecosystems) (Figure 25) and groundwater dependent terrestrial ecosystems (Figure 26).

A test to identify the risk of **saline or other intrusions** and to assess its impact on the quantitative status of GWB was performed only in those GWBs where threshold values have been established for chloride (Cl^-) and/or sulfate (SO_4^{2-}) ions, characterizing intrusion processes. The first step was to determine whether a statistically significant upward trend in the annual average chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations (aggregated data by whole GWB) have been identified and/or whether these concentrations have exceeded the established threshold values (by single monitoring point) (Figure 24). If there were no statistically significant upward trends identified (in the aggregated data by whole GWB) and the average concentrations in the individual monitoring points were lower than the threshold values, the GWB was considered to be in good chemical status (high confidence), according to this test (Marandi et al., 2020).

If there was a statistically significant upward trend identified based on chloride (Cl^-) and/or sulfate (SO_4^{2-}) ions concentrations in the aggregated data by whole GWB and/or if these concentrations have exceeded the established threshold values (by single monitoring point), it was determined whether statistically significant downward trend in groundwater levels has been identified at any of the monitoring points. If no statistically significant downward trend in groundwater levels was identified at any of the monitoring points, the GWB was considered to be in good quantitative status (high confidence). However, if a statistically significant downward trend in groundwater levels was identified at any of the monitoring points, the relationship between the downward trend in groundwater levels and exceedances of average chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations was inspected (Figure 24).

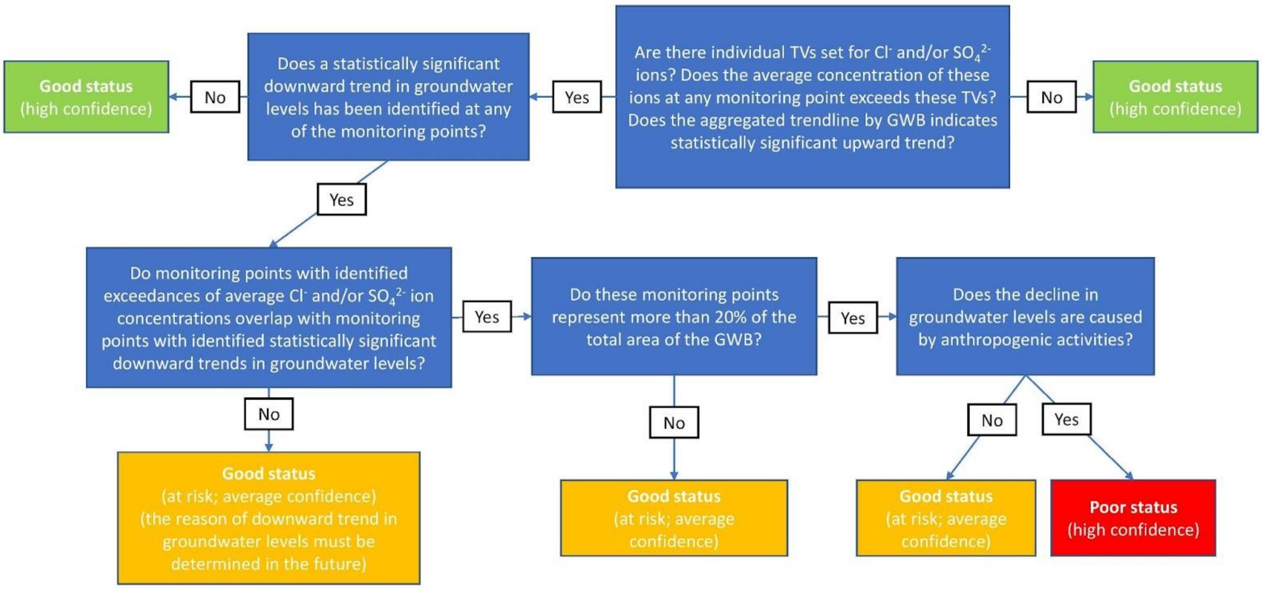


Figure 24. Flow diagram of the saline or other intrusions assessment test (Marandi et al., 2020)

If monitoring points with identified exceedances of average chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations did not overlap with monitoring points with identified statistically significant downward trends in groundwater levels, the GWB was considered to be in good status but at risk (average confidence) (additional studies must be carried out in the future to determine the reason for the increase in concentrations of pollutants in the GWB). However, if monitoring points with identified exceedances overlapped with monitoring points with identified downward trends in groundwater levels, the extent of it was assessed (Figure 24).

If the overlap between the two processes was identified, it was further determined whether such monitoring points represent more than 20% of the total area of the GWB (according to the Thiessen polygon method). If the 20% threshold was not exceeded, GWB was considered to be in a good quantitative status but at risk (average confidence). In a situation where such monitoring points represented more than 20% of the total area of the GWB, the interrelationship between the upward trend of chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations, the downward trend in groundwater levels and groundwater abstraction was examined (Figure 24).

If there was no link between intensive groundwater abstraction and downward trend in groundwater levels identified, the GWB was considered to be in good quantitative status but at risk (low confidence). But if the downward trend in groundwater levels and the associated upward trend of chloride (Cl^-) and/or sulfate (SO_4^{2-}) ion concentrations was linked to the pressure of groundwater abstraction, the GWB was considered to be in poor quantitative status (high confidence) (Figure 24).

The purpose of the **surface waters** test was to assess whether the lowering of groundwater levels due to groundwater abstraction may result in unfavorable status of groundwater associated aquatic ecosystems (GAAEs)/surface water bodies. The test initially included groundwater associated watercourses (Terasmaa et al., 2015; Vainu et al., 2019; Marandi et al., 2019) which have previously undergone a hydromorphological assessment (Auväärt et al., 2019). As the status assessment for standing water bodies regarding water abstraction has not been previously done and the water levels of lakes was generally not constantly monitored in Estonia, the assessments of groundwater associated standing water bodies presented in the work by Tallinn University (Vainu et al., 2019) were taken into account.

The first step of the surface waters assessment test was the selection of GWBs in which groundwater associated aquatic ecosystems (surface water bodies) have been previously identified. If no groundwater associated aquatic ecosystems were previously identified in the GWB, it was considered to be in good status (high confidence). If otherwise, the test was continued with the next step - assessment of groundwater contribution to surface waters (Figure 25).

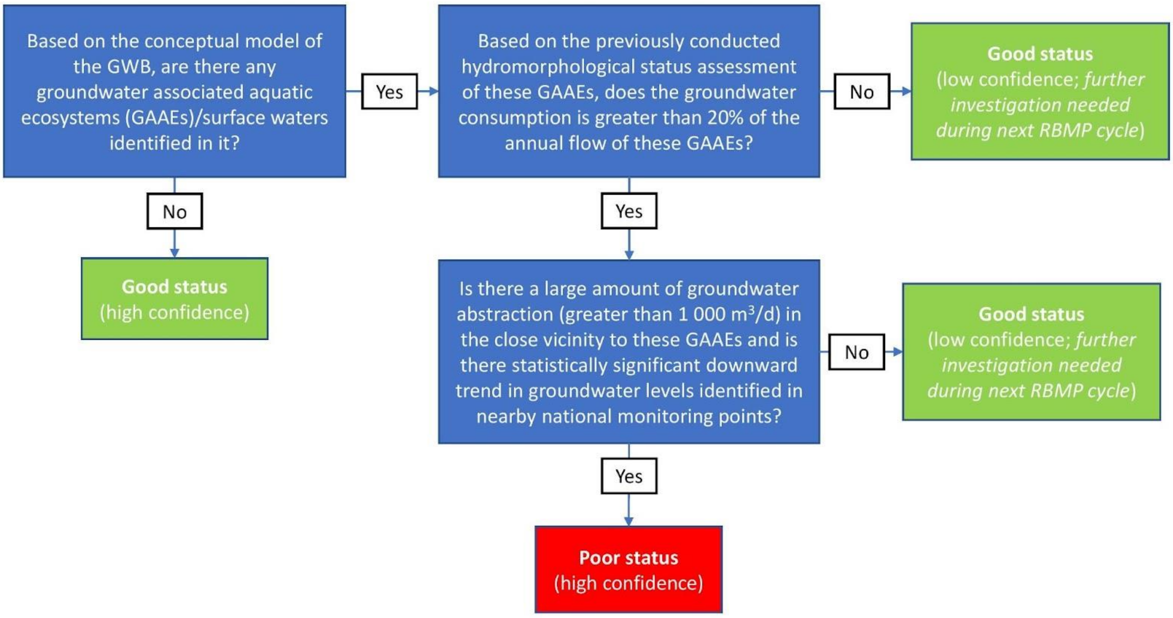


Figure 25. Flow diagram of the surface waters assessment test (Marandi et al., 2020)

If, based on results of hydromorphological assessment, groundwater consumption was less than 20% of the surface waters annual flow, GWB was considered to be in good status (low confidence; further investigation needed during next RBMP cycle). If otherwise, the test was continued with the next step - groundwater abstraction assessment (Figure 25).

If no large amount of groundwater abstraction (greater than 1000 m^3/d) was identified in the close vicinity to in the previous step identified GAAEs and no statistically significant downward trend in groundwater levels was identified in nearby monitoring wells,the GWB was considered to be in good quantitative status (low confidence; further investigation needed during the next RBMP cycle). But if the opposite conditions were met, the GWB was considered to be in poor quantitative status (high confidence).

The purpose of the **groundwater dependent terrestrial ecosystems** (GDTEs) test was to assess whether the groundwater abstraction may lead to the disadvantage of these ecosystems. The connections of GDTEs and with GWBs have been highlighted in the 2015 study of the Institute of Ecology of Tallinn University (Terasmaa et al., 2015).

The first step of the GDTEs assessment test was the selection of GWBs in which such ecosystems have been previously identified. If no GDTEs were previously identified in the GWB, it was considered to be in good status (high confidence). If otherwise, the test was continued with the next step - condition of GDTEs according to the assessment based on the Habitats Directive (92/43/EEC) (Figure 26).

If the condition of all identified GDTEs was good (greater than poor or unfavorable) according to ecological and/or physical criteria according to the assessment based on the Habitats Directive, the GWB was considered to be in good status (average confidence). Howerever, if at least one GDTE was in poor or unfavorable condition, the test was continued with the next step - assessment of groundwater contribution to GDTEs in poor or unfavorable condition (Figure 26).

If during the assessment of based on the Habitats Directive no groundwater abstraction and no lowering of the groundwater levels have been identified as the cause of the unfavorable condition of respective GDTEs, the GWB was considered to be in good status (low confidence; further investigation needed during next RBMP cycle). But if the opposite conditions were met, the test was continued with the last step - groundwater abstraction assessment (Figure 26).

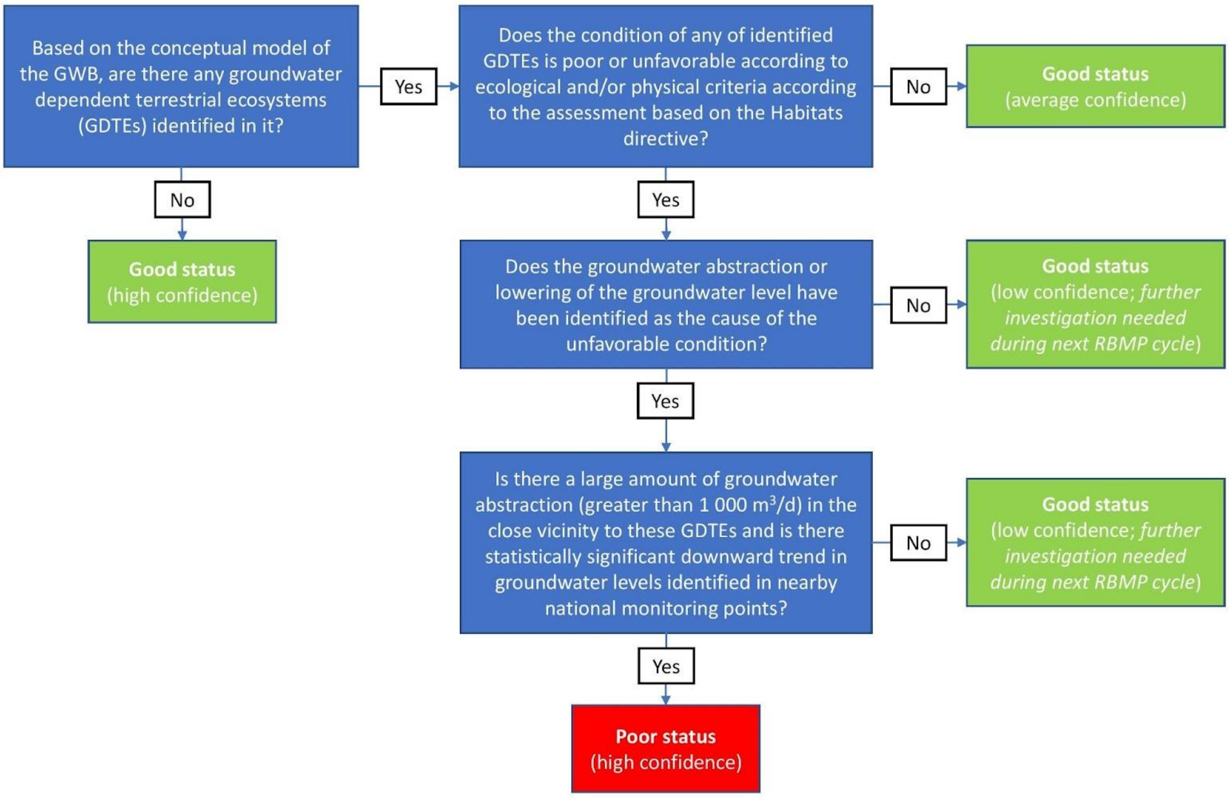


Figure 26. Flow diagram of the groundwater-dependent terrestrial ecosystems assessment test (Marandi et al., 2020)

If no large amount of groundwater abstraction (greater than 1000 m^3/d) was identified in the close vicinity to in the previous step identified GDTEs and no statistically significant downward trend in groundwater levels was identified in nearby monitoring wells, the GWB was considered to be in good status (low confidence; further investigation needed during the next RBMP cycle). But if the opposite conditions were met, the GWB was considered to be in poor status (high confidence) (Figure 26).

2.4. Methodology of assessing the state of groundwater bodies in Poland

The overriding goal of the groundwater monitoring is to assess the state of GWB. The assessment of the condition of GWB consists of tests from the assessment of both the chemical and quantitative status. Both assessments are equivalent to each other, and the worse result of the above-mentioned assessments is assumed as the final status of groundwater.

In 2020, the GWB condition assessment methodology was updated (Palak-Mazur et al., 2020a). The update is entitled "Update of the GWB condition assessment methodology along with the development of a methodology for analysing pollution trends reversal". The study was carried out by the Polish Geological Institute - National Research Institute at the request of the Chief Inspectorate for Environmental Protection, as part of the implementation of Stage III of the contract No. 25/2018 / F of July 12, 2018, entitled Chemical status monitoring and assessment of the status of groundwater bodies in river basins in 2018–2021. The previous methodology was described in the study "Adaptation of the methodologies presented in the EU guides on chemical and quantitative groundwater assessment; developing procedures and "macros" for carrying out analyses, calculations and evaluations" (Kuczyńska et al., 2015). The needs for changes resulted from the provisions of the national law concerning the criteria and method of assessing the state of groundwater bodies, the availability of data and the need to detail or supplement individual classification tests and supporting analyses. The procedure for assessing the status of groundwater bodies has been presented in a graphical manner on Figure 27.

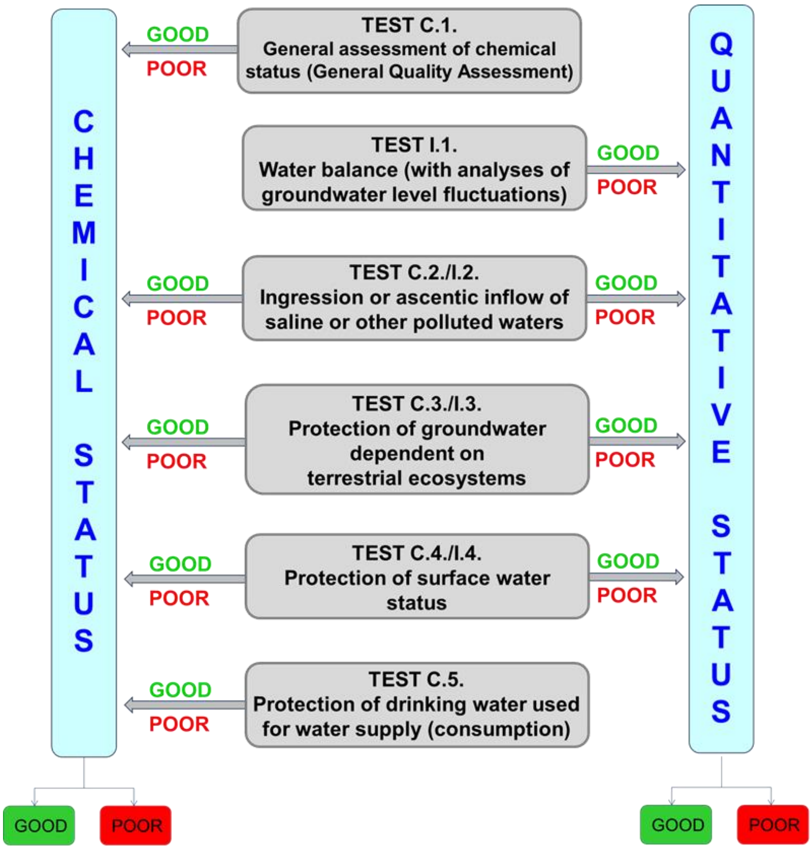


Figure 27. Diagram of the procedure for assessing the status of groundwater bodies (Palak-Mazur et al., 2020b)

The scope of the development of the methodology for the assessment of the state refers to the Regulation of the Minister of Maritime Economy and Inland Navigation of October 11, 2019 *on the criteria and method of assessing the status of groundwater bodies* (Journal of Laws 2019 item 2148), Directive 2000/60/EC (WFD) and Directive 2006/118/EC (DWP), taking into account the guidelines of the European Commission presented in EU guides, in particular in the guide *"Guidance on groundwater status and trend assessment"* (CIS Guidance Document No. 18).

The assessment of the status of GWBs is based on the performance of nine classification tests targeted at the needs of various groundwater recipients.

As part of the chemical status assessment, five classification tests are performed:

1. Test C.1 - General chemical assessment;
2. Test C.2 / I.2 - Ingression / ascension test;
3. Test C.3 - Test of the protection of terrestrial groundwater dependent ecosystems;
4. Test C.4 - Surface water protection test;
5. Test C.5 - Test of protection of groundwater intended for human consumption.

As part of the quantitative assessment, four classification tests are performed:

1. Test I.1 - Water balance;
2. Test C.2 / I.2 - Ingression / ascension test;
3. Test I.3 - Protection of terrestrial groundwater dependent ecosystems;
4. Test I.4 - Protection of surface waters.

Apart from the classification tests, there are also two supporting analyses concerning long-term changes. These are the analysis of the tendency of changes in the concentrations of physio-chemical indicators and the analysis of the level of the water table.

According to the EU guidelines (CIS Guidance Document No. 18), each of the chemical tests is performed in relation to the concentration limits, which are defined appropriately for each test, depending on the analysed problem. In test C.1. - General assessment of the chemical status, limit values are called threshold values, specified in the currently applicable Regulation of the Minister of Maritime Economy and Inland Navigation of October 11, 2019 *on the criteria and method of assessing the state of groundwater bodies* (Journal of Laws 2019, item 2148), while in the remaining tests they are criterion values. On the basis of the criterion values, it is ascertained whether groundwater quality has the potential to adversely affect groundwater dependent terrestrial ecosystems, surface waters or the quality of drinking water.

An important element of the procedure for assessing the status of groundwater bodies is the expert analysis of the results, which is used in all classification tests.

2.4.1. Methodology for the assessment of the quantitative status of groundwater

As part of the chemical status assessment, the following classification tests are performed:

<u>Test C.1 - General Assessment of Chemical Status</u>

The purpose of the test is to identify the risk related to groundwater pollution in the entire GWB area by establishing a range of indicators affecting the poor chemical status of the GWB, as well as the spatial extent of groundwater pollution. The condition for determining the good chemical status of GWB in the test is to demonstrate that the threshold value of good chemical status is not exceeded, and in the case of exceedances, to demonstrate that the area in which the exceedance was identified is not greater than 20% of the total area for single-complex GWB and 40% for multi-complex GWB.

C.2 / I.2 test - Ingression / ascension test

The purpose of the test is to identify the occurrence of ascendancy or ingression processes of salt waters and other waters degraded to freshwater levels in the GWB area and to assess whether these phenomena were caused by anthropogenic factors (e.g. increased exploitation of intakes, mining or other drainage, e.g. agricultural drainage etc.).

The assessment is based on determining whether the criterion values of good groundwater chemical status have been exceeded, in relation to the indicators of salt water ingression or ascension (EC and indicators, e.g. Cl, Na and SO_4), in connection with the assessment of significant and sustained upward trends concentrations of the analysed indicators and the identification of coexistence of anthropogenic pressure causing both processes.

Test C.3 - Test of the protection of terrestrial groundwater dependent ecosystems

The aim of the test is to identify threats to the functioning and biodiversity of groundwater-dependent terrestrial ecosystems (GDTEs) caused by anthropogenic change in the chemical composition of groundwater in the GDTE supply area. The threat is identified by determining whether in the groundwater supplying GDTE, the criteria values of the concentrations of biogenic elements limiting primary production, i.e. N, P and K have been exceeded.

Test C.4 - Surface water protection test

The purpose of the test is to determine whether a GWB has a significant negative effect on the ecological or chemical status of surface water bodies (SWBs) in direct hydraulic connection with it.

Test C.5 - Test of protection of groundwater intended for human consumption

The aim of the test is to determine whether, due to human activity, there are elevated, persistent concentrations of pollutants and deterioration of the quality of groundwater intended for human consumption, which may result in the need to modify water treatment processes or introduce groundwater treatment in groundwater intakes.

2.4.2. Methodology of assessing the chemical status of groundwater

Analysis of the level of the water table at quantitative monitoring points:

The analysis of the level of the groundwater table is aimed at determining whether, as a result of anthropogenic activities, there were no unfavourable changes in the level of the groundwater table or changes in the directions of groundwater flow leading to its contamination. The purpose of the analysis is to define the zone of states in the hydrological year covered by the assessment (among the zones of: high, medium or low states), and to determine the directions of changes in the level of the water table compared to the results from the previous year, as well as in case of points with a long-term observation cycle (over 20 years) to determine whether there was a clear downward trend in the level of the groundwater table. In addition, the assessment should identify observation points that are clearly negatively influenced by anthropogenic pressure. In order to determine the fluctuation state zone of the groundwater table, a well-documented period of at least 10 years, with a large amplitude of groundwater fluctuations, is considered a representative multi-year period. The analysis is performed using statistical methods.

The following four classification tests are performed as part of the chemical assessment:

Test I.1 - Water balance

The purpose of the test is to establish whether the intake of groundwater in individual GWB did not exceed the groundwater resources available for management. The test is performed on the basis of a comparison of the average value over a long period of actual consumption from groundwater intakes with the amount of groundwater resources available for management. The test is carried out on the basis of data on groundwater abstraction, taking into account the estimates of unmeasured abstraction and data on ordinary groundwater resources available for management. In the final stage of the analysis, the results of the analysis of changes in the position of the water table are taken into account, which are helpful in interpreting the extent of the zone subjected to the pressure of abstraction from intakes or drainage in the entire GWB or in the case of low reserves of resources.

Test C.2 / I.2 - Assessment of the impact of ingression and ascension of salt or other degraded waters on the condition of groundwater

The test is performed together with test C.2. The results of the C.2 test in terms of assessing the poor state of GWB have a direct impact on the results of the quantitative test I.2. in terms of reducing the amount of water of good chemical status.

Test I.3 - Protection of terrestrial groundwater dependent ecosystems

The aim of the test is to identify the risk of reducing the water resources available to groundwater-dependent terrestrial ecosystems in the GWB area by analysing the amount of groundwater inflow to the discussed ecosystems, with particular emphasis on the impact of anthropogenic pressure on its reduction.

Test I.4 - Protection of surface waters

The purpose of the test is to determine whether the abstraction of groundwater within the boundaries of the GWB has a significant negative environmental impact within the boundaries of the corresponding SWBs. The test uses the results of ecological status classification and information on failure to achieve environmental flow in SWBs. The assessment of the condition takes into account the potential impact of local groundwater exploitation on surface waters on the SWB scale. In the test, the assessment includes information on the ecological status of the SWB, flow values, data on groundwater intake and discharges, and the ranges of regional depression cones (Kuczyńska et al., 2015; Palak-Mazur et al., 2020a).

2.4.3. Analysis of trends in changes in pollutant concentrations in the assessment of the chemical status of groundwater

Pursuant to the provisions included in Annex IV of Directive 2006/EC/118, Member States are required to identify significant and sustained upward trends in pollutant concentrations in all GWBs deemed at risk of failing to achieve environmental targets. A significant and sustained upward trend means any statistically and environmentally significant increase in the concentration of pollutants in groundwater, therefore there is a need to reverse this trend. A statistically significant trend is a trend that has been identified using generally recognized time-series statistical methods, such as regression analysis. An environmentally significant trend is a trend that is statistically significant and the reversal of which may lead to the failure to achieve the environmental objectives within the meaning of the WFD.

The starting point for initiating measures to reverse significant and sustained upward trends is when the pollutant concentration reaches 75% of the quality standard parameters or the threshold value of good chemical status. Accordingly, statistically significant upward trends were considered as significant upward trends, for which the threshold value of 75% of the good chemical status was exceeded.

Since 2012, PGI-NRI has been performing a trend analysis as a test supporting the assessment of the chemical status of GWBs. Significant and sustained upward trends are identified both at individual monitoring points and at the level of GWBs. The analysis is performed using the linear regression method. To assess the quality of fit of the regression function, the coefficient of determination R2 is used (those time series for which the coefficient of determination R2 > 0.6 are qualified for further analysis). In addition, a number of methodological assumptions necessary for the proper performance of the analysis must be met (Palak - Mazur et al, 2020a). One of them is to ensure the minimum length of the time series. For water samples taken once a year, it is 8 measurement years, while 2007 is assumed as the base year for the analysis of the trend of concentration changes (Stojek & Palak-Mazur, 2021).

As part of the GWB status assessment, the trend analysis performed at monitoring points is extended to identify the following types of trends:

- downward trend;
- upward trend;
- significantly downward trend.

The analysis of trends in 2019 was carried out for 1,369 points and 37 physico-chemical indicators. Among the 458 designated trends, 24 of them were significant and sustained upward trends, 224 - upward, 20 - significant downward and 190 - downward (Palak - Mazur et al, 2020b).

Based on the series of data, the trend analysis also allows to predict how the concentrations will behave over time. For this purpose, trends are studied and the extrapolation of the function of the trend lines to the end of the current planning cycle. An exemplary graph of the analysis of the trend of concentration changes at the monitoring point is presented in Figure 28, while its forecast until 2027 is shown in Figure 29.

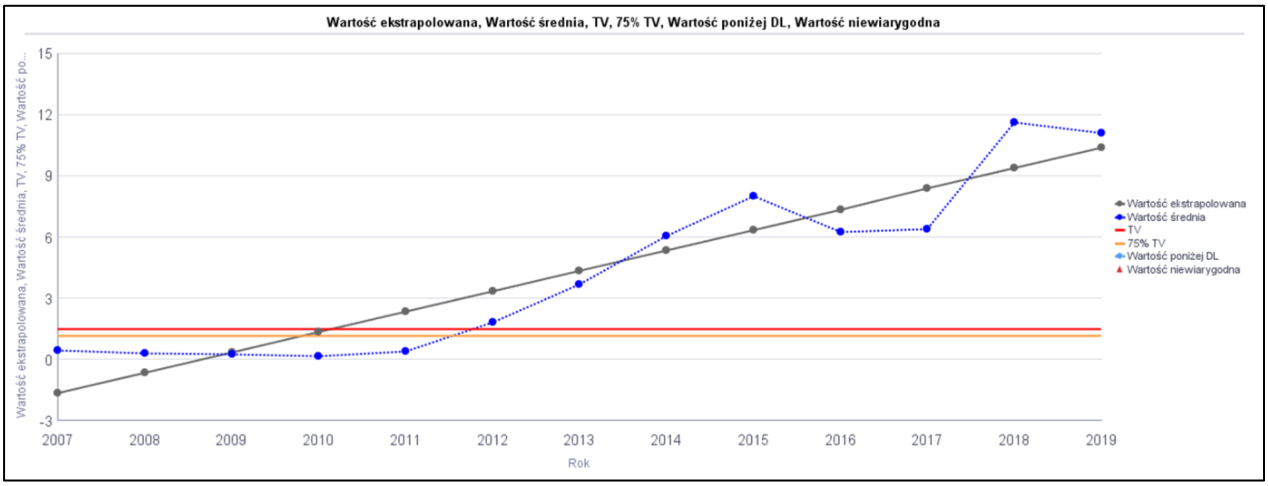


Figure 28. An example of a trend diagram of changes in concentrations of indicators in groundwater at a monitoring point

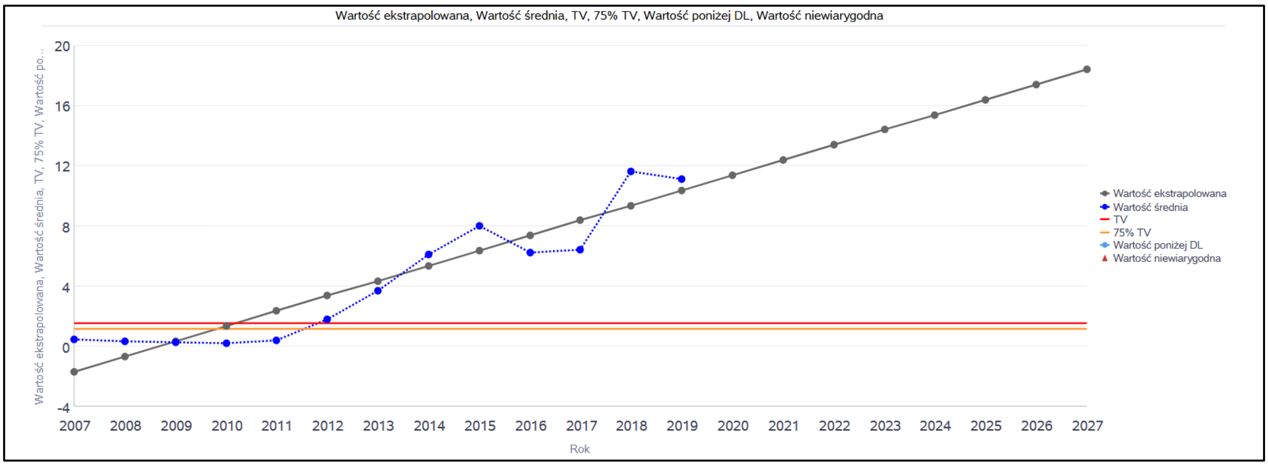


Figure 29. An exemplary graph of the trend of concentration changes at the monitoring point with the forecast

In GWBs considered at risk of failing to achieve environmental goals, significant and sustained upward trends in pollutant concentrations in GWB areas are identified. The analysis is performed on the basis of spatially aggregated data from representative groundwater monitoring points, taking into account the vertical schematization of the GWB into aquifers. This is to determine whether a given GWB area shows sustained anthropogenically induced growth trends or not. An exemplary graph of the trend analysis of concentration changes in the GWB area, taking into account the 95% confidence interval and the p value, is shown in Figure 30.

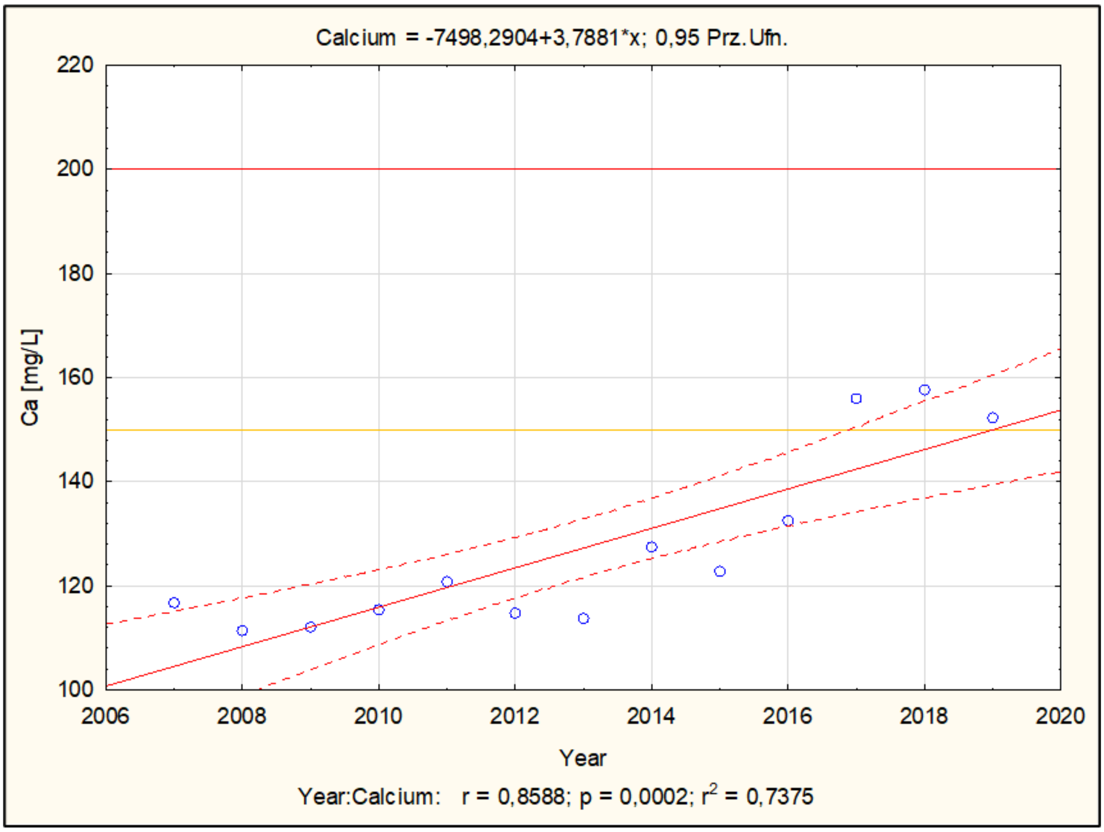


Figure 30. An example of a trend diagram of changes in calcium concentrations in groundwater in the GWB area

The GWBs condition assessment report in the 2022-2027 planning cycle, in which the trend analysis will be performed, is scheduled for 2023. In 2025, a separate analysis of the trend of changes in the concentrations of physico-chemical indicators at points of the operational monitoring network will be carried out for the first time.

2.5. Methodology of the assessment of groundwater state in Ukraine

The main document regulating water relations in Ukraine is the Water Code. To comply with its requirements in Ukraine developed, agreed and approved by the Cabinet of Ministers of Ukraine a number of regulations containing legal norms on the use, management and control in the field of water use and protection and prevention of their harmful effects, accounting for water use, liability for violations, etc.

In general, water resources in Ukraine are assessed in terms of compliance with the standards adopted for drinking water. State standards for drinking water should be periodically revised once every five years in order to take into account and implement the latest scientific advances in the impact of pollutants on human health, new technologies for drinking water treatment and quality control (Article 27 of the Law of Ukraine drinking water and drinking water supply).

Groundwater sources are preferred for drinking water supply to the population, as they are reliably protected from biological, chemical and radiation pollution.

Assessments of drinking water quality are used in accordance with the norms set forth in ДСанПіН 2.2.4-171 ("State sanitary norms and rules" Hygienic requirements for drinking water intended for human consumption "approved by the Order of the Ministry of Health of Ukraine from 12.05.2010)

Hygienic assessment of safety and quality of drinking water is carried out according to the indicators:

- epidemic safety (microbiological, parasitological);
- sanitary-chemical (organoleptic, physico-chemical, sanitary-toxicological);
- radiation.

Parasitological indicators are determined in drinking water of surface and ground (groundwater) sources of drinking water supply of the population, and in case of complication of sanitary-epidemic situation - also in interlayer pressureless and pressure (artesian) groundwater.

There should be no pathogens, *Escherichia coli* bacteria, *Pseudomonas aeruginosa*, etc. in drinking water. This is enshrined in regulations at the state level. In Ukraine, this is regulated by ДСанПіН 2.2.4-171.

Safety and quality of drinking water on organoleptic, physicochemical and sanitary-toxicological indicators should correspond to the hygienic specifications given in appendix 2 ДСанПіН 2.2.4-171.

Organoleptic indicators include odour, colour, turbidity, taste. These indicators indicate the taste and appearance of water.

Physicochemical parameters include inorganic components such as hydrogen index, total iron, total hardness, manganese, copper, sulphates, dry residue, free chlorine residue, zinc and organic components: residual chlorine bound, petroleum products and surfactants anionic, etc.

Analysis for sanitary and toxicological indicators is carried out to determine the safety of water for humans. This group of components includes:

- inorganic components (Al, NH_3^-, ClO_2, Cd, Si, As, Mo, Na, NO_3, NO_2, residual ozone, Hg, Pb, Ag, F^-, Cl^-, Co, Ni, Se, Cr);
- organic components (residual polyacrylamide, formaldehyde, chloroform, benzopyrene, dibromochloromethane, pesticides, trihalomethanes);
- integral index (permanganate oxidation).

The maximum permissible concentrations of these indicators and their comparison with those in Polish legislation are given in the Table 12.

Table 12. Maximum permissible concentrations for drinking water in Ukraine and Poland

№	Name of indicators	Units	Standards for drinking water in Ukraine (ДсанПіН 2.2.4-171-10)	MPC for drinking water of the Republic of Poland (Item 2294)
1	2	3	4	6
1	Odour	mark	≤2	Odourless
2	Colour	degrees	≤20	colourless
3	Turbidity	nephelometric unit (1NU=0,58 mg/dm^3	≤1,0	1,0
4	Taste	mark	≤2	No taste
5	Hydrogen index pH	units pH	6,5-8,5	6,5-9,5
6	Total iron (Fe)	mg/dm^3	≤0,2	0,2
7	Total rigidity	$mmol/dm^3$	≤7,0	
8	Manganese (Mn)	mg/dm^3	≤0,05	0,05
9	Cuprum (Cu)	mg/dm^3	≤1,0	2,0
10	Polyphosphates	mg/dm^3	≤3,5	
11	Sulphates	mg/dm^3	≤250	250
12	Dry residue	mg/dm^3	≤1000	200-500
13	Residual chlorine	mg/dm^3	≤0,5	0,3
14	Chlorides (Cl^-)	mg/dm^3	≤250	250
15	Zinc (Zn)	mg/dm^3	≤1,0	
16	Residual chlorine is bound	mg/dm^3	≤1,2	
17	Petroleum products	mg/dm^3	≤0,1	
18	Surfactants	mg/dm^3	≤0,5	
19	Aluminium (Al)	mg/dm^3	≤0,2	0,2
20	Ammonium (HN_3)	mg/dm^3	≤0,5	0,5
21	Chlorine dioxide (ClO_2)	mg/dm^3	≥0,1	
22	Cadmium (Cd)	mg/dm^3	≤0,001	0,005
23	Silicon (Si)	mg/dm^3	≤0,10	
24	Arsenic (As)	mg/dm^3	≤0,01	0,01
25	Molybdenum (Mo)	mg/dm^3	≤0,07	
26	Sodium (Na)	mg/dm^3	≤200	200
27	Nitrates (NO_3)	mg/dm^3	≤50	50
28	Nitrites (NO_2)	mg/dm^3	≤0,5 (0,1)	0,5
29	Ozone is residua	mg/dm^3	0,1-0,3	0,05
30	Mercury (Hg)	mg/dm^3	≤0,0005	0,001
31	Lead (Pb)	mg/dm^3	≤0,01	0,01
32	Argentum (Ag)	mg/dm^3	not determined	0,010

33	Fluorides (F^-)	mg/dm^3	≤1,5	1,5
34	Cobalt (Co)	mg/dm^3	≤0,1	
35	Nickel (Ni)	mg/dm^3	≤0,02	0,02
36	Selenium (Se)	mg/dm^3	≤0,01	0,01
37	Total chrome (Cr)	mg/dm^3	≤0,05	0,05
38	Residual polyacrylamide	mg/dm^3	≤2,0	
39	Formaldehyde	mg/dm^3	≤0,05	
40	Chloroform	µg/dm^3	≤60	30
41	Benzopyrene	µg/dm^3	≤0,005	0,010
42	Dibromochloromethane	µg/dm^3	≤10	
43	Pesticides	mg/dm^3	≤0,0001	0,0001
44	Pesticides (sum)	mg/dm^3	≤0,0005	0,0005
45	Trihalomethanes (sum)	µg/dm^3	≤100	100
46	Cyanides (CN)	mg/dm^3	≤0,05	0,05
47	Permanganate oxidation	mg/dm^3	≤5,0	5
48	Benzene	mg/dm^3	≤0,001	0,001
49	Antimony (Sb)	mg/dm^3	≤0,005	0,005
50	Trichlorethylene and tetrachlorethylene (sum)	µg/dm^3	≤10	10
51	1,2- dichloroethane	µg/dm^3	≤3	3
52	Total organic carbon	mg/dm^3	≤8	Unchanged
53	Boron (B)	mg/dm^3	≤0,5	1,0
54	Σ chlorates and chlorites	mg/dm^3		0,7
55	chloramines	mg/dm^3		≤0,5
56	bromodichloromethane	µg/dm^3		15
57	conductance	µS/sm	-	2,500
58	Epichlorohydrin	µg/dm^3		≤0,1
59	Polycyclic aromatic hydrocarbons	µg/dm^3		≤0,1
60	Acrylamide	µg/dm^3		0,1
61	Vinyl chloride	µg/dm^3		0,5
62	bromates	µg/dm^3		10
63	Beryllium (Be)	mg/dm^3	≤0,0002	
64	Chlorites	mg/dm^3	≤0,2	
65	Magnesium (Mg)	mg/dm^3	not determined	7-125
66	Strontium (Sr)	mg/dm^3	≤7	
67	Carbon tetrachloride	µg/dm^3	≤2	
68	Phenols are volatile	mg/dm^3	≤0,001	
69	Chlorophenols	mg/dm^3	≤0,0003	

Scale for comparing the maximum permissible concentrations of a substance in drinking water

🟩 MPC is the same in Ukraine and Poland;
🟥 MPC is different;
🟨 MPC is in the normative documents of one of the countries;
🟦 There is no MPC.

Comparison of standards for drinking water of Ukraine and Poland showed that the absolute values coincide with 25 indicators (turbidity, Fe, Mn, sulphates, chlorides, Al, NH_3, As, Na, nitrates, nitrites, Pb, fluorides, Ni, Se, Cr, pesticides, pesticides (sum), trihalomethanes (sum), cyanides, permanganate oxidation, benzene, antimony, trichlorethylene and tetrachlorethylene (sum), 1,2-dichloroethane) and 13 do not match of which Cu, Cd, Hg, benzopyrene, boron have values are higher than the Ukrainian ones, and the dry residue content, residual chlorine content, residual ozone, chloroform are lower than the Ukrainian ones.

In addition, such indicators of water quality assessment as total hardness, polyphosphates, zinc, silicon, molybdenum, cobalt, etc. are not evaluated according to the Polish item 2294, and in the Ukrainian ДСанПіНі there is no assessment of water quality on such indicators as vinyl chlorides, bromates, chloramines, which are in Polish.

During the hygienic assessment of radiation safety of drinking water in the areas of water intakes of surface and underground sources of drinking water supply, the specific total alpha and beta activities are pre-determined. The total alpha activity should not exceed 0.1 Bq / dm^3, and the total beta activity should not exceed 1 Bq/dm^3. In case of exceeding these indicators, additional studies on the content of radionuclides (ДСанПіН) are conducted. Table 13 shows that in Ukraine and Poland there are only 5 radionuclides for determining the MPC in drinking water. Moreover, the MPC for the specific activity of ^{222}Rn is the same. The values of specific activity of ^{226}Ra and ^{228}Ra are higher for Ukraine, and the values of specific activity of ^{137}Cs and ^{90}Sr are higher for Poland. In Ukraine, the analysis of the total activity of the natural mixture of uranium isotopes is carried out, while in Poland ^{238}U and ^{234}U are determined separately. In Poland, Tritium, Indicative dose, specific activity ^{210}Pb, specific activity ^{210}Po, ^{14}C, ^{239}Pu / ^{240}Pu, ^{241}Am, ^{60}Co, ^{134}Cs, ^{131}I are also determined. In conclusion, Ukraine needs to reconsider the importance and feasibility of conducting these analyses for drinking water.

Table 13. Radiation safety indicators of drinking water

№	Name of indicators	Units	Standards Ukraine	Standards Poland
1	2	3	4	5
1	The total activity of a natural mixture of isotopes U	Bq/l	≤1	-
2	Specific activity of ^{226}Ra	Bq/l	≤1	0,5
3	Specific activity of ^{228}Ra	Bq/l	≤1	0,2
4	Specific activity of ^{222}Rn	Bq/l	≤100	100
5	Specific activity of ^{137}Cs	Bq/l	≤2	11
6	Specific activity of ^{90}Sr	Bq/l	≤2	4,9
7	Tritium	Bq/l	-	100
8	Indicative dose	mSv/year	-	0,1
9	Specific activity of ^{238}U	Bq/l	-	3
10	Specific activity of ^{234}U	Bq/l	-	2,8
11	Specific activity of ^{210}Pb	Bq/l	-	0,2

№	Name of indicators	Units	Standards Ukraine	Standards Poland
12	Specific activity of ^{210}Po	Bq/l	-	0,1
13	^{14}C	Bq/l	-	240
14	$^{239}Pu/^{240}Pu$	Bq/l	-	0,6
15	^{241}Am	Bq/l	-	0,7
16	^{60}Co	Bq/l	-	40
17	^{134}Cs	Bq/l	-	11
18	^{131}I	Bq/l	-	6,2

Groundwater monitoring allows to assess the state of groundwater and changes in this state. Groundwater monitoring in Ukraine is carried out in accordance with the geological task provided by the order of the State Geological Survey of Ukraine. Groundwater monitoring works are performed in accordance with the sectoral normative document “Groundwater monitoring system of the territory of Ukraine. State level ". (Dnepropetrovsk, 2002).

The main purpose of groundwater monitoring is to achieve good chemical and quantitative status of groundwater.

To achieve the above goal, it is necessary to continue long-term monitoring of groundwater quantitative status at the state and regional levels, monitoring of groundwater chemical status, assessment of changes in hydrogeological conditions under man-made influence, maintaining the Groundwater database in Oracle.

According to the methodology, groundwater monitoring includes field work and in-house processing of results.

Water sampling for analysis was performed once a year during field hydrogeological works. Wells should be flushed before sampling, as this is a mandatory procedure for chemical water sampling to accurately assess changes in groundwater quality. The well is washed by pumping water with an immersion electric pump for 1-3 hours, or until complete purification of water. Upon completion of hydrogeological studies, samples are taken for analysis. The sample size depends on the type of analysis. For a complete chemical analysis is selected 1.5-2 litres. A 0.5 L water sample is used to determine the iron content, and 1 L of water is taken to determine the H_2S content. Glass and plastic bottles are usually used for sampling. Only glass bottles are used to analyse the iron and hydrogen sulphide content. Sodium acetic acid and acetic acid are used as preservatives for iron. Cadmium acetic acid and acetic acid are used to preserve hydrogen sulphide.

The analysis of physicochemical parameters is performed on the basis of certified laboratories that have a certificate of conformity of the measurement control system issued by the Centers for Standardization, Metrology and Certification. Analysis for phenols and radiological studies are performed as needed.

Control over the chemical status of groundwater is carried out through inspections at enterprises, water intakes of centralized water supply and by inspection at the sites of discharge of industrial waste of small enterprises. During the inspections, the presence of the conclusions of the State Sanitary and Epidemiological Service of Ukraine on the suitability of water for drinking and the final results of chemical and bacteriological tests of water is checked.

The obtained results are entered into Excel and Oracle databases.

2.6. Adaptation of the Ukrainian methodology for assessing the status of groundwater to the WFD standards

The process of implementing Ukrainian water legislation into the WFD began in 2016. Since then, a number of government regulations, standards and industry recommendations have been adopted at the national level to implement the requirements and principles set out in the directive (paragraph 1.2).

The process of implementing the WFD in Ukraine is still ongoing. There are still issues about the assessment of groundwater quality.

At present, Ukraine does not have a state-approved methodology for assessing the state of groundwater.

In general, water resources in Ukraine are assessed in terms of drinking water (see section 2.5).

At the state level in Ukraine there is only one document in which the assessment of groundwater quality is separated from the generalized concept of drinking water quality assessment, it is ДСТУ 4808: 2007 "Sources of centralized drinking water supply. Hygienic and environmental requirements for water quality and selection rules "

In this ДСТУ groundwater is assessed according to hygienic and environmental criteria. The classification covers 71 indicators used to assess the quality of drinking water in accordance with sanitary legislation and has seven separate groups:

- Group I - 4 organoleptic parameters;
- Group II - 14 general sanitary indicators of chemical composition of water;
- Group III - 2 hydrobiological indicators;
- Group IV - 6 microbiological indicators;
- Group V - 2 parasitological indicators;
- Group VI - 9 indicators of radiation safety;
- Group VII - 34 priority toxicological indicators of chemical composition of water (of which: 27 - inorganic and 7 organic components).

Hygienic indicators - I, II, IV, V, VI, VII groups.

Ecological indicators - II, III, V, VI, VII groups.

The range of values of water quality indicators is divided into four classes:

- Grade 1 - excellent, desirable water quality;
- Grade 2 - good, acceptable water quality;
- Grade 3 - satisfactory, acceptable water quality;
- Grade 4 - mediocre, limited suitability, undesirable water quality.

Table 13 compares the ranges of values of general sanitary indicators of water chemical composition and toxicological indicators for groundwater according to DSTU 4808: 2007 and MPC for groundwater according to the Polish document Poz.2148.

This table does not list such groups as organoleptic, hydrobiological, microbiological, parasitological and radiation safety indicators, which are in ДСТУ 4808: 2007 and are not in Poz.2148. These indicators are purely to determine the safety of drinking water, and in Poz.2148 there is no such data.

Table 14. Comparison of ranges of values for groundwater for centralized water supply according to ДСТУ 4808:2007 and MPC for groundwater according to the Polish Item 2148

		Value ranges in quality classes (ДСТУ 4808:2007)				MPC in quality classes (Item 2148)				
Indicator	Units	1	2	3	4	1	2	3	4	5
1	2	3	4	5	6	7	8	9	10	11
General sanitary chemical indicator										
Dry residue (mineralization)	mg/dm^3	<500	500-1000	1001-1500	>1500					
Sulfates	mg/dm^3	<250	250-350	351-500	>500	60	250	250	500	>500
Chlorides	mg/dm^3	<250	250-300	301-350	>350	60	150	250	500	>500
Magnesium	mg/dm^3	<10	10-20	21-30	>30	30	50	100	150	>150
harshness	ммоль/dm^3	<4	4-7	8-10	>10					
Alkalinity	ммоль/dm^3	<1.5	1.5-4.0	4.1-6.5	>6.5					
Hydrogen index	pH	6.5-7.0	6.0-8.0	6.0-8.5	>8.5	6,5-9,5	6,5-9,5	6,5-9,5	<6,5 or >9,5	<6,5 or >9,5
NH_3	mgN/dm^3	miss	0.05-0.50	0.51-2.00	>2.00	0,5	1	1,5	3	>3
NO_2^-	mgN/dm^3	<0.05	0.05-0.50	0.51-1.00	>1.00	0,03	0,15	0,5	1	>1
NO_3^-	mgN/dm^3	<5.0	5.0-7.0	7.1-10.0	>10.0	10	25	50	100	>100
PO_4^{3-}	mgP/dm^3	<0.3	0.3-0.5	0.6-1.0	>1.0	0,5	0,5	1	5	>5
Permanganate oxidation	mgO/dm^3	<4	4-5	5,1-6,0	>6,0					
Dichromatic oxidation	mgO/dm^3	<4	4-6	6,1-10,0	>10.0					
Total organic carbon	mgC/dm^3	<2	2-3	3,1-4,0	>4.0	5	10	10	20	>20

Toxicological indicators of water chemical composition

1	2	3	4	5	6	7	8	9	10	11
Al	µg/dm^3	miss	<500	501-2000	>2000	100	200	200	1000	>1000
Ba	µg/dm^3	<100	100-200	201-1000	>1000	300	500	700	3000	>3000
Be	µg/dm^3	<0.2	0.2-1.0	1.1-2.0	>2.0	0,5	50	100	200	>200
B	µg/dm^3	<200	200-500	501-1000	>1000	500	1000	1000	2000	>2000
Br$^-$	µg/dm^3	<10	10-25	26-100	>100					
V	µg/dm^3	<10	10-50	51-100	>100	4	20	50	500	>500
Fe (заг)	µg/dm^3	<300	300-1000	1001-2000	>2000	200	1000	5000	10000	>10000
Cd	µg/dm^3	<1	1-2	3-4	>4	1	3	5	10	>10
Co	µg/dm^3	<10	10-50	51-100	>100	20	50	200	1000	>1000
Li	µg/dm^3	<10	10-20	21-30	>30					
Mn	µg/dm^3	<50	50-100	101-500	>500	50	400	1000	1000	>1000
As	µg/dm^3	<10	10-20	21-50	>50	10	10	20	200	>200
Cu	µg/dm^3	<1	1-2	3	>3					
Mo	µg/dm^3	<200	200-300	301-500	>500					
Ni	µg/dm^3	<20	20-50	51-100	>100	5	10	20	100	>100
Hg	µg/dm^3	<0.5	0.5-1.0	1.1-2.0	>2.0	1	1	1	5	>5
Pb	µg/dm^3	<10	10-30	31-100	>100	10	25	100	100	>100
H2S	µg/dm^3	miss	<5	5-10	>10					
Se	µg/dm^3	<1	1-10	11-15	>15	5	10	10	50	>50
Sb	µg/dm^3	miss	<10	10-20	>20	5	5	5	100	>100
Sr	µg/dm^3	2000-7000	2000-7000	<10	2000-7000					
Tl	µg/dm^3	miss	<0.5	0.5-1.0	>1.0	1	10	20	100	>100
F$^-$	µg/dm^3	<700	700-1000	1001-1500	>1500	500	1000	1500	2000	>2000
Cr(III)	µg/dm^3	<100	100-200	201-500	>500					
Cr(IV)	µg/dm^3	<10	10-20	21-50	>50	10	50	50	100	>100
Zn	µg/dm^3	<100	100-500	501-1000	>1000	50	500	1000	2000	>2000
CN	µg/dm^3	miss	<10	10-50	>50	10	50	50	100	>100

Note: "good waters" are marked in green, "bad waters" are marked in red according to Item 2148

Indicators such as conductivity, temperature, dissolved oxygen, Sn, K, Na, Ag, Ti, U, Ca, HCO_3 – are absent in ДСТУ 4808:2007.

Instead, it should be noted that the MPCs for water of good quality in Ukraine are less stringent than in Poland. These include the following indicators:

- Sulphates 500 mg/dm^3 (UA) > 250 mg/dm^3 (PL);
- Chlorides 350 mg/dm^3 (UA) > 250 mg/dm^3 (PL);
- Nitrites 1 mg/dm^3 (UA) > 0.5 mg/dm^3 (PL);
- Al 500 µg/dm^3 (UA) > 200 µg/dm^3 (PL);
- Ba 1000 µg/dm^3 (UA) > 700 µg/dm^3 (PL);
- V 100 µg/dm^3 (UA) > 50 µg/dm^3 (PL);
- As 50 µg/dm^3 (UA) > 20 µg/dm^3 (PL);
- Ni 100 µg/dm^3 (UA) > 20 µg/dm^3 (PL);
- Hg 2 µg/dm^3 (UA) > 1 µg/dm^3 (PL);
- Se 15 µg/dm^3 (UA) > 10 µg/dm^3 (PL);
- Sb 20 µg/dm^3 (UA) > 5 µg/dm^3 (PL).

It is recommended to use the Polish MPC values for the above indicators.

At the same time, where Ukrainian MPCs are more stringent than Polish ones, it is recommended that Ukraine revise and slightly lower the MPCs where possible. This applies to the following elements: Mg, pH, NO_3^-, TOC, Be, Fe, Cd, Co, Mn, Tl.

Ukraine needs a document that would take into account all the requirements of the Directive on groundwater quality assessment and within the EU-WATERRES project it is necessary to recommend the Ministry of Ecology of Ukraine and the State Standard of Ukraine to start developing such a document.

It should cover the issues to be considered, according to the WFD:

1) classification of physicochemical elements according to the international system;
2) classification of the quantitative state of groundwater and their chemical state;
3) methods of interpretation of test results for quantitative physicochemical elements;
4) ways of presenting their condition (maps, etc.);
5) the frequency of assessment of their condition;
6) threshold values, which are environmental quality standards, expressed as a concentration of a given pollutant, a group of these substances or substances expressed as an indicator, which should not be exceeded in order to protect the environment and human health.

3. Program of transboundary groundwater monitoring for the Latvian-Estonian cross-border border area

The development of a transboundary groundwater monitoring program is mainly determined by the following regulatory documents: The WFD (2000/60/EC) (Article 8), the Groundwater Directive and The Water convention (Article 9). The requirements of these documents were transposed into the national legislation in both Latvia and Estonia, which is described in more detail in Chapter 1. On the basis of the above-mentioned documents, Member States sharing a GWBs should coordinate their monitoring activities in order to assess the status of the GWB and to prevent, limit and reduce existing or potential transboundary impacts on groundwater in a timely manner. Particular attention must be paid to transboundary GWBs or parts thereof that have been identified as transboundary GWBs at risk, stated or objected to with intense anthropogenic pressure, and in particular in areas where there is a significant transboundary groundwater flow and potential for transboundary pollution. Based on the results of the previous output "Assessment of the resources of transboundary groundwater reservoirs for the 2 pilot areas" and the previous output "Integrated groundwater observation network in Latvian Estonian transboundary area" it was concluded that the Latvian-Estonian case area is not subject to intense anthropogenic pressures and no GWBs of poor quality or quantity have been identified in the border area. More intensive groundwater flows between national borders have been identified only in the eastern part of the international Gauja-Koiva river basin district, and it was considered that this area should be given more attention if anthropogenic pressures increase. Attention should also be paid to the transboundary area of Valka-Valga cities in the future. Although no significant transboundary groundwater flows have been identified here, there is a relatively high anthropogenic pressure in this urban area.

Despite the fact that there are currently no identified problems in the transboundary area that could affect the status of groundwater in the border area, Latvia and Estonia must take care to protect groundwater and maintain the good status of common groundwater bodies. Accordingly, in order to further ensure the full-fledged management of transboundary GWBs in the border area, the first transboundary groundwater monitoring program is being developed within the framework of the EU-WATERRES project. The program is based on a conceptual understanding of the transboundary territory and the current knowledge base on the principles of groundwater monitoring in Latvia and Estonia, as well as the existing monitoring points in the transboundary area. The program has only a recommendatory status. In order to fully integrate it into the overall transboundary groundwater monitoring strategy and ensure the sustainability of developed cooperation, it is necessary to coordinate it between the Estonian and Latvian authorities involved in transboundary groundwater management and agree on a regular data exchange and groundwater assessment process (develop harmonized methodologies).

Currently, 18 active groundwater monitoring points (15 wells and 3 springs) have been identified in the Latvian-Estonian transboundary area, which may initially be included in the transboundary groundwater monitoring network and provide the necessary information on a regional scale. Of these, groundwater quality monitoring is provided at 14 monitoring points and quantitative monitoring at 11 monitoring points. In order to be able to harmonize the principles of groundwater monitoring between countries and to establish a sustainable transboundary groundwater monitoring program, information on the existing monitoring approach (observable indicators, observational frequencies, etc.) and the use of analytical methods is initially collected. These data were compiled using new long-term groundwater monitoring programs currently being developed in both countries with a 6-year cycle, which helps to monitor the achievement of environmental objectives, assess the impact of human activities and obtain reliable data on the actual environmental status of water bodies at the national level. In the case of Latvia, it is for the period from 2021 to 2026, but in the case of Estonia - from 2022 to 2027.

It should be noted that the main purpose of groundwater monitoring in both countries is to monitor the chemical and quantitative status of GWBs (changes and trends in quality indicators) in order to obtain a comprehensive overview of the status of groundwater bodies in each river basin area. Groundwater monitoring in Latvia and Estonia provides systematic, regular and targeted data on the quantitative and chemical status of GWBs. This is the strategic monitoring objective in any year of the monitoring program period - to achieve good groundwater status in all GWBs and to assess the risk of not achieving this objective.

3.1. Scope, frequency and research methodology of transboundary monitoring of the quantitative state

The purpose of transboundary groundwater quantitative monitoring is to assess the quantitative status of common GWBs (aquifers) by identifying GWBs at risk or areas where good groundwater quantity cannot be achieved due to intense anthropogenic pressures. The monitoring should also provide sufficient data to assess the direction and velocity of groundwater flow across the border of a Member State, which is one of the tasks of the WFD in the context of shared groundwater management.

The following points indicate the good quantitative status of GWB:

- the use of available groundwater resources does not exceed the long-term average annual consumption indicator. This implies the calculation of the groundwater balance of the aquifer, having to know inputs (natural and artificial recharge, inputs from other aquifer units, if any) and outputs (discharge to surface water bodies);
- groundwater levels and flow directions are sufficient to ensure the smooth functioning of the associated surface waters and ecosystems. In which case, information about the groundwater balance is needed in combination for environmental indicators of the status of the GDEs;
- anthropogenic interference with groundwater levels and flows does not result in saline or other intrusions.

The most important indicator that determines the quantitative status of a groundwater resource is the change in the groundwater level. Direct measurements of groundwater levels from observation wells are the main source of information on the hydrological pressures on aquifers / groundwater bodies and the impact of these pressures on groundwater recharge, storage and discharge.

Groundwater heads are the basic information to answer some of the most basic questions to manage an aquifer, however not the only. Additional information, such as: (1) groundwater related: spring flows, groundwater abstraction (and artificial recharge); (2) surface water related: stage levels of surface water courses, stage levels in significant groundwater dependent wetlands and lakes; (3) recharge related: rainfall and the components required to calculate evapo-transpiration (UNESCO, 2020).

At present, no significant water abstraction pressure has been identified in the Latvian-Estonian transboundary area, which may affect the quantity of common GWBs and indicate the depletion of groundwater resources, or change the direction and velocity of groundwater flow between national borders. It was further considered that at the current water abstraction pressure, the quantitative status of groundwater did not require increased attention and the installation and maintenance of new monitoring wells in the border area was not rational and financially justified.

Therefore, it is currently recommended that the transboundary groundwater quantitative network include 11 existing groundwater quantitative monitoring wells, mainly to strengthen cooperation between countries. Recommendations for the improvement of existing groundwater monitoring are provided at the end of the chapter, but the existing principles for groundwater quantity monitoring in both countries are given below.

The main indicator of groundwater quantitative monitoring in both countries is the groundwater level. In Estonia, if necessary, quantitative monitoring also includes measuring the amount of water flow in springs and watercourses, while in Latvia it is only planned to consider the possibility of including spring flow measurement (at least for falling springs) in groundwater quantitative monitoring. Measurements of groundwater levels in groundwater quantitative monitoring wells identified in a transboundary area are provided in two ways: manually or automatically. Most of the wells in the countries are equipped with automatic water level meters, which provide water level data collection with a frequency of 2-8 times a day (see Table 15).

Table 15. Frequency of groundwater quantity observations at monitoring points in Latvia and Estonia

Database code	GWB	Aquifer	Filter interval, m		Frequency (measures type)
			from	to	
Monitoring points in Estonia					
7588	24	D_2ar-br	48.3	133.5	8 times a day (automatic)
7592	23	D_2	16.6	18.5	8 times a day (automatic)
10656	25	D_2	153.1	189.3	12 times a year (manual)
13376	25	D_2; gQIII	9.6	15.5	12 times a year (manual)
24521	26	D_3	42	70	12 times a year (manual)
Monitoring points in Latvia					
22652	A10	gQ_3ltv	3.7	5.7	2 times a day (automatic)
9601	A10	gQ_3ltv	3.2	5.6	2 times a day (automatic)
9600	A10	D_2br	35.8	40.2	2 times a day (automatic)
9602	A10	D_2br	23.3	28.2	2 times a day (automatic)
22653	A10	gQ_3ltv	3.5	5.8	2 times a day (automatic)
9637	A8	D_2ar	97.5	122	4 times a year (manual)

It should be noted that a project has been launched in Latvia to improve the existing State Monitoring Network, during which it is planned to install three monitoring stations with 11 wells, which will be located in the Latvian-Estonian transboundary area and will allow groundwater quantity monitoring (will provide monitoring of the active water exchange zone). New wells are planned to be equipped with modern water level data loggers, which will ensure reading and loading of groundwater level data online. The location of the existing and new wells is shown in Figure 31.

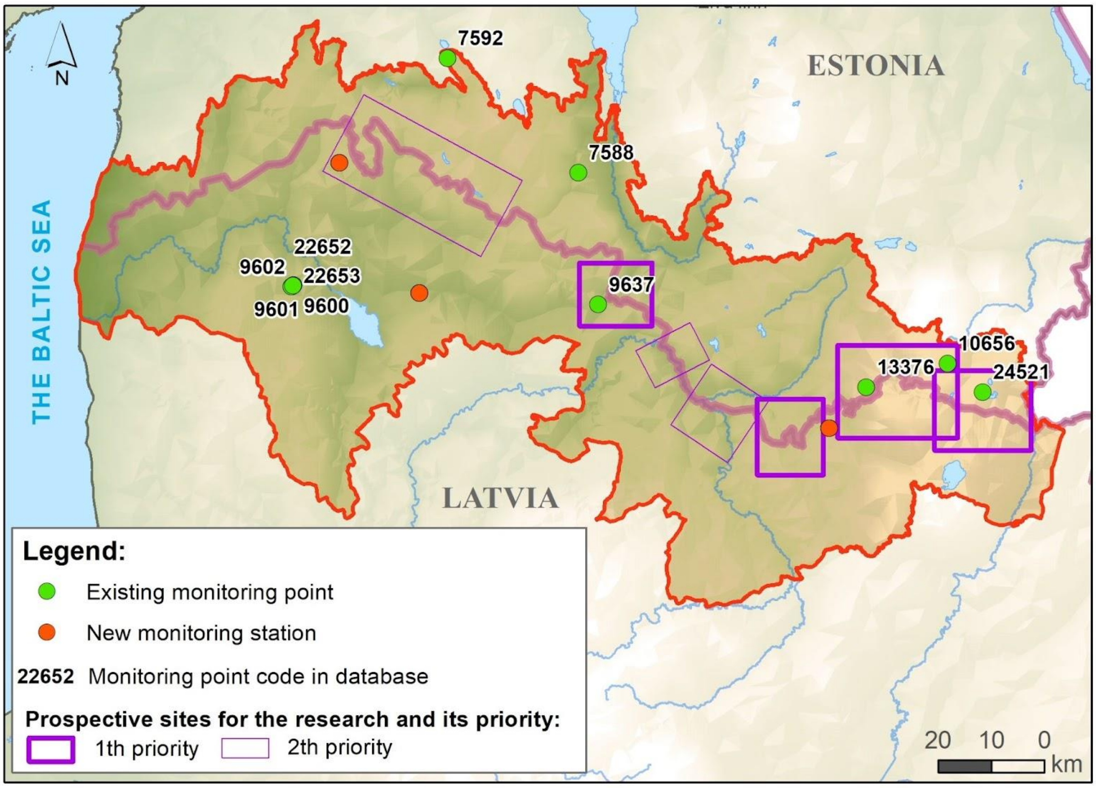


Figure 31. Groundwater quantity monitoring points in Latvian-Estonian transboundary area

Manual measurements usually really involve lowering a measuring tape along the piezometer, and measuring the distance between the well rim and the water table inside the piezometer, thus the depth to the groundwater in the well. The most used instrument for this purpose is the electric probe attached to a graduated measurement tape (UNSECO, 2020). On the other hand, automatic water level measurements are performed with automatic water level data loggers (Figure 32).

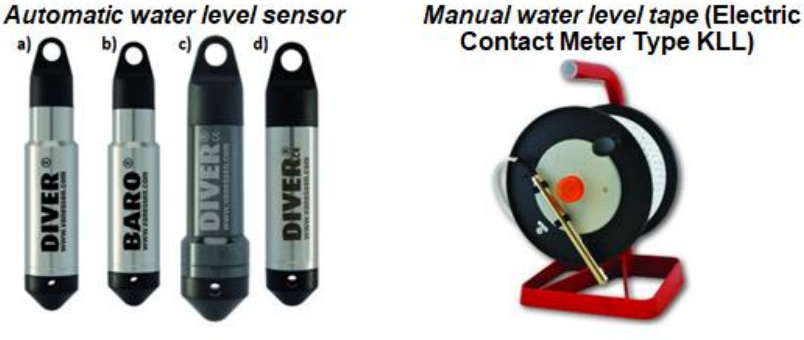


Figure 32. Groundwater level measuring devices

Based on the above, the following initially is recommended to exchange quantitative measurement data on an annual basis to the extent currently provided for in the existing monitoring programs in both countries. As the density of monitoring points is currently insufficient, to provide sufficient data to assess the direction and speed of groundwater flow across the border of the Member State, it is further recommended that countries consider improving the existing transboundary quantitative monitoring network. The focus needs to be on areas where a significant groundwater flow is currently identified or a potential increase in water abstraction that could change the direction of groundwater flow. Existing transboundary monitoring can be improved:

- by integrating other monitoring or water abstraction wells. However, it should be remembered that although water abstraction wells can provide a wide range of data on exploited aquifers, data from abstraction and water supply wells are more difficult to interpret (water level is affected by the drawdown-recovery cycle). Accordingly, such water wells can only be integrated into the existing monitoring network if pumping is stopped for a certain period of time before the groundwater level is measured and the water levels are stabilized to the natural groundwater level;
- by identifying springs characterizing transboundary aquifers and providing spring discharge measurements. Initially, in order to obtain a detailed overview of the flow dynamics of such springs, it is recommended to perform measurements during all seasons (to identify seasonality). The measurements can be made manually or automatically by water management authorities, but also can be obtained through citizen science and engagement of the public (see Chapter 1.1.4).

However, it should be noted that the inclusion of new monitoring points in the existing groundwater program may place an additional burden on funding, which is not always acceptable and justified at low anthropogenic pressures. In order to further improve the assessment of groundwater quantitative status in the transboundary area and to identify the significance of the existing water abstraction pressure on total groundwater resources, it is recommended to further develop and improve the existing hydrogeological model (local mathematical hydrogeological models are recommended for areas of greater interest). It should also be noted that the establishment of a transboundary groundwater monitoring program is an interactive process, and both the recommendations and the program itself may be revised after new data have been obtained or existing data have been updated.

3.2. Scope, frequency and research methodology of transboundary monitoring of the chemical state

The purpose of transboundary groundwater quality monitoring is to assess the qualitative or chemical status of common GWBs (aquifers) by identifying GWBs at risk or areas where good groundwater quality cannot be achieved due to intense anthropogenic pressures. The monitoring should also identify and control the potential transboundary movement of pollutants in a timely manner, which is also one of the main tasks of the WFD in the context of the management of shared groundwater bodies.

Good chemical status of groundwater bodies may have been achieved under the following conditions:

- threshold values of substances have not been exceeded;
- no salt water or other intrusions have been detected in the GWB;
- the quality of groundwater does not impair the quality of the associated surface water bodies and ecosystems.

Taking into account that currently no significant anthropogenic pressure has been identified in the Latvian-Estonian case area, which may affect the quality of common transboundary GWBs, it was considered that the assessment of the quality status, hydrochemistry and pollutants of these bodies can be ensured only by surveillance monitoring. Operational monitoring can be envisaged in common GWBs that have been recognized as “endangered” or in GWBs for which a poor status has been established (currently this is not relevant in the case of Latvia-Estonia).

In order to move towards a harmonized groundwater quality monitoring program, information on the existing principles of groundwater monitoring in Latvia and Estonia was initially collected. After the analysis of the collected data on the sampling and analysis methods as well as the equipment used during the field sampling, it was concluded that:

- Groundwater samples in both countries are taken, transferred and analyzed in accordance with national methods, which are standardized and in accordance with the requirements of Article 8, Paragraph three of the WFD; Water sampling according ISO standards - EVS EN ISO 5667-1, EVS EN ISO 5667-3, EVS EN ISO 5667-11, EVS EN ISO 5667-14 un EVS EN ISO 5667-15, which were incorporated in the internal instructions;
- In both countries, the analysis of water samples is performed in accredited laboratories in accordance with the requirements of EN ISO/IEC 17025, which guarantees the reliability of the data. In Latvia, it is provided by the Latvian Environment, Geology and Meteorology Center (national accreditation No.LATAK-T-105-34-97), while in Estonia the analysis of water samples is performed by the Estonian Environmental Research Center (national accreditation No. L008);
- Groundwater sampling is provided by well-trained specialists - in Latvia, sampling specialists are authorized to take samples, and the head of the laboratory quality system inspects sampling at least once a year, while in Estonia sampling is provided by a certified specialist, who must renew certification every four years by completing training;
- The methods of analysis used in the countries are standardized and, in many cases, the same. Differences in the methods are mainly noted for the detection of pesticides and other chemical pollutants.

In general, the quality system in place in both countries can be considered to guarantee the reliability of monitoring data from sampling to data analysis, as the certification and accreditation system guarantees control and monitoring throughout the data supply chain. Thus, the existing monitoring system in Latvia and Estonia provides an opportunity to jointly assess the quality of transboundary GWBs, as the underlying analysis methods are in many cases comparable.

However, in order to verify and compare the performance of the two laboratories and the equivalence of the data obtained, it is recommended that laboratory intercalibration and quality control of field measurements be performed in the future. It is recommended that laboratories in both countries perform analysis on samples of predictable composition (standard sample) so that the accuracy of the analyzes can be compared under laboratory conditions. There are also a variety of methods in practice to ensure that representative sample collection and analysis under field conditions are more comparable. It is recommended to organize a joint sampling campaign, in which joint sampling is carried out, followed by testing in both laboratories. Field duplicates can also be collected (in the same way as primary samples) to ensure sampling accuracy. Blank samples are recommended to ensure that no contamination occurs during sampling, storage and transportation.

Frequency of groundwater quality monitoring and sampling

The frequency of transboundary monitoring is not specified in national law. The WFD, Groundwater Directive and Nitrates Directives also do not set specific requirements for the frequency of groundwater monitoring observations (except for the operational monitoring of GWBs at risk, which must be carried out at least once a year), but only the frequency (cyclicality). In its turn, the EC guidelines No. 15 “Guidance on Groundwater Monitoring” provide recommendations for the frequency of sampling in both monitoring and operational groundwater monitoring (Guidance Document No.15, 2007) (see Tables 16 and 17).

Table 16. Proposed monitoring frequencies for surveillance monitoring (where understanding of aquifer systems is inadequate)

		Aquifer flow Type				
		Confined	Unconfined			
			Intergranular flow significant		Fracture flow only	Karst flow
			Significant deep flows common	Shallow flow		
Initial frequency – core & additional parameters		Twice per year	Quarterly	Quarterly	Quarterly	Quarterly
Long term frequency – core parameters	**Generally high-mod transmissivity**	Every 2 years	Annual	Twice per year	Twice per year	Twice per year
	Generally low transmissivity	Every 6 years	Annual	Annual	Annual	Twice per year
Additional parameters (on-going validation)		Every 6 years	Every 6 years	Every 6 years	Every 6 years	-

Table 17. Proposed frequencies for operational monitoring

		Aquifer flow Type				
		Confined	Unconfined			
			Intergranular flow significant		Fracture flow only	Karst flow
			Significant deep flows common	Shallow flow		
Higher vulnerability groundwater	Continuous pressures	Annual	Twice per year	Twice per year	Quarterly	Quarterly
	Seasonal/ intermittent pressures	Annual	Annual	As appropriate	As appropriate	As appropriate
Lower vulnerability groundwater	Continuous pressures	Annual	Annual	Twice per year	Tice per year	Quarterly
	Seasonal/ intermittent pressures	Annual	Annual	As appropriate	As appropriate	As appropriate
Trend assessments		Annual	Twice per year	Twice per year	Twice per year	-

Accordingly, the recommended sampling frequency for monitoring monitoring may vary from 2 times per year for shallow wells with the highest risk of contamination to 6 years for deeper wells with the lowest risk of contamination - the frequency of initial assessment may vary from 4 to 2 times per year (see Table 16). However, it should be noted that the water sampling frequencies proposed in the previous table are recommended to be implemented only in cases when the conceptual understanding of the study area is limited and the available data on the chemical composition of groundwater are not available. Otherwise, the frequency of samples may be different.

Consequently, the frequency of observations may depend not only on the observation tasks and the hydrogeological characteristics of each common GWB, but also on the existing knowledge base on the groundwater system and, of course, the financial aspect must not be ruled out. At present, the transboundary groundwater monitoring network includes 14 existing active groundwater quality monitoring points (springs and wells), which are currently located in the Latvian-Estonian transboundary area and mainly provide monitoring in the existing national monitoring networks (Figure 33).

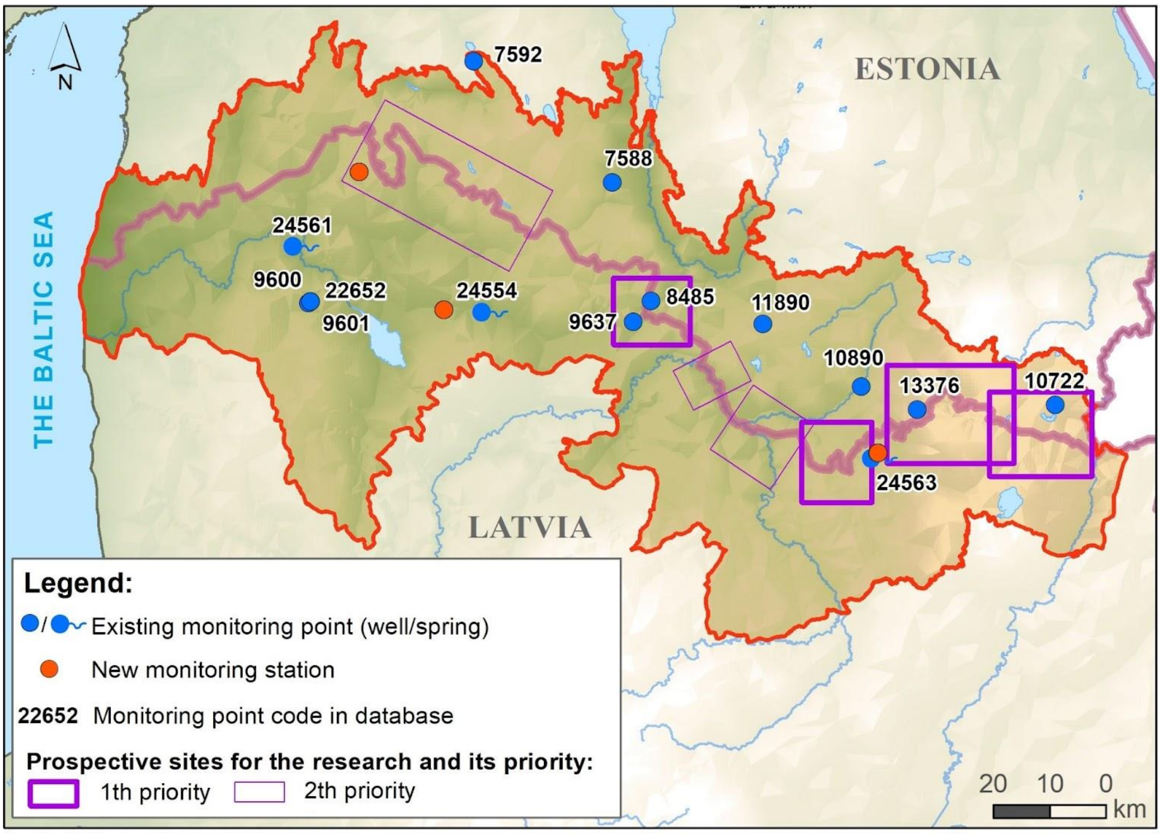


Figure 33. Groundwater quality monitoring points in Latvian-Estonian transboundary area

After data collection, it can be seen that there is no coincidence in Latvia and Estonia in the frequency of groundwater quality surveys and the frequency of water sampling at previously identified groundwater monitoring points (see Table 18). It was concluded that in Estonia the frequency of water sampling at all monitoring points within the study area takes place once a year during the summer period, while in Latvia the frequency of water sampling at monitoring points varies from 4 times a year to 1 time per year (the frequency mainly depends on the degree of protection of the monitoring point, seasonality).

Table 18. Frequency of groundwater quality monitoring at monitoring points in Latvia and Estonia

Parameter*	Survey frequency (from-to)		Sampling frequency (from-to)		Sampling points
	Latvia	Estonia	Latvia	Estonia	
Core	3 times in 6 years – 2 times in 6 years	Annual – 3 times in 6 years	Once a year – 4 times in year	Once a year	All points
Additional	3 times in 6 years – 2 times in 6 years	3 times in 6 years – 1 time in 6 years			In Latvia case - only at points with the lowest protection; In Estonia case – all points

*More detailed information on observer parameters is provided below, in the subchapter “Observed indicators of groundwater quality”.

Table 19 below provides more detailed information on the current frequency of monitoring at existing monitoring points and the frequency of water sampling, which is planned to be implemented in the next 4-5 years. In the previous monitoring cycle, sampling in the monitoring wells took place annually.

Table 19. The current frequency of monitoring at monitoring points and the frequency of water sampling in Latvia and Estonia

Database number	Type	GWB	Aquifer	Filter interval, m		Survey frequency		Sampling frequency
				from	to	Core parameters	Additional parameters	
Monitoring points in Estonia								
7588	well	24	D_2ar-br	48.3	133.5	6 times in 6 years	1-3 times in 6 years	1
7592	well	23	D_2	16.6	18.5	3 times in 6 years	1 time in 6 years	1
8485	well	24	D_2br-ar	50	80	6 times in 6 years	1-3 times in 6 years	1
10722	well	26	D_3	44	70	3 times in 6 years	1 time in 6 years	1
10890	well	25	D_2	83	123	3 times in 6 years	1 time in 6 years	1
11890	well	25	D_2tr	74.2	90	3 times in 6 years	1 time in 6 years	1
13376	well	25	D_2; gQIII	9.6	15.5	3 times in 6 years	1 time in 6 years	1
Monitoring points in Latvia								
24563	spring	D6	D_3pl	-	-	3 times in 6 years	3 times in 6 years	4
24561	spring	A10	D_2br	-	-	3 times in 6 years	-	2
24554	spring	A10	D_2br	-	-	3 times in 6 years	-	2
22652	well	A10	gQ_3ltv	3.7	5.7	3 times in 6 years	3 times in 6 years	2
9601	well	A10	gQ_3ltv	3.2	5.6	3 times in 6 years	3 times in 6 years	2
9600	well	A10	D_2br	35.8	40.2	twice in 6 years	twice in 6 years	1
9637	well	A8	D_2ar	97.5	122	twice in 6 years	twice in 6 years	1

Taking into account the collected information, it was recommended to maintain the frequency of surveyed groundwater quality at all existing transboundary monitoring points – at least 3 times in 6 years, while for additional parameters the sampling frequency may be maintained according to the already developed monitoring program. On the other hand, in the new monitoring points, where the hydrochemical conditions of the territory must be known or additional information must be obtained, the frequency of sampling may be provided annually in accordance with the recommendations of Table 16. It should be noted that such detailed water quality monitoring must be continued for at least 3-4 years in order for a site to be considered a good reference site. The sampling frequency can then be reduced (reference to section 1.1.5). In turn, at monitoring points where exceedances or problems are identified, sampling should be provided annually.

However, due to a lack of information, it is currently not possible to fully harmonize the frequency of cross-border monitoring. To do this, it is first necessary to develop common principles for the frequency of groundwater quality surveys and water sampling by establishing a common sensitivity map for the transboundary area. At present, different principles are used in the countries to determine their frequency - in the case of Latvia, the frequency of surveyed indicators at the monitoring points mainly decreases with increasing depth of aquifer and decreasing degree of risk of surface pollution infiltration. In Estonia, the frequency of protection is not specifically assigned to the sampling frequency monitoring points. At monitoring points where problems and exceedances have been identified, sampling takes place every year, regardless of the level of protection (criterion applies in both countries).

Observed indicators of groundwater quality.

In order to characterize the quality of groundwater and assess its status, universal indicators must be established at all monitoring points and specific indicators at monitoring points that characterize the relevant anthropogenic pressure and may affect the GWB or the aquifer used. According to Annex V of the WFD, dissolved oxygen, pH, conductivity, nitrate and ammonium are the core parameters that need to be monitored. Additionally, Eh (redox potential) and turbidity can also be monitored, as well as major anions and cations – Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, NH_4^+, NO_2^-, NO_3^-, un P_{tot} or PO_4^3. The last are extremely important, especially during the first years of operation in order to confirm the conceptual model and interpret the core geochemical parameters. Moreover, the norm indicates that major constituent analysis is highly recommended in transboundary water bodies, which are relevant for the protection of all of the uses supported by the groundwater flow. It should be noted that the main ions and field work parameters are also needed for quality control of water samples during sampling and analysis (mainly for ion balance calculation). It should also be noted that other trace ions will depend on the aquifer lithology, as they may be clues to depict flow path, recharge areas, and so on. Moreover, trace ions may be directly related to some identified pressure and, therefore, they become indicative of the risks to and impacts on groundwater from identified pressures. In such a case, they must be included in the analysis.

The list of additional parameters must be determined in accordance with the objectives of the directive and the risks identified in the body of groundwater which prevent the achievement of good groundwater status or jeopardize its quality. Annex II of the Groundwater Directive also identified the need to monitor specific indicators, including at least As, Cd, Pb, Hg, as well as trichlorethylene, tetrachloroethylene and other synthetic substances (monitoring these parameters at least once during the water management period). In turn, Annex I of the Groundwater Directive also required the control not only of nitrate pollution of groundwater, but also of pesticide pollution. The information is summarized in Table 20.

Table 20. List of sampling parameters according to EU directives and guidance report

Parameter (indicator)	Type	Annex V of the WFD	Annex II of the GWD	Annex I of the GWD	EU recommen-dations (guidance, reports)
List of parameters, which should be measured in the field					
Electrical conductivity (EC)	mandatory	x	x		x
Oxygen Content (DO)	mandatory	x			x
pH value	mandatory	x			x
Temperatura (t)	recommended				x
Redox potential (Eh)	recommended, if necessary				x
Turbidity	recommended, if necessary				x
Minimum list of parameters, which should be analyzed in the laboratory					
Calcium (Ca)	recommended				x
Magnesium (Mg)	recommended				x
Sodium (Na)	recommended				x
Potassium (K)	recommended				x
Bicarbonates (HCO_3)	recommended				x
Sulphates (SO_4)	recommended		x		x
Chlorides (Cl)	recommended		x		x
Ammonium (NH_4)	mandatory	x	x		x
Nitrites (NO_2)	recommended		x		x
Nitrates (NO_3)	mandatory	x		x	x
Total organic carbon (TOC)	recommended				x
Phosphate phosphorus and phosphates (PO_4)	recommended		x		x
Total phosphorus (P_{tot})	recommended		x		x
Lead (Pb)	recommended		x		x
Cadmium (Cd)	recommended		x		x
Mercury (Hg)	recommended		x		x
Arsenic (As)	recommended		x		x
Minimum additional list of parameters, which should be analyzed in the laboratory					
Pesticide	mandatory			x	x
Pesticide (total)	mandatory			x	x

Trichlorethylene	recommended		x		
Tetrachlorethylene	recommended		x		
Other trace elements	recommended, if necessary				x
Other chemical pollutant or organic compounds	recommended, if necessary				x

The collected data show that in order to characterize the quality and assess the status of groundwater bodies in both countries, basic (core) indicators are defined at all monitoring points and specific indicators. In Latvia, sampling of specific indicators are performed at monitoring points, which characterize the respective anthropogenic pressure or characterize the shallow aquifer. In deeper aquifers is envisaged only if excesses of these parameters have been detected in the upper layer. In Estonia, on the other hand, they are monitored in shallow wells once or twice during a 6-year period, and in the deepest wells once during 6-year period. Table 21 below summarizes the information on the list of analyzed indicators and their coincidence in both countries.

Table 21. Observed indicators of groundwater quality in Latvia and Estonia

Parameters	Latvia	Estonia
Descriptive determinants (field work)	pH, temperature, Electrical conductivity, Dissolved oxygen (O_2), Redox potential (Eh), Fe_{tot}	pH, temperature, Electrical conductivity, Dissolved oxygen (O_2)
Core parameters	Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, total hardness (calculated), PO_4^{3-}, P_{tot}, Fe_{tot}*, Mn, NH_4^+, NO_2^-, NO_3^-, N_{tot}, TOC, DOC, UV absorption, permanganate index	Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, total hardness, PO_4^{3-}, P_{tot}*, Fe_{tot}, Dry residue, NH_4^+, NO_2^-, NO_3^-, N_{tot}*, Total dissolved solids (Dry residue), Chemical Oxygen Demand (COD), CO_2 (calculated)
Heavy metals	Cd, Pb, Hg, As, Ni	Cd, Pb, Hg, As, Ba, Zn*, Cu*, Ni*
Chemical pollutants	Trichlorethylene, tetrachloroethylene, 1,2-dichloroethane, trichloromethane, BTEX, Watch list indicators perflour (PFAS) – separate parameters, Chemical Oxygen Demand (COD), Synthetic Surfactants, Strontium, Bromide ions, Iodide ions	Trichlorethylene, tetrachloroethylene, 1,2-dichloroethane, Sum of Polyaromatichydrocarbons (PAH sum), Benzene (Benseen), Hydrocarbon oil index (C10 - C40), Watch-list indicators Pharmaceuticals, Watch-list indicators perfluor (PFAS), Monobasic Phenolic compounds, Dibasic Phenolic compounds
Pesticides	Atrazine, simazine, bentazone, MCPA, promethrin, propazine, 2,4-D, isoproturon, aclonifen, bifenox, aldrin, dieldrin, heptachlor, dimethoate, cypermethrin, trifluralin, tebuconazole*, epoxiconazole*, diflufenican*, metribazuzan*, metribazuran*, MCPB, heptachlor epoxy, alpha-cypermethrin, pendimethalin*, azoxystrobin*, prochloraz*	Atrazine, simazine, bentazone, MCPA, promethrin, propazine, 2,4-D, isoproturon, aclonifen, bifenox, aldrin, dieldrin, heptachlor, dimethoate, cypermethrin, trifluralin, tebuconazole, epoxiconazole, diflufenican, metribuzin, metazachlor + *other pesticides*

Notes: Basic parameters, Additional parameters, **Mn** – a parameter measured in only one country.
***** Components are included in the new monitoring program.

According to the collected data, it can be seen that the monitoring of groundwater quality in both Latvia and Estonia takes into account the recommendations of the EC, as well as the requirements of the Groundwater Directive. Accordingly, a minimum list of universal and specific indicators has been observed in both countries. However, discrepancies have also been noted, mainly related to the characteristics of each country's monitoring, as well as to observed anthropogenic pressures and other factors. For example, in Latvian monitoring to check the reliability of data, to correct the obtained data and increase the accuracy, which is very important in typically low concentrations or, conversely, very high mineralization amplitude, the list of water quality indicators includes control indicators: total hardness, UV absorption or permanganate index and N_{tot} (also allows the identification of groundwater impacts on surface water bodies and terrestrial ecosystems). As manganese (Mn) is characterized by high migration capacity in groundwater and Latvian conditions are also characterized by natural excesses of manganese concentration, this parameter is included in the universal list of indicators.

In Estonia, no control indicators are currently measured beside the main water quality indicators. During the next 6-year cycle, N_{tot}, P_{tot}, PO_4 and increase the determination of Ba are included in the Estonian monitoring program in order to identify groundwater impacts on surface water bodies and terrestrial ecosystems. Estonia has established a list of terrestrial and aquatic ecosystems that are directly dependent on groundwater bodies. From here, the status of GWBs are assessed to determine whether groundwater chemical quality indicators can lead to unfavorable status for surface water bodies or terrestrial ecosystems feeding on groundwater. N_{tot} and P_{tot} measurements from groundwater make it possible to compare monitoring data between surface water and groundwater, as it is also measured from surface water. Heavy metals Ni, Cu, Zn will also be added as they were standardized in drinking water and will need to be monitored under the new Drinking Water Directive. Also have been added the Watch-list indicators – Pharmaceuticals (drug residues) and perfluor (PFAS) substances.

Laboratories in both countries provide testing results in quality control procedures: at least the percentage of total concentrations of cation and anion equivalents tested, as well as simple correlations between parameters ($P/PO_4 < P_{tot}$, $N/NO_3 + N/NH_4 + N/NO_2 < N_{tot}$ mg/l). In turn, the used groundwater laboratory analysis methods in Latvia and Estonia are summarized in Table 22, trying to find an opportunity to jointly analyze the obtained results (data are summarized for common indicators and identifying similar methods). In turn, more detailed information on the methods used in each country for each parameter and their diversity is provided in Annex 1.

Table 22. Groundwater laboratory analysis methods in Latvia and Estonia*

Parameter	Latvian method	Estonian method
Calcium (Ca)	LVS EN ISO 11885:2009	EVS-EN ISO 11885
	LVS EN ISO 7980:2000	ISO 6058
	-	SFS 3003
	-	EN ISO 14911
Magnesium (Mg)	LVS EN ISO 11885:2009	EVS-EN ISO 11885
	LVS EN ISO 7980:2000	ISO 6059
	-	EN ISO 14911
Sodium (Na)	LVS ISO 9964-3:1993	EVS-ISO 9964-3
	LVS EN ISO 11885:2009	EN ISO 14911
Potassium (K)	LVS ISO 9964-3:1993	EVS-ISO 9964-3
	LVS EN ISO 11885:2009	EN ISO 14911
Bicarbonates (HCO3)	SM 2320 B:2017	EVS-EN ISO 9963-1
Sulphates (SO4)	LVS EN ISO 10304-1:2009	EVS-EN ISO 10304-1
Chlorides (Cl)	LVS EN ISO 10304-1:2009	EVS-EN ISO 10304-1
Phosphate phosphorus and phosphates (PO_4)	LVS EN ISO 6878:2005, 4.nod	EVS-EN ISO 6878
	-	ISO 15681-2

Total phosphorus (P_{tot})	LVS EN ISO 6878:2005, 7.nod.	ISO 15681-2
Total nitrogen (N_{tot})	LVS EN ISO 11905-1:1998	ISO 11905
	LVS EN 12260:2004	-
Ammonium (NH_4)	LVS EN ISO 11732:2005	EVS-EN ISO 11732
	QuAAtro Method no. Q-080-06 Rev.2:2008	SFS 3032
Nitrites (NO_2)	LVS ISO 6777:1984	EVS-EN ISO 13395
Nitrates (NO_3)	LVS EN ISO 13395:2004	EVS-EN ISO 13395
	-	EVS-EN ISO 10304-1
Total hardness	SM 2340 C:2017	SM 2340 C:2017
	-	ISO 6059
	-	SFS 3003
Total iron (Fe_{tot})	LVS EN ISO 11885:2009	ISO 6332
Lead (Pb)	LVS EN ISO 11885:2009	EVS-EN ISO 11885
	-	EVS-EN ISO 17294-2
Nickel (Ni)	LVS EN ISO 11885:2009	EVS-EN ISO 11885
	-	EVS-EN ISO 17294-2
Cadmium (Cd)	LVS EN ISO 15586:2003	EVS-EN ISO 17294-2
	LVS EN ISO 11885:2009	EVS-EN ISO 11885
Mercury (Hg)	LVS EN ISO 17852:2008	EVS-EN ISO 17852
	-	EVS-EN ISO 12846
Arsenic (As)	LVS EN ISO 15586:2003	EVS-EN ISO 17294-2
	-	EVS-EN ISO 11885
Atrazine	EN ISO 10695:2000*	STJnrU63
Simazine	EN ISO 10695:2000*	STJnrU92
Propazine	EN ISO 10695:2000*	STJnrU63
Bentazone	US EPA Method 8151A:1996*	STJnrU92
MCPA	US EPA Method 8151A:1996*	STJnrU92
Aldrin	ISO 6468:1996	STJnrU63
Dieldrin	ISO 6468:1996	STJnrU63
Heptachlor	ISO 6468:1996	STJnrU63
2,4-D	BIOR-T-012-162-2015	STJnrU92
Isoproturon	BIOR-T-012-162-2015	STJnrU92
Aclonifen	BIOR-T-012-162-2015	STJnrU63
Biphenox	BIOR-T-012-162-2015	STJnrU63
Promethrin	BIOR-T-012-162-2015	STJnrU63
Dimethoate	BIOR-T-012-162-2015	STJnrU92
Cypermethrin	BIOR-T-012-162-2015	STJnrU63
Trifluralin	BIOR-T-012-162-2015	STJnrU63
Tebuconazole	BIOR-T-012-162-2015	STJnrU92
Epoxiconazole	BIOR-T-012-162-2015	STJnrU63
Diflufenican	BIOR-T-012-162-2015	STJnrU92
Metribuzin	BIOR-T-012-162-2015	STJnrU63
Metazachlor	BIOR-T-012-162-2015	STJnrU92
Trichlorethylene	ISO 10301:1997	ISO 20595
Tetrachlorethylene	ISO 10301:1997	ISO 20595
1,2-dichloroethane	ISO 10301:1997	ISO 20595

Notes: Methods are not comparable, Methods are comparable

* The data is for a specific date; data can be updated as needed

The methods of analysis used in the countries are standardized and, in many cases, the same. Differences in the methods are mainly noted for the detection of pesticides and other chemical pollutants. Also in the previous period, in Latvia the assessment of the total iron concentration was performed at the time of sampling, but in Estonia the sample is delivered to the laboratory. At present, the methods are not comparable, because during the transfer of the sample, the iron in the water precipitates at the bottom of the vessel. However, according to the new monitoring program, the iron content in the water in the case of Latvia will also be determined under laboratory conditions.

The parameters with which the monitoring data should be exchanged and their recommended sampling frequency are given in Table 23. The list of parameters is mainly based on the results of the anthropogenic pressure assessment, the long-term results of groundwater quality monitoring in each country and the existing knowledge base on the hydrogeological conditions of the transboundary area. Also, the choice of parameters and frequencies did not exclude the financial aspect and the monitoring programs currently developed in both countries, which have different principles for determining the parameters to be analyzed and the frequency of their sampling (including no common vulnerability map or principles for determining vulnerability). Therefore, further cooperation is needed to develop a high-quality long-term monitoring program.

Table 23. Agreed list of parameters and frequency for exchange of groundwater quality monitoring data in Latvian-Estonian transboundary area

Parameters		Frequency (monitoring points)
Basic (universal) parameters		
Descriptive determinants (field parameters)	Temperature, pH, Electrical conductivity, dissolved oxygen (O_2)	3 times in 6 years (springs and wells which represent GWB 23, 25, 26, A8, A10 and D6);
Major ions and nitrogen compounds	Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, total hardness, Fe_{tot}, NH_4^+, NO_2^-, NO_3^-	
Additional parameters		
Metals	Cd, Pb, Hg, As	1 time in 6 years (in the all monitoring points)
Chemical pollutants	Trichlorethylene, Tetrachlorethylene, 1,2-dichloroethane	1 time in 6 years (only in the monitoring points, which parameters analyzed)
Pesticides	Atrazine, Simazine, Propazine, Bentazone, MCPA, Aldrin, Dieldrin, Heptachlor, 2,4-D, Isoproturon, Aclonifen, Bifenox, Promethrin, Dimethoate, Cypermethrin, Trifluralin, Tebuconazole, Epoxiconazole, Diflufenican, Metribuzin, Metazachlor	

In the future, it is recommended to start exchanging data on groundwater monitoring points for at least the main parameters (field measurements, main ions, nitrate compounds). It is recommended that they be monitored in springs and wells that characterize GWB 26, D6, A8 and A10 at least 3 times over a 6-year period. If exceedances are found in the monitoring results, the sampling frequency may be increased to 1 time per year. However, in the case of Latvia, in order to perform the above-mentioned monitoring frequency, it will be necessary to increase the sampling frequency in separate monitoring wells (No. 9600 and No. 9637, which characterize

GWBs A8 and A10), as it currently takes place twice every 6 years.

In turn, additional parameters (heavy metals, chemical pollutants, pesticides) must be performed at least once every 6 years - heavy metals must be determined at all monitoring points, but chemical pollutants and pesticides only at those monitoring points where they have been detected. In turn, additional parameters (heavy metals, chemical contaminants, pesticides) must be performed at least once every 6 years - heavy metals must be collected at all monitoring points, but chemical contaminants and pesticides only at those monitoring points where they can be detected or may indicate possible contamination, as also in places with the lowest level of protection (analyzed according to the national monitoring programs of both countries). Additional indicators should be measured at the same time as the key indicators. In order to achieve a continuous data exchange process in the future, the two parties (LEGMC and EEA) should conclude a data exchange agreement with each other in order to provide each other with appropriate monitoring results on an annual basis. The list of sites to be monitored and the parameters to be exchanged, the frequency of their sampling may be specified after the acquisition of new data on pollution sources and the hydrogeological conditions of the site, as well as after the development of a harmonized vulnerability map. Thus, this is only an initial list, mainly to improve cooperation between countries and to introduce a continuous exchange of monitoring data.

3.3. Collecting, verifying and archiving the results of transboundary groundwater monitoring

For a monitoring programme to be successful, data needs to be collected, stored, interpreted and translated into useful information. In the case of the transboundary monitoring programs this process presents another level of complexity as all these steps should be agreed between riparian countries (UNSECO, 2020). The Figure 34 shows the stages and key elements of the monitoring process, from data collection at monitoring points to information analysis, status assessments that provide information on the overall transboundary groundwater situation, so that experts can decide on further development of the monitoring strategy.

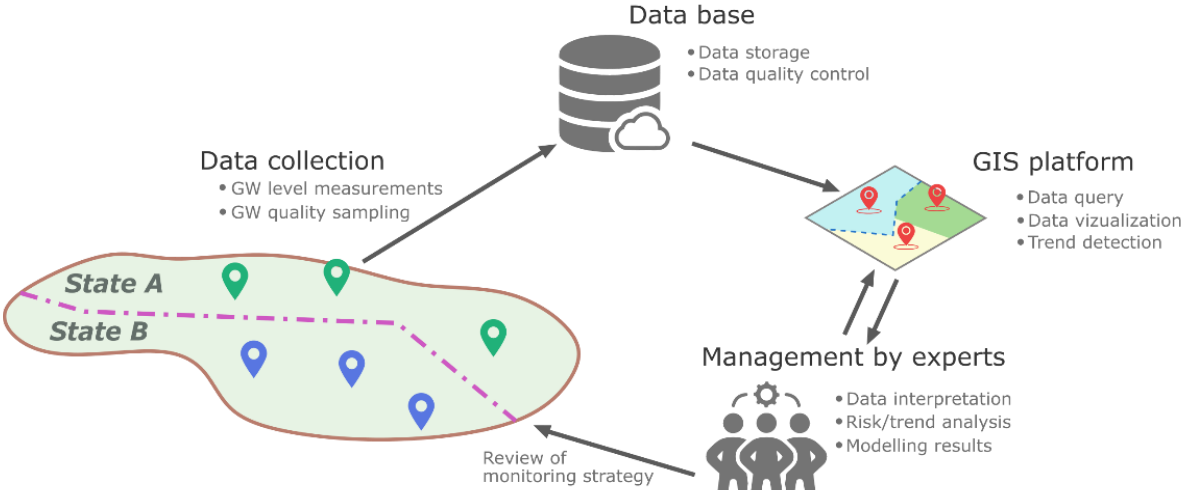


Figure 34. Dataflow in a transboundary groundwater monitoring network (modified by UNSECO, 2020)

According to the developed transboundary groundwater monitoring program, each country performs data collection (groundwater sampling, water level measurements).

At the monitoring points in the Latvian-Estonian transboundary area, water level measurements are determined both automatically (automatic sensors are installed) and manually (Table in section 3.1). Level data are collected quarterly at monitoring points equipped with automatic sensors.

Data collection can be facilitated by the installation of a telemetry station at monitoring points equipped with automatic sensors. As a result, data is automatically sent to the data storage via a satellite signal. Monitoring points equipped in this way allow to quickly detect changes in water levels and identify the causes of problems. Due to high costs, no telemetry station is installed at any of the Latvian and Estonian monitoring points, so data collection must be performed manually by the responsible specialist inspecting each monitoring point.

As mentioned in the previous chapters, in Latvia and Estonia, according to the national long-term monitoring programs, the frequency and time period of sampling / data collection at transboundary monitoring points are different.

After the monitoring data is collected, the data is stored in each country's data repository. The process of data analysis and quality control follows. As mentioned above, in the case of both Latvia and Estonia, the principles of groundwater quality determination are performed in accordance with the recommendations of the EC as well as the requirements of the Directives, therefore the principles of laboratory analysis and data quality control are similar in both countries.

Once the monitoring data has been collected and each country has verified the quality of the data and/or performed data treatment, the data should be stored in a common, harmonized database (data exchange). It should be mentioned that in the case of Latvia and Estonia, evaluating the analysis methods and data quality control processes, it has been concluded that the approaches of both countries are relatively similar. Thus, in the current situation (at least in the initial phase of cross-border monitoring), no specific harmonization is required.

Existing guidelines do not specify how these data should be stored. For example, in the case of Latvian-Lithuanian cooperation (B-solutions, 2018), a common template was created in the MS Excel application environment, where once a year, in accordance with the agreement, the two countries exchange data, and the database is updated with the current monitoring data. International organizations such as IGRAC and UNECE have developed information systems and GIS-based online platforms where coastal states can store their data sets in a transparent way (GGIS, WINS).

Within the EU-WATERRES project, a common integrated geoinformation platform also was developed, which provides access to geological and hydrogeological information from the countries involved in the project (including Latvia and Estonia), as well as monitoring data on transboundary pilot areas. The platform will be able to store monitoring data, display the results on maps, as well as show trends, thus assessing and controlling the groundwater situation in the transboundary area. Such a GIS platform is a very practical and important tool as it is easily accessible to all partners, thus facilitating cooperation and data exchange between riparian countries.

As monitoring is an iterative process, the interpretation of monitoring results in such a GIS platform (visualization, trend detection) is essential for the development and refinement of a cross-border monitoring strategy. Close cooperation between Latvian and Estonian experts also plays an important role here in order to jointly assess transboundary groundwater resources and take joint decisions on the further development of the transboundary monitoring strategy.

4. Program of transboundary groundwater monitoring for the Polish-Ukrainian cross-border border area

4.1. Monitoring of the quantitative state of groundwater

Monitoring observations in scope of measuring the position of the groundwater table and the efficiency of sources in Poland began in 1974 as part of the network of stationary groundwater observations, organized by the Polish Geological Institute. In 2006, as a result of the amendment to the Water Law Act, the network of stationary groundwater observations was combined with the national groundwater quality monitoring network carried out under the State Environmental Monitoring, which resulted in the launch of a groundwater observation and research network. Research within this network is carried out at groundwater measurement and control points (wells, piezometers, springs). Two types of hydrogeological stations are distinguished in the observation network:

- First order hydrogeological stations located in places representative of selected hydrogeological regions. They include hydrogeological observation boreholes capturing useful aquifers in a given hydrogeological region,
- Second order hydrogeological stations, which are single hydrogeological wells or springs.

In selected border zones of Poland, as well as in areas exposed to strong anthropogenic pressure, groundwater monitoring studies are carried out at research monitoring points of the state hydrogeological survey.

Selected monitoring points are equipped with automatic measuring devices for the depth of the groundwater table, atmospheric pressure and groundwater temperature.

The organization of the national monitoring of the quantitative status of groundwater of the Polish Geological Institute-National Research Institute (PGI-NRI) assumes the division of the territory of Poland into regions assigned to regional branches of the PGI-NRI. Within each region, the care and supervision of groundwater monitoring points is carried out by a regional coordinator, who is responsible for the proper selection of representative points for the existing aquifers, the technical condition of monitoring points and measuring equipment installed at monitoring points, as well as for the organization and correctness of observation of the level of the groundwater table or the efficiency of springs conducted at the observation points. Supervision over the group of regional coordinators is performed by the national coordinator

The criteria for determining the measurement and control points of the national observation and investigative network for the monitoring of groundwater bodies are defined in the Regulation of the Minister of Infrastructure of 13 July 2021 on the forms and methods of monitoring surface water bodies and groundwater bodies (Journal of Laws 2021 item 1576) and take into account:

1) location of measurement points;
2) determining the number of measurement points;
3) conditions of measuring points, where the conditions include:
    - enabling selective water intake from the investigated aquifer;
    - hydraulic efficiency and enabling correct water sampling or water table level measurement;
    - type of material the measuring point is made of;
    - protection against interference by unauthorized persons;

- availability of geological documentation referred to in the Act of June 9, 2011 - Geological and Mining Law (Journal of Laws 2021, item 1420);
- regulated legal status of the real estate on which the measuring point is located.

The scope of measurements carried out at the monitoring points of the PGI-NRI groundwater observation and investigative network includes:

- manual measurements of the depth to the groundwater table or the efficiency of sources; performed once a week - on Mondays at 06:00 UTC, or at selected observation points in accordance with the guidelines for individual research monitoring networks;
- daily automatic measurements (in case of monitoring points equipped with automatic measuring devices);
- control measurements.

In addition to measuring the depth of the groundwater table and the efficiency of springs, sampling and testing are also carried out at selected points of the PGI-NRI quantitative monitoring to determine the chemical composition of groundwater and assess the technical condition of the points. In addition, the observation and investigative points of the quantitative status monitoring network or the results of monitoring observations carried out therein may be additionally used for the purpose of carrying out tests as part of the monitoring of the chemical status of groundwater of the Chief Inspectorate of Environmental Protection (CIEP), and for the purposes of carrying out studies or interpretations as part of the PGI-NRI investigative monitoring.

4.2. Monitoring of the chemical state of groundwater

Works and field studies related to the implementation of chemical monitoring are carried out by the PGI-NRI in Warsaw on behalf of the CIEP. Teams of hydrogeologists of the State Hydrogeological Survey (SHS) participate in the implementation of the works and field research, including those from the branches of the PGI-NRI in Warsaw, Szczecin, Gdańsk, Wrocław, Sosnowiec, Kraków, Kielce and Lublin.

The Regulation of the Minister of Infrastructure of 13 July 2021 on the forms and methods of monitoring surface water bodies and groundwater bodies (Journal of Laws 2021 item 1576) as part of the monitoring of the chemical status of groundwater bodies defines two types of monitoring:

- Diagnostic monitoring;
- Operational monitoring.

Diagnostic monitoring is carried out in order to supplement and verify the procedure for assessing the impacts resulting from natural and anthropogenic conditions, and to assess significant and sustained trends in increasing concentrations of pollutants resulting from natural conditions and anthropogenic impacts (Journal of Laws of 2021, item 1576). In the years 2016–2021, in accordance with the monitoring program of the GWBs in force at that time (Kazimierski et al., 2015), diagnostic monitoring was carried out at three-year intervals: in 2016 and 2019. In the years 2022–2027, as well as in the next 6-year water management cycles, it is planned to conduct diagnostic monitoring only in the first year of the cycle (Kuczyńska et al., 2020).

In 2019, in the diagnostic monitoring of GWBs, water samples were collected from a total of 1,289 monitoring points located in 172 GWBs, in case of 153 water samples, organic indicators were determined for the purpose of analysing parameters and physio-chemical indicators. The quality control procedure included the collection and analysis of the results: 99 duplicate samples, 40 field blank samples and 40 transport blank samples (Rojek et al., 2019).

In 2022, it is planned to perform a single sampling of 1,400 observation points located in 174 groundwater bodies, including 100 samples for organic compounds. The field quality control program included the collection and analysis of 100 duplicate samples, 50 field blank samples and 50 transport blank samples.

Operational monitoring of groundwater bodies is carried out in order to assess the chemical status of groundwater bodies considered at risk of failure to meet their environmental objectives and to identify significant and sustained trends in increasing concentrations of pollutants caused by anthropogenic impacts (Journal of Laws of 2021, item 1576). Pursuant to the guidelines of the Regulation, operational monitoring was performed twice a year, except for the year in which diagnostic monitoring was carried out.

In 2021, 380 points of the groundwater chemical status monitoring network were tested in operational monitoring, both in the spring and autumn series. In the spring series, organic indicators were determined in 106 samples. The quality control consisted of collecting and analysing the results of 25 duplicate samples, 16 field blank samples and 16 transport blank samples - in the spring series, and 25 duplicate samples, 15 field blank samples and 15 transport blank samples - in the fall series. The points designated for testing were located in 44 water bodies of groundwater (divided into 172 GWBs). The operational monitoring covered 39 GWBs considered to be at risk of failing to achieve the environmental objectives in the Groundwater Monitoring Program for 2016-2021 (Kazimierski et al., 2015), based on the list prepared for the update of water management plans for 2016-2021 and developed on the basis of the assessment of the condition of UGB, performed with the use of data from 2012 and on the basis of extended characteristics of groundwater bodies divided into 172 units. In addition, 5 GWBs were sampled, the status of which, on the basis of the evaluation carried out in 2020, according to the data from 2019, was defined as poor (Rojek et al., 2021b). In the new planning cycle for 2022-2027, the division into 174 GWBs will apply.

The Ordinance of the Minister of Infrastructure of 13 July 2021 *on the forms and methods of monitoring surface water bodies and groundwater bodies* (Journal of Laws 2021 item 1576) in Annex No. 7 defines the scope of physical and chemical parameters that may be included in the monitoring of the chemical status of groundwater. It lists the elements with mandatory testing: general (specific electrolytic conductivity at 20°C, pH, total organic carbon (TOC), temperature and dissolved oxygen) and inorganic elements (ammonium ion, antimony, arsenic, nitrates, nitrites, boron, chlorides, chromium, free cyanides, fluorides, phosphates, aluminium, cadmium, magnesium, manganese, copper, nickel, lead, potassium, mercury, selenium, sulphates, sodium, silver, calcium, bicarbonates, iron). Moreover, 10 inorganic elements (bar, beryllium, tin, zinc, cobalt, molybdenum, thallium, titanium, uranium, vanadium) and 13 organic parameters were indicated as non-obligatory parameters. Until 2022, the scope of indicators examined during operational monitoring is the same as during diagnostic monitoring and covers all the above-mentioned inorganic elements, while for selected monitoring points, organic compounds, such as: pesticides, trichlorethylene, tetrachloroethene, phenol index, polycyclic aromatic hydrocarbons - PAHs and volatile aromatic hydrocarbons - BTX. In the following years, in operational monitoring, apart from general elements and parameters necessary for calculating the ion balance, which is the basis for assessing the quality of the analyses performed, it is proposed to perform tests in the scope of indicators indicative for individual types of pressure.

4.3. Groundwater monitoring in the border areas of Poland (scope, form and frequency of measurements and tests)

Groundwater monitoring observations in individual border zones of Poland are carried out in a varied scope as part of the implementation of the dedicated task 5 of the State Hydrogeological Survey (SHS) entitled: "Monitoring of groundwater in the border zones of the Republic of Poland for the purposes of implementing contracts and international cooperation". Theme 5 is a continuous task and is carried out annually in accordance with the scope specified in the project information sheet for a given year, entitled: "Tasks of the State Hydrogeological Service".

Groundwater measurements and monitoring studies are carried out in Poland's border zones with neighbouring countries, and in selected border regions, surface waters are additionally monitored. Works related to increasing the number of groundwater research monitoring points in selected regions of the Polish border zone are also continued. New observation points for research monitoring are located in regions where it is not planned to include new points of the National Observation and Research Network (NORN) in the observation. The discussed works are aimed at creating a coherent groundwater monitoring system together with the already existing points of the national groundwater monitoring network of the state hydrogeological survey (quantitative monitoring network and national chemical monitoring of the Chief Inspectorate of Environmental Protection: diagnostic and operational), which will allow for a comprehensive assessment of the chemical and quantitative status of groundwaters in individual border zones of Poland. The scope and frequency of measurements and monitoring studies should be adapted to the specificity and individual needs of selected areas, in a way that allows tracking changes caused by both human activity and natural origin, and the assessment of identified or potential cross-border impacts.

The State Hydrogeological Service (SHS) participates in international and interstate cooperation, which is the implementation of the state's policy in the field of management and protection of groundwater. Some of the activities of PHS are related to the direct implementation of tasks coordinated by the Minister of Infrastructure, the Minister of Climate and Environment, the Polish Water Holding and the Chief Inspectorate of Environmental Protection.

Cooperation between Poland and Ukraine in the field of water protection is implemented at the national level on the basis of the provisions of the Agreement of October 10, 1996 concluded between the Government of the Republic of Poland and the Government of Ukraine *on cooperation in the field of water management in border waters*. The agreement entered into force on January 6, 1999. In order to implement activities related to water management and their protection, the Polish-Ukrainian Commission for Border Waters was established, within the structure of which Working Groups were appointed, inter alia for the Protection of Border Waters against Pollution.

Currently, there are differences in the water monitoring systems used in Poland and Ukraine, also in relation to the monitoring of groundwater. The development of international cooperation should assume the setting of common priorities for the monitoring of the cross-border area.

Measurements and monitoring of groundwater in the border zone between Poland and Ukraine as part of the national monitoring of groundwater quantitative status of PGI-NRI are carried out at 14 points of the observation and research network: II / 337/1, II / 514/1, II / 551/1 , II / 594/1, II / 598/1, II / 599/1, II / 842/1, II / 1077/1, II / 1078/1, II / 1079/1, II / 1080/1, II / 1520/1, II / 1672/1 and II / 1673/1. Manual measurements of the groundwater table level at the observation points in question are performed with the frequency of 1 measurement a week, every Monday at 6.00 UTC time. Measurements are carried out by field observers with a hydrogeological whistle installed on a graduated tape measure. In some points of the national network, automatic recorders of groundwater level measurements have been installed or planned to be installed, with the transmission of measurement data to the server memory located at the Polish Geological Institute - National Research Institute.

Most of the points of the national quantitative status monitoring network were carried out before the commencement of works for the task of the state hydrogeological service entitled: "Monitoring of groundwater in the border zones of the Republic of Poland for the purposes of the implementation of contracts and international cooperation" or they were performed in the border groundwater bodies of uniform GWBs taking into account the implementation of another purpose. Due to the lack of representativeness of the locations of the observation points in question in the cross-border context, in most cases the results of measurements and monitoring studies carried out there are not useful for the analysis of the border area. In connection with the above, a decision was made to develop monitoring observations as part of investigative monitoring of groundwater in the border zone between Poland and Ukraine. Especially for this purpose, four piezometers for investigative monitoring of the border zone were designed and then included in the research: No. 401001, 401002, 401003 and 401005. In 2021, the observation borehole No. 401006 was also included in the groundwater research monitoring network, in which groundwater observations are carried out in the aquifer of the Cretaceous layer. As a rule, the newly incorporated investigative monitoring observation points perform functions both in terms of measuring the level of the groundwater table and conducting physicochemical measurements of water. All investigative monitoring observation boreholes, located in border zones, must have profile and structure documentation.

Due to the nature of land development in the areas of investigative monitoring points in the border area between Poland and Ukraine, it is particularly important to carry out research on water chemistry. Duplicate samples, field blank samples and transport blank samples are collected at selected observation points. All the work related to testing as part of the implementation of Theme 5 of SHS is carried out in accordance with the requirements of accreditation for sampling and analysis of physicochemical indicators and quality control, implemented at the Polish Geological Institute - National Research Institute.

In selected observation boreholes of investigative monitoring, located in the border zones of Poland, monitoring measurements of the depth to the groundwater table are performed with the use of automatic recorders. Due to the usually poor coverage of the mobile network in border areas, automatic sensors have been used, the results of which are read in the field into the memory of a laptop computer. The results of measurements of the level of the water table are constantly subjected to compensation which takes into account the influence of atmospheric pressure.

Additionally, two observation points no. 401P01 and 401P02, located on the rivers Smolinka and Lubaczówka, were included in the monitoring of surface waters in the border zone between Poland and Ukraine. All investigative monitoring observation points are located in the Polish border zone, not far from the state border.

4.3.1. Collecting, verifying and archiving the results of cross-border research

The results of research carried out at the PGI-NRI groundwater monitoring observation points located in border areas are collected, verified and archived in accordance with the procedures applicable to the PGI-NRI groundwater observation and investigative network points.

Manual measurements at observation points for investigative monitoring of groundwater located in the border zones of Poland (depth of the groundwater table, source efficiency or measurement result read from the manometer) are carried out once a month or once a week. Weekly measurements are taken on Mondays at 06:00 UTC. Measurement data is recorded in the log of hydrogeological observations, and after the end of the month, it is transferred to the observation point coordinator. The coordinator enters the received data in the SHS measurements application and transmits it in digital form to the administrator of the Groundwater Monitoring database (GMD).

Measurements performed with the use of automatic recorders of the depth to the groundwater table are performed once a day, at 06:00 UTC. Measurement data are read from automatic recorders on a quarterly basis (in the hydrological year system), then converted - converted to the depth value of the groundwater table, calculated from the ground surface [m] and then transferred in digital form to the GMD administrator.

At least twice a year, at the observation points of investigative monitoring of groundwater located in border areas, control measurements of the depth of the groundwater table or the efficiency of sources are carried out by the coordinators of the points, in order to verify the correctness of hydrogeological observations by field observers and to verify the correct operation of automatic recorders depth of the groundwater table. The results of manual control measurements are saved in the hydrogeological observation logs or coded directly in the SHS measurements application, and then they are transmitted on an ongoing basis to the GMD administrator.

Verification of the correctness of manual measurements performed at the observation points of the PGI-NRI investigative monitoring network is performed by the coordinator of a given point. The coordinator performs an initial control of the measurement data recorded in the hydrogeological observation logs for irregularities, and then during the recording of the observation results from the logs to the SHS measurements application, based on the analysis of control charts of changes in the level of the groundwater table or the efficiency of sources. Verification of the correctness of the results of automatic measurements read from the measuring device takes place in the field - after converting the measurement data, the coordinator checks their correctness by comparing their results with the simultaneous result of manual measurement. At this stage, the completeness of the data is checked, their chronological compliance and the so-called gross errors.

The next stage of verifying the correctness of the measurement data takes place after importing the data to the digital GMD. The team of GMD administrators, using the SHS Platform software, conducts a monthly comparative analysis of charts for observation sequences obtained from the measurement data: manual, automatic and control. During the implementation of the discussed stage, measurement inconsistencies are detected, e.g. between the results of manual measurements and control measurements, the results of automatic measurements and control measurements, etc. The identified discrepancies are consulted, diagnosed and explained with the participation of the coordinators of individual groundwater observation points of the PGI-NRI.

Measurement data obtained from groundwater monitoring observation points of the PGI-NRI are archived in an analogue form in the form of hydrogeological observation logs in the handy archives of monitoring point coordinators, while digital versions of measurement results - in the form of copies of hydrogeological observation logs are stored in a digital archive located on the PGI-NRI server. In addition, all measurement data from groundwater research monitoring observation points located in the border areas of Poland are also archived on the same server. The results of the discussed measurements are delivered to the coordinators and the GMD administrator directly in digital form - e.g. measurement data obtained from automatic recorders of the depth of occurrence of the groundwater table.

The results of observations coded in the application of SHS measurements are archived in the form of *.xml cache files.

The Groundwater Monitoring Database, which is located on the PGI-NRI server, is supplied by the administrator once a month. The database stores data on groundwater monitoring points, results of manual measurements, automatic measurements, control measurements, as well as annotations about missing measurement results and their reasons, as well as information on possible unreliability of measurement results.

4.3.2. Sharing and presenting the results of measurements and monitoring of groundwater in border areas

The results of groundwater measurements and monitoring performed at the observation points of the investigative monitoring network, located in the border areas of Poland, are collected in the database of the Groundwater Monitoring Database in PGI-NRI. They are made available directly to applicants in the form of raw (unprocessed) data via the National Geological Archive of PGI-NRI, based on the legal regulations contained in the Water Law Act of 20 July 2017 (Journal of Laws 2021, item 624). The works in question are carried out as part of SHS activities. The scope of the shared data includes information about observation points (identification and location data, basic data on, among others, the functioning of the point, the captured aquifer, etc.), the results of observation of the level of the groundwater table (results of manual measurements, automatic measurements, measurements of the efficiency of sources) and the results of determination of the chemical composition of groundwater.

Data on monitoring points are made available on the basis of free access via map websites:

- SHS Data Processing System (SHS DPS), enabling searching and browsing data of the Central Bank of Hydrogeological Data (CHDB), collection databases and GWMD. Access to the website is possible via the website at: http://spd.pgi.gov.pl/PSHv8/Psh.html,
- e-PSH map viewer that allows you to view spatial data contained in hydrogeological databases: Hydrogeological Map of Poland - Main Useful Aquifer (HMoP-MUA), Main Groundwater Reservoirs (MGR), Uniform Groundwater Bodies (UGB), Central Hydrogeological Database (CHD), Groundwater Monitoring Database (GMD), Intakes, Mineral Waters, MWP, INTAKE, Mineral waters, Available resources, Areas at risk of flooding. The website is available at the internet address: http://epsh.pgi.gov.pl/epsh/

Starting from April 2022, in accordance with the provisions of the Act of August 11, 2021 on open data and the re-use of public sector information (Journal of Laws of 2021, item 1641), information on groundwater monitoring points along with the results of observations of the level of the groundwater table, carried out in points of the groundwater observation and investigative network (GOIN) PGI-NRI, including observation points for investigative monitoring of groundwater located in border areas are available through the map websites of the Polish Geological Institute - National Research Institute:

- GEOLOGIA – a website that provides access to detailed information collected in the multi-domain CGD. It is located at: https://geologia.pgi.gov.pl/
- GeoLog – application for public sharing information from the CGD. The website is available at: https://geolog.pgi.gov.pl/.

The results of groundwater monitoring tests carried out at selected observation points located in the border areas of Poland have been presented since 2019 in a statistically processed form in the SHS` Quarterly Information Bulletins of Groundwater and in the SHS` Hydrogeological Annals. The above-mentioned publications are available in digital form (in the form of PDF files) on the PGI-NRI website at: https://www.pgi.gov.pl/psh/materialy-informacyjne-psh.html

The results of monitoring carried out at the observation points of the Polish Geological Institute - National Research Institute are periodically published in the studies of the SHS issued as part of the tasks of the SHS, specified in the Water Law Act of July 20, 2017 (Journal of Laws of 2017, item 1566): *Groundwater Quarterly Information Bulletins of the State Hydrogeological Survey* and in the *Hydrogeological Yearbook of the State Hydrogeological Survey*. Based on the *Regulation of the Minister of Maritime Economy and Inland Navigation of June 28, 2019 on warnings, forecasts, communications, bulletins and annuals of the state hydrological and meteorological service and the state hydrogeological survey* (Journal of Laws 2019, item 1215) both publications are being developed and issued in digital version in PDF format.

Quarterly Bulletins (Figure 35) are prepared for individual quarters of a given hydrological year, while the Hydrogeological Yearbook (Figure 36) includes a summary of the results of observations and monitoring studies along with their analysis for the entire hydrological year.

The Bulletins contain information about the observation and investigative groundwater network, investigative monitoring network of border areas and the methodology of interpreting the results of groundwater table level surveys, a summary of information on research points of the quantitative state monitoring network and research monitoring, located in the border zones of Poland, and tables with the results of calculations in the hydrological quarter system: monthly and quarterly levels of groundwater, deviation of the average monthly and quarterly levels from the monthly and quarterly averages for the period 1991-2015, monthly and quarterly spring yields, deviations of monthly and quarterly averages of the spring yields from the monthly and quarterly mean yields for the multiannual period 1991-2015.

The yearbook contains information on the groundwater observation and research network, investigative monitoring network of border areas and the methodology of interpreting the results of groundwater level measurements, a summary of information on research points of the quantitative status monitoring network and investigative monitoring, and tables with the results of the calculations in the hydrological year system: minimal, average and maximum groundwater levels and source yields (monthly, quarterly, semi-annual, annual), deviations of average groundwater levels and source yields from the corresponding levels and yields for the period 1991-2015 (monthly, quarterly, half-yearly, annual), selected parameters in years 1991-2015 and the change in the average and average productivity status compared to the previous year, indicators of changes in groundwater retention (monthly, quarterly, semi-annual, annual), ground drought risk indicators (monthly).

In addition, the Yearbook contains the results of chemical analyses of water samples taken at quantitative, chemical and research monitoring points, analysis of the results of calculations in hydrogeological regions, an assessment of the current hydrogeological situation (characteristics of the variability of the groundwater table, chemical composition and quality of groundwater).

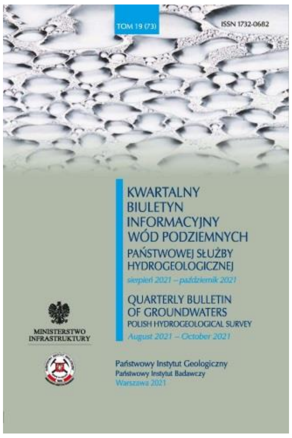


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Figure 35. The Groundwater Quarterly Information Bulletin of the State Hydrogeological Survey, Volume 20 (74)

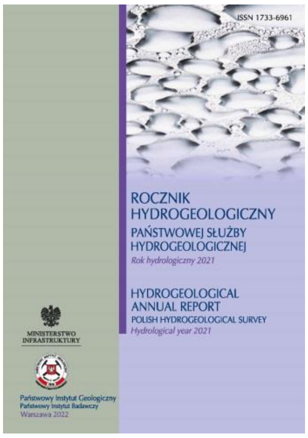

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Figure 36. Hydrogeological Yearbook of the State Hydrogeological Survey - hydrological year 2021

As a supplement to the publications, maps showing the location of observation points against the background of UGB, MUA, hydrogeological regions and water regions were developed.

Transmission, archiving, processing and sharing of the results of cross-border monitoring studies should be obligatorily subject to the guidelines and limitations resulting from the requirements of the data sharing policy in force at the Polish Geological Institute - National Research Institute - in the case of data from Poland and competent institutions responsible for groundwater monitoring and sharing data in this regard from Ukraine.

The results of cross-border research, after obtaining the necessary formal decisions and permits, can be published on an ongoing basis in a mutually agreed form, e.g. on the website of the EU-WATERRES project, while access to a particular scope of data and results may be different for project team and other users, as a result of granting appropriate access rights.

4.4. Recommendations for prospective areas in terms of the location of new groundwater investigative monitoring points in the border area between Poland and Ukraine

Based on the results of validation of prospective regions in terms of the location of observation points for groundwater investigative monitoring, carried out at an earlier stage of the EU-WATERRES project study, in the aspect of Polish-Ukrainian cross-border cooperation, as well as taking into account the field criteria (including the possibility of access to the observation point, the nature of land development, etc.) affecting the performance and further functioning of the newly included monitoring points, as a result of the selection, a total of nine areas were designated, in which the location of investigative groundwater monitoring points in the border zone between Poland and Ukraine is recommended (Figure 37). The newly incorporated monitoring points will also be able to act as points of the Polish-Ukrainian network of transboundary groundwater monitoring.

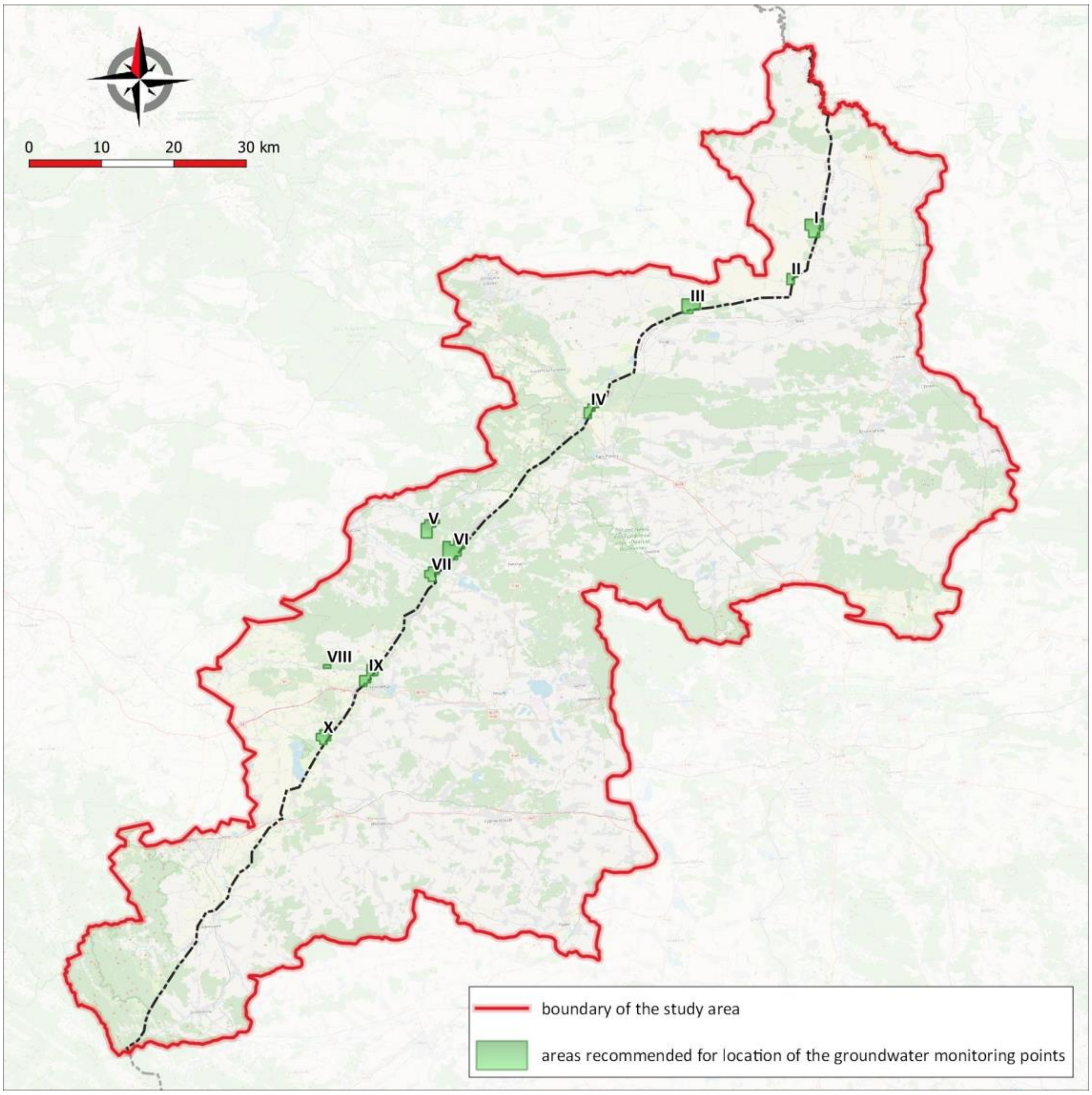

Figure 37. Perspective areas in terms of the location of new investigative groundwater monitoring points in the area on the border between Poland and Ukraine

Area I (Figure 38) - located in the immediate vicinity of the Polish-Ukrainian border, in the northern part of the border zone covered by the study, in the Dołhobyczów commune (Hrubieszów county). The area under consideration covers approximately 5.25 km^2 and is located approximately 1.5 km east of the villages of Hulcze and Chochłów, in the geographical mesoregion of Grzęda Sokalska. Within a strip of less than 0.5 km along the border, the area is covered with forest, while the rest of it is covered by arable fields and meadows. The flow of groundwater in the Upper Cretaceous Main Usable Aquifer from Ukraine towards Poland. The considered area I is located in the eastern part of the groundwater body no. 121 (UGB, numbering according to UGB 174), in its central part and in the south-eastern part of the MUA no. 407 - Lubelski Basin (Chełm-Zamość). The closest towns on the Ukrainian side of the border are Waręż (ukr. Варяж) - located about 1.5 km north-east of Area I and Rusin (ukr. Русин), located approx. 2.0 km south of the selected area, in the Lviv Oblast, in the Sokal region.

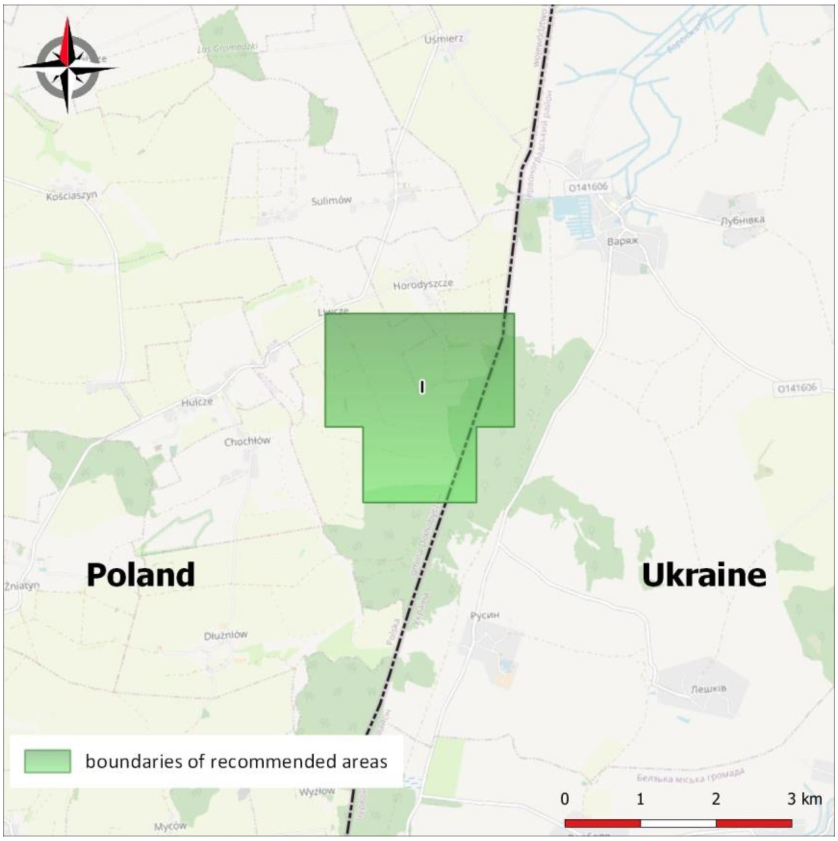

Figure 38. Location of area I

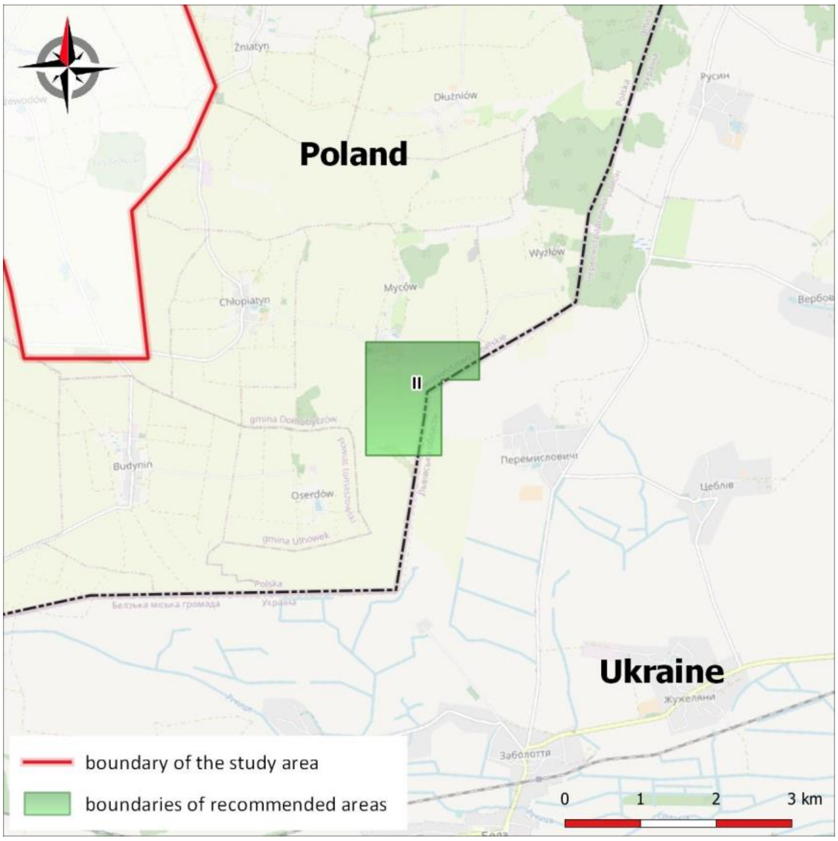

Figure 39. Location of the area II

Area II (Figure 39) – located at the Polish-Ukrainian border, approximately 5.7 km south-west of the area I described above, in the southern part of the Dołhobyczów commune (Hrubieszowski County). The area covers 1.75 km^2, it is located south of the town of Myców, in the immediate vicinity of this town, in the geographical mesoregion of Grzęda Sokalska. Area II is dominated by arable fields and meadows. The nameless right-bank tributary of the Warężanka River flows near the town of Myców. Groundwater flow in the Upper Cretaceous Main Usable Aquifer is from Poland to Ukraine. Area II is located in the southern part of UGB No. 121, as well as in the southern part of MUA No. 407 - Lubelski Basin (Chełm-Zamość). The nearest town on the borderland of Ukraine is Przemysłów (Ukrainian: Перемисловичі), located in the Sokal region, in the Lviv Oblast, approximately 1.0 km south-east of the boundaries of Area II. In the selected area, in the town of Myców, there is already an investigative monitoring point number 401006.

Figure 40. Location of the area III

Area III (Figure 40) – located on the Polish-Ukrainian border, approximately 13.0 km south-west of the area II described above, in the Ulhówek commune (Tomaszów County). This area covers about 4.5 km^2, it is located about 300 m south of the town of Tarnoszyn, in the geographical mesoregion Bełska Plain. In area III, they dominate mainly as arable fields and meadows, while in the north-eastern corner of the area there is a forest. In the area of Tarnoszyn, the left-bank tributaries of the Bug, the Szyszła and Rzeczyca rivers, both run from west to east. In the north-eastern part of area III there is the western part of the Special Protection Area of the Natura 2000 network "Tarnoszyn". Groundwater flow in the Upper Cretaceous MUA takes place from Ukraine to Poland. Area III is located in the southern part of UGB No. 121, as well as in the southern part of MUA No. 407 - Lubelski Basin (Chełm-Zamość). The nearest town on the borderland of Ukraine is Korczów (ukr. Корчів), located in the Sokal region, in the Lviv Oblast, approximately 1.0 km south-east of the border of Area III. A railway line runs along the Polish-Ukrainian border, approx. 900 m from the border, on the Ukrainian side.

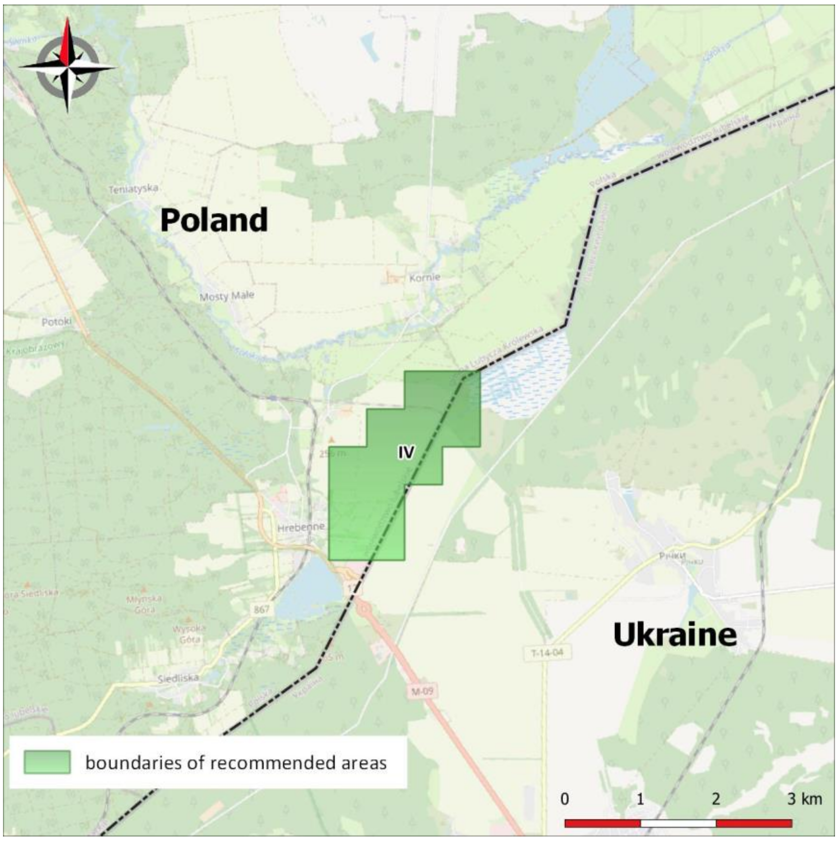

Figure 41. Location of the area IV

Area IV (Figure 41) – located directly at the Polish-Ukrainian border, approximately 16.5 km south-west of Area III, in the southern part of the Lubycza Królewska commune (Tomaszów County). The area covers approximately 3.0 km^2. It is located near the town of Hrebenne, to the northeast of the town limits, in the geographical mesoregion Bełska Plain. Area IV is dominated by arable fields and meadows, to the north of the area there are intensely drained areas on the southern side of the Sołokija River (left-bank tributary of the Bug). About 0.5 km to the south-west of Area IV, in the immediate vicinity of the border crossing in Hrebenne, there is a water reservoir with an area of approximately 0.5 km^2. The entire area IV is located within the Special Protection Areas of the Natura 2000 network "Roztocze" and "Sołokija Valley". About 1.5 km to the south-west of the selected area, there is the South Roztocze Landscape Park. The flow of groundwater in the Upper Cretaceous MUA takes place from Ukraine towards the territory of Poland. Area IV is located in the southern part of UGB No. 121 and in the southern part of MUA No. 407 - Lubelski Basin (Chełm-Zamość). The nearest town on the Ukrainian side is Rzyczki (ukr. Річки) in the Żółkiew region, Lviv Oblast, located about 1.7 km south-east of the borders of Area IV. To the north-east of the selected area, on the Ukrainian side, there are wetlands, from which the waters are discharged through the drainage system to the north, to the Sołokija River.

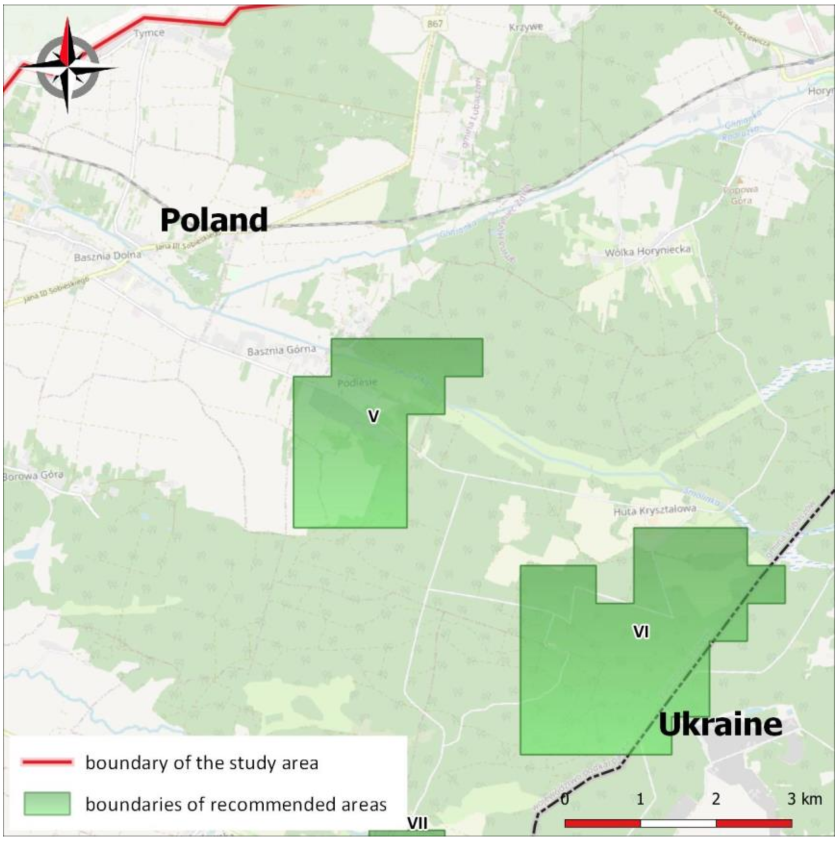

Figure 42. Location of the area V

Area V (Figure 42)– located approximately 4.5 km from the Polish-Ukrainian border, approximately 23.3 km south-west of Area IV, on the border of Lubaczów and Horyniec Zdrój communes in Lubaczów County, in the geographical mesoregion of Tarnogród Plateau. The area covers about 4.25 km^2. It is located between the villages of Podlesie and Wólka Horyniecka, about 2.5 km east of Basznia Dolna. It is situated between the rivers Smolinka (the right-bank tributary of the Lubaczówka) and its tributary - the Glinianka river. Forest areas dominate in area V, and to a lesser extent, meadows and arable fields. Most of the area in question is within the Special Protection Area of the Natura 2000 network "Horyniec". At a distance of about 5.0 km to the north-east of the selected area, there is the South Roztocze Landscape Park. Area V is located in the southern part of UGB no. 136. In the south-west, the area border is adjacent to the mining area of the active sulfur mine Basznia II, in which mining is carried out using the borehole smelting method.

Area VI (Figure 43) - located directly at the Polish-Ukrainian border, approximately 2.0 km south of area V, in the eastern part of the Lubaczów commune (Lubaczów County). The area covers approximately 7.25 km^2. It is located about 1.0 km south of Huta Kryształowa, in the geographical mesoregion Tarnogród Plateau. Area VI is entirely covered by forests belonging to the Lubaczów Forest District. The flow of groundwater in the Quaternary MUA is from Ukraine towards Poland. The area under consideration is located in the southern part of UGB no. 136. About 12.0 km to the north-east of the selected area is the area of the South Roztocze Landscape Park. The nearest towns on the Ukrainian side are Szawary (ukr. Шавapi) in the Jaworowski region, in the Lviv oblast, located about 2.2 km east of the borders of area VI, and Hruszów (ukr. Грушів) in the Jaworowski district, in the Lviv oblast, approximately 2.5 to the south of the selected area. Near the selected area, at a distance of 0.5 km from the state border, on the Ukrainian side there is the site of the inactive Niemirów opencast sulfur mine (Ukrainian: Немирів). In the selected area, in the border zone with Ukraine, there are two investigative monitoring points - number 401001 and 401002.

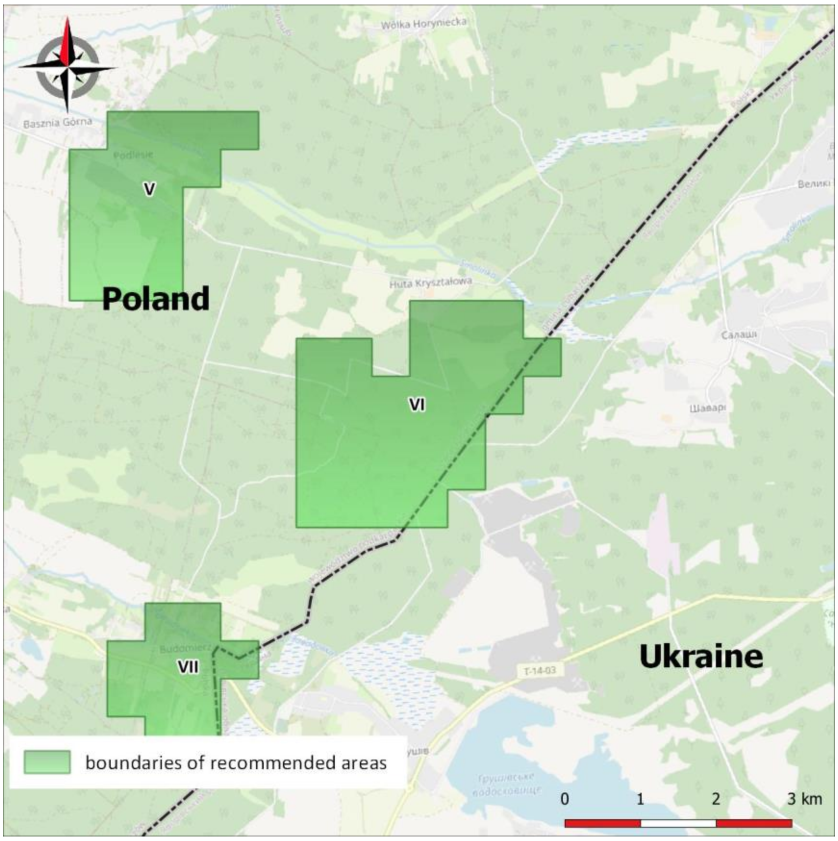

Figure 43. Location of the area VI

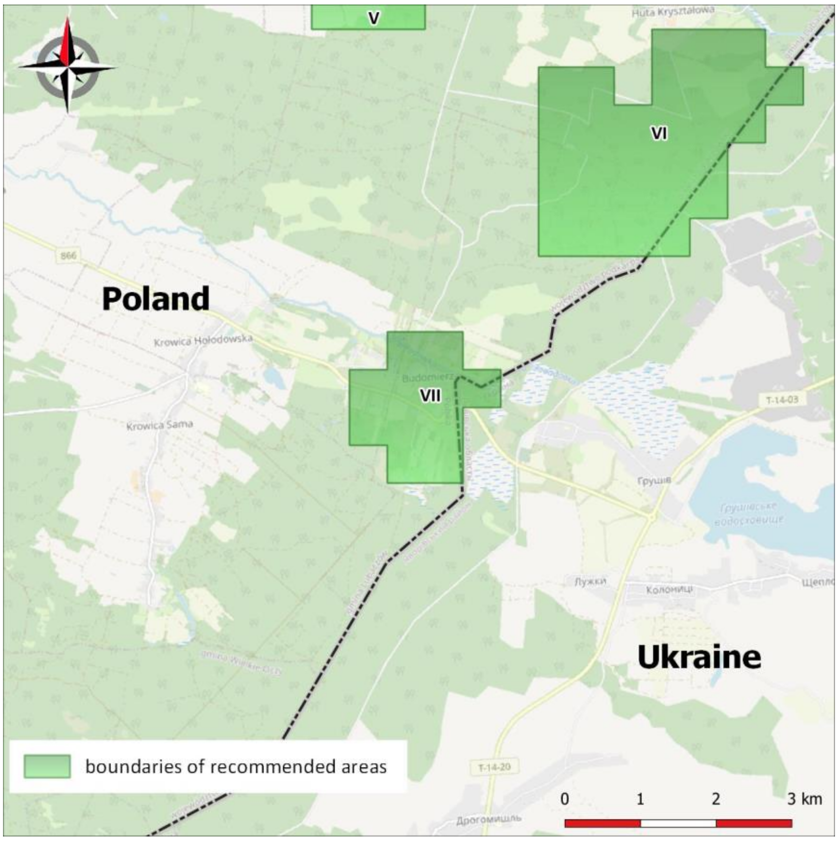

Figure 44. Location of the area VII

Area VII (Figure 44) – located in the immediate vicinity of the Polish-Ukrainian border, approximately 1.7 km south-west of area VI, in the eastern part of the Lubaczów commune (Lubaczów County). The area covers approximately 2.75 km^2. It is located in the vicinity of the village of Budomierz, in the geographical mesoregion Tarnogród Plateau. The area is dominated by rural areas, arable fields and meadows. The Zawadówka River flows through the selected area, carrying surface waters flowing from the territory of Ukraine, from the area of the inactive Niemirów opencast sulfur mine (Ukrainian: Немирів). The flow of groundwater in the Quaternary MUA is from Ukraine towards Poland. This area is located in the southern part of UGB no. 136. The nearest town on the Ukrainian side is Hruszów (ukr. Грушів) in the Jaworowski region, in the Lviv Oblast, about 1.5 km east of the boundaries of the VII area. In the vicinity of the selected area, 5.0 km from the state border, on the Ukrainian side there are the areas of the inactive Niemirów opencast sulfur mine (Ukrainian: Немирів). Surface water from the area of the former mine (Zavadowo reservoir, Ukrainian: Завадово) runs with watercourses on the Polish side to the Lubaczówka River.

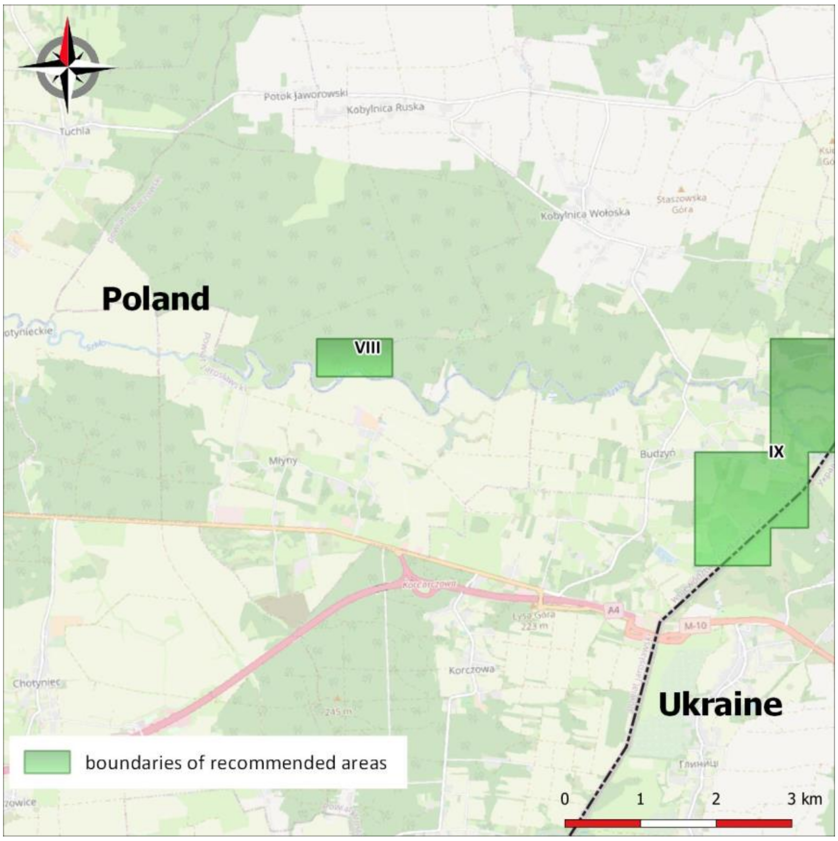

Figure 45. Location of the area VIII

Area VIII (Figure 45) – located approximately 9.5 km from the Polish-Ukrainian border, 28 km south-west of Area VII, in the southern part of the Wielkie Oczy commune (Lubaczów County), in the Tarnogród Plateau geographical mesoregion. The area covers approximately 0.5 km^2. It is located less than 2.0 km north of the town of Młyny. The area under consideration is located in the southern part of UGB No. 136. The area is dominated by forests. The area in question is in the immediate vicinity of the Szkło River valley on its northern side. In the selected area, in the border zone with Ukraine, there is an investigative monitoring point number 401004.

Figure 46. Location of the area IX

Area IX (Figure 46) – located directly at the Polish-Ukrainian border, approximately 21.5 km south-west of area VII, in the eastern part of the border of the Wielkie Oczy commune (Lubaczów County) and the commune of Radymno (Jarosław County), in the geographical mesoregion of Tarnogród Plateau. The area covers about 4.25 km^2. It is located in the vicinity of the village of Budzyń and the hamlet of Czaplaki. In area IX there are rural areas, arable fields and meadows, along the state border and in the southern part of the area - forest areas. The Szkło River flows through the area - the right-bank tributary of the San River, running surface waters flowing from the territory of Ukraine, from the area of the closed sulfur opencast mine in Jaworów (Ukrainian: Яворів). The flow of groundwater in the MUA of the Quaternary floor takes place from Ukraine to Poland. The area in question is located in the southern part of UGB No. 136. The nearest town on the Ukrainian side is Krakowiec (Ukrainian: Краковець), located in the Jaworowski region, in the Lviv Oblast. It is located approximately 1.3 km east of the border of this area. About 20 km east of the state border, on the Ukrainian side, there is a closed sulfur opencast mine in Jaworów (Ukrainian: Яворів). The excavation left after the end of exploitation, with an area of about 1,200 ha, was reclaimed in 2005, and the surface waters from the Jaworowski Reservoir built in its place are led by a system of watercourses to the Szkło River, which flows into Poland in the vicinity of Budzyń and Skolin. In the selected area, there are two investigative monitoring points in the border zone with Ukraine - number 401003 and 401005.

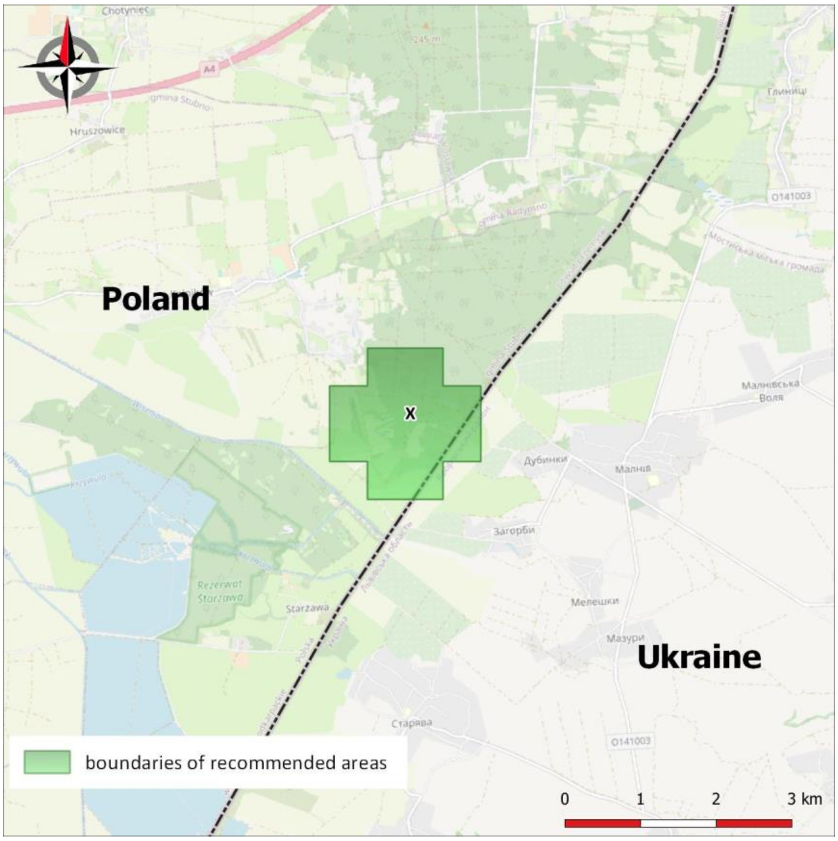

Figure 47. Location of area X

Area X (Figure 47) – extending directly to the Polish-Ukrainian border, located approximately 11.5 km south-west of area IX, in the eastern part of the Stubno commune (Przemyśl County), within the geographical mesoregion Tarnogród Plateau. The area covers approximately 3.0 km^2. It is located near the villages of Zagroble and Kowaliki. This area is dominated by forests, in the western and southern parts, arable fields and meadows are the dominant form of land development. The flow of groundwater in the MUA of the Quaternary level takes place from the border territory of Ukraine towards Poland. The area in question is located in the southern part of UGB No. 136. On its south-west side flows the Vishnia River, which is a right-bank tributary of the San River, running surface waters flowing from the territory of Ukraine. Approximately 1.0 km south-west of the selected area, there is the Starzawa nature reserve. The nearest towns on the border of Ukraine are Dubinki (ukr. Дубинки) in the Moscisk region of the Lviv oblast, located about 1.3 km east of the border of the area in question, and Zahorby (Ukrainian: Загорби) - in the Moscisk region, in the Lviv region, distance approximately 1.0 east of the proposed area.

It should be clearly emphasized that the above-described proposals for potentially prospective areas in terms of the location of new investigative groundwater monitoring points in the border zone between Poland and Ukraine, which may also be useful in the context of the implementation of cross-border monitoring tasks, refer to general criteria and are not final. The designation of areas was the next stage of qualification in the process of selecting representative locations for the construction of new observation points. A more detailed definition of the distribution and boundaries of the areas in which new groundwater observation points should be located should be carried out after providing more detailed information on the individual pressures identified in the Polish-Ukrainian border area. Determining the location of objects that may have a negative impact on groundwater, both in terms of quantity and quality, and their actual or potential impact, will certainly allow for optimization of decisions regarding the target location of individual observation points. In the process of selecting the location for observation points, it is important to take into account also protected areas and groundwater dependent ecosystems, reacting to changes in the aquatic environment.

Regardless of the issues taken into account during the validation of prospective areas as well as when selecting areas recommended for the construction of new monitoring points, an important, and often even decisive factor in the process of determining the location of representative monitoring points is the availability of land on which investigative monitoring observation boreholes are to be made. Based on many years of experience, it should be emphasized that many times the issues of land ownership and the related consent of the owners are a key element in this process.

Nevertheless, priority should be attached to good and effective further international cooperation and mutual exchange of information, e.g. on the identification of the geological structure and hydrogeological conditions, aimed at creating transboundary groundwater monitoring observation courses. In the opinion of the authors, the optimal approach to the undertaken project activities would be the location of new monitoring points allowing the observation of the same aquifers with a transboundary spread, taking into account the locations of already existing, representative hydrogeological research wells ("linking" to the already existing, representatively located groundwater monitoring points) or agreeing on effective solutions in this regard in the form of ongoing international cooperation. The parties should also regularly exchange information on identified or new transboundary pressures on groundwater (including unregistered pollution hotspots, e.g. illegal landfills and spills) and protected areas, with particular emphasis on terrestrial groundwater dependent ecosystems.

The organization of the investigative monitoring network in the Polish border zone and the scope of the recommended groundwater monitoring tests should comply with the applicable provisions of European Union law and Polish law. The national observation and investigative network, due to its nationwide or regional nature and the applied criteria for selecting the location of observation points, does not allow for a reliable and comprehensive study of the processes and threats to groundwater in Poland's border zones, resulting from the economic activity of the neighbouring country. For this reason, there is a clear need to expand the investigative groundwater monitoring network in a manner that is subordinate to the specific needs of this monitoring.

In accordance with the authors' intention, a fully justified approach seems to be to locate monitoring points in corresponding pairs or groups of points, where one of them should be as close as possible to the state border, which would make it possible to be sure that the chemical composition of the water collected from this point for analysis and / or the level of the groundwater table at this point is shaped in the neighbouring country (e.g. in the territory of Ukraine, when the flow is directed towards Poland) and the groundwater included in this point is not subject to pressure after crossing the state border.

4.5. Quality management in groundwater research and monitoring observations

The quality management system for groundwater monitoring in Poland covers works performed by the state hydrogeological survey, the tasks of which have been entrusted to the Polish Geological Institute - National Research Institute (PGI-NRI). It is implemented in accordance with the internationally accepted practices of the management system specified in the PN-EN ISO / IEC 17025 standard. The confirmation of the implementation and functioning of the management system is the accreditation of the PGI-NRI No. AB283 granted to PGI-NRI by the Polish Centre for Accreditation (hereinafter PCA). It covers both, the sampling stage, testing the physical properties of water in the field by the Water Sampling Team (WST) of the PGI-NRI as well as physical and chemical tests carried out at the Chemical Laboratory (ChL) of the PGI-NRI.

Systemic activities related to controlling the quality of results cover two basic areas (Bulska, 2008):

- Quality assurance (QA) is a set of procedures that creates a system that will ensure that the best possible conditions are created and adapted to the type of research being conducted;
- Quality control (QC) is a process in which selected quality indicators are checked with the appropriate frequency and their values are constantly compared with predetermined requirements.

Their aim is to assess the quality of the tests performed, achieve the appropriate level of quality, continuous monitoring of changes, and in the event of any irregularities, it is a signal to implement corrective measures (Dobecki ed., 1998).

Monitoring works covered by the management system are provided with two-stage quality supervision. The first stage includes internal control and the second stage - the external control system. Internal quality control includes the assessment of the results obtained during measurements, in which, in addition to the basic samples, the samples intended for quality control (blank samples, duplicate samples, standards) are also analysed, and the implementation of internal audits. The second stage - external control system - is carried out through annual assessments of the certification body (PCA) and participation in PT / ILC (proficiency tests and interlaboratory comparisons).

The basis for the development of technical specifications as well as methods for monitoring data quality improvement is knowledge of the legal basis for groundwater and internationally accepted management system practices. Both the national regulations on groundwater monitoring and the standards of the Polish Centre for Accreditation define how to proceed to ensure the quality of the results is at the highest level. A simplified diagram showing the different types of documents related to the management system and quality control is shown in Figure 48.

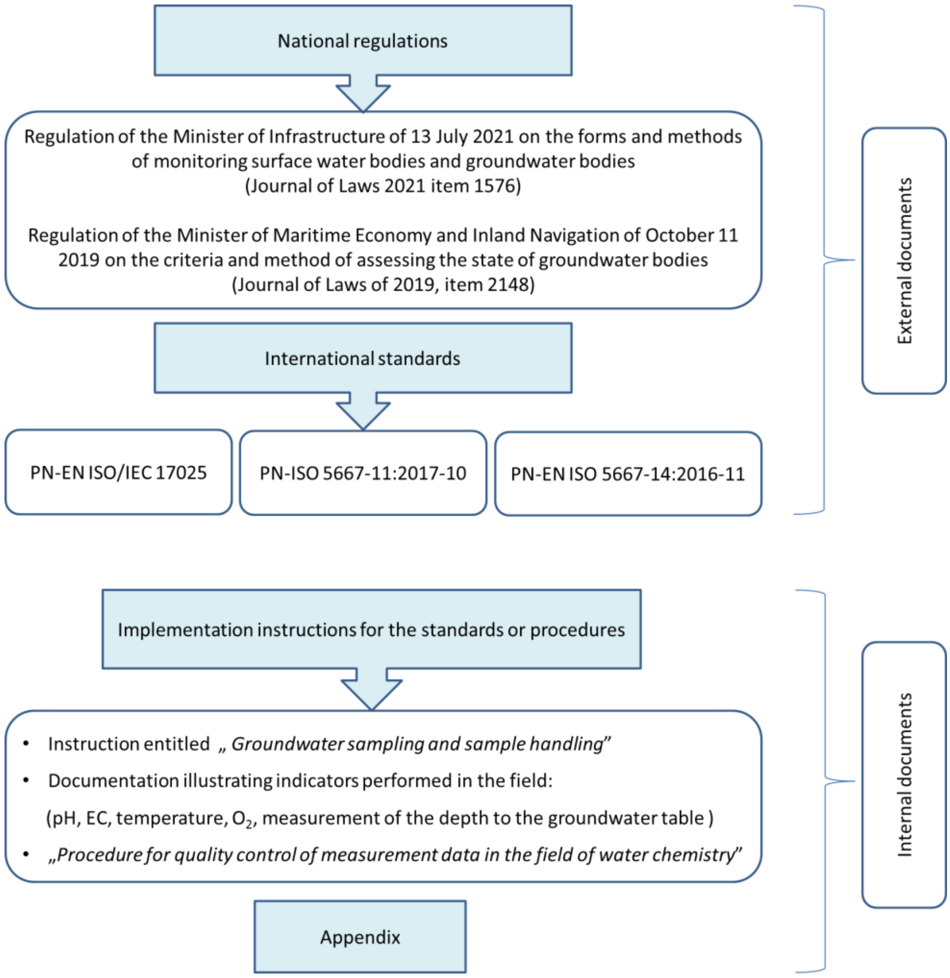

Figure 48. Types of documents related to the management system and data quality control in groundwater monitoring

Pursuant to the Regulation of the Minister of Infrastructure of 13 July 2021 *on the forms and methods of monitoring surface water bodies and groundwater bodies* (Journal of Laws No. 2021 item 1576) the entire groundwater sampling process carried out by PGI-NRI is covered by the quality control system, from sampling, through their preservation, transport, storage and laboratory determinations. A number of requirements necessary for proper sampling as well as obtaining reliable results were included in the test procedures and implementation instructions for the standards, which are constantly updated. One of the internal procedures that determines the supervision over the quality of tests is the "Procedure for quality control of measurement data in the field of water chemistry". Taking care of the quality of measurement results requires both – good organization, the use of appropriate field equipment and the competence of the people collecting the samples. All stages of the research are documented on properly prepared forms, and the statistical analysis of the results of control samples is reported in annual reports (performed separately for diagnostic monitoring and collectively for other monitoring carried out as part of the tasks of the state hydrogeological service) or twice a year for operational monitoring, after the end of the spring and autumn testing series.

The above-mentioned Regulation specifies a number of conditions that must be met in order for the results to be considered valid. They concern the limits of quantification of the tested indicators, determination methods, uncertainty and the method of presenting the results. The limits of determination for all tested physico-chemical indicators should not exceed 30% of the environmental quality standards, understood as the limit values of parameters and indicators for class III groundwater quality, which are threshold values for good chemical status, while the estimated measurement uncertainty should not exceed 50 %. Physico-chemical indicators should be determined with reference methods specified in Annex 8 to the above-mentioned Regulation. Laboratory and field methods should be validated and properly documented, in accordance with the PN-EN ISO / IEC 17025 standard. Estimated levels of confidence, uncertainty and accuracy should be given along with the measurement results.

4.5.1. Requirements for the implementation of field research

The stage of sampling and measurements of physical and chemical parameters in the field is carried out by the "field laboratory for water monitoring" - the Water Sampling Team of the PGI-NRI. There are a number of requirements necessary for the proper sampling process, which are defined, among others, by PN-ISO 5667-11: 2017 standard "Water quality. Sampling Part 11: Guidelines for groundwater sampling”. On the basis of the guidelines of the standard, internal procedures and instructions have been prepared, which are available to all persons participating in the monitoring works at the Polish Geological Institute - National Research Institute. Each stage, from preparation to sampling, selection of the sampling method, taking a representative water sample, description of the handling of the sample through documentation and transfer of the taken samples to the chemical laboratory should be clearly defined and recorded (Figure 49). Knowledge of the applicable sampling rules and continuous improvement are the basis for the correct sampling of groundwater.

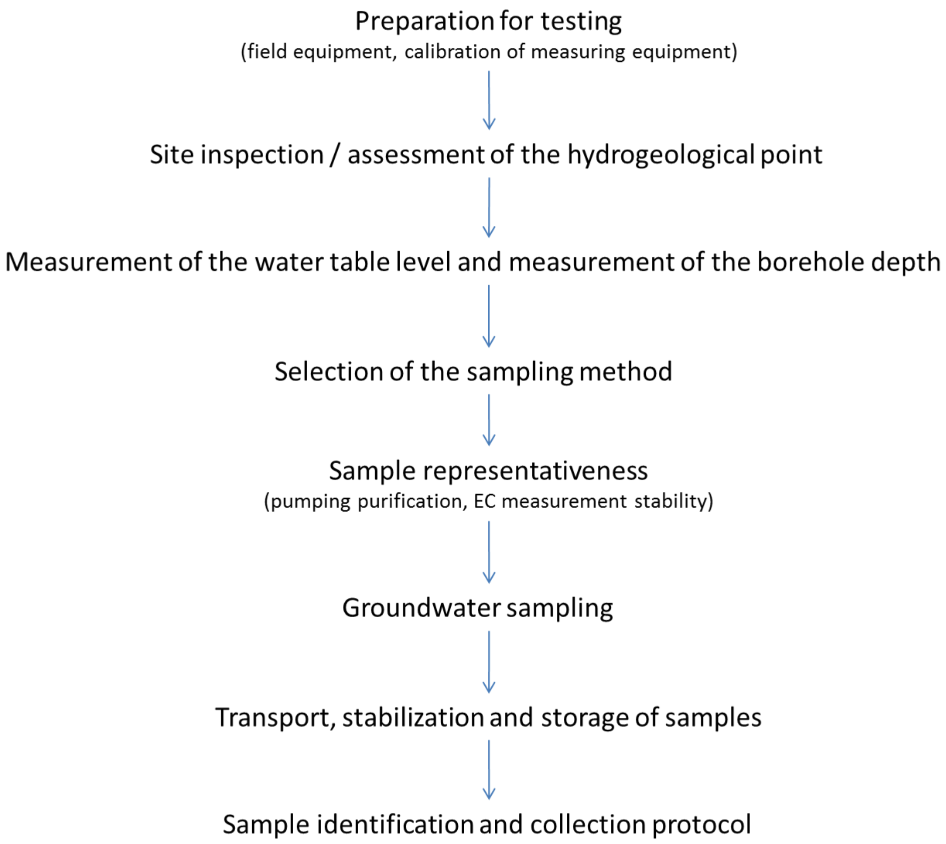

Figure 49. Workflow for the groundwater sampling process

An important field activity is the assessment of the technical condition of the borehole and the assessment of land use near the sampling point. The on-site inspection is aimed at precisely locating the observation point, identifying potential new pollutants and documenting the sampling site, e.g. a well, piezometer or source.

Before starting pumping, the position of the groundwater table in the observation borehole and the depth of the borehole should be measured. Performing the measurement should be preceded by checking the technical condition of the measuring device. Measurements are performed using electric meters with a sound and light signalling device, equipped with a measuring probe installed on a measuring tape with a centimetre scale. A hydrogeological whistle suspended on a graduated tape measure may be used as an auxiliary, with the zero of the set being on the lower edge of the hydrogeological whistle. Measurement of the groundwater table level and the subsequent measurement of the depth of the observation borehole (confirmation of possible backfilling in the borehole, checking the openness of the borehole) should be performed from the measurement point permanently marked on the casing of the observation hole, e.g. on the flange of the borehole or the edge of the hatch. Contact of the measuring probe with the surface of the groundwater table is signalled by both a sound and a light signal (a lamp or a diode installed on the meter cylinder lights up). After signalling, person performing the measurement should raise the measuring probe by a few centimetres above the groundwater table, until the sound and light signal is turned off. The measurement should be repeated by lowering the probe slowly, in such a way that it is possible to precisely determine the measurement result, with an accuracy of 1 cm. The measurement result should be recorded on the appropriate form. When performing cross-border measurements, it is recommended to use properly calibrated electrical meters with a valid calibration certificate.

Due to the measurement of the occurrence of the groundwater table with calibrated measuring devices characterized by a specific measurement uncertainty and cyclical participation in accreditation procedures, twice the maximum uncertainty specified by the calibration laboratory is assumed. Moreover, it is expected that at least 5% of duplicated measurements will be performed during the implementation of individual measurement series.

In the event of damage or faulty operation of the acoustic-light meter, the measurement of the groundwater table level should be performed with a spare hydrogeological whistle suspended on a calibrated measuring tape. The result of the measurement, with a note about its implementation, should be recorded in the appropriate form. When pumping, one should additionally measure the dynamic mirror (determine the maximum depression).

In some of the PGI-NRI groundwater observation points, stationary measurements of the depth to the groundwater table are performed with the use of automatic measurement. In border zones, due to the usually poor coverage of the mobile telephone network, automatic water level recorders are commonly used, from which the measurement results are read into the memory of a portable computer directly in the field. The results of automatic measurements of the groundwater table level are then recalculated (compensated) taking into account the results of automatic measurements of atmospheric pressure. If it is not possible to perform manual control measurements of the depth to the groundwater table, due to the automatic measurement installed in a given borehole, automatic recorders should be removed from the observation borehole for the duration of the measurements in question.

Both the stationary and field laboratories should have an equipment identification system and a developed traceability system by calibrating and checking the measuring equipment. One of the factors determining the obtaining of reliable data from individual monitoring observation points is the field verification of the correct operation of individual measuring devices. All measuring devices undergo regular laboratory calibration. If necessary, they are calibrated in the field with the use of standard solutions: pH and electrolytic conductivity. In the field, it is obligatory to check the measuring device using appropriate reference materials before taking water samples and taking measurements of physical and chemical parameters at the place of sampling.

Depending on the expected values of the measurement results for the real sample, in the checking process, standards in appropriate concentrations are used. The following standards are used in chemical monitoring:

- For pH determinations - standard 6.865;
- For EC determinations - standard 0.147 mS/cm;
- For EC determinations in highly mineralized waters - standard 12.80 mS / cm;
- For oxygen determination - self-test result: the value of the R coefficient should be within the range of 0.50-1.50.

If the measurement results with the use of appropriate standards fall within the given range of values, one can proceed to the next testing stage and select the sampling method appropriate to the sampling site and available equipment. There are several ways to collect a groundwater sample used at groundwater chemical monitoring observation points:

- tap on the pump pipe;
- transportable pump set;
- suction pump;
- Gigant or Gigant & While pump;
- a vessel from a source;
- bucket;
- self-outflow;
- overflow;
- procedure of water sampling from groundwater intakes, with limited contact of people involved in the work.

Each groundwater sampling method is described in detail in the appendices and is available to accredited PGI-NRI employees collecting samples.

When taking a groundwater sample, one should make sure that it is representative. For this purpose, the value of electrolytic conductivity (EC) is monitored on an ongoing basis during purification pumping, consisting in the replacement of a minimum of 3 volumes of water in the observation well (guidelines according to PN-ISO 5667-11: 2017). Continuous EC measurement is performed until steady state readings are obtained (difference between consecutive EC readings <10%) or 6 volumes of water are pumped out. Before taking a groundwater sample, in addition to reading the result of electrolytic conductivity, measurements of other field physico-chemical parameters of water are performed (

Table). Measurements are performed using flow systems.

Table 23. List of physical and chemical parameters determined during monitoring tests performed in the field and analytical methods used by the Water Sampling Team of the PGI-NRI

No.	Water quality indicators	Unit	Analytical method	Methodology
1	Electrolytic conductivity at 20 ° C (in situ measurement during water sampling)	[µS/cm]	Conductometric	PN-EN 27888:1999
2	pH (in situ measurement during water sampling)		Potentiometric	PN-EN ISO 10523:2012
3	Temperature (in situ measurement during water sampling)	[°C]	Thermometry	PN-C-04584:1977 (standard withdrawn)

4	Dissolved oxygen (in situ measurement during water sampling)	[mg/l]	Electrochemical	Research procedure; method not covered by accreditation

When carrying out activities related to taking groundwater samples, the presence of at least two people is recommended: one person should remain on the surface ready to call for help if there are hazardous conditions or if there is any risk for the person conducting the activities related to taking samples in the well casing. The presence of two people at the monitoring point, apart from ensuring safety, allows the sampling to be carried out in accordance with the *"Clean Hands - Dirty Hands"* principle. The "Dirty Hands" person is responsible for preparing the sampling equipment and carries out all activities that are not directly related to sampling (pump preparation, operation, equipment connection, taking notes, cleaning). The "Clean Hands" person is only responsible for taking the samples and transferring them to the containers in which they will be transported, and is the only one to touch the containers (bottles) in which the samples will be stored. This principle allows to limit the impact of pollutants on the collected water samples.

Containers with collected water samples should be clearly and unambiguously labelled. Transport time and stabilization are agreed with the Laboratory that performs chemical analyses. Groundwater sampling documentation is kept by individual samplers on an ongoing basis in the field. Activities performed in the field are recorded in specially prepared standard forms. As part of the monitoring work, the following are completed:

- field documentation of groundwater sampling,
- documentation of checking measuring instruments,
- a sample submission form to the laboratory.

4.5.2. Requirements of the PGI-NRI chemical laboratory

The analyses of the parameters of the physicochemical indicators of groundwater are performed at the Chemical Laboratory of the PGI-NRI in Warsaw. The laboratory sets certain requirements that must be met in order for water samples to be accepted for testing. It determines which containers should be sampled, which fixers should be used for selected parameters, how to transport the collected samples and what time is required to deliver the samples to the laboratory after their collection in the field.

For the purposes of sampling as part of chemical monitoring of groundwater, the Laboratory of the PGI-NRI in Warsaw prepares six containers for determination of inorganic indicators. All bottles are made of polyethylene (PE) and have a capacity from 15 ml to 250 ml, depending on the range of parameters tested. Fixing substances are used to determine the content of cations, mercury and free cyanides. For the determination of organic substances in the Laboratory, three glass containers are used, with a capacity: from 30 ml to 1000 ml. A fixative is included in the phenolic index bottle.

Sets of containers for determination of inorganic physico-chemical elements in groundwater, prepared by the Chemical Laboratory of the PGI-NRI are as follows:

1) PE container with a capacity of 250 ml - for samples for the determination of anions;
2) PE container with a capacity of 250 ml - for samples for pH, EC and bicarbonate determinations;
3) PE container with a capacity of 30 ml - for samples for the determination of cations, containing nitric acid (1 + 4) as a preservative of water samples;
4) PE container with a capacity of 30 ml for mercury samples, containing nitric acid (1 + 4) and a 1% potassium chromate solution as a preservative for water samples;

5) PE container with a capacity of 30 ml - for samples for the determination of free cyanides, containing sodium hydroxide (1.0 mol / l solution) as a preservative of water samples;
6) PE container with a capacity of 15 ml - for samples for the determination of total organic carbon.

Sets of containers for measurements in the field of physico-chemical organic elements prepared by the Chemical Laboratory of the PGI-NRI are as follows:

1) A stained glass container with a PE cap and an aluminium foil washer, 1000 ml capacity for PAH determination;
2) A stained glass container with a PE cap and an aluminium foil washer, 100 ml capacity for samples for the determination of trichlorethylene, tetrachloroethene and BTX as volatile aromatic hydrocarbons;
3) A stained glass container with a capacity of 30 ml for samples for the determination of the phenolic index, containing hydrochloric acid (1 + 1) as a sample preservative.

Due to the change and expansion of the analytical scope of organic compound determinations and the current lack of the possibility to perform them at the PGI-NRI, from 2021 pesticide tests as part of chemical monitoring of groundwater are commissioned to an external laboratory. The substances are selected from the list of substances recommended in 2018 by the Ministry of Agriculture and Rural Development for testing in groundwater. The contract specification defines the conditions necessary to be met by potential subcontractors:

- having the accreditation of the Polish Centre for Accreditation in the field of testing the declared substances,
- performing analyses in accordance with the conditions set out in the Regulation of the Minister of 13 July 2021 *on the forms and methods of monitoring surface water bodies and groundwater bodies* (Journal of Laws 2021 item 1576),
- deadline for carrying out the tests (in line with the deadline for carrying out monitoring tests) and
- the minimum number of substances declared for testing (at least 50).

Sets of containers for the determination of organic indicators, prepared in 2022 by the LABTECH external laboratory include:

- 100 ml plastic container - for pesticide determination;
- 1000 ml plastic container - for pesticide determination;

Water samples are collected in accordance with the guidelines received from the Chemical Laboratory - Form *"Guidelines for the use of sample vessels for tests performed in the Chemical Laboratory"* and from the External Laboratory (Table).

Table 24. Laboratory guidelines on containers for groundwater samples, collection and transport of water samples submitted for analytical tests

Type of test	Bottle capacity	Rinsing the bottle with the tested water sample	Filter the sample through a 0.45 µm syringe filter	Filling the sample container	Water sample transport
Inorganic compounds - PE bottles (guidelines from LCh PGI-NRI)					
anions	250 ml	yes	acceptable	under the plug, no air bubbles	chilled
pH, EC, HCO_3	250 ml	yes	acceptable	under the plug, no air bubbles	chilled

cations	30 ml	no	yes	up to the line marked on the container	chilled
mercury	30 ml	no	yes	up to the line marked on the container	chilled
cyanides	30 ml	no	yes	up to the line marked on the container	chilled, store in the dark
TOC	15 ml	yes	allowed	under the plug, no air bubbles	chilled
Organic compounds - glass bottles (guidelines from LCh PGI-NRI)					
trichloroethene, tetrachloroethene, BTX	100 ml	yes	no	under the plug, without air bubbles, protect the plug with aluminum foil	chilled
PAH	1000 ml	yes	no	under the plug, without air bubbles, protect the plug with aluminum foil	chilled
phenols	30 ml	no	yes	up to the line marked on the container	chilled, store in the dark
Organic Compounds - Plastic Bottles (Guidelines from the External Laboratory)					
pesticides	100 ml	yes	no	to the neck of the	store in the dark
	1000 ml	yes	no	under the plug, screw it off quickly	store in the dark

All samples are stored chilled both in the field (including refrigerators powered by a 12V installation) and during their transport to the Chemical Laboratory of the PGI-NRI in Warsaw (isothermal container with a cooled cartridge).

The transport of all types of groundwater samples for determination of inorganic compounds can be carried out in one thermal container, but the sample bottles for the analysis of cations, mercury and cyanide are additionally packed separately in a bag or plastic container to isolate them from contact with samples collected for containers without used fixers. This is to prevent contamination of the samples. Samples sent for the determination of organic indicators are transported in a separate thermal container, while the sample bottle for phenol analysis should be additionally packed in a bag or container separately, due to the fixative used.

Groundwater samples for inorganic determinations should be submitted to the Chemical Laboratory as soon as possible, not later than 72 hours from their collection. It is assumed that analysis should be performed within 5 days of sampling. However, samples for the determination of organic indicators should be submitted within 48 hours of collection, from Tuesday to Thursday. Each batch of samples submitted to the laboratory is accompanied by a form containing a list of samples with unique numbers assigned by the laboratory and with the numbers of observation points.

In the case of samples taken for pesticide determination, there is no need to chill them, provided that the samples are sent on the day they are taken. These samples should be stored in a shaded place.

The Chemical Laboratory of PGI-NRI has validated measurement methods, according to which the analyzes of individual physico-chemical indicators listed in Table 25 and the determination of organic indicators listed in Table 26 are carried out.

In 2021, the LABTECH s.r.o. laboratory based in Brno (Czech Republic) carried out analyses for 263 pesticide substances, including: 16 organochlorine pesticides, 29 organophosphorus pesticides, 6 triazine pesticides, 14 carbamates, 3 thiocarbamates, 2 pyrazoles, 8 perrythroids, 2 phenoxyacetic acid derivatives and 183 ungrouped pesticides. Liquid and gas chromatography methods were used to test organic compounds (Rojek et al., July 2021a).

Table 25. List of general and inorganic elements, the determinations of which are performed for the purposes of groundwater monitoring tests and analytical methods used at the Chemical Laboratory of the PGI-NRI in Warsaw

No.	Water quality indicator	Unit	Analytical method	Methodology
1	Electrolytic conductivity in 20°C	[μS/cm]	Conductometric	PN-EN 27888:1999
2	pH		Potentiometric	PN-EN ISO 10523:2012
3	Total organic carbon	[mgC/l]	Spectrophotometric	Research procedure
4	Ammonium ion	[mgNH$_4$/l]	Spectrophotometric	Research procedure
5	Antimony	[mgSb/l]	ICP-MS	Research procedure
6	Arsenic	[mgAs/l]	ICP-MS	Research procedure
7	Nitrates	[mgNO$_3$/l]	IC	Research procedure
8	Nitrites	[mgNO$_2$/l]	IC	Research procedure
9	Boron	[mgB/l]	ICP-OES	Research procedure
10	Chlorides	[mgCl/l]	IC	Research procedure
11	Chrome	[mgCr/l]	ICP-OES	Research procedure
12	Cyanides free	[mgCN/l]	CFA with spectrophotometric detection	PN-EN ISO 14403-2:2012
13	Fluorides	[mgF/l]	IC	Research procedure
14	Phosphates	[mgPO$_4$/l]	IC	Research procedure
15	Aluminum	[mgAl/l]	ICP-MS	Research procedure
16	Cadmium	[mgCd/l]	ICP-MS	Research procedure
17	Magnesium	[mgMg/l]	ICP-OES	Research procedure
18	Manganese	[mgMn/l]	ICP-OES	Research procedure
19	Copper	[mgCu/l]	ICP-MS	Research procedure
20	Nickel	[mgNi/l]	ICP-MS	Research procedure
21	Lead	[mgPb/l]	ICP-MS	Research procedure
22	Potassium	[mgK/l]	ICP-OES	Research procedure
23	Mercury	[mgHg/l]	AAS with the amalgamation technique	Research procedure
24	Selenium	[mgSe/l]	ICP-MS	Research procedure
25	Sulfur	[mgSO$_4$/l]	IC	Research procedure
26	Sodium	[mgNa/l]	ICP-OES	Research procedure
27	Silver	[mgAg/l]	ICP-MS	Research procedure
28	Calcium	[mgCa/l]	ICP-OES	Research procedure

No.	Water quality indicator	Unit	Analytical method	Methodology
29	Bicarbonate	[mgHCO$_3$/l]	Potentiometric titration	PN-EN ISO 9963-1:2001+Ap1:2004
30	Iron	[mgFe/l]	ICP-OES	Research procedure
31	Barium	[mgBa/l]	ICP-OES	Research procedure
32	Beryllium	[mgBe/l]	ICP-MS	Research procedure
33	Tin	[mgSnl]	ICP-MS	Research procedure
34	Zinc	[mgZn/l]	ICP-OES	Research procedure
35	Cobalt	[mgCo/l]	ICP-MS	Research procedure
36	Molybdenum	[mgMo/l]	ICP-MS	Research procedure
37	Thallium	[mgTl/l]	ICP-MS	Research procedure
38	Titanium	[mgTi/l]	ICP-OES	Research procedure
39	Uranium	[mgU/l]	ICP-MS	Research procedure
40	Vanadium	[mgV/l]	ICP-MS	Research procedure

Explanations to the table:

Abbreviation of the method		Full name of the analytical method
IC	-	Ion chromatography
AAS	-	Atomic absorption spectrometry
CFA	-	Continuous flow analysis
ICP-MS	-	Inductively coupled plasma – Mass Spectrometry
ICP-OES	-	Inductively coupled plasma – Optical Emission Spectrometry

Table 26. List of organic elements determined during groundwater monitoring tests and analytical methods used at the Chemical Laboratory of the PGI-NRI in Warsaw

No.	Organic water quality indicators	Unit	Abbreviation	Analytical method	Methodology
1	Phenols (phenol index)	[mg/l]		CFA with spectrophotometric detection	PN-EN ISO 14402:2004, point 4
2	Tetrachloroethene	[mg/l]		HS-GC-MS	Research procedure
3	Trichloroethene	[mg/l]		HS-GC-MS	Research procedure
4	Acenaphthylene	[mg/l]	WWA	GC-MS	Research procedure
5	Acenaften	[mg/l]	WWA	GC-MS	Research procedure
6	Fluoren	[mg/l]	WWA	GC-MS	Research procedure
7	Phenanthrene	[mg/l]	WWA	GC-MS	Research procedure
8	Anthracene	[mg/l]	WWA	GC-MS	Research procedure
9	Fluoranthene	[mg/l]	WWA	GC-MS	Research procedure
10	Pyrene	[mg/l]	WWA	GC-MS	Research procedure
11	Benzo [a] anthracene	[mg/l]	WWA	GC-MS	Research procedure
12	Chrysen	[mg/l]	WWA	GC-MS	Research procedure
13	Benzo [b] fluoranthene	[mg/l]	WWA	GC-MS	Research procedure
14	Benzo [k] fluoranthene	[mg/l]	WWA	GC-MS	Research procedure
15	Benzo [e] pyrene	[mg/l]	WWA	GC-MS	Research procedure

No.	Organic water quality indicators	Unit	Abbreviation	Analytical method	Methodology
16	Benzo [a] pyrene	[mg/l]	WWA	GC-MS	Research procedure
17	Perylene	[mg/l]	WWA	GC-MS	Research procedure
18	Indeno [1,2,3-cd] pyrene	[mg/l]	WWA	GC-MS	Research procedure
19	Dibenzo [a, h] anthracene	[mg/l]	WWA	GC-MS	Research procedure
20	Benzo [g, h, i] perylene	[mg/l]	WWA	GC-MS	Research procedure
21	Benzene	[mg/l]	BTX	HS-GC-MS	Research procedure
22	Toluene	[mg/l]	BTX	HS-GC-MS	Research procedure
23	Ethylbenzene	[mg/l]	BTX	HS-GC-MS	Research procedure
24	1,4-dimethylbenzene	[mg/l]	BTX	HS-GC-MS	Research procedure
25	1,3-dimethylbenzene	[mg/l]	BTX	HS-GC-MS	Research procedure
26	1,2-dimethylbenzene	[mg/l]	BTX	HS-GC-MS	Research procedure

Explanations to the table:

Abbreviation of the method		Full name of the analytical method
CFA	-	Continuous flow analysis
GC-MS	-	Gas chromatography with mass spectrophotometry detection
HS-GC-MS	-	Headspace – Gas Chromatography – Mass Spectrometry

4.5.3. Field chemical data quality control program

The application of sampling rules in force in groundwater monitoring should be systematically checked and assessed in terms of effectiveness. For this purpose, quality supervision is used, i.e. systematic supervision over the technical activities carried out, including the control of selected parameters (quality indicators). Systematic evaluation of these parameters allows to ensure that the system works effectively, and possible deviations can be noticed in time, so that it is possible to prevent and take appropriate corrective actions (Bulska, 2008). The field program of quality control of chemical data is one of the tools used as quality supervision and has been in force since 2010 under the chemical monitoring commissioned by the Chief Inspectorate for Environmental Protection. In the task Groundwater monitoring in the border zones of the Republic of Poland, for the purposes of the implementation of contracts and international cooperation, control samples have been collected annually since 2016. In 2021, the quality control also covered other monitoring tasks performed as part of the State Hydrogeological Survey (SHS), maintaining consistency between all surveys (Stojek et al., 2021).

Field quality control program includes collection of control samples that constitute from 10% to 30% of the total population of normal samples collected from the monitoring network during the ongoing measurement campaign (Witczak et al., 2013). The number of control samples collected in 2021 as parts of the SHS monitoring networks and the operational monitoring networks have been given in Table 27 and Table 28 respectively.

Table 27. Number of control samples collected as part of the SHS groundwater monitoring in 2021 (Stojek et al., 2021)

TYPE OF MONITORING	Basic samples for the determination of inorganic physico-chemical indicators	Internal quality control of groundwater						
		DOUBLE ANALYSIS in-situ				DOUBLE SAMPLES	BLANK SAMPLES	
		EC	pH	O_2	Temperature	determination of inorganic physico-chemical indicators	field	transport
Assessment of the technical state	390	23	23	23	23	23	10	10
Transboundary monitoring	38	4	4	4	4	4	3	3
Investigative monitoring	42	4	4	3	4	4	1	1
Sum	470	31	31	30	31	31	14	14
%		7%	7%	6%	7%	7%	3%	3%

Table 28. Number of control samples collected as part of the operational monitoring of groundwater in 2021 (Rojek et al., 2021)

Operational monitoring 2021	Basic samples for the determination of inorganic physico-chemical indicators	Internal quality control of groundwater			
		DOUBLE ANALYSIS in-situ	DOUBLE SAMPLES	BLANK SAMPLES	
			determination of inorganic physico-chemical indicators	field	transport
Number of samples - autumn	380	25	25	15	15
Number of samples - spring	380	25	25	16	16
Sum	760	50	50	31	31
%		7%	7%	4%	4%

Several types of QA/QC samples can be distinguished:

- Double samples
- Field blank samples
- Transport blank samples

Double samples

The groundwater sampling strategy is based on the applied simplified research scheme consisting in a single analysis of basic and duplicate samples (Figure 50), in accordance with the guidelines of the PN-EN ISO 5667-14: 2016-11 E standard entitled “Water Quality, Sampling Part 14 Guidelines for Quality Assurance and Quality Control in Sampling and Handling of Environmental Waters”. Two independent groundwater samples are collected from selected monitoring points: basic and doubled.

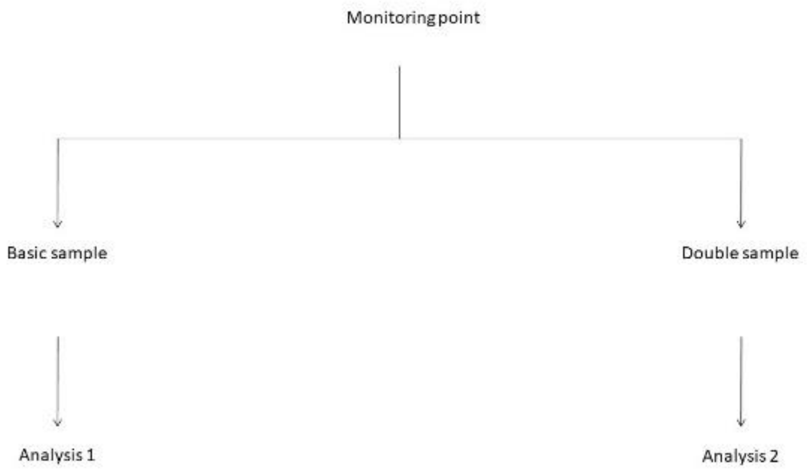

Figure 50. Groundwater sampling scheme for a field quality control and analytical testing program used to evaluate the precision of the results

As part of the field quality control program, six bottles for basic physicochemical determinations and six duplicates (sequential replication) are collected at the measuring point. Containers with water samples, both for primary and duplicate determinations, have their own unique numbers, which are placed by the sampler during the sampling (Figure 51). Containers with samples should be clearly and unambiguously labelled and all details recorded on field forms.

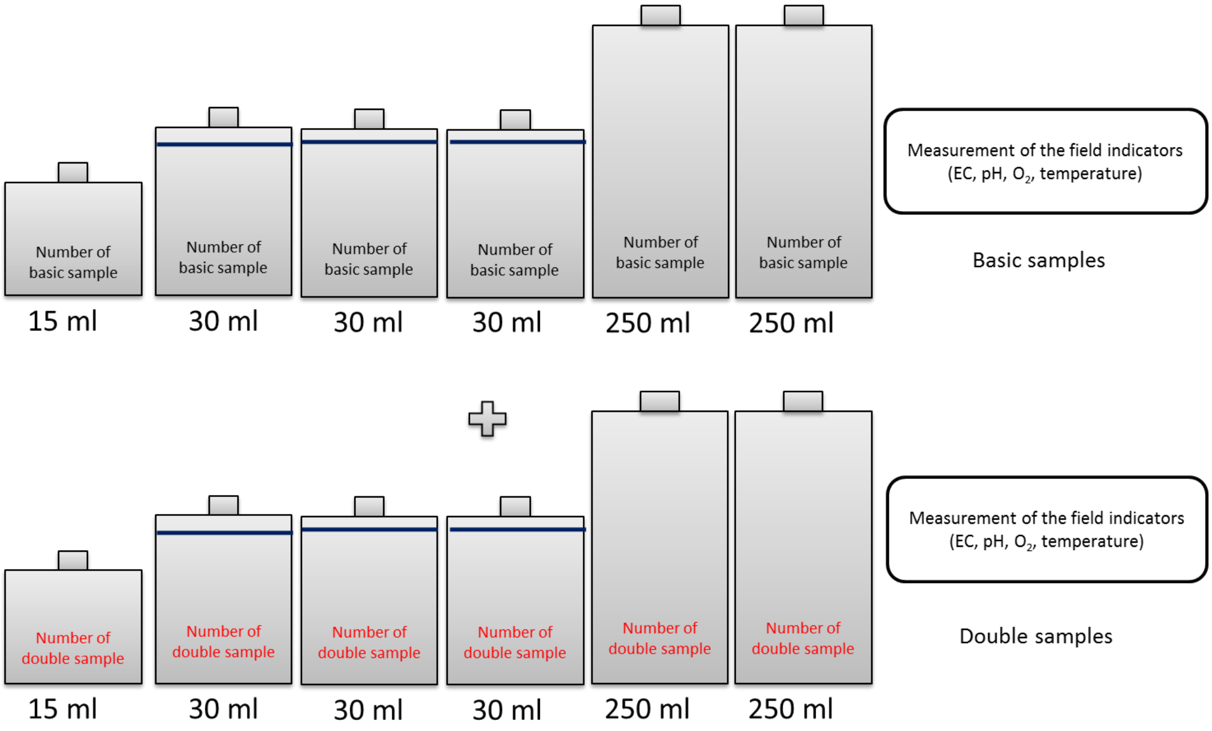

Figure 51. Sets of containers for basic and duplicate samples for determination of physico-chemical indicators

As duplicate controls are taken as duplicates of the primary samples, the entire initial stage of preparation of the point for sampling is also checked. It consists of tracking changes in water quality by constantly monitoring the value of electrolytic conductivity (EC) during purification pumping, consisting of the replacement of a minimum of 3 volumes of water in the borehole (guidelines according to PN-ISO 5667-11: 2017-10) in order to ensure the inflow of "fresh" groundwater directly from the aquifer and the collection of representative groundwater samples.

From the same monitoring point from which the duplicated sample was taken, double field analyses are performed: pH, electrolytic conductivity at 20°C, temperature and dissolved oxygen.

Blank samples

Quality control also includes blank sampling techniques to monitor sources of contamination and the effect of transport on the sampling process. In both cases, deionized water is used as the medium. The following division of blank samples is adopted:

- field - are treated as closely as possible to dealing with real samples. Sterile water is poured from one container to another in the field to mimic sampling activities. The field blank is then transferred to the laboratory with the primary samples and analysed in the same lot. They can be used to identify errors related to sampling, further handling and transport. They determine if the environmental conditions on site have affected the integrity of the sample;
- transport - are treated as "unused". They contain sterile water in a laboratory sample container. They must be ordered in advance from the lab and delivered in the same cool container as your other water sample bottles. This kind of blank sample is never opened, it stays with the remaining water sample bottles. They can be used to identify errors related to transporting samples. They determine if sample bottle preparation, delivery, handling, and / or storage procedures have affected sample integrity.

Physical and chemical analyses of groundwater samples are carried out at the Chemical Laboratory of the PGI-NRI in compliance with the requirements of PN-EN ISO / IEC 17025: 2018-02 in the scope of accreditation No. AB 283. Basic samples and duplicate samples taken in parallel are analysed in the following scope of quality indicators and physical and chemical properties of water: specific electrolytic conductivity at 20°C, pH, total organic carbon, ammonium ion, antimony, arsenic, nitrates, nitrites, boron, chlorides, chromium, free cyanides, fluorides, phosphates, aluminium, cadmium, magnesium, manganese, copper, nickel, lead, potassium, mercury, selenium, sulphates, sodium, silver, calcium, bicarbonates, iron and 10 additional (optional in diagnostic monitoring) indicators: barium, beryllium, tin, zinc, cobalt , molybdenum, thallium, titanium, uranium, vanadium. The analysis of blank samples does not include mercury determinations and, from 2022, the pH value. All the above-mentioned indicators are then subjected to statistical analysis.

4.6. Statistical analysis in the evaluation of the quality of the results of physico-chemical tests

The reliability of hydrogeochemical tests in groundwater monitoring is assessed in two stages. In the first stage, the quantitative assessment is based on the calculated relative errors (according to the PN-89 C-04638/02 standard). It applies to all samples in which physico-chemical analyses were performed. The second stage of the assessment of the reliability of chemical data is the statistical analysis of control samples for both field measurements and indicators analysed in the stationary laboratory. This procedure applies to pairs of primary, duplicate and blank samples.

4.6.1. Assessment of the correctness of the performed chemical analyses

The correctness of the performed chemical analyses of water is assessed by determining the compliance of the sum of cations ($\sum rK$) with the sum of anions ($\sum rA$) expressed in mval / dm^3. The control assumption is that the sum of the equivalents of cations and anions in the water sample should be equal, that is:

$$\sum rK = \sum rA$$

The final assessment consists in calculating the relative error in the analysis balance according to the formula:

$$B = \frac{\left|\sum rK - \sum rA\right|}{\sum rK + \sum rA} \times 100\%$$

where:

B – the size of the error [%];
$\sum rK$ – sum of the cations content [mval/dm^3];
$\sum rA$ – sum of the contents of anions [mval/dm^3].

For the calculation of the ionic water balance, the main and minor components are taken into account: HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, K^+, Na^+, Mg^{2+}, Ca^{2+}, NH_4^+, Fe^{2+} (Witczak et al., 2013). Determination values below the limit of quantification (LOQ) are replaced with a value equal to half the limit of quantification (<LOQ = ½ LOQ). Low values of the calculated error of the analysis confirm the correct performance of the determinations and high reliability of the source data. The results are presented in a histogram (Figure 52).

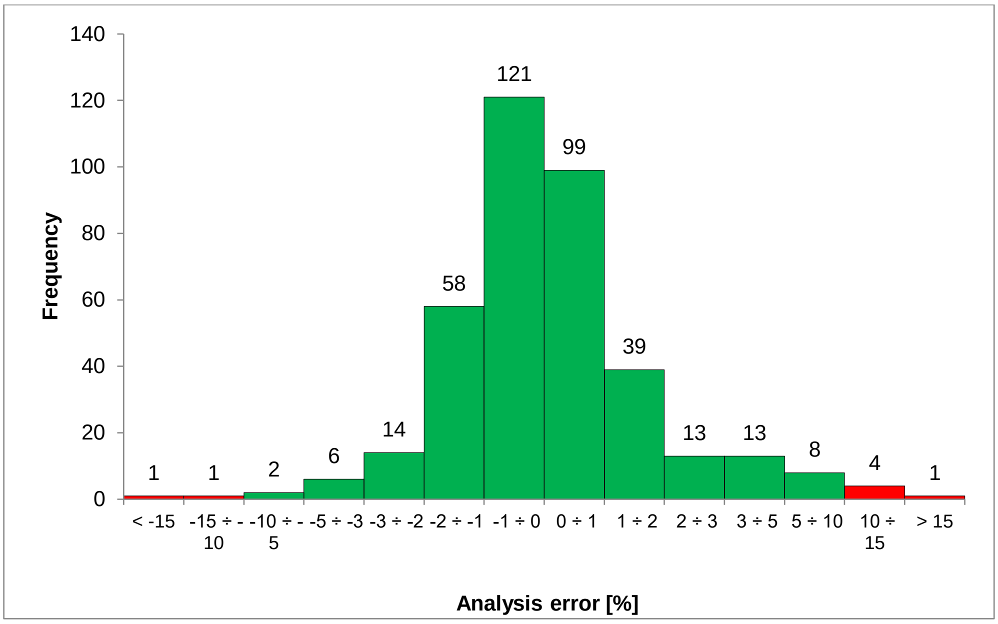

Figure 52. Distribution of the analysis error based on the ionic water balance for 380 analyzes of groundwater samples collected as part of operational monitoring in 2021 - autumn sampling (Rojek et al., 2021)

4.6.2. Statistical analysis of control samples

The obtained results of physical and chemical analyses from the field quality control program are statistically analysed and their final result confirms the reliability of the data and the high quality of the research. The methodology of calculating the results of the analysis of control samples is based on a graphical method in the form of graphs, descriptive statistics, determination of the correlation coefficient, creation of control charts and detailed statistical analysis using the ANOVA method of variance. The results of duplicate and blank samples are analysed separately, using different methods, in accordance with the assumptions of the monitoring program of groundwater bodies in the river basin system for the years 2022-2027 (Kuczyńska et al., 2020). A diagram describing internal quality control with a division into statistical methods used to develop the results of duplicate and blank samples in groundwater monitoring is presented in Figure 53.

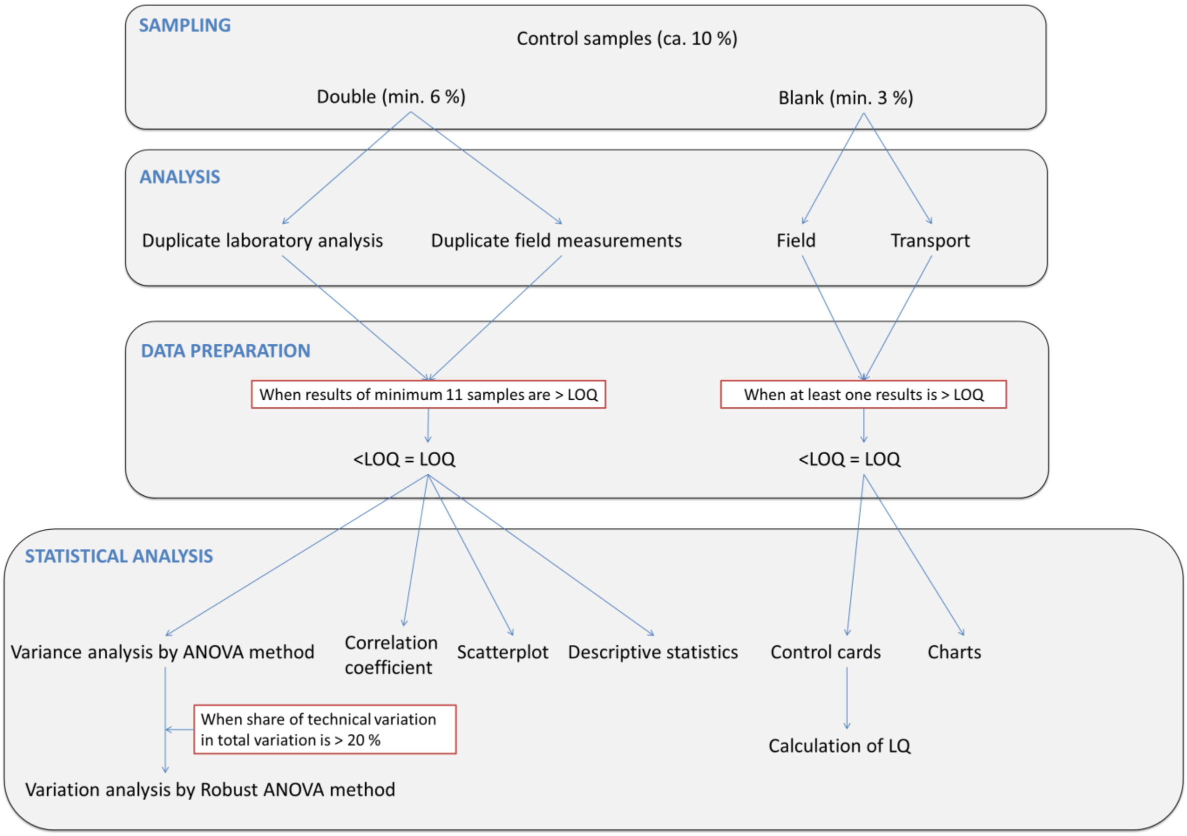

Figure 53. Diagram of internal quality control of chemical data

4.6.3. Statistical analysis of duplicate samples

The analysis of duplicate samples includes both the sampling process (duplicate samples collected in the field) and the double measurement of physico-chemical indicators performed at the sampling site. Duplicated samples are used to assess the precision of the results, i.e. the degree of compliance between independent test results (PN-EN ISO 5667-14: 2016-11). Scatterplots are prepared for each physico-chemical indicator to present the results graphically. Scatterplots, which illustrate the relationship between variables, are a preliminary step in assessing the reliability of the data. On their basis, the degree of linear correlation between the results of the basic and duplicate samples can be determined. An example of a scatter plot is shown in Figure 54.

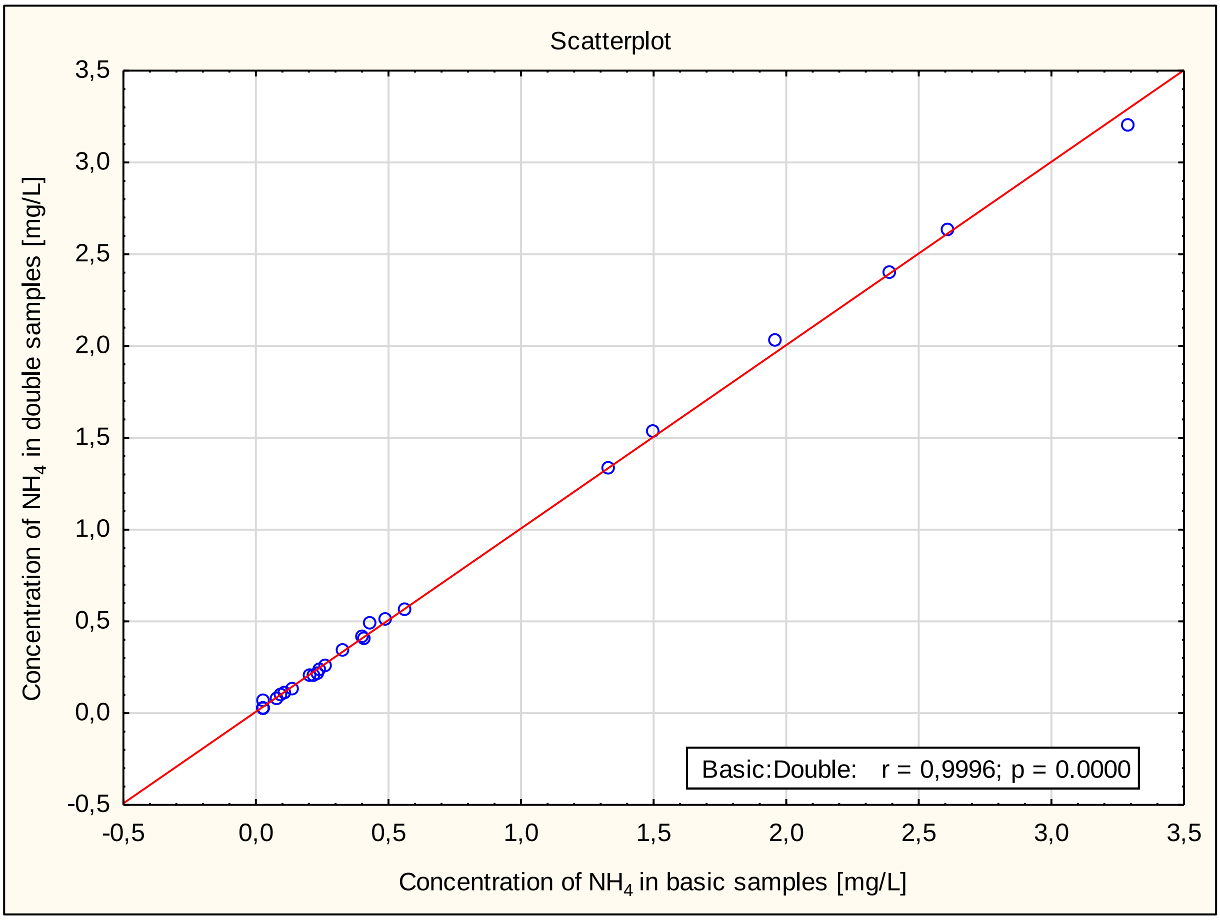

Figure 54. Scatterplot of ammonium ion determinations in basic and duplicate samples
(Stojek et al., 2021)

Then, a statistical analysis of variance ANOVA is performed. Determination values below the limit of quantification (LOQ) are replaced by values equal to the limit of quantification (<LOQ = LOQ). The calculations do not take into account those pairs of samples for which the results of determinations in both samples - basic and duplicate - are lower than the limit of quantification LOQ. The introduction of such data into the calculations would cause an unjustified increase in the precision of the results of hydrogeochemical tests. In order for the data obtained as a result of the analysis of variance to be reliable, calculations are made for pairs of samples for which at least 11 sets of results obtained values higher than the laboratory limit of quantification. Due to the use of a simplified sampling scheme, the technical variance is assessed, which is the sum of the sampling and analytical effects, and the hydrogeochemical variance related to the natural spatial variability of the hydrogeochemical indicators of water. The share of technical variance in the total variance should not exceed 20% (Szczepańska, Kmiecik, 1998; Szczepańska, Kmiecik, 2005). If the critical value of 20% is exceeded, additional calculations are performed using the robust statistics method. This is called a method of flexible handling, which consists in adapting outliers without the need to reject gross errors. The results of the analysis are presented in tabular form.

Another method of presenting and comparing the results of pairs of primary and doubled samples is a range control chart on which a control line is drawn as a limit value. To perform the analysis, it is required to know the uncertainty of the sampling process and the analytical process obtained on the basis of validation (POLLAB Newsletter, 1/52/2009). If the sampling and measurement uncertainty values are respectively u_s and u_a, then the complex standard uncertainty is:

$$u_{meas} = \sqrt{u_s^2 + u_a^2}$$, where:

u_{meas} – complex standard uncertainty;
u_s – uncertainty of sampling;
u_a – measurement uncertainty;

The one-sided control chart specifies:

- The center line 1,128 u_{meas}
- Warning line 2,83 u_{meas} (with a confidence interval of 95%)
- The line of action 3,69 u_{meas} (with a confidence interval of 95%)

The difference between the results of the basic and doubled sample and D (%) is calculated according to the following formulas:

$$D = [x_1 - x_2]\text{, where:}$$

D – absolute difference;
x_1 – primary sample result;
x_2– duplicate sample result.

$$D(\%) = (D/\bar{x}) * 100\%\text{, where:}$$

$D(\%)$ – relative percentage difference;
D – absolute difference;
$\bar{x}$ – mean.

The calculated D (%) values can be directly compared with the action line and the obtained results (if their number is sufficient) presented on a control card. On this basis, the set of chemical analysis results of the primary and duplicate samples can be analysed and defined as data (Stojek, Gidziński, 2020):

DW	-	Reliable data (high precision)
DO	-	Warning data
DN	-	Data unreliable (low precision)

The D (%) value exceeding the control value means that the result is characterized by low precision and appropriate steps should be taken, e.g. to trace the field documentation, try to determine at what stage an error in the results could have occurred (during the sampling or measurement), in order to clarify the situation.

In the case of single duplicate sample results and insufficient validation data, the acceptable D (%) relative percent difference between the results is set to 20%. When interpreting the results of the analysis, however, one should bear in mind how high the concentrations of the analytes are compared to the detection limits of the analytical procedure (Methodology for the Sampling of Groundwater, 2016).

4.6.4. Statistical analysis of blank samples

The purpose of testing blank samples is to determine the practical limit of quantification (LQ) and to compare it with the limit of quantification declared by the Laboratory (LOQ). For the measurement results lower than the LOQ quantification limit for the calculations, it was assumed that <LOQ = LOQ. For the analysed indicators, charts are prepared in the form of control cards for individual measurements, which enable the identification and exclusion of results with gross errors from further observations (Figure 55, Figure 56).

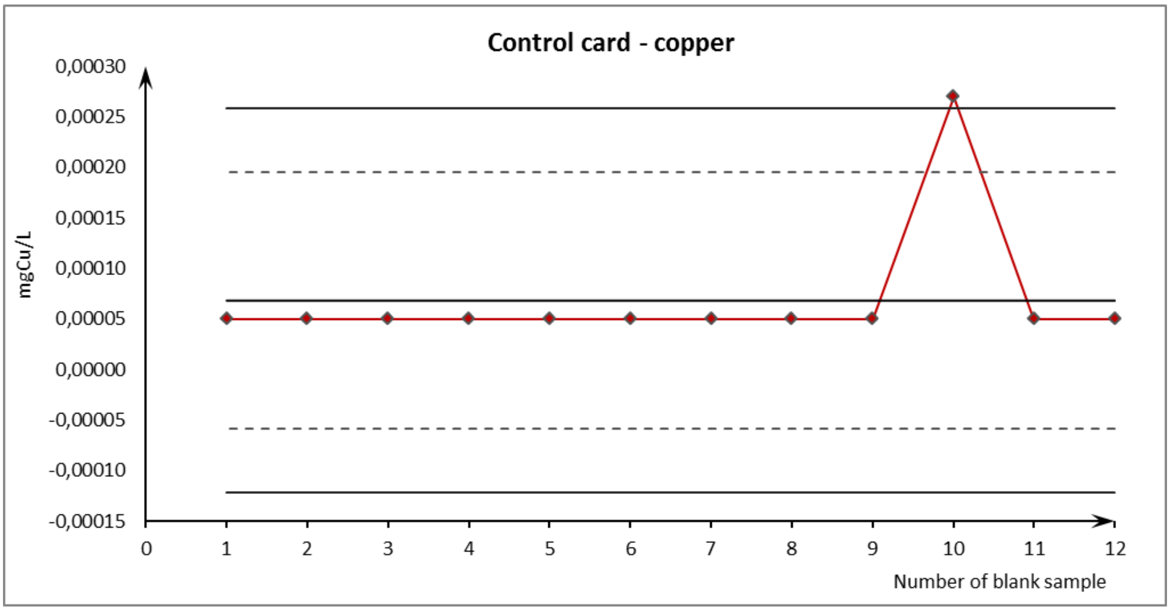

Figure 55. Control card for single measurements of copper determinations in blank samples (Stojek, Gidziński, 2020)

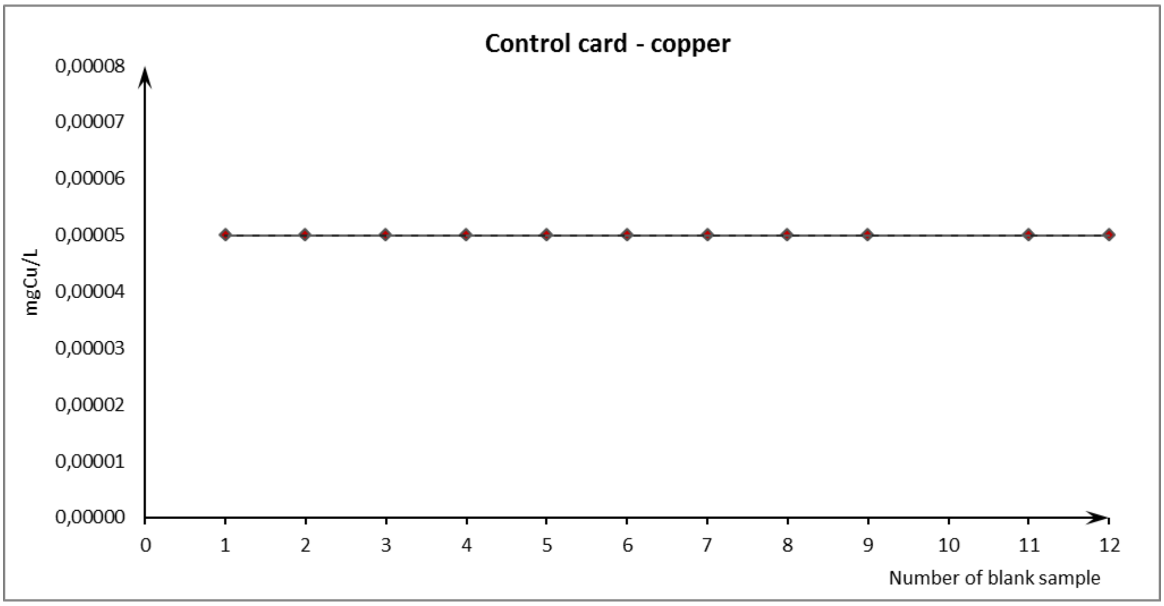

Figure 56. Control card for single measurements of copper determinations in blank samples after switching off point signals (Stojek, Gidziński, 2020)

The next step is to calculate the practical limit of quantification (LQ) using the formula:

$$LQ = \bar{x}_{zer} + 6\sigma_{zer}$$, where:

$\bar{x}_{zer}$ $\bar{x}_{zer}$ – mean value of the determinations

σ_{zer} σ_{zer} – standard deviation value

The obtained practical limits of quantification (LQ) are compared with the limits of quantification of analysis (LOQ) declared by the laboratory performing the analysis, as well as the limit values for the 1st class of groundwater quality, in accordance with the Regulation of the Minister of Maritime Economy and Inland Navigation of October 11, 2019 *on the criteria and method of* *assessing the status of groundwater bodies* (Journal of Laws of 2019, item 2148). The practical limit of quantification should be as close as possible to the laboratory's limit of quantification. The results of the analysis are presented in tabular form.

The obtained results from the calculations of the ion balance and the statistical analysis of control samples each time require an individual approach and detailed interpretation. The experience of the people taking the samples, the cyclical nature of the research and an expert approach to the interpretation of the results from the obtained monitoring tests is important. The end result is quality control reports, taking into account the above-mentioned graphical and tabular forms, and confirmation of the suitability of the results for further analyses, e.g. for groundwater classification, assessment of the chemical status of groundwater bodies (UGB) and the detection of long-term anthropogenic trends in increasing pollution levels.

4.7. Proposed scope and frequency of implementation (jointly with Ukraine) of cross-border groundwater monitoring studies

In the field of joint Polish-Ukrainian groundwater monitoring studies, in the first stage of their implementation, it is proposed to perform periodic field studies in the border area, aimed at collecting groundwater samples for the analysis of physicochemical parameters and indicators. Initially, 2 or 3 monitoring points on the Polish and Ukrainian side of the border should be designated for testing. Every year, water samples for laboratory analyses will be collected from selected observation points. The points in question should be located in a way that allows for the observation of the designated, same aquifer that continues cross-border in the territory of Poland and Ukraine. The following may be selected for joint research: piezometers, inactive drilled wells adapted for observation and monitoring tests or exploited drilled wells. However, in the case of the last of these types of observation points, the scope of monitoring observations will be limited only to physicochemical tests of waters. At each of the designated monitoring points, two sets of samples should be collected, independently by representatives of the Polish side and the Ukrainian side, in accordance with the sampling methodology in force in each of the countries under consideration. The implementation of joint work and field research will enable familiarization with the practical aspects of the methodology of pumping and field measurements as well as the groundwater sampling procedures used in Poland and Ukraine. This will allow for the identification of similarities, but also differences in the applied research methods, while the results of the conducted analytical research will constitute the basis for further comparative analysis.

Containers for groundwater samples should be permanently and legibly marked, allowing for their unambiguous identification. Some of the containers used by the Polish side, submitted for research from the chemical laboratory of the PGI-NRI, will contain preservatives. The chemical laboratory of the PGI-NRI prepares a set of 6 containers for groundwater samples, 2 of which are intended for collecting anionic samples, including one for titration determinations. Four other containers for TOC, cation and free cyanide and mercury determination should be filled with use of 0.45 µm membrane filters using a disposable medical syringe. Sample containers for the determination of cations, cyanides and mercury are fixed. Nitric acid is used to fix the samples for the determination of cations, sodium hydroxide (1.0 mol/l solution) is used to fix the samples for the determination of the concentration of cyanides, and nitric acid and potassium dichromate (1% aqueous solution) are used to fix the samples intended for the determination of mercury concentration. Containers containing fixatives should be stored and transported in tightly closed packages in order to avoid contamination of other water samples. When taking water samples, avoid contact of the filter and the syringe with the containers, and in particular with their rims. After sampling, the water samples should be stored in a chilled state (at a temperature of up to 8°C) in isothermal containers with frozen thermal inserts in them. During storage and transport, individual types of samples of water with fixatives should be packed separately, in plastic bags, without access to containers with samples for determination of anion and TOC content. Along with the transfer of samples to the chemical laboratory of the PGI-NRI, the appropriate sample submission form, i.e. the list of samples, is completed. The basic set of samples should be delivered to the chemical laboratory of the PGI-NRI up to 72 hours from their collection, taking into account the possibility of performing laboratory analyses within the next 48 hours. All activities related to the measurement of field parameters and the taking of groundwater samples for laboratory tests should be carried out in disposable, powder-free gloves (i.e. without the addition of talcum powder).

Analyses of the collected water samples should be performed independently in the chemical laboratory of the Polish Geological Institute - National Research Institute and in the chemical laboratory of the Ukrainian Geological Survey. As far as possible, laboratories to which groundwater samples will be transferred should be accredited for carrying out analyses of all or most of the parameters and indicators tested, while for the Polish side the above-mentioned requirement should be treated as obligatory. The results of the analyses should be provided on an ongoing basis by e-mail or during joint Polish-Ukrainian working meetings. The meetings will also be an opportunity to discuss in detail the results of cross-border research.

Before commencing pumping, the technical condition of the casing of observation wells should be assessed, an on-site inspection should be carried out in order to verify and possibly update the assessment of land use in the vicinity of the observation point and to determine whether (new) pollution hotspots have been identified in the vicinity.

Before pumping hydrogeological wells in order to collect water samples, the technical condition of each observation point should be assessed and in each of them the depth to the groundwater table should be measured, from the measurement point (mark) marked on the casing of the observation well. Measurements should be made by each of the Parties participating in cross-border studies. Measurement at designated points should be possible to carry out both at the lowest and the highest position of the groundwater table. The Polish side will measure the occurrence of the groundwater table with electric meters with acoustic and light signalling devices, with a calibration certificate and having a specific measurement uncertainty. If the probe comes into contact with water, it will be signalled by a sound and a light signal. After lifting the probe, the measurement should be repeated by slowly lowering the probe of the meter in order to make a precise reading on the measuring tape. The measurement result should be determined with an accuracy of 1 cm. After the measurements of the depth to the groundwater table have been made, their results should be compared, and in the event of a discrepancy, the cause should be clarified on an ongoing basis. In the event of damage or incorrect operation of the electric meter, measurements should be made with a hydrogeological whistle mounted on a calibrated measuring tape. Before measuring the position of the groundwater table, the measuring automatics should be removed from the observation hole if it makes it difficult or impossible to carry out the measurements.

When pumping groundwater from observation wells in the field, measurements should be made in the following areas: electrolytic conductivity at 20°C, water temperature at the outflow, dissolved oxygen content and water pH. Before starting the measurements, the correct operation of all measuring devices should be checked, and in the event of a negative result, they should be calibrated. In accordance with the test methodology used by the SHS the value of electrolytic conductivity (EC) is monitored on an ongoing basis during pumping. A groundwater sample should be taken after the replacement of at least three volumes of water column present in a given monitoring well. Continuous EC measurement is performed until the set readings are obtained (the difference between successive EC measurements should not exceed 10%) or until

6 volumes of water are pumped out. During the above-mentioned measurements of field parameters, the electrodes are placed in the flow cell.

The *"basic"* scope of analyses of inorganic physicochemical indicators determined in groundwater collected for research from investigative monitoring sites of the National Institute - National Research Institute, located in the border areas of Poland, includes the following parameters and indicators:

ammonium ion, antimony, arsenic, nitrates, nitrites, bar, colour, beryllium, boron, bromides, chlorides, chromium, COD (chemical oxygen demand), free cyanides, tin, zinc, anionic detergents (SUR), specific electrolytic conductivity at 20°C , fluorides, phosphates, aluminium, cadmium, cobalt, lithium, silica, magnesium, manganese, turbidity, copper, molybdenum, nickel, pH, lead, potassium, mercury, selenium, sulphates, sodium, silver, strontium, anionic surfactants, total dissolved solids, thallium, TOC (total organic carbon), temperature, dissolved oxygen, titanium, total hardness, uranium, vanadium, calcium, bicarbonate, carbonate, total alkalinity, mineral alkalinity, iron. Analyses should be performed in a certified laboratory. Groundwater samples should be collected, stored, transported and transferred to a chemical laboratory using the current procedures, quality policy and accreditation guidelines in force in Poland and Ukraine. During transport, containers with groundwater samples should be properly secured against destruction or damage and against unauthorized access to them.

In accordance with the guidelines of the Regulation of the Minister of Infrastructure of 13 July 2021 on the forms and methods of monitoring surface water bodies and groundwater bodies (Journal of Laws 2021 item 1576), Annex 7 specifies the scope of physical and chemical parameters that can be included in the monitoring of groundwater chemical status. It lists the elements with mandatory marking: general (specific electrolytic conductivity at 20°C, pH, total organic carbon, temperature and dissolved oxygen) and inorganic elements (ammonium ion, antimony, arsenic, nitrates, nitrites, boron, chlorides, chromium, free cyanides, fluorides, phosphates, aluminium, cadmium, magnesium, manganese, copper, nickel, lead, potassium, mercury, selenium, sulphates, sodium, silver, calcium, bicarbonates, iron). Moreover, 10 inorganic elements (bar, beryllium, tin, zinc, cobalt, molybdenum, thallium, titanium, uranium, vanadium) and 13 organic elements were indicated as non-obligatory parameters.

The following parameters and indicators were considered the obligatory scope of determinations according to the guidelines of the Water Framework Directive: dissolved oxygen in water, pH value, specific electrolytic conductivity value, nitrates and ammonium nitrogen. Directive 2006/118/EC of 12 December 2006 covers the tests of the following indicators and parameters of groundwater: arsenic, cadmium, lead, mercury, ammonium ions, chloride ions, sulphate ions, man-made substances: trichlorethylene, tetrachlorethylene and EC. As a result of updating Annex II, nitrites and phosphates (phosphorus) have been added to the indicators for which threshold values should be established. The above-mentioned indicators should also mostly be included in the mandatory marking for the needs of Polish-Ukrainian cross-border research. The exceptions are tests of organic substances: trichlorethylene, tetrachlorethylene, the contents of which in groundwater do not have to be tested obligatorily in the first stage during Polish-Ukrainian tests and for which it is recommended to include in the scope of determinations in groundwater as indicative parameters related to land development or type pressure on groundwater.

Bearing in mind the above guidelines, field measurements in the following scope should be considered as recommended for implementation during joint cross-border studies: electrolytic conductivity, outflow water temperature, dissolved oxygen content and water pH. As far as the parameters and indicators tested in the chemical laboratory are concerned, it is also recommended to measure all the above-mentioned parameters and also to mark: *nitrogen* *compounds (ammonium ion, nitrates, nitrites), antimony, arsenic, colour, boron, bromides, chlorides, chromium, free cyanides, fluorides, phosphates, aluminium, cadmium, magnesium, manganese, copper, nickel, lead, potassium, mercury, selenium, sulphates, sodium, silver, total dissolved substances, TOC (total organic carbon), calcium, bicarbonate, iron.* Moreover, the scope of determinations in individual cases should be each time appropriately adapted and, if necessary, extended with parameters indicative or resulting from the identified or predicted impact of anthropogenic pressure on groundwater.

The final range of parameters and physicochemical indicators, the contents of which should be obligatorily determined in groundwater during transboundary tests, should be determined on the basis of consultations and arrangements with the Ukrainian side.

Decisions regarding the possibility of transferring the results of groundwater chemical composition tests taken for analysis from other representative observation points for groundwater monitoring, located in the border zones of Poland with Ukraine, are possibly the subject of further consultations and international agreements and should be taken taking into account the results of analyses of water samples taken from the group of monitoring points designated to conduct cross-border surveys on both sides of the border.

4.8. Exchange of research results on the so-called transboundary groundwater

The results of jointly conducted measurements and monitoring studies at designated groundwater observation points should be mutually communicated in the mutually agreed scope, date and format.

At the same time, it should be emphasized that the transfer, archiving, processing and sharing of the results of cross-border monitoring studies should be subject to the guidelines and limitations resulting from the requirements of the data sharing policy in force at the Polish Geological Institute - National Research Institute - in the case of data from Poland and competent institutions responsible for monitoring groundwater and the provision of data in this regard from Ukraine.

The provision of raw data, prior to its processing at the Polish Geological Institute - National Research Institute, should be based on appropriate procedures implemented at the Institute. At PGI-NRI, applications related to this type of data are examined by the team of the National Geological Archives dealing with sharing geological / hydrogeological data. Sharing data from PGI-NRI (including raw data) within the Project participants is possible provided that the PGI-NRI decision is obtained in advance, i.e. after expressing the formal consent of authorized employees of the Institute to disclose this data.

The results of jointly conducted measurements of the groundwater table should be compiled both as actual results, taken in the field from the measurement point, marked on the casing of the observation borehole, and in the form of results from the ground surface [m below the sea level] with the highest possible accuracy, e.g. up to 1 cm .

The results of field determination of parameters and physico-chemical indicators should be determined and compiled by the cooperating parties in agreed, identical units. If it is necessary to recalculate a part of the obtained result values, necessary actions should be taken in this regard before the measurement data and test results are transferred to the cooperating party. It is recommended to provide the results of groundwater monitoring measurements on agreed dates, with the optimal organization of periodic consultations during joint working meetings, which would also be an opportunity to analyse and discuss the results and present the needs for the continuation of cooperation in the implementation of international groundwater surveys in the Polish border area with Ukraine.

In the first stage of the implementation of cooperation in the field of groundwater monitoring, the analysis and interpretation of the obtained results of monitoring studies should be carried out independently in accordance with the guidelines, norms and standards in force in Poland and Ukraine. Then, the results of groundwater monitoring tests, along with their interpretation, should be considered jointly during bilateral consultations.

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Regulation No. 48 of 1 October 2019 by Minister of the Environment: *Põhjaveekogumite nimekiri ja nende eristamise kord, seisundiklassid ja nende määramise kord, seisundiklassidele vastavad keemilise seisundi määramiseks kasutatavate kvaliteedinäitajate väärtused ja koguselise seisundi määramiseks kasutatavate näitajate tingimused, põhjavett ohustavate saasteainete nimekiri, nende sisalduse läviväärtused põhjaveekogumite kaupa ja kvaliteedi piirväärtused põhjavees ning taustataseme määramise põhimõtted* (*The list of groundwater bodies, their status classes, delineation procedures, the quality criteria for assessing their chemical status and quantitative status, the list of dangerous substances in groundwater, their threshold values in groundwater bodies, groundwater quality standards and principles for delineating natural background values*; unofficial translation). (in Estonian).

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Annex I. **Groundwater laboratory analysis methods in Latvia and Estonia**

Parameter	Latvia					Estonia				
	Used method	Principle of the method	MDL	QL	Unit	Used method	Principle of the method	MDL	QL	Unit
Calcium (Ca)	LVS EN ISO 11885:2009	Inductively coupled plasma optical emission spectrometry	0.04	0.1	mg/l	EVS-EN ISO 11885	Inductively coupled plasma atomic emission spectrometry (ICP-OES)	0.05	-	mg/l
	LVS EN ISO 7980:2000	Atomic absorption spectrometry with flame atomization	0.2	0.6	mg/l	ISO 6058	Titrimetric determinations (TITR)	2	-	mg/l
	-	-	-	-	-	SFS 3003	Titrimetric determinations (TITR)	12	-	mg/l
	-	-	-	-	-	EN ISO 14911	Ion chromatography (IC)	0.04	-	mg/l
Magnesium (Mg)	LVS EN ISO 11885:2009	Inductively coupled plasma optical emission spectrometry	0.04	0.1	mg/l	EVS-EN ISO 11885	Inductively coupled plasma atomic emission spectrometry (ICP-OES)	0.02	-	mg/l
	LVS EN ISO 7980:2000	Atomic absorption spectrometry with flame atomization	0.1	0.4	mg/l	ISO 6059	Titrimetric determinations (TITR)	2	-	mg/l
	-	-	-	-	-	EN ISO 14911	Ion chromatography (IC)	0.02	-	mg/l
Sodium (Na)	LVS ISO 9964-3:1993	Atomic absorption spectrometry with flame atomization	0.2	0.5	mg/l	EVS-ISO 9964-3	Flame-emission spectrometry (FES); Atomic absorption spectrometry (AAS)	0.01	-	mg/l
	LVS EN ISO 11885:2009	Inductively coupled plasma optical emission spectrometry	0.08	0.3	mg/l	EN ISO 14911	Ion chromatography (IC)	0.02	-	mg/l
Potassium (K)	LVS ISO 9964-3:1993	Atomic absorption spectrometry with flame atomization	0.1	0.4	mg/l	EVS-ISO 9964-3	Flame-emission spectrometry (FES); Atomic absorption spectrometry (AAS)	0.01	-	mg/l
	LVS EN ISO 11885:2009	Inductively coupled plasma optical emission spectrometry	0.01	0.03	mg/l	EN ISO 14911	Ion chromatography (IC)	0.02	-	mg/l
Bicarbonates (HCO_3)	SM 2320 B:2017	Potentiometric titration	1.2	3.7	mg/l	EVS-EN ISO 9963-1	Titrimetric determinations (TITR)	1	-	mg/l
Sulphates (SO_4)	LVS EN ISO 10304-1:2009	Ion chromatography	0.024	0.079	mg/l	EVS-EN ISO 10304-1	Ion chromatography (IC)	0.1	-	mg/l
Chlorides (Cl)	LVS EN ISO 10304-1:2009	Ion chromatography	0.039	0.13	mg/l	EVS-EN ISO 10304-1	Ion chromatography (IC)	0.07	-	mg/l
Phosphate phosphorus andphosphates (PO_4)	LVS EN ISO 6878:2005, 4.nod	Spectrophotometry, ammonium molybdate method	0.0052	0.019	mg/l	EVS-EN ISO 6878	Spectrophotometry (UV-VIS)	0.06	-	mg/l
	-	-	-	-	-	ISO 15681-2	Spectrophotometry (UV-VIS)	0.006	-	mg/l
Total phosphorus (P_{tot})	LVS EN ISO 6878:2005, 7.nod.	Mineralization with persulphate, spectrophotometry, ammonium molybdate method	0.0017	0.008	mgP/l	ISO 15681-2	Spectrophotometry (UV-VIS)	0.002	-	mg/l
Total nitrogen (N_{tot})	LVS EN ISO 11905-1:1998	Mineralization with persulphate, segmented flow spectrophotometry, Cd column method	0.02	0.06	mgN/l	ISO 11905	Spectrophotometry (UV-VIS)	0.1	-	mg/l
	LVS EN 12260:2004	Catalytic combustion, detection of chemiluminescence	0.14	0.48	mgN/l	-	-	-	-	-
Ammonium (NH_4)	LVS EN ISO 11732:2005	Continuous flow indophenol spectrophotometric method	0.042	0.149	mg/l	EVS-EN ISO 11732	Spectrophotometry (UV-VIS)	0.013	-	mg/l
	QuAAtro Method no. Q-080-06 Rev.2:2008	Fluorometric determination with o-phthalaldehyde (OPA) using segmented flow analysis	0.0059	0.024	mg/l	SFS 3032	Spectrophotometry (UV-VIS)	0.01	-	mg/l
Nitrites (NO_2)	LVS ISO 6777:1984	Spectrophotometry	0.00055	0.002	mg/l	EVS-EN ISO 13395	Spectrophotometry (UV-VIS)	0.016	-	mg/l
Nitrates (NO_3)	LVS EN ISO 13395:2004	Segmented flow spectrophotometry, Cd column method	0.053	0.19	mg/l	EVS-EN ISO 13395	Spectrophotometry (UV-VIS)	0.02	-	mg/l
	-	-	-	-	-	EVS-EN ISO 10304-1	Ion chromatography (IC)	0.1	-	mg/l
Total hardness	SM 2340 C:2017	Titrimetry	0.034	0.12	mgeq/l	-	-	-	-	-
	-	-	-	-	-	ISO 6059	Titrimetric determinations (TITR)	0.1	-	mgeq/l
	-	-	-	-	-	SFS 3003	Titrimetric determinations (TITR)	0.9	-	mgeq/l
Total iron (Fe_{tot})	LVS EN ISO 11885:2009	Inductively coupled plasma optical emission spectrometry	3	10	µg/l	ISO 6332	Spectrophotometry (UV-VIS)	0.02	-	mg/l
Lead (Pb)	LVS EN ISO 11885:2009	Inductively coupled plasma optical emission spectrometry	0.4	1	µg/l	EVS-EN ISO 11885	Inductively coupled plasma atomic emission spectrometry (ICP-OES)	0.1	-	µg/l

	-	-	-	-	-	EVS-EN ISO 17294-2	Inductively coupled plasma mass spectrometry (ICP-MS)	0.1	-	µg/l
Nickel (Ni)	LVS EN ISO 11885:2009	Inductively coupled plasma optical emission spectrometry	0.7	2	µg/l	EVS-EN ISO 11885	Inductively coupled plasma mass spectrometry (ICP-MS)	0.05	-	µg/l
	-	-	-	-	-	EVS-EN ISO 17294-2	Inductively coupled plasma atomic emission spectrometry (ICP-OES)	20	-	µg/l
Cadmium (Cd)	LVS EN ISO 15586:2003	Atomic absorption spectrometry with electrothermal atomization	0.007	0.024	µg/l	EVS-EN ISO 17294-2	Inductively coupled plasma mass spectrometry (ICP-MS)	0.02	-	µg/l
	LVS EN ISO 11885:2009	Inductively coupled plasma optical emission spectrometry	0.09	0.3	µg/l	EVS-EN ISO 11885	Inductively coupled plasma atomic emission spectrometry (ICP-OES)	0.02	-	µg/l
Mercury (Hg)	LVS EN ISO 17852:2008	Cold vapor atomic fluorescence spectrometry	0.003	0.01	µg/l	EVS-EN ISO 17852	Fluorescence spectometry (AFS)	0.005	-	µg/l
	-	-	-	-	-	EVS-EN ISO 12846	Cold vapor atomic absorption spectrometry (AAS)	0.015	-	µg/l
Arsenic (As)	LVS EN ISO 15586:2003	Atomic absorption spectrometry with electrothermal atomization	0.2	0.6	µg/l	EVS-EN ISO 17294-2	Inductively coupled plasma mass spectrometry (ICP-MS)	0.05	-	µg/l
	-	-	-	-	-	EVS-EN ISO 11885	Inductively coupled plasma atomic emission spectrometry (ICP-OES)	0.05	-	µg/l
Atrazine	EN ISO 10695:2000*	Gas chromatography /mass spectrometry	6.5	20	ng/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.0005	-	µg/l
Simazine	EN ISO 10695:2000*	Gas chromatography /mass spectrometry	12	36	ng/l	STJnrU92	Liquid chromatography mass-spectrometry (LC-MS)	0.003	-	µg/l
Propazine	EN ISO 10695:2000*	Gas chromatography /mass spectrometry	6.5	20	ng/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.01	-	µg/l
Bentazone	US EPA Method 8151A:1996*	Gas chromatography with electron capture detector	12	36	ng/l	STJnrU92	Liquid chromatography mass-spectrometry (LC-MS)	0.02	-	µg/l
MCPA	US EPA Method 8151A:1996*	Gas chromatography with electron capture detector	15	45	ng/l	STJnrU92	Liquid chromatography mass-spectrometry (LC-MS)	0.01	-	µg/l
Aldrin	ISO 6468:1996	Gas chromatography with electron capture detector	0.3	1	ng/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.001	-	µg/l
Dieldrin	ISO 6468:1996	Gas chromatography with electron capture detector	0.2	1	ng/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.001	-	µg/l
Heptachlor	ISO 6468:1996	Gas chromatography with electron capture detector	0.2	1	ng/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.0001	-	µg/l
2,4-D	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.01	0.03	µg/l	STJnrU92	Liquid chromatography mass-spectrometry (LC-MS)	0.02	-	µg/l
Isoproturon	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.1	0.03	µg/l	STJnrU92	Liquid chromatography mass-spectrometry (LC-MS)	0.001	-	µg/l
Aclonifen	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.0012	0.0036	µg/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.001	-	µg/l
Biphenox	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.00012	0.0004	µg/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.001	-	µg/l
Promethrin	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.008	0.024	µg/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.01	-	µg/l
Dimethoate	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.01	0.03	µg/l	STJnrU92	Liquid chromatography mass-spectrometry (LC-MS)	0.002	-	µg/l
Cypermethrin	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	8E-07	2E-06	µg/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.0004	-	µg/l
Trifluralin	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.003	0.009	µg/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.001	-	µg/l
Tebuconazole	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.01	0.03	µg/l	STJnrU92	Liquid chromatography mass-spectrometry (LC-MS)	0.002	-	µg/l
Epoxiconazole	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.01	0.03	µg/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.005	-	µg/l
Diflufenican	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.01	0.03	µg/l	STJnrU92	Liquid chromatography mass-spectrometry (LC-MS)	0.01	-	µg/l
Metribuzin	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.01	0.03	µg/l	STJnrU63	Gas Chromatography Mass-spectrometry (GC-MS)	0.01	-	µg/l
Metazachlor	BIOR-T-012-162-2015	Gas or liquid chromatography with mass spectrometry	0.01	0.03	µg/l	STJnrU92	Liquid chromatography mass-spectrometry (LC-MS)	0.002	-	µg/l
Trichlorethylene	ISO 10301:1997	Gas chromatography with electron capture detector	0.2	0.6	µg/l	ISO 20595	Gas Chromatography Mass-spectrometry (GC-MS)	0.1	-	µg/l
Tetrachlorethylene	ISO 10301:1997	Gas chromatography with electron capture detector	0.2	0.6	µg/l	ISO 20595	Gas Chromatography Mass-spectrometry (GC-MS)	0.1	-	µg/l
1,2-dichloroethane	ISO 10301:1997	Gas chromatography with electron capture detector	0.1	0.3	µg/l	ISO 20595	Gas Chromatography Mass-spectrometry (GC-MS)	0.1	-	µg/l