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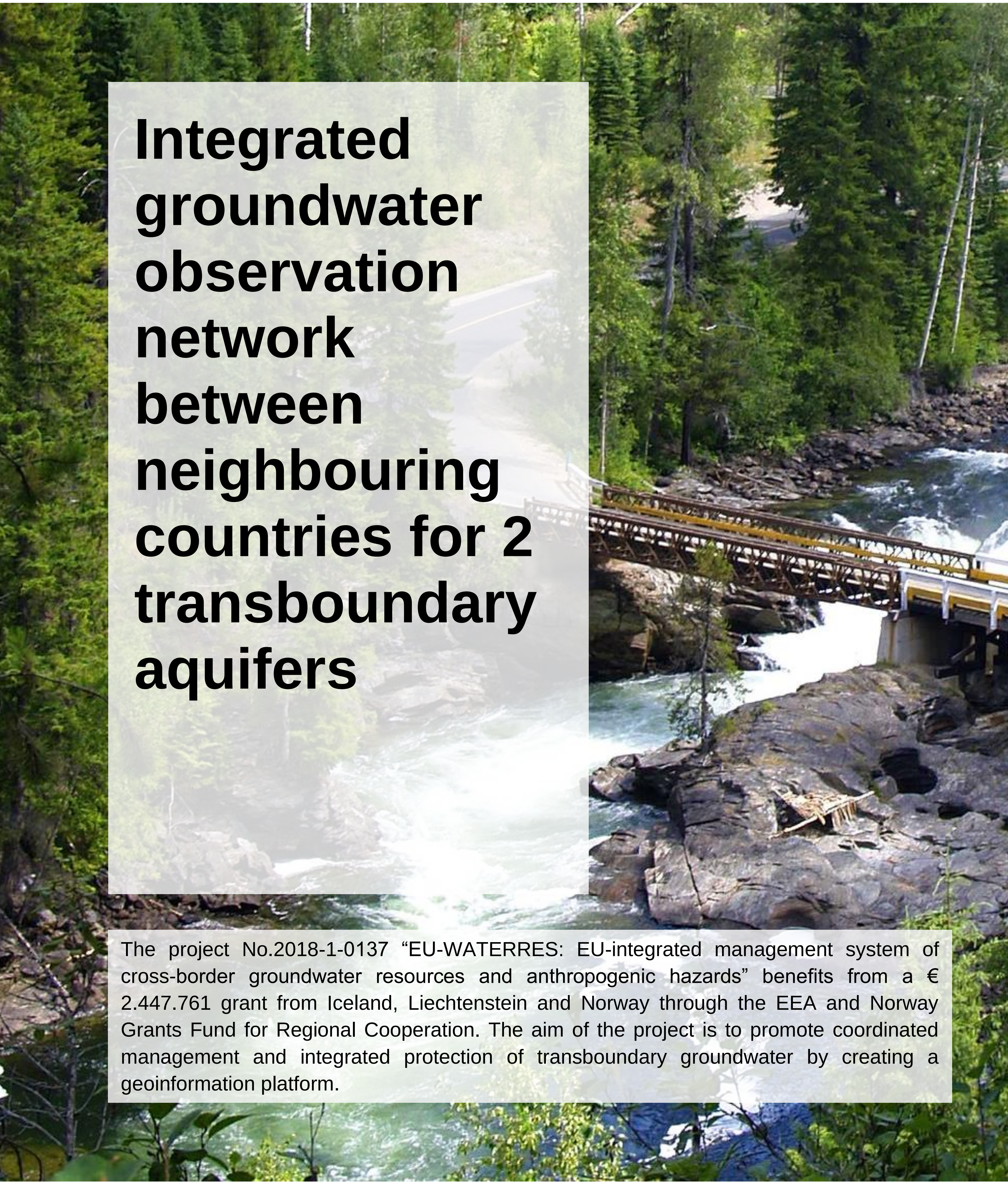

Integrated groundwater observation network between neighbouring countries for 2 transboundary aquifers

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

The aim of this report was to develop the principles of designing the Polish-Ukrainian and Estonian-Latvian transboundary groundwater monitoring network in relation to the needs of assessing their quantitative and chemical status. The recommendations were developed taking into account the potential of the existing national networks and the requirement of EU law. This report is the implementation of the first stage of creating the internationally integrated monitoring of transboundary groundwater reservoirs. The development of a joint program for monitoring the state of transboundary aquifers, which is also the task of the EU-WATERRES project. The developed guidelines of the organization of the transboundary groundwater monitoring network are aimed at helping the national authorities responsible for monitoring groundwater in implementing the issue of transboundary monitoring. In addition, the key target group are the institutions responsible for the management of transboundary groundwater reservoirs at the national and international level and the organizations responsible for the environmental issues in terms of transboundary impacts.

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.

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Preface

This report, on the principles of designing Polish-Ukrainian and Estonian-Latvian transboundary groundwater monitoring networks in terms of the need to assess their quantitative and chemical status, was created as part of the EU-WATERRES (EU-integrated management system of cross-border groundwater resources and anthropogenic hazards) project.; www.eu-waterres.eu), financed by the EEA and Norway Grants Fund for Regional Cooperation.

The work on the report was coordinated by the 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 authorities responsible for groundwater monitoring in 4 countries:

- Estonia - Geological Survey of Estonia (*Team leader: Andres Marandi)*
- Latvia - Latvian Environment, Geology and Meteorology Centre (*Team leader: Ieva Bukovska*);
- Ukraine – Zahidukrgeologiya (*Team leader: Dmytro Panov*) and Ukrainian Geological Company (*Team leader: Volodymyr Klos*);
- Poland - Polish Geological Institute – National Research Institute (*Team leader: Tomasz Gidziński*).

The report is a precursor to the establishment of a Polish-Ukrainian and Estonian-Latvian transboundary groundwater monitoring network. The presented recommendations concern the establishment of common rules for the creation of a transboundary groundwater monitoring network and a proposal regarding the criteria for qualifying national monitoring points to this network and an indication of locations with prospects for its development.

The guidance is based on studies of best practices for monitoring and assessing the status of groundwater and the results of the assessment of transboundary groundwater flows. (Output 1 of the EU-WATERRES project entitled “Assessment of the resources of transboundary groundwater reservoirs for the 2 pilot areas”).

The report has been divided into two parts with regard to the individual pilot areas:

- Part 1. Principles of development of a Polish-Ukrainian transboundary groundwater monitoring network: methodological foundations and practical solutions (*Polish – Ukrainian Team leader: Tatiana Solovey*);
- Part 2. Principles of development of a Latvian-Estonian transboundary groundwater monitoring network: methodological foundations and practical solutions (*Latvian – Estonian Team leader: Jekaterina Demidko*).

This report is the implementation of the first stage of creating an internationally integrated monitoring of transboundary groundwater reservoirs. Once the rules for this network have been established, EU-WATERRES is also scheduled to develop a joint program to monitor the state of transboundary aquifers.

November 2021,

Tatiana Solovey, Professor

Coordinator EU-WATERRES

Polish Geological Institute – National Research Institute (PGI-NRI)

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Abbreviations

BAB – Baltic Artesian Basin

EC – European Commission

EEA - European Environment Agency

EU – European Union

GWB – Groundwater Body

RBD – River basin district

RBMPs – River basin management plans

TGR – Transboundary Groundwater Reservoirs

UNECE – United Nations Economic Commission for Europe

UNESCO – United Nations Educational, Scientific and Cultural Organization

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

PART I. Principles of development of a Polish-Ukrainian transboundary groundwater monitoring network: methodological foundations and practical solutions

Introduction

The Water Framework Directive (WFD, 2000) and the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention, 1992) contain important provisions on the monitoring and assessment of the state of transboundary groundwater reservoirs, assessment of the effectiveness of measures taken to prevent, control and limit transboundary impacts for groundwater. For transboundary groundwater monitoring, these recommendations are quite general. The directive sets the following objectives for transboundary groundwater monitoring:

- assessment of the direction and intensity of groundwater flow across the borders of Member States;
- tracking groundwater quality of transboundary layers;
- identification and control of cross-border transport of potential pollutants.

In the Polish-Ukrainian borderland there are 4 rich transboundary strata - 1) alluvial (Qal) aquifer, 2) fissure Upper Cretaceous (K_2) aquifer, 3) fissure-karst-pore Lower Neogene (N_1) 4) pore Quaternary fluvioglacial (Qf-g). However, only the fissure Upper Cretaceous (K_2) aquifer is of key importance in shaping strategic groundwater resources, and is included in the main groundwater reservoir with a regional range and large resources - the Lublin-Lviv transboundary groundwater reservoir. This reservoir is the main groundwater resource for two large urban agglomerations of Lublin and Lviv, moreover, it plays a key role in water supply to the municipal, industrial and agricultural sectors. Due to the special economic importance of this reservoir, the neighboring countries are obliged to undertake joint activities aimed at monitoring the condition of groundwater resources, which may ensure water supply in the long-term perspective.

This report contains provisions on the establishment of common principles for the creation of a Polish-Ukrainian transboundary groundwater monitoring network and a recommendation on the criteria for qualifying national monitoring points to this network and an indication of prospective locations for its development. For this purpose, the criteria for locating transboundary groundwater monitoring points were formulated and a spatial analysis of environmental and economic conditions was performed on the basis of selected criteria. The locations identified in this way were assessed in favor of the presence of hydrogeological wells or points of the national monitoring network within them. All identified boreholes or measurement points were considered useful for qualification for the transboundary groundwater monitoring network. In the absence of the above measurement points or hydrogeological wells or boreholes, it was recommended to install a new measurement point.

This report is the implementation of the first stage of creating the internationally integrated monitoring of transboundary groundwater reservoirs, i.e. the organization of the transboundary network. After determining the principles of creating this network and testing example solutions, only further integration can be made - the development of a joint program for monitoring the state of transboundary aquifers, which is also the task of the EU-WATERRES project. The key aspects of this program will concern the harmonization of procedures for measuring the position of the water table and chemistry tests, taking into account the scope, frequency and methodology of the tests. It also provides for the development of integrated databases of groundwater monitoring results.

The developed guidelines of the organization of the Polish-Ukrainian transboundary groundwater monitoring network are aimed at helping the national authorities responsible for monitoring groundwater in implementing the issue of transboundary monitoring. In addition, the key target group are the institutions responsible for the management of transboundary groundwater reservoirs at the national and international level and the organizations responsible for the environmental issues in terms of transboundary impacts.

1 Groundwater monitoring structure

1.1 Groundwater monitoring in Poland

As a result of the decision of the geological administration in 1969, the Polish Geological Institute began preparations for the organization of groundwater monitoring covering the entire territory of the country. In 1972, a project was developed (Pich, Załuski, 1971), and two years later, observations of the position of the groundwater table began. In the following years, along with the changes in the objectives set for monitoring, the concept and principles of its operation were changed, and therefore new annexes were developed (Duchnowski, Mieczniki, 1983; Pich, Przytuła, 1993) or new projects for its operation (Pich, Kazimierski, 1994). An important event was the beginning of research on the chemical composition of groundwater as part of the newly established State Environmental Monitoring in 1991. The developed chemical monitoring project (Hordejuk et al. 1994) defined the structure and principles of its functioning. Therefore, from 1991, two monitoring networks were in operation, and it was only in 2003 that a decision was made to combine them and adapt them to the principles set out in the Water Law Act (2001) and WFD.

In relation to the monitoring of groundwater in Poland, new tasks have now been set, which result directly from the implementation of the requirements of the European Union Directives (WFD, 2000; Groundwater Directive, 2006; Nitrate Directive, 1991) and national legislation (laws and regulations) in the field of water resources protection and management. The primary objective is to monitor and assess the state of groundwater bodies in terms of quantity and quality, for the purposes of water management planning and the achievement of environmental objectives.

The monitoring results should allow for:

- assessment of the quantitative and chemical status of groundwater bodies;
- documentation and evaluation of the dynamics of changes in the groundwater table level in observation boreholes, the efficiency of sources and groundwater chemistry. Provide data for the preparation of reports for the EC, the EEA, water management and protection plans and other studies and documents;
- assessment of the hydrogeological situation in the country and in its individual regions;
- detection of significant and sustained trends in increasing concentrations of pollutants due to anthropogenic impacts;
- determining the impact of the status of groundwater bodies on protected areas included in the lists of protected areas;
- forecasting the development of the hydrogeological situation in relation to the division into administrative units;
- assessment of hydrogeological hazards caused by flooding and drought / hydrogeological low water;
- collecting, sharing and disseminating information about the dynamics and state of groundwater (Quarterly Information Bulletins and Hydrogeological Annals of the Polish Hydrogeological Survey);
- implementation of tasks related to international and bilateral cooperation (Kazimierski B., Gidziński T., 2011).

The method of monitoring is also regulated by appropriate methodological guides and procedures. Pursuant to the provisions of the Water Law Act (Journal of Laws, 2021; item 624, 784, as amended), the Polish Hydrogeological Survey (PSH) is responsible for the functioning of groundwater monitoring in Poland. The role of PSH is fulfilled by the Polish Geological Institute - National Research Institute. Pursuant to the Water Law Act, groundwater observation points of the PSH are protected by law. The tasks of quantitative monitoring in the scope of measuring the level of the groundwater table and the recharge of sources, as well as research monitoring tasks in the border zones of Poland and in areas of intense anthropogenic pressure are carried out as part of the activities of the PSH. On the other hand, chemical monitoring of groundwater in a division into Uniform Groundwater Bodies (JCWPd) in Poland functions as part of the activities of the State Environmental Monitoring (PMŚ) and is supervised by the Chief Inspectorate for Environmental Protection (GIOŚ).

Pursuant to the provisions of § 1, section 2a of the Regulation of the Minister of Infrastructure of 13 July 2021 on the forms and methods of monitoring of surface water bodies and groundwater bodies (Journal of Laws, 2021, item 1576), prepared on the basis of Article 350 par. 1 of the Act of 20 July 2017 - Water Law (Journal of Laws, 2021; items 624, 784 and 1564), referring to the guidelines of the WFD, following items had been defined:

1) types of monitoring and the goals of their establishment;
2) criteria for selecting water bodies for monitoring;
3) criteria for determining measurement and control points;
4) scope and frequency of monitoring;
5) reference methodologies and conditions for ensuring the quality of monitoring.

Pursuant to § 14 of the Regulation, the following types of monitoring of groundwater bodies have been distinguished:

1) chemical state monitoring;
2) monitoring of the quantitative state;
3) research monitoring.

Pursuant to § 15, the following types of monitoring of the chemical status of groundwater bodies are defined:

1) diagnostic monitoring of the chemical status of groundwater bodies, established on the basis of the characteristics of groundwater bodies and the assessment of the impact of anthropogenic impacts;
2) operational monitoring of the chemical status of groundwater bodies, established on the basis of the characteristics of groundwater bodies and the assessment of the impact of anthropogenic impacts and diagnostic monitoring.

Pursuant to Art. § 16. 1. of the Regulation, the diagnostic monitoring of the chemical status of groundwater bodies is established for the purpose of:

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

The operational monitoring of the chemical status of groundwater bodies is established in order to:

1) assess the chemical status of bodies of groundwater recognized as at risk of failure to meet the environmental objectives set out for them, referred to in Art. 59 of the Act;
2) notice the existence of significant and sustained trends in the concentration of pollutants caused by anthropogenic impacts.

Section 17 provides the following criteria for selecting groundwater bodies to be monitored:

1) diagnostic monitoring of the chemical status of groundwater bodies is carried out in the case of groundwater bodies that provide an annual average of more than 100 m^3 per day of water intended for human consumption;
2) operational monitoring of the chemical status of groundwater bodies is carried out in the case of groundwater bodies recognized, on the basis of diagnostic monitoring and impact assessment, as at risk of failure to meet the environmental objectives specified for them, referred to in Art. 59 of the Act;
3) monitoring of the quantitative status of groundwater bodies is carried out in the case of groundwater bodies that provide an annual average of more than 100 m^3 per day of water intended for human consumption.

The scope of the diagnostic monitoring of the chemical status of groundwater bodies includes the measurements of the physicochemical elements specified as mandatory in Annex 7 to the Regulation. This scope may be extended to the measurements of physicochemical elements defined as optional in Annex 7 to the Regulation.

The scope of operational monitoring of the chemical status of groundwater bodies includes the measurements of the physicochemical elements specified in Annex 7 to the Regulation:

1) characterizing anthropogenic impacts affecting the status of groundwater, identified pursuant to Art. 317 paragraph. 1 point 3 of the Act;
2) whose values, determined on the basis of diagnostic monitoring of the chemical status of groundwater bodies, are higher than the threshold values specified in the regulations issued on the basis of art. 53 sec. 1 of the Act.

According to the regulation, monitoring of the quantitative status of groundwater bodies is established in order to assess the quantitative status of groundwater bodies, including the establishment of reserves of available groundwater resources and the analysis of the groundwater table location for each groundwater body. In Poland, measurements of the position of the water table and the efficiency of sources in the national groundwater observation and research network (the so-called quantitative status monitoring) are carried out periodically with a frequency sufficient to assess the quantitative status of groundwater bodies. In addition, as part of a separate, dedicated PSH task, works related to the determination of the actual groundwater abstraction in relation to each groundwater body are carried out.

Research monitoring of groundwater bodies or parts of groundwater bodies is established with the purpose to:

1) explain the reasons for failure to meet the environmental objectives set for a given body of groundwater, if the reasons cannot 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, concentration and extent of pollution, if contamination of a body of groundwater has occurred or there are grounds to conclude that such a pollution risk exists;
3) identify the extent of a significant decrease in the groundwater level causing the risk of non-compliance with the environmental objectives for a given groundwater body.

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 the environmental objectives or on specific remedial measures against the effects of pollution.

In reference to the above-mentioned objectives of research monitoring, in the border zones of Poland this type of research is often an effective supplement to the scope of monitoring observations, allowing for a more comprehensive and, consequently, more reliable assessment of the impact of identified or potential transboundary pressures on the quantitative status and chemical status of groundwater. The number of monitoring points of national networks for quantitative monitoring and monitoring of the chemical status of groundwater bodies in many border zones, often remains insufficient in the state border profile or monitoring points are located unrepresentatively in relation to the implementation of the monitoring objectives of border areas (which is described in detail in the next chapter 3 of this study), hence the need to develop effective research as part of research monitoring. Also, the type and nature of impacts can clearly determine the method of monitoring research conducted as part of research monitoring.

Groundwater monitoring is carried out on three spatial scales: nationwide, regional and local.

The main role is played by nationwide monitoring, which is an observation and research network of groundwater, covering the entire country and all useful aquifers and groundwater levels. According to the data at the end of 2020, the nationwide groundwater observation and research network includes (Fig.1):

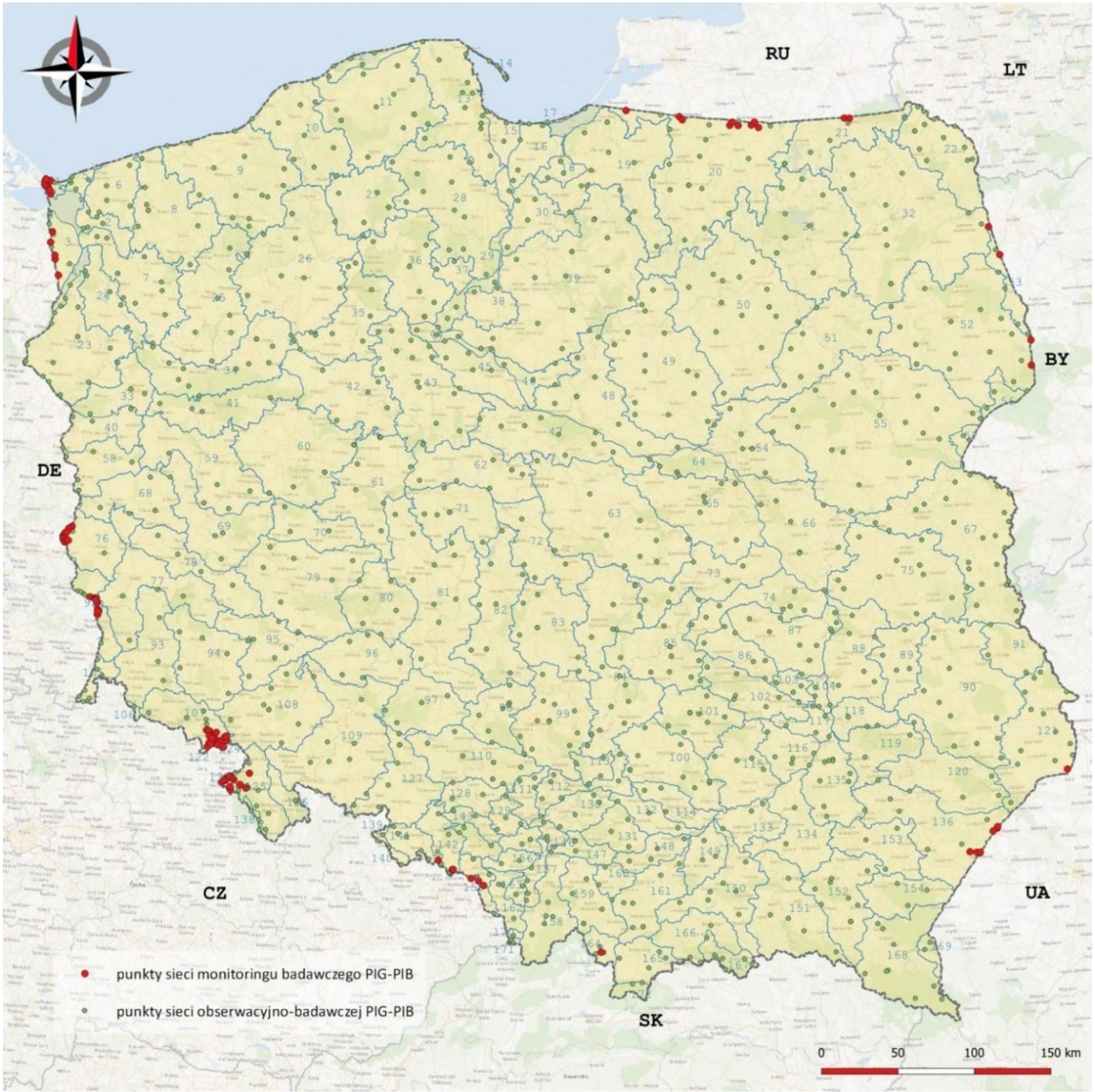


Figure 1 Groundwater monitoring points in Poland

- 1243 quantitative status monitoring points;
- 1289 chemical status monitoring points (diagnostic monitoring 2019);
- 513 research monitoring points.

Monitoring on a regional scale includes:

- water chemical status monitoring networks subordinated to Voivoidship Inspectorate of Environmental Protection (VIEP) (voivodeship or part of a voivodeship);
- monitoring of waters within protected areas (subordinated to National Parks and other managers of protected areas).

Local monitoring was established to assess the impact of facilities posing a threat to the condition of groundwater, in particular - waste landfills, sewage treatment plants, mines, oil-derivative storage facilities, petrol stations, etc.

1.2 Groundwater monitoring in 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 (groundwater bodies 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.

The **main purpose of groundwater monitoring** is to monitor the groundwater condition as one of the most important components of the environment, to prepare the necessary information and forecasts for various purposes, as well as to develop scientifically sound recommendations for decision-making to prevent negative changes in groundwater regime and compliance environmental safety.

The main tasks of **groundwater monitoring** at the stage of working documentation or working design are:

- development of an operational control system and early prevention of groundwater depletion and pollution and flooding;
- assessment of the dynamics of hydrogeodynamic (depletion, flooding),

hydrogeochemical (chemical pollution) and hydrogeothermal (thermal pollution) indicators;
- study and assessment of patterns of dynamics of pollutants migration in the aeration zone and in groundwater;
- forecasting the nature of the processes of groundwater pollution and depletion, flooding of territories, intensification of karst-suffusion processes, subsidence and subsidence of the earth's surface, etc.;
- control and evaluation of the effectiveness of environmental measures.

The hydro-regime information obtained during groundwater monitoring should provide an assessment of:

- geoecological state of groundwater;
- conditions of interaction of groundwater with the environment;
- forecasts of groundwater regime, including forecasts of geoecological processes;
- soil condition of the aeration zone;
- groundwater balance in natural and disturbed conditions;
- spatio-temporal patterns of the regime;
- filtration and migration parameters of groundwater;
- characteristics of zones of technogenic disturbances in groundwater.

The creation of a plan for the location of observation networks should be preceded by ecological and hydrogeological zoning, on the basis of which groundwater monitoring observation points are planned.

The main tasks of groundwater monitoring are:

- collection, systematization and accumulation of information on groundwater monitoring;
- assessment of groundwater state and forecasting changes in groundwater regime;
- preparation of hydrogeological information and various forecasts of groundwater regime;
- providing information on groundwater state at the request of central and local executive bodies, enterprises that use information on groundwater state.

As a result of works following items are prepared:

- annual information to the National Report on the State of the Environment in Ukraine;
- annual forecasts of groundwater levels on the territory of Ukraine, intended for planning, hydrometeorological, water management, agricultural and geological organizations; various ministries and agencies conducting water-ecological and ecological-geological research can be used to address issues related to the conditions of groundwater formation, the relationship of groundwater and surface water;
- hydrogeological yearbooks on the state of groundwater in Ukraine, containing generalized information within the administrative regions and basins of groundwater on the groundwater regime in natural and disturbed conditions, the quality of groundwater (main and potential sources of groundwater pollution, pollutants, groundwater content water pollutants, groundwater quality at water intakes): https://geoinf.kiev.ua/wp/wp-content/uploads/2021/08/schorichnyk_pv_2020.pdf.

Groundwater monitoring is carried out in general on the territory of Ukraine using the database AIS PEC, which was created in DNVP "Geoinform Ukraine" and contains following information (with the possibility of selecting data by region, water area, groundwater basins and river basins): (a) general data by water point, (b) index and interval of aquifer, (c) geological section of water point, (d) hydrogeological characteristics of water point (test results: flow, decrease, pressure, static level, filtration coefficients, water conductivity; filter: type, diameter, installation interval, etc.), (e)observation data on groundwater level position, (f) chemical composition catalogue of groundwater of the water station - general data and macrocomponents.

Groundwater monitoring in Ukraine is **carried out at two levels**:

- regional **-** in the state regional geological enterprises on the territory of activity where the primary information which is transferred to the state level is processed;
- state **-** in DNVP "Geoinform of Ukraine", which generalizes information at the regional level, stores it, analyses and processes it.

As of 2020, the network of observation points of state monitoring in the Vistula River Basin (Bug and San River Basins) includes 20 observation points, of which 12 are operational, 1 needs repair and 7 require inspection (Fig. 1).

Figure 2 State of observation points of the state groundwater monitoring of Ukraine by river basin districts for 2020.

Groundwater monitoring in Ukraine according to regulatory documents includes**:**

1) regional monitoring;
2) local monitoring;
3) special monitoring;
4) background monitoring.

1. Regional monitoring is organized and carried out within the administrative-territorial units, in the territories of separate economic and natural regions. At the regional level, the approach to monitoring is based on the fact that pollutants, when released into the environment, are dispersed, included in the cycle of substances in the biosphere. As a result, the state of the abiotic component of the environment changes, and as a consequence, there are changes in the biota (exogenous successions). Each economic event that takes place on a regional scale is reflected in the regional background - changes the state the abiotic and biotic component balance. The regional observation network studies the quality, level and regime of groundwater in large areas, where their condition is largely determined by natural hydrogeological conditions, the quality of infiltration of precipitation, the state of surface waters and soils. Observation points are selected so as to cover all aquifers perspective for drinking water supply. At the regional level, on a quarterly basis, an analysis of the relevant information received is carried out, the state of water bodies in their jurisdiction is assessed and management decisions to take the necessary measures to improve the situation (carried out by regional state administrations of executive authorities on environmental protection).

2. Local groundwater monitoring is carried out:

- at waste disposal and storage facilities with an area of more than 25 m^2 and (or) capacity of more than 5 thousand m^3/year;
- treatment facilities with a capacity of 50 thousand m^3/day and more that have sludge sites and sludge storage sites;
- livestock complexes with agricultural irrigation fields;
- oil storage facilities, oil refineries;
- other objects that have a harmful effect on groundwater, according to the results of special hydrogeological studies to assess the extent of harmful effects.

Other facilities that have a detrimental effect on groundwater, where local groundwater monitoring may be carried out, include:

- sites of industrial enterprises;
- places of storage and transportation of industrial products;
- places of collection and storage, objects of sorting, transportation, disposal, processing and placement of industrial waste, municipal and household waste;
- places of accumulation, objects of treatment (processing) and transportation of municipal, domestic and industrial sewage;
- facilities for treatment and transportation of rainwater;
- facilities for storage, transportation and release of oil and oil products, gas stations;
- categories of lands on which fertilizers, pesticides, plant protection products and other substances that may cause groundwater pollution are applied (agricultural lands, horticultural conglomerations societies and country houses, forest fund);
- agricultural production and facilities;
- landfills for the disposal of radioactive and radionuclide-contaminated substances, pesticides and other toxic substances;
- cooling ponds;
- contaminated areas of surface water bodies that supply groundwater;
- contaminated areas of relations (low-water) horizons (complexes), naturally or artificially connected with adjacent aquifers and surface waters;
- wells, quarries, mines and other mine workings areas;
- landfills for toxic substances and industrial waste;
- underground storage facilities for gas, oil and oil products;
- military facilities;
- areas contaminated with radionuclides;
- areas of infiltration of polluted precipitation.

The main tasks of local groundwater monitoring are:

- systematic observations for timely detection of groundwater pollution;
- study of the size and dynamics of groundwater pollution (speed and migration direction determination of pollution);
- study of pollutants migration in the groundwater, taking into account the physico-chemical interaction processes of these substances with groundwater and rocks and natural processes of self-purification of contaminated groundwater;
- forecast of the spread of polluted waters in the aquifer based on the results of observations of their actual movement to prepare proposals for water protection measures;
- delivery of information to support the management and control in the field of groundwater protection.

Criteria for locating local groundwater monitoring points are:

- representativeness of the network of groundwater monitoring points;
- minimum sufficiency of observation points to obtain the necessary information;
- the ratio of the accuracy of the information received and the cost of obtaining indicators over the years.

3. Special monitoring is designed to detect local groundwater pollution in areas of large industrial and agricultural facilities and centralized water intakes. Its main task is to assess the characteristics of the groundwater regime in terms of active anthropogenic activity. The information collection on the dynamics of changes in various ecological and hydrogeological parameters should be aimed at forecasting groundwater state in the future depending on the types and intensity of economic activity.

The main task in the field of control is to create a specialized monitoring network of wells in the area of large industrial and agricultural facilities and centralized water intakes, the activities of which are associated with groundwater pollution.

The tasks of specialized groundwater monitoring in areas of man-made impact are:

- systematic observations and timely detection of groundwater pollution, size determination of the pollution area;
- assessment of the scale and direction of hydrogeodynamic processes and modern groundwater pollution, study of the development of groundwater pollution in time and its area;
- forecast of changes in the levels and process of groundwater pollution, study of the pollutants migration in groundwater and preparation of proposals for water protection measures;
- study of pollutants migration in groundwater and migration parameters determination by observations of the dynamics of pollution;
- obtaining systematic and operational information on regime and quality changes of groundwater in order to prevent and take the necessary measures to prevent possible negative consequences.

4. Background monitoring is designed to study the natural (background) state of groundwater, which acts as a baseline, in relation to which the anthropogenic changes observed in groundwater are assessed. Background observations are rather a complex problem, as anthropogenic changes in areas not affected or slightly affected by economic activities and are difficult to detect, but their detection is necessary for timely action**.**

Background monitoring is carried out through systematic observations of water bodies that are not directly affected by anthropogenic impact, in order to obtain information for assessing and forecasting changes in the state of water bodies due to industrial and economic activities.

The background quality of groundwater is assessed by the reference observation network of wells. The background is divided into man-made and natural. The natural background of fresh groundwater includes such a state of water when the values of their quality indicators are close to or equal to the values of these indicators in natural conditions, that is, they differ from them by no more than 10%. The technogenic background includes the state of groundwater, when the values of quality indicators exceed the natural ones by more than 10%, and continue to remain at this level or grow over time.

The natural background within the studied aquifer is established by wells remote from sources of pollution, or by literature stock data. In cases where the original background of wells or literature sources cannot be established, the actual background is taken as natural. The background quality of groundwater is assessed by the wells of the reference observation network, which are outside the hydrochemical anomalies of groundwater due to the direct impact of man-made sources of pollution, i.e. along the contour of the area of man-made pollution.

Background quality is characterized by the groundwater horizon and the main operated pressure aquifer. To characterize the background quality of groundwater, the observation network state is first analysed in terms of: (a) the number of wells on the studied aquifers and (b) their distribution over the area; (c) depths of observation wells; (d) starting date of observations; and (e) technical condition of wells (suitable or unsuitable for observations). The information refers to those wells from which samples are taken for the chemical composition of groundwater.

Processing of materials for water quality observations in observation wells is carried out on separate horizons. For each well, the average annual values of mineralization, total hardness, oxygen concentration, Cl^-, $S0_4^{2-}$, NO_3^-; Fe^-, Mn^{2+}, F, Zn^{2+}, Pb^{2+}, t (temperatures) are determined. Working graphs of the values of these indicators are developed each year.

2 Principles of the organization of the transboundary network for monitoring the position of the water table and chemical monitoring

2.1 Recommendations contained in EU law and European Commission guidelines

The guidelines of WFD state that:

*„Common principles are needed in order to coordinate Member States' efforts to improve the protection of Community waters in terms of quantity and quality, to promote sustainable water use, **to contribute to the control of transboundary water problems**, to protect aquatic ecosystems, and **terrestrial ecosystems and wetlands directly depending on them**, and to safeguard and develop the potential uses of Community waters."*

Point 35 of the WFD states that:

"Within a river basin where use of water may have transboundary effects, the requirements for the achievement of the environmental objectives established under this Directive, and in particular all programs of measures, should be coordinated for the whole of the river basin district. For river basins extending beyond the boundaries of the Community, Member States should endeavor to ensure the appropriate coordination with the relevant non-member States. This Directive is to contribute to the implementation of Community obligations under international conventions on water protection and management, notably the United Nations Convention on the protection and use of transboundary water courses and international lakes, approved by Council Decision 95/308/EC(15) and any succeeding agreements on its application."

In line with the guidelines of the WFD: for bodies of groundwater where groundwater flow exceeds Member State boundaries, a sufficient number of monitoring points shall be provided to guide and estimate groundwater flow across Member State boundaries.

Based on the WFD guidelines, the aim of the transboundary groundwater monitoring network can be considered:

- assessment of the direction and intensity of groundwater flow across the state border;
- tracking groundwater quality of transboundary layers;
- identification and control of migration of potential pollutants across the state border.

According to the information provided in the previous chapter, the number of monitoring points in the quantitative monitoring network is insufficient to reliably determine the direction and estimate the amount of groundwater flow and to estimate the amount of groundwater flow in the state border profile. In practice, the discussed goal for individual border zones with neighboring countries has been implemented in detail as part of the implementation of dedicated tasks of the Polish Hydrogeological Survey: *"Estimation of the direction and size of flows and determination of groundwater chemistry in the profile of the state border with the countries of the European Union" and "Development of numerical models for JCWPd at risk of failing to achieve environmental objectives, with a weak state and for JCWPd proposed as transboundary".*

The guidelines of the EU methodological guides recommend the development of conceptual models of the JCWPd groundwater bodies, in order to, inter alia, determine the groundwater circulation system in the analyzed aquifer. Particular attention should be paid to JCWPds, the condition of which has been identified as endangered due to the identified or forecasted anthropogenic pressures. In the EU-WATERRES project, the level of detail of the study in this regard can be described as higher, due to the development of a numerical model of the groundwater filtration field, which covered the cross-border area of the Polish-Ukrainian borderland.

The observation and research network, due to its nationwide character and the applied criteria for selecting the location of observation points, does not allow for a comprehensive study of groundwater processes in the border zones of Poland, resulting, inter alia, from the economic activity of a neighboring country. Therefore, there is a need to expand the research monitoring network. Research on groundwater chemistry and their changes in border zones, as well as in selected areas, the impact of quantitative pressures are carried out in specially organized and developed groundwater research monitoring networks.

Groundwater research monitoring points are located taking into account the actual and potential impacts of pressures located on the territory of border states with a transboundary spread. Thus, one of the priority research monitoring tasks is implemented in accordance with 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), i.e., *identify the type, concentrations and extent of the pollution, if the body of groundwater has been contaminated or there are grounds for concluding that such a pollution hazard exists*. The research monitoring network complements the national monitoring network in zones that require additional diagnosis of the hydrogeological situation for reasons specific to a given area.

The following EU legal acts that apply in the organization of monitoring surveys in Poland's border zones are the following directives:

- Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration (Groundwater Directive, 2006);
- Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption (Drinking Water Directive, 1998).

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 Nº 3. Analysis of Pressures and Impacts (European Communities, 2003a);
- guidance document Nº 7. Monitoring under the Water Framework Directive (European Communities, 2003b);
- guidance Document Nº 15. Guidance on Groundwater Monitoring (European Communities, 2007a);
- guidance document Nº 16. Guidance on Groundwater in Drinking Water Protected Areas European Communities, (2006);
- guidance document Nº 17. Guidance on preventing or limiting direct and indirect inputs in the context of the groundwater directive 2006/118/EC (European Communities, 2007 b);
- guidance document Nº 18. Guidance on groundwater status and trend assessment European Communities, (2009a);
- guidance document Nº 21. Guidance for reporting under the Water Framework Directive

European Communities, (2009b);

- guidance document Nº 26. Guidance on risk assessment and the use of conceptual models for groundwater (European Communities, 2010);
- UNECE Task Force on Monitoring and Assessment. State of the art monitoring and assessment of groundwater. Uil, H., van Geer, F.C, Gehrels, J.C., Kloosterman, F.H. (1999) (Uil H. et al, 1999);
- technical report on groundwater quality trend and trend reversal assessment, (European Communities, 2019);
- guidelines on monitoring and assessment of transboundary groundwater (UNECE, 2000);
- 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.

2.2 The issue of border GWB

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

Border groundwater bodies are those units where at least one of the sections defining the border of JCWPd coincides with the state border, except for JCWPd bordering only the sea. The boundary of these JCWPd may be a land boundary, along a river or a border lake. The main research problem posed for these water bodies is:

- in the case of JCWPd located along the land border, if there are flows of groundwater through the border zone, and if they exist, in what direction and with what intensity, and whether substances classified as pollutants are transferred with the waters migrating across borders, or whether there is a pressure on the territory of a neighboring country that may affect the quantitative status of groundwater. If a transfer of pollutants is found, then their concentrations and pressure should be determined, pollutant hotspots causing their appearance in groundwater should be identified or the impact of pressure on the quantitative status determined and remedial measures established in cooperation with the neighboring country;
- in the case of JCWPd located along the border river, it is necessary to determine the nature of hydraulic connection of groundwater with surface waters (whether the river is draining or has an infiltrating nature), whether there may be a transboundary groundwater flow downstream of the river bed. If such a flow occurs, then it should be established within which aquifers or complexes, whether there is a transfer of pollutants with groundwater, or whether there is a pressure in the territory of a neighboring country that may affect the quantitative status of the groundwater. After determining the transfer of pollutants, one should determine their concentration and pressure, identify the pollution hotspots causing their appearance in groundwater or determine the impact of pressure on the quantitative status and determine remedial measures in cooperation

with the neighboring state.

Monitoring observations of the water table level and research of the chemical status of groundwater along the Polish borders are carried out as part of the task of the Polish Hydrogeological Survey entitled: *"Monitoring of groundwater in the border zones of the Republic of Poland for the purposes of implementing agreements and international cooperation"*.

The Polish Hydrogeological Survey (PSH) 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 PSH are related to the direct implementation of tasks coordinated by the Minister of Maritime Economy and Inland Navigation, the Minister of the Environment, the State Water Holding, the Chief Inspectorate of Environmental Protection. They are carried out in international Commissions and Working Groups, in the works of which representatives of the Polish Geological Institute - National Research Institute participate as delegates or experts:

- The International Commission for the Protection of the Odra River against Pollution (MKOOpZ);
- Commission for Border Waters: Polish-German, Polish-Czech, Polish-Slovak, Polish-Ukrainian and Polish-Lithuanian.

Arrangements regarding the scope and form of groundwater monitoring in border zones, which are subject to the activities of individual international commissions, take precedence over national arrangements. The number of transboundary monitoring points and study areas depends on the decisions made by the committees for border waters.

A very important element in creating a representative transboundary monitoring network is international cooperation and the exchange of information on hydrogeological conditions, data on pollution hotspots and the volume and structure of water use along individual border sections. Demonstrating or confirming the existence or absence of transboundary groundwater flows is also important for the assessment of the credibility and the obtained degree of harmonization of the assessment of the state of JCWPd on an international scale.

2.3 Principles of the organization of the transboundary groundwater monitoring network

Due to the tasks set for individual types of groundwater monitoring functioning in Poland, a special role was decided to the research aspects of the development of monitoring studies under the EU-WATERRES project.

The main principles of the organization of the transboundary groundwater monitoring network in the Polish-Ukrainian border zone include the following criteria:

- groundwater monitoring should be carried out in border zones where transboundary groundwater flows occur;
- the groundwater monitoring network should be organized in a way that allows to obtain a consistent monitoring of the groundwater table level and physicochemical tests of groundwater in the border zone, especially in the areas of potential impact on the quantitative status and allowing for the assessment of the pressure of substances classified as pollutants that move or potentially migrate in groundwater flowing across borders;
- efforts should be made to jointly develop and implement coherent actions regarding a unified approach towards: the scope and method of groundwater monitoring in the

Polish-Ukrainian border area, which will allow obtaining measurement and monitoring results of a comparable standard;

- the scope and frequency of chemical monitoring of groundwater should be adapted to the nature and magnitude of anthropogenic impact causing pressure or likely to affect transboundary aquifers;
- the methodology of joint measurements and monitoring tests should be developed with the use of reference methods, in accordance with accreditation standards in force in cooperating countries, standardized for the purposes of international cooperation, possibly also taking into account international recommendations and standards. Appropriate quality management systems should be introduced at all stages of measurement and monitoring. The results of measurements and tests should be supported by reporting the results of the assessment of levels of uncertainty, confidence and accuracy.

A very important element of international cooperation is the exchange of information on hydrogeological conditions, pollution hotspots and the size and structure of water use in individual border areas.

The organization of the transboundary monitoring network should be guided by its tasks, therefore the starting point for the design of this network should be the results of the characteristics of transboundary GWB, including conceptual models, and the assessment of the risk of groundwater pollution within them.

Due to the high contrast of entry (starting) conditions for the development of rules for the organization of transboundary monitoring networks between Poland and Ukraine, this task is not that simple. In Poland, transboundary GWB have already been defined, conceptual models of JCWPd have also been developed and an assessment of anthropogenic hazards, the susceptibility of groundwater to the impact of anthropogenic pressure and the risk of pollution has been defined. In Ukraine, however, work on the delineation of GWB has only just begun. The remaining issues are at the stage of research and local approvals. For this reason, the transfer of experience is very important. It will allow Ukraine, already at the stage of developing its assumptions, to implement a unified approach with Poland, based on EU law.

In line with Ukraine's national regulations, the purpose of the transboundary groundwater monitoring network is to prevent adverse transboundary impacts. When organizing this network, the priorities are as follows:

- Identification of transboundary groundwater masses and boundary groundwater bodies;
- Harmonisation and identification of aquifers occurring in the transboundary setting;
- Identification of transboundary flows and their directions;
- Identification of potential sources of groundwater pollution and routes of harmful substances migration.

In line with the above tasks of the transboundary network and the position of Ukrainian experts in the field of groundwater monitoring, the following principles should guide the organization of a transboundary groundwater monitoring network:

- to monitor groundwater bodies being classified as the transboundary ones;
- to consider the direction of groundwater flow across the national border in order to detect the migration of harmful substances;
- to harmonise and unify forms and procedures used for groundwater monitoring by neighbouring states to obtain reliable and valid data;
- to provide reliable estimates of the variability of transboundary flows based on the extent

and frequency of quantitative monitoring;
- to determine the intensity of pressures within the transboundary area based on the extent and frequency of the chemical monitoring;
- to comply with international standards in terms of measurement and research methodologies.

On the basis of the Polish-Ukrainian arrangements carried out under the EU-WATERRES project, common rules for the organization of the transboundary groundwater monitoring network were formulated:

- monitoring should be carried out in an area that has been jointly identified as an area with transboundary groundwater flows;
- the design of the network is done in a way that allows to obtain a coherent and comprehensive picture of the groundwater flow through the border zone and the substances transferred by them, classified as pollutants;
- the approaches to the form and method of monitoring will be consistent and harmonized between Ukraine and Poland, with the goal of using reliable and comparable methods of groundwater monitoring;
- the scope and frequency of quantitative monitoring should be sufficient to make a reliable assessment of the variability of the intensity of transboundary flows;
- the scope and frequency of chemical status monitoring should depend on the nature of the identified anthropogenic impacts affecting transboundary aquifers;
- measurement and research methodologies should be based on reference methods standardized by international standards. Moreover, the quality of measurements and research should be ensured, inter alia, by operating a two-stage control system. Appropriate quality management systems defined in international standards should be introduced at all stages of measurement and testing. The results of measurements and research should be supported by reporting the results of the assessment of levels of uncertainty, confidence and accuracy.

3 Criteria for designating measurement points for a transboundary groundwater network for monitoring the position of the water table and chemical monitoring

3.1 Requirements for selecting a measuring point according to WFD and national regulations

According to the WFD, the selection of the measuring point should enable:

- reliable assessment of the quantitative status of JCWPd and obtaining a coherent and comprehensive picture of the chemical status of groundwater;
- obtaining representative data from monitoring studies;
- identification of significant and sustained upward trends in pollutant concentrations sufficiently to distinguish them, with an appropriate level of certainty and precision, from natural changes, and over time to apply measures to prevent or at least mitigate as far as possible environmentally significant adverse changes in groundwater quality.

In accordance with the *Regulation of the Minister of Maritime Economy and Inland Navigation of 9 October 2019 on the forms and methods of monitoring of surface water bodies and groundwater bodies (Journal of Laws, 2019; item 2147)*, groundwater observation points in Poland should meet the following criteria:

- enabling selective water intake from the investigated aquifer;
- monitoring of transboundary aquifers;
- hydraulic efficiency, appropriate (good) technical condition and enabling proper water sampling and water level measurement;
- type of material the observation point is made of;
- protection against interference by unauthorized persons;
- availability of geological documentation referred to in *the Act of 9 June 2011 Geological and Mining Law (Journal of Laws, 2019; item 868, as amended)*; geological profile and hydrogeological object card, containing data on the structure of the borehole and the hydrogeological parameters of the aquifer;
- regulated legal status of the real estate on which the measuring point is located;
- consent to conduct long-term groundwater monitoring observations.

Taking into account the priorities of chemical groundwater monitoring, observation points of the transboundary network should be located representatively, taking into account: the location and nature (local, area) of existing or forecast anthropogenic pressures (pollution hotspots) on the quality of groundwater and the sensitivity of the aquifer to the penetration or inflow of substances classified as pollutants. The most important elements of determining representative locations of monitoring points include: hydrogeological parameters of transboundary aquifers, groundwater flow conditions and the aquifers' susceptibility to pollution, including lithology and the characteristics of the overburden and the soil layer. The number of monitoring points focused on chemical research should be increased in areas with increased susceptibility of aquifers to pollution, under the influence of pollution hotspots and JCWPds identified as endangered. Both piezometers, out of service hydrogeological wells and active drilled wells in municipal or rural groundwater intakes can be included in the chemical status observations.

In case of the location of monitoring points for observation of the level of the groundwater table, in addition to the criterion of representativeness allowing for the determination or verification of the directions of transboundary groundwater flows and the monitoring of the amount of water transboundary flowing, it is important to locate some of the points in selected areas exposed to quantitative pressures, e.g. the impact of high water abstraction. The scope and frequency of the monitoring measurements carried out should allow for the identification of significant trends in changes, characteristic for the examined unit / structure.

3.2 Principles of designating measurement points for the transboundary groundwater monitoring network

Principles of designating measurement points for the organization of a transboundary groundwater monitoring network are:

- the location of groundwater monitoring points should take into account the diversity of hydrogeological conditions, with particular emphasis on the occurrence and functional properties of aquifers with transboundary spread;
- location of groundwater monitoring points in relation to the location of protected areas, including groundwater-dependent ecosystems, main groundwater reservoirs and anthropogenic transboundary impacts;
- the number of measurement points should depend on the degree of complexity of the conditions of occurrence of transboundary aquifers / aquitards, the nature and intensity of anthropogenic pressure on groundwater and the susceptibility of the aquifers in question to the penetration of pollutants.

In accordance with the *Regulation of the Minister of Maritime Economy and Inland Navigation of 9 October 2019 on the forms and methods of monitoring surface water bodies and groundwater bodies (Journal of Laws, 2019, item 2147)*, monitoring points should meet the following criteria:

- enable selective water intake from a given aquifer;
- have hydraulic efficiency, which enables correct water sampling or water level measurement;
- be made of materials that do not change the chemical composition of water;
- be protected against interference by unauthorized persons;
- have geological documentation referred to in the Act of June 9, 2011 Geological and Mining Law (Journal of Laws, 2020; item 1064) and documentation of the well construction and equipment;
- have a regulated legal status of the real estate on which the observation point is located.

In addition to the criteria directly resulting from the provisions of the Regulation (Journal of Laws 2019, item 2147), observation points should:

- have the possibility of year-round, unlimited travel and access to them;
- have technical capabilities to install and operate automatic measuring devices, e.g. in scope of groundwater table level measurements.

With regard to the tasks of transboundary monitoring and taking into account the framework requirements for the measurement points presented above, the principles of designating measurement points integrated between Poland and Ukraine for the purposes of this monitoring have been proposed:

- the location of points should take into account the variety of conditions for transboundary flows, in particular the presence and characteristics of transboundary useful aquifers;
- the location of protected areas, including the main groundwater reservoirs and the extent of anthropogenic transboundary impacts;
- the number of measurement points should depend on the complexity of the conditions of

the presence of transboundary aquifers, the intensity of anthropogenic pressure and the susceptibility of these aquifers to the migration of pollutants;

- measurement points should enable selective water collection from the monitored aquifer; have hydraulic efficiency, which enables correct water sampling or water table measurement; be made of materials that do not change the chemical composition of the water; be protected against interference by unauthorized persons; have geological documentation and documentation of the structure and equipment of the borehole.

In line with the guidelines set out above, the following key criteria for designating measuring points for the organization of a transboundary groundwater monitoring network are:

- the occurrence and properties of transboundary aquifers of major useful aquifer character;
- vulnerability of groundwater to contamination, assessed mainly basing on percolation of water through the aeration zone, soil composition and geology;
- risk areas where the groundwater system is exposed to contamination or lowering of the water table;
- areas of identified water quality problems in transboundary aquifers (e.g. acidification, nutrients, salinity, pollution, etc.);
- areas prone to adverse transboundary impacts;
- the location of protected areas, especially due to the presence of groundwater-dependent ecosystems.

3.3 Method of designating places of particular importance for the development of a transboundary groundwater monitoring network

Significant criteria for determining the location of observation points for the organization of a transboundary groundwater monitoring network should take into account the following elements:

- the occurrence and characteristics of transboundary aquifers of the importance of the main useful level or other useful level important due to its resources and its linkage with water-dependent ecosystems;
- groundwater susceptibility to pollution, assessed mainly on the basis of seepage of water through the aeration zone and formation of overburden deposits;
- areas at risk of anthropogenic pressures, where groundwater is exposed to pollution or impacts on the water table;
- areas with identified water quality problems in transboundary aquifers (e.g. pollution, saline inflow, increased acidification, nutrients, nitrogen and phosphorus compounds, etc.);
- aquifers in border areas which are or may be exposed to adverse transboundary impacts;
- the location of protected areas, especially due to the presence of groundwater-dependent ecosystems.

In the first stage of substantive works, an assessment of the suitability of the already existing monitoring points of national (Polish and Ukrainian) observation and research networks (quantitative monitoring) for research in the transboundary monitoring network was carried out.

In Poland, based on the verification of the representativeness of the discussed objects, there were no relevant points that, due to their location, would meet the criteria for points useful in cross-border research. In the years 2015-2016, for the needs of research in the border area between Poland and Ukraine, piezometers for research monitoring were specially designed and made. Piezometers were located in the villages of: Budzyń, Skolin and two observation wells in the vicinity of Huta Kryształowa, in the areas of potential impact of transboundary pressures on groundwater in the Polish border zone. Additionally, the monitoring studies included surface waters: the Lubaczówka River (Nowa Rzeka) and the Szkło River, which flow from Ukraine into the territory of Poland. Surface water research include, inter alia, cyclical physicochemical analyzes of water samples.

In Ukraine, the assessment of the representativeness of the points of the national groundwater monitoring network in relation to the requirements for points useful for the transboundary network was carried out in the following steps:

1) the main usable aquifers in the border area were agreed between the representatives of the working groups of Poland and Ukraine. For this purpose, information and cartographic materials were exchanged and meetings were held to agree a common position. As a result, vector maps and hydro-geological cross-sections (profiles) have been generated based on hydro-geological materials and their analysis. With use of the mathematical modeling methods the flow directions have been identified and the balance of transboundary useful aquifer has been evaluated. Moreover, it was established that the transboundary groundwater flow in usable aquifers between Poland and Ukraine takes place at certain parts of the border;
2) transboundary floods are triggers for the transit of pollutants and harmful substances between the territories of two countries. Therefore, exactly this parameter (criterion) is decisive for the designation of monitoring points placement. When deciding on their location, the presence of potential pollution sources (mining, chemical, food industry, agriculture, utility facilities) should be taken into account;
3) groundwater quality monitoring points should be located in the areas where pollution risks may arise as well as at already identified sites hosting polluted waters. Moreover, the establishment of such points within the protected territories and protection areas will ensure monitoring of waters in their natural condition, free from anthropogenic pressure. Such results can be taken as a "reference sample", which will allow for identification of harmful elements or their concentrations in the waters being at risk of pollution. Sometimes elevated concentrations of certain components in the groundwater are of quite natural origin and are attributed to their intense leaching caused by the water-bearing or overlying rocks;
4) quantitative monitoring points should be located within the protected territories, in wetlands where groundwater level decrease poses a risk to the ecosystems. Furthermore, in order to prevent aquifer depletion, quantitative monitoring points should be designed in the vicinity of existing water intakes. It is practical to arrange boreholes in such a manner that the magnitude of a depression cone can be measured. In most cases, both quantitative and qualitative monitoring can be carried out at the same point;
5) when indicating the suitability of the existing monitoring points to the transboundary network following data were taken into consideration: complete and valid geological and technical information related to a borehole, the "history", i.e. monitoring done in previous years, location in a protected environment, confinement to a specific aquifer, the borehole equipment material should not significantly change the water composition.

Basing on the concept of a uniform approach to designating potentially prospective areas in terms of the location of new groundwater monitoring points in the border zone between Poland and Ukraine, for the development of cross-border cooperation, in the first stage of the work, a unique approach using the validation method was implemented. In the validation method, it was proposed to take into account factors, some of which were directly related. The following seven parameters were analyzed:

1) occurrence and spatial distribution of transboundary aquifers, possible transboundary flows, hydrogeological characteristics and hydrodynamic conditions;
2) pollution hotspots;
3) water-dependent ecosystems;
4) mining areas and unreclaimed mining areas;
5) active groundwater intakes;
6) protected areas;
7) groundwater susceptibility to pollution.

The designation of sites with particular perspectives in terms of the potential location of measuring points useful in the transboundary groundwater monitoring network was carried out on the basis of the validation of the terrain surface with a method based on a system assigning a specific value to individual parameters considered as decisive for the assessment. The work in the described scope was carried out in the GIS software with the use of, inter alia, spatial analysis. The research area, adjusted to the range of the hydrodynamic numerical model in the Polish-Ukrainian border zone, was covered with a discretization grid dividing the space into blocks of 500 x 500 m.

The individual parameters included in the considered method were analyzed as spatial information concerning:

1) identification of appropriate hydrogeological conditions ensuring the transboundary continuity of the aquifer and the possibility of transboundary flows;

2) the occurrence of pollution outbreaks with a possible transboundary impact on groundwater and related elements of the environment. Analysis of GIS information layers for spatial identification of: municipal or industrial wastewater treatment plants, petrol stations, waste landfills, storage of hazardous substances, landfills for the most hazardous substances, etc. From the group of the above-mentioned objects, there were selected those located in areas with favorable hydrogeological conditions, which may favor the transboundary migration of the pressure of pollutants;

3) the occurrence of water-dependent ecosystems. The GIS analysis covered the presence of permanent and periodic wetlands with an area of over 1 ha;

4) occurrence of mining areas and unreclaimed mining areas. Analysis of cartographic information for the spatial identification of mining areas with a possible negative, transboundary impact on the soil and water environment, including groundwater;

5) identification of active groundwater intakes - the analysis covers the existence of active groundwater intakes or groups of groundwater intakes with approved exploitation resources in the amount exceeding 50 m^3/d, collecting waters of aquifers with transboundary spread. The results of this analysis were to enable the selection of intakes that could potentially have an impact on a significant lowering of the groundwater table (range of the depression cone), exceeding the state border. Moreover, the results of the analysis of this parameter were considered in the context of the location of new monitoring points on the groundwater inflow to municipal intakes, which are a source of collective drinking water supply and for economic purposes;

6) the presence of protected areas - analysis of spatial information about the existence of nature reserves, national parks, landscape parks and protected areas of the European

Natura 2000 Network;

7) vulnerability areas to groundwater pollution, which can penetrate from the ground surface according to the hydrogeological mapping divisions.

Table 1 Parameters and criteria for area validation

Validation parameters	Validation criteria	
	occurs	doesn`t occur
Parameter 1. Transboundary continuity of the aquifer and possible transboundary flows	1	0
Parameter 2. Pollution hotspots	1	0
Parameter 3. Water-dependent ecosystems	1	0
Parameter 4. Mining areas and unreclaimed mining areas	1	0
Parameter 5. Active groundwater intakes	1	0
Parameter 6. Protected areas	1	0
Parameter 7. Vulnerability areas to groundwater pollution	1	0

Discretization grid blocks that received a positive validation qualification were qualified for the next stage of the analysis, which consisted of verifying the presence of observational hydrogeological wells within them. Project partners from Poland and Ukraine were left to decide in the order of applying individual criteria and significance of validation parameters. The expert analysis was of key importance after the initial assessment with the validation method. All monitoring sites selected in this process should be considered as potentially useful for qualification to the transboundary groundwater monitoring network. Priority should be given to points of national groundwater monitoring networks, while additional points should be given to drilled wells and hydrogeological wells with appropriate technical condition, where groundwater abstraction in the surrounding areas does not have a significant impact on the natural changes in the position of the groundwater table. In the absence of representative observation points or hydrogeological wells, it was recommended to designate prospective areas for making new observation wells.

4 Characteristics of measuring points qualified for the organization of the transboundary groundwater monitoring network

4.1 Observation points qualified for the creation of a Polish-Ukrainian transboundary groundwater monitoring network in Ukraine

The existing Ukrainian national groundwater monitoring network for the Vistula River basin in the near-border areas includes 19 monitoring points distributed unevenly over the sub-basin territories (Fig. 3). In the sub-basin of the Bug River (in Ukraine, the river is called the Western Bug) there are 10 observation points located individually (pointwise), whereas in the sub-basin of the San River there are 9 points of which 6 exist within the limits of Shklo settlement (medicinal mineral water field).

Figure 3 National groundwater monitoring network in the Vistula River Basin

National groundwater monitoring of near-border areas is focused on the alQ (alluvial sandstone deposits in river floodplains and supra-floodplain terraces), N_1 (sandstone and limestone porous-fractured sediments) and K_2 (marl-chalk fractured sediments) aquifers.

The network is designed for the quantitative and qualitative groundwater monitoring. It is formed by monitoring boreholes built in the 60s–80s of the last century and equipped with casing metal pipes of 108–168 mm in diameter.

Table 2 provides the characteristics of existing observation points located within the region adjacent to the Polish border.

Table 2 Characteristics of existing observation points within the Vistula River basin (Ukraine)

No. p/o	Settlement	Wellhead range [m]	Hydrostratigraphic index	Start of monitoring [year]	Well depth	Groundwater table level [m]	Location type	Aquifer interval [m]	Aquifer type	Technical status
				The Bug River sub-basin Lviv Region						
360485	Stare Selo	233.3	K_2	1985	60.3	1.7	natural	26-35	confined	active
368440	Klebany	265.9	K_2	1985	49.9	3.0	natural	19-49	confined	active
368441	Zamok	265.9	K_2	1985	35	2.0	natural	23-42	confined	active
368438	Monastyrok	260.9	K_2	1985	35	+0.5	natural	17-35	confined	active
680011	Mezhyrichcha	190.4	K_2	1981	12.5	2.5	mineral extraction	32-72	confined	active
268684	Kulychkiv	204.9	K_2	1987	50.0	2.3	natural	25-50	confined	active
268683	Kulychkiv	204.8	Q	1986	6.0	+0.16	natural	1-6	Semi-confined	active
721986	Staivka	199.2	K_2	1987	70	1.97	melioration area	15-50	confined	needs clearing
				Volyn Region						
020001	Svytiaz	165.2	K_2	1986	90	+0.1	natural	6.5-90	confined	active
021005	Omeliane	167.6	K_2	1986	80	1.9	natural		confined	inactive
				The San River sub-basin						
670007	Kruviaky	199.1	Q	1979	36	0.8	natural	2.4-16	semi-confined	active
678808	Sokolia	202.6	Q	1988	15	2.04	natural	7-13	confined	active
400003	Shklo (health resort)	247.8	N_1s_1	1966	14.2	6.0	natural	6.5-14	semi-confined	active
400006	Shklo (health resort)	248.1	N_1b_2	1967	60.3	25.0	natural	24-64	confined	active
400015	Shklo (health resort)	247.5	N_1b_2	1967	61.3	20.0	natural	23-61	confined	active
400017	Shklo (health resort)	247.8	N_1S_1	1967	6.6	1.0	natural	1.5-6	semi-confined	active
110017	Shklo	275.6	Q	1974	10.7	0.2	water intake impact	3.4-7.8	semi-confined	active
110021	Shklo	274.7	N_1b	1974	38.8	32.0	water intake impact	31-35	confined	active
658544	Seredkevychi	292.2	N_1	1985	58.4	+0.72	natural	30-58	confined	temporarily inactive

Based on the criteria given in Section 3.2, the eligibility of the points of the national network has been qualified for the purposes of transboundary monitoring (Table 3).

Table 3 Qualification of existing monitoring points in the Vistula River basin (within Ukraine) for the purposes of transboundary groundwater monitoring

No. p/o	Location	Parameters						
		1	2	3	4	5	6	7
	The Bug River sub-basin Lviv Region							
360485	Stare Selo	1	0	0	0	1	1	1
368440	Klebany	1	0	1	0	0	1	1
368441	Zamok	0	0	0	0	0	0	1
368438	Monastyrok	1	0	0	0	0	0	1
680011	Mezhyrichcha	1	1	1	1	0	0	1
268684	Kulychkiv	1	1	1	0	0	1	1
268683	Kulychkiv	1	1	1	0	0	1	1
721986	Staivka	1	0	0	0	0	0	1
	Volyn Region							
020001	Svytiaz	0	0	0	0	0	1	1
021005	Omeliane	0	0	0	0	0	0	1
	The San River sub-basin							
670007	Kruviaky	1	0	0	0	0	0	1
678808	Sokolia	1	0	0	0	0	0	1
400003	Shklo (health resort)	1	0	1	1	1	1	1
400006	Shklo (health resort)	1	0	1	1	1	1	1
400015	Shklo (health resort)	1	0	1	1	1	1	1
400017	Shklo (health resort)	1	0	1	1	1	1	1
110017	Shklo	1	0	1	1	1	1	1
110021	Shklo	1	0	1	1	1	1	1
658544	Seredkevychi	1	0	0	0	0	0	1

Under the performed assessment, eight points of the national network have been selected for the purposes of transboundary monitoring (Table 4).

Given the absence of transboundary flows in the TGR of the Bug River within the Volyn region, the existing wells are not considered to be included in the transboundary monitoring network.

Within the TGR of the Bug River all four specified wells are suitable for comprehensive (quantitative and qualitative) monitoring of the K_2 aquifer.

Within TGR of the San River transboundary groundwater monitoring can be performed for N_1 and alQ aquifers. Given the location of points No. 670007, 678808 and 110017 in zones influenced by water intakes, only groundwater quality monitoring can be performed there. Observation point No. 400006 is eligible for integrated monitoring.

Table 4 Observation points qualified for the transboundary groundwater monitoring network

No. p/o	Location	Aquifer	Well depth [m]	Groundwater table level [m]	Aquifer interval [m]	Location type	Aquifer type	Monitoring type
TGR Bug								
360485	Stare Selo	K_2	60.3	1.7	26-35	natural	confined	integrated
368440	Klebany	K_2	49.9	3.0	19-49	natural	confined	integrated
368438	Monastyrok	K_2	35	+0.5	17-35	natural	confined	integrated
721986	Staivka	K_2	70	1.97	15-50	melioration area	confined	integrated
TGR San								
670007	Kruviaky	alQ	36	0.8	2.4-16	water intake	semi-confined	chemical
678808	Sokolia	alQ	15	2.04	7-13	water intake	confined	chemical
400006	Shklo (health resort)	N_1	60.3	25.0	24-64	natural	confined	integrated
110017	Shklo	alQ	10.7	0.2	3.4-7.8	water intake	semi-confined	chemical

4.2 Observation points qualified for the creation of a Polish-Ukrainian transboundary groundwater monitoring network in Poland

In the border zone between Poland and Ukraine, there are points of the national groundwater observation and research network (Table 5), as well as groundwater research monitoring points (Table 6), included in the monitoring network specifically for the needs of border / cross-border research.

Table 5 Observation points for the national groundwater observation and research network, located in the border zone between Poland and Ukraine.

Point number of the groundwater observation and research network	Voivodeship	District	Community	Type of point	Stratigraphy	Type of aquifer	JCWPd 172
II/337/1	lubelskie	hrubieszowski	Werbkowice	Drilled well	K_2	porous-fracture	121
II/514/1	lubelskie	włodawski	Wola Uhruska	Drilled well	K_2	porous-fracture	67
II/551/1	podkarpackie	lubaczowski	Horyniec-Zdrój	Drilled well	K_2	fracture-karst	121
II/594/1	lubelskie	włodawski	Wola Uhruska	Drilled well	K+Q	fracture-karst	67
II/598/1	podkarpackie	lubaczowski	Lubaczów	Drilled well	Q	porous	136
II/599/1	podkarpackie	lubaczowski	Narol	Drilled well	K		120

Point number of the groundwater observation and research network	Voivodeship	District	Community	Type of point	Stratigraphy	Type of aquifer	JCWPd 172
II/842/1	podkarpackie	bieszczadzki	Ustrzyki Dolne	Drilled well	PgOl	porous-fracture	169
II/1077/1	lubelskie	tomaszowski	Telatyn	Drilled well	K_2	porous-fracture	121
II/1078/1	lubelskie	hrubieszowski	Dołhobyczów	Drilled well	K_2	Porous-fracture-karst	121
II/1079/1	lubelskie	hrubieszowski	Horodło	Drilled well	K_2	porous-fracture	121
II/1080/1	lubelskie	chełmski	Dubienka	Drilled well	K_2	porous-fracture	121
II/1520/1	lubelskie	hrubieszowski	Dołhobyczów	Drilled well	K_2	porous-fracture	121
II/1672/1	podkarpackie	bieszczadzki	Lutowiska	piezometer	Pg	porous-fracture	168
II/1673/1	podkarpackie	bieszczadzki	Ustrzyki Dolne	piezometer	Pg+Q	porous-fracture	169

The points of the national groundwater observation and research network, which are located in the border zone between Poland and Ukraine, pursue other objectives and are not located representatively in terms of research on transboundary aquifers. Most of the points in question monitor the waters of the main usable aquifers, most often the Cretaceous and Quaternary (in the southern part of the border zone). The research results from these points may constitute the basis for the assessment of the chemical state of the border parts of JCWPd, however, due to the distance from the state border or location in relation to hydrodynamic zones, they do not provide data for the assessment of transboundary impacts.

In view of the above, a decision was made to develop monitoring studies at research monitoring points in the border area specially made for this purpose. Groundwater research monitoring observation sites mostly meet the criteria of representativeness for the border zone monitoring points. Most of the discussed points are located in the southern part of the border with Ukraine, in the area of the potential impact of areas related to sulfur mining. The usable aquifer in these areas is developed in the Quaternary formations. In addition, monitoring studies were supplemented with monitoring studies of surface waters, which are carried out at points located on the rivers crossing the Polish-Ukrainian border: Lubaczówka and Szkło.

Table 6 Observation points for research monitoring of groundwater and monitoring of surface waters, located in the border zone between Poland and Ukraine.

Point number of the groundwater observation and research network	Voivodeship	District	Community	Type of point	Stratigraphy	Type of aquifer	JCWPd 172
401001	podkarpackie	włodawski	Lubaczów	piezometr	Q	porous	136
401002	podkarpackie	lubaczowski	Lubaczów	piezometr	Q	porous	136
401003	podkarpackie	hrubieszowski	Radymno	piezometr	Q	porous	136
401004	podkarpackie	lubaczowski	Wielkie Oczy	drilled well	Q	porous	136
401005	podkarpackie	bieszczadzki	Wielkie Oczy	piezometr	Q	porous	136
401006	lubelskie	włodawski	Dołhobyczów	drilled well	K_2	Fracture-karst	121
Surface water monitoring observation points							
401P01	podkarpackie	tomaszowski	Radymno	surface water monitoring site			136
401P02	podkarpackie	lubaczowski	Lubaczów	surface water monitoring site			136

The locations of the points of the national groundwater observation and research network and groundwater research monitoring are shown in Figure 4.

Figure 4 Observation points of the groundwater observation and research network and groundwater research monitoring network, located in the border zone between Poland and Ukraine, against the background of the division into groundwater bodies

4.3 Observation points qualified for the creation of a Ukrainian-Belarusian transboundary groundwater monitoring network in Ukraine

Analysis of hydrogeological conditions and parameters within the border areas of the Volyn region according to the criteria adopted by the EU-WATERRES project for transboundary groundwater monitoring network shows the absence of significant transboundary groundwater flows between Ukraine and Poland. Virtually all groundwater flows in this area end with their unloading in the Bug riverbed at the UKR-PL border.

At the same time, in the north-western part of the Volyn border area in the interfluve of the rivers Pripyat and Bug Shatsk National Nature Park is located (quantitative monitoring point 9, Fig. 5). Since 2002 the Park has become a part of the Transboundary Biosphere Reserve "Western

Polissya" organized by the UNESCO International Environment Program "Man and Biosphere". By the nature of the lake and wetland complex, the territory of Shatsk National Park has no analogues in Ukraine.

Over the last two decades, environmental problems have been observed within this area due to the lowering of the surface and groundwater level, which threatens the preservation of the entire ecosystem of the protected area of international importance.

This problem is of a great concern to the scientific community of Ukraine and has been the subject of long discussions in recent years. One of the reasons of this problem is the development of a deposit storage site of building materials (sand, chalk, mining of which began in 2009) within the limits of the Khotyslavsky quarry, which is located in the Republic of Belarus (0.4 km from the border with Ukraine). Hydrogeological conditions for field development are unfavorable, as the extraction of sand and chalk-marl raw materials is carried out resulting in a decrease of the level of groundwater, which leads to geoecological changes in the vicinity of the quarry and aquatic landscape (Martyniuk et al., 2020).

According to the latest news the Institute of Water Problems and Land Reclamation of NAAS of Ukraine has performed scientific research in the interfluve of the Pripyat and Bug rivers. The current state and peculiarities of hydrological and hydrogeological conditions of Shatsk Lakes were studied and the main causes of natural water level fluctuations were analyzed (Yatsiuk et al., 2021).

Significant shallowing of the lake Svityaz in 2019 and the uncertainty of the impact of anthropogenic factors on this process, led to the implementation of water balance calculations of the lake and surrounding areas according to the ongoing hydrometeorological and hydrogeological monitoring for the entire period of observations until 2020 (Fig. 5-7).

According to scientists, precipitation (rain, snow) and partial discharge of water from the Cretaceous horizons are the main sources of water in rivers, lakes and groundwater in the study area (Yatsiuk et al., 2021). In recent years, there has been a trend of significant changes of precipitation amount by months during the year. In addition, there are a number of concern factors related to the increasing intensity of Upper Cretaceous confined aquifer exploitation in the period, large-scale changes in the first from the ground level aquifer (intensive private agricultural use of land adjacent to the lake), and the continuation of building material extraction in the Khotislavsky quarry with a significant drainage of groundwater.

Studies of the groundwater level of existing wells have shown that in 2020 their levels increased slightly compared to 2015-2019, due to the significant amount of precipitation during this period, i.e. insufficient moisture changed to the excess moisture. The regime of groundwater levels in the Shatsk Lakes is directly dependent on precipitation and air temperature (Fig. 6-7).

The negative effects of climate change, in addition to the direct impact, reinforces the negative role of other factors in the formation of the regional water balance. The hydrological feature of the territory of Shatsk National Park is the close hydraulic and dynamic interconnection of aquifers, which do not have a clear impermeable layer. This pattern allows us to conclude that the violation of at least one component of the water regime causes deformation of the regime and balance of all components of the aquatic ecosystem (Yatsiuk et al., 2021).

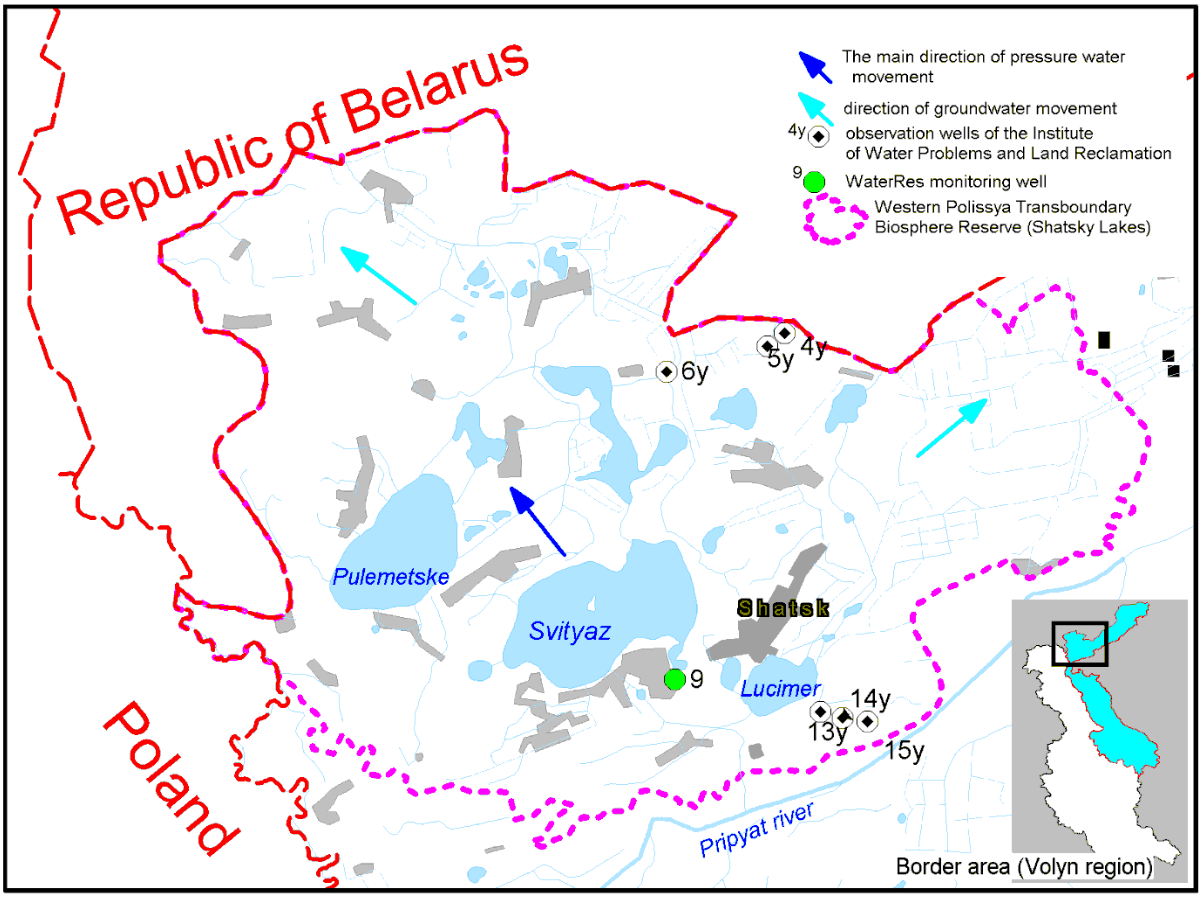


Figure 5 Hydrological scheme of the Transboundary Biosphere Reserve "Western Polissya" (Shatsk Lakes)

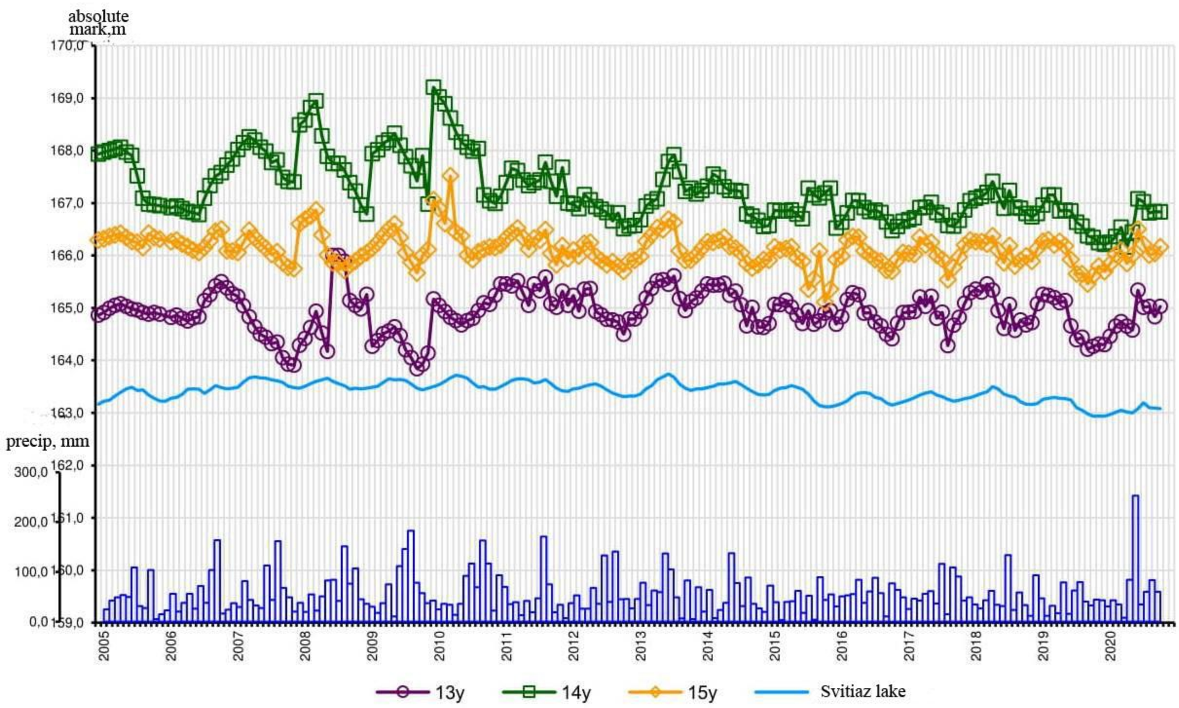


Figure 6 Fluctuations of groundwater levels in Quaternary sediments on wells 13y, 14y, 15y and the level of Lake Svityaz

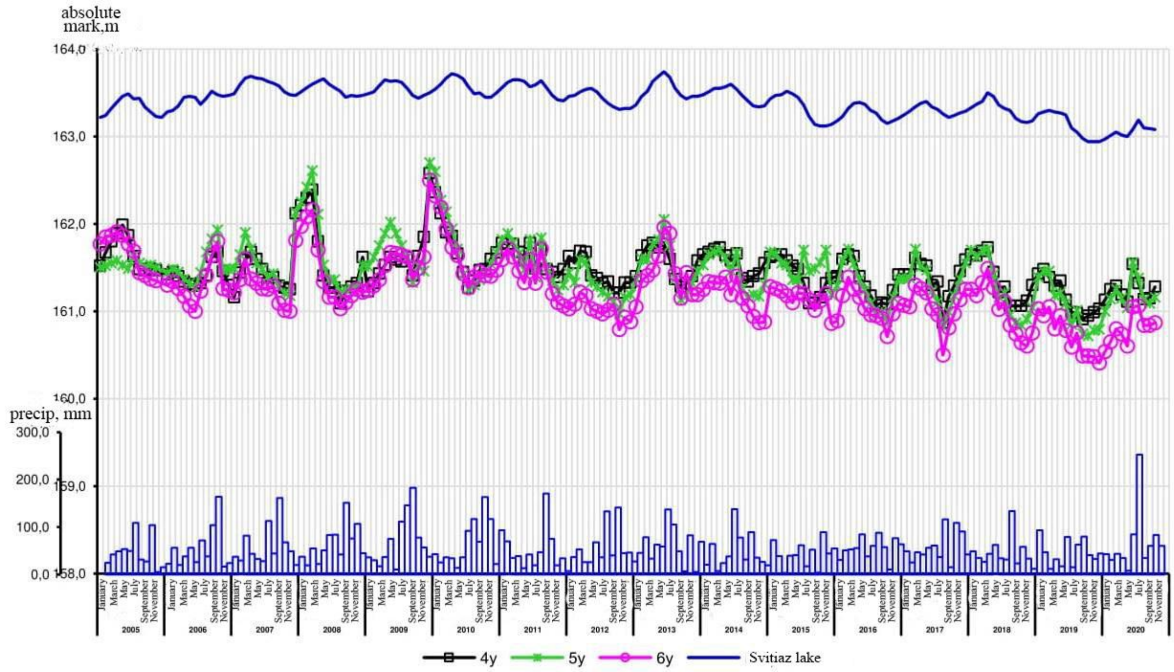


Figure 7 Fluctuations of groundwater levels in Quaternary sediments on wells 4y, 5y, 6y and the level of Lake Svityaz

While maintaining the rate of warming, which worsens the recharge conditions of the confined aquifer and causes an increase in the water losses for the Shatsky lakes, groundwater and the growth of drainage (which is already observed) in the Khotyslav quarry may affect the regimes of groundwater level near the Shatsky lakes.

The relevance of hydrogeological monitoring studies of confined groundwater in this area is obvious, and the presence of hydrogeological wells for quantitative monitoring of UGC - Svityaz (quantitative monitoring point 9, Fig. 5) is appropriate and desirable.

Administratively, the points of quantitative monitoring Svityaz (wells 1 and 2) is located in the eastern outskirts of the village Svityaz, Kovel district, Volyn region and 150 m south of the south-western bay of Lake Svityaz. Well no. 1 was drilled to a depth of 90 meters in the Turonian-Maastricht deposits of the Upper Cretaceous (K_2t-m) age. The well revealed the following lithological section:

- 0-0.5 m - peat;
- 0.5-5.0 m - light gray sand, medium grain size;
- 5.0-6.5 m - light gray loam;
- 6.5-90 m - white dense cracked chalk.

Up to a depth of 12 meters, the well is fixed with casings with a diameter of 127 mm, then the well is drilled with a diameter of 93 mm and the casings are not fixed. During the drilling period, the static ground water table level was set at a depth of 1.20 meters below the ground level. In the confined aquifer, from 1986 to 2020, the piezometric water level ranged from -1.85 to +0.57 m from the earth's surface (absolute mark 165.2 m).

Well 2 was drilled 3 meters from well 1 to a depth of 6.0 meters on the aquifer complex in the lake - swamp deposits of the Holocene (Q) period. The well is fixed by a filter column with a diameter of 108 mm to a depth of 6 meters. During the drilling period, the static groundwater table level was set at a depth of 0.3 meters below the ground level (absolute mark 165.2 m).

In geomorphological terms, the Svityaz quantitative monitoring point is located within the south-western part of the Polissya lowland (Volyn Polissya). According to the morphology of the relief, the territory of the research belongs to the weakly transformed undulating plain. The general slope of the territory is from southeast to northwest. In this direction there is a flow of confined groundwater with discharge in the bed of the Bug river. The absolute marks of the earth's surface vary from 162 m to 172 m. The territory belongs to the Baltic Sea basin.

In hydrogeological terms, quantitative monitoring point Svityaz is located within the north-western part of the Volyn-Podilsky artesian basin. Climatic conditions of the area and significant fracturing of rocks of the upper horizons led to active water exchange to a considerable depth (up to 700 m) and the formation of fresh water with salinity up to 1 g/l in this interval. The absence of impermeable sediments in the plan and section causes a close hydraulic connection between the aquifers. According to the geological structure and conditions of groundwater in this area, there are two hydrogeological complexes: aquifer complex in Quaternary sediments (Q) and aquifer complex in the Turonian-Maastricht deposits of the Upper Cretaceous (K_2t-m) age.

The above facts and assumptions indicate that the quantitative monitoring points Svityaz (wells 1 and 2) in the north-western part of the border area of the Volyn region meet the objectives of the EU-WATERRES project (located within the international protected area with high anthropogenic pressure) and research on it can be continued within the project.

Existing anthropogenic threats to the environment within the Transboundary Biosphere Reserve "Western Polissya" must be identified and prevented in a timely manner, subject to the expansion of the existing hydrogeological monitoring system.

5 Characteristics of prospective areas for the location of new observation points of the Polish-Ukrainian transboundary groundwater monitoring network

In order to identify areas with prospects for the development of the transboundary groundwater monitoring network, places validation was carried out in accordance with the methodology presented in chapter 4.3.

It was decided to present the results of the validation of prospective areas in terms of the location of groundwater monitoring points in the aspect of Polish-Ukrainian cross-border cooperation separately for the quantitative criterion - in the scope of measurements of the groundwater table level and the efficiency of springs, and for the chemical criterion concerning the physicochemical tests of waters from the aquifers that are planned to be monitored.

Suitability of the location for monitoring changes in groundwater table level

- *Criterion 1. Cross-border continuity of the water-layer and possibility of transboundary flows*

The first validation criterion, i.e. the transboundary spread of an aquifer with appropriate parameters and the possibility of transboundary flows, should be treated as mandatory both in the process of identifying potentially useful areas for the location of quantitative monitoring points and chemical monitoring. The absence of transboundary aquifers or the lack of groundwater flows within them crossing the state border between Poland and Ukraine excluded the need to perform subsequent stages of validation using the method adopted. As a result, areas without the Main Useful Aquifer in Poland according to the information layers of serial hydrogeological maps on the scale of 1: 50,000, integrated as part of another task of the EU-WATERRES project were not considered as prospective from the point of view of the implementation of the discussed criterion. In addition, the aquifers meeting the transboundary criteria, located along the hydrodynamic elements in the form of valleys of larger rivers, including border ones, e.g. on the Bug (Western Bug in Ukraine), which constitute a regional drainage base in natural conditions, not disturbed by anthropogenic factors, were defined as not prospective in terms of the possibility of locating representative transboundary monitoring boreholes.

For the purposes of designating specific locations for research monitoring piezometers, a detailed analysis of the parameters should be carried out for the aquifers which have been selected as prospective for monitoring studies at the stage of validation and expert assessments.

For the West Bug Basin in Ukraine, the main transboundary aquifer is the Upper Cretaceous (K_2) one, and therefore the transboundary flow is traced along it. Generally, the groundwater flow runs from Poland to Ukraine. The flow territory relevant for the monitoring purposes is confined to the left-bank valley of the Bug River and its tributaries Varenzhanka, Solokia, Bolotnia, and the Rata. The Western Bug River serves as a boundary of the territory of transboundary flows passing to the north and east and acts as a "drainage", for the partial groundwater discharge, while the Rata River, which is the left tributary of the Western Bug, borders the territory in the south.

The first subsurface aquifer in the alluvial Quaternary sediments is also common in the basin of the West Bug though it does not represent the main source of groundwater for this area. Therefore, no flows have been determined in this area. However, in the areas where due to the absence of an impermeable insulating layer it is hydraulically connected with the Upper Cretaceous sediments, it is recommended to undertake qualitative (chemical) groundwater monitoring of the alluvial aquifer as well.

In the San Basin in Ukraine the first subsurface and the main aquifer is found in the alluvial Quaternary sediments (alQ). It is confined to channel and terrace deposits of the Liubachuvka, Shklo, Retychyn, Vyzhomlia, Vyshnia, and Viar river valleys. The directions of transboundary flows fixed in this aquifer are sub-parallel to the directions of rivers of the San Basin and in terms of their distribution practically repeat the contours of alluvial aquifer development. In general, the flow moves from Ukraine to Poland. Only in the mountainous Carpathian region, where the flow replicates the direction of the Viar River upstream, the flow direction is from Poland to Ukraine. Downstream of the river, however, its direction, and consequently the direction of the aquifer flow, changes initially to the north-eastern, goes along the state border, where it changes to the western one, i.e. from Ukraine to Poland. Given that in the mountainous part the river valleys are narrow and alluvial deposits are thin, as well as favorable conditions for the fast discharge of soil and groundwater into surface streams, this "local" flow directed from Poland to Ukraine is of little significance.

Besides the alluvial aquifer, within the San Basin fluvioglacial sediments are identified, to which sporadically distributed groundwater is confined. This aquifer is of low thickness (< 5 m) and is not used for the centralized water withdrawal, so it is not considered to be the main aquifer. No flow rates have been determined in respect of this aquifer. However, hydraulically it is directly connected to the alluvial aquifer discharges in this horizon as well as in the surface waters, which in turn serve as a feeder of the alluvial aquifer. Therefore, chemical monitoring should include additional examination of fluvioglacial aquifers.

Besides aquifers in the Quaternary sediments in the San Basin in Ukraine, there is a Neogene aquifer used by the local population.

The results of the validation with regard to Criterion 1 and broken down into the Bug and San catchment areas are presented in Fig. 8-9.

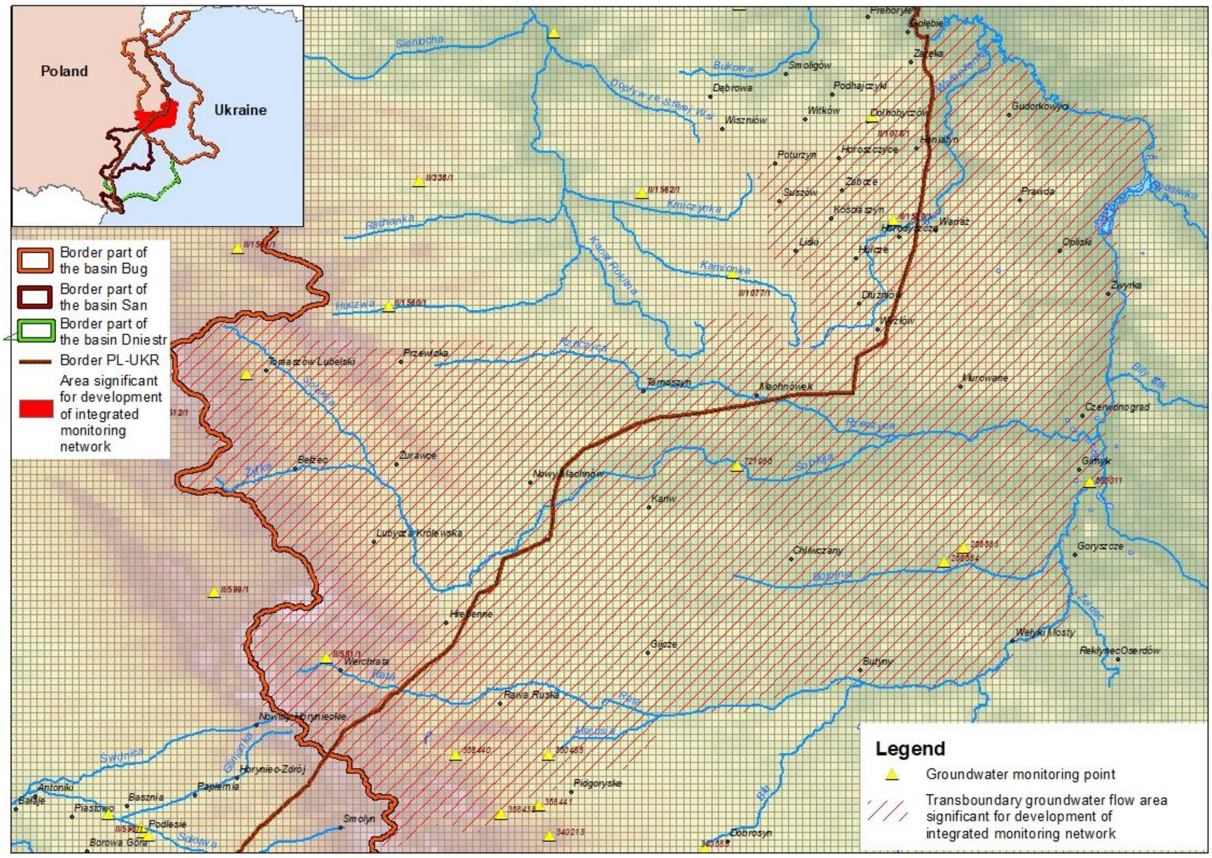


Figure 8 Cross-border continuity of the water-layer and possibility of transboundary flows in the Bug river basin (Criterion 1)

In the Bug catchment area, the area of particular importance due to the occurrence of transboundary groundwater flows covers the catchments of the left-bank tributaries of the Bug - Warenżanka, Solokia, Bołotnia and Rata.

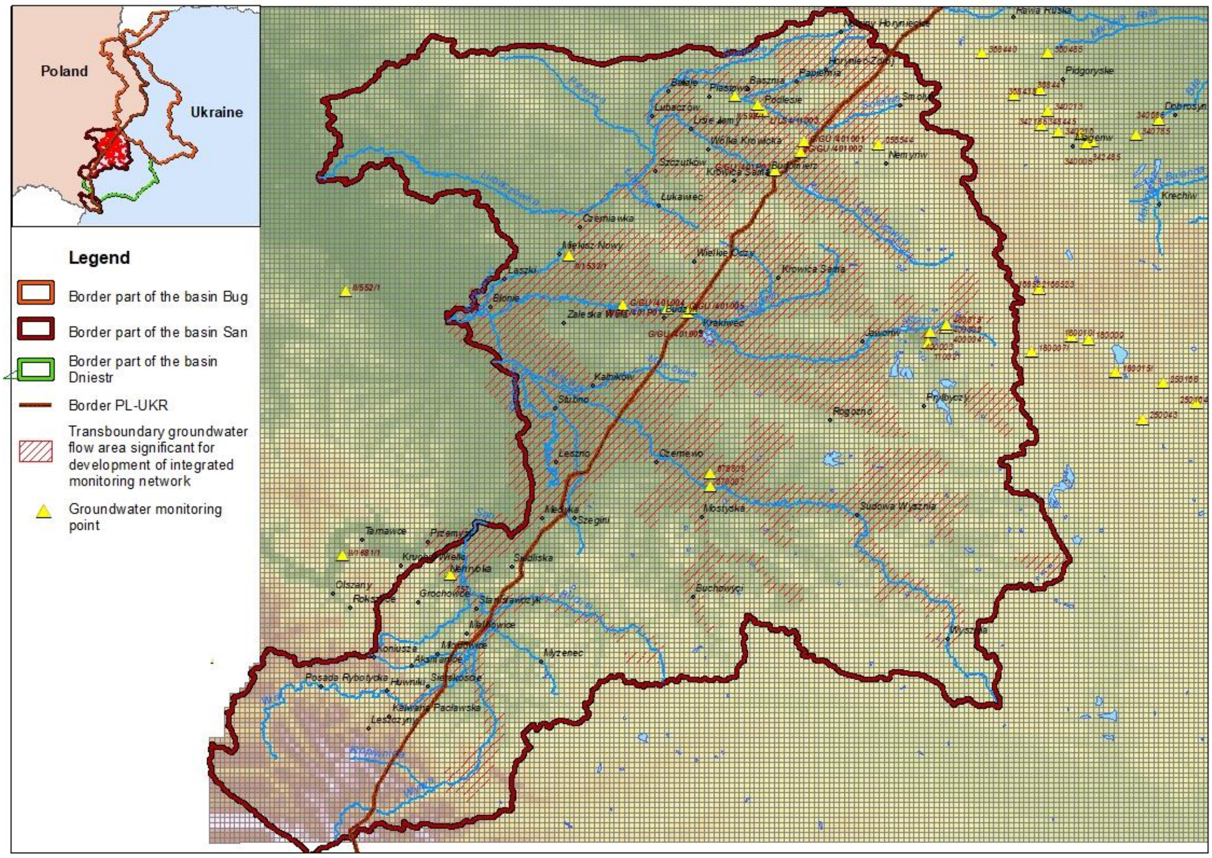


Figure 9 Cross-border continuity of the water-layer and possibility of transboundary flows in the Bug river basin (Criterion 1)

In the San basin, the area of particular importance due to the occurrence of transboundary groundwater flows includes the river valleys of the right-bank tributaries of the San - Lubaczówka, Szkło, Wiśnia and Wiar.

- *Criterion 2. Occurrence of pollution hotspots and Criterion 7. Vulnerability of aquifers to pollution*

While the validation method criterion described above is applicable to both quantitative and chemical status assessments, the next criterion relating to the presence of pollution hotspots should be considered primarily in the context of incorporating new chemical status monitoring points. The factor that is directly related to this assessment element is the criterion of the vulnerability of aquifers to pollution (criterion 7). Due to the tasks assigned to the monitoring of border and cross-border areas, directly relating to the conduct of observations in the scope that allows the assessment of the size of the pressure of transboundary transported substances considered as pollutants, the criterion concerning pollution hotspots should be considered as one of the key importance. Its use, however, gives some freedom in terms of the type of monitoring points, allowing also the inclusion of exploited hydrogeological objects (active drilled wells) in the research.

Groundwater pollution hotspots in the Bug basin in Ukraine are mainly related to villages, small towns (Rava Ruska, Sokal, Velyki Mosty) and the city of Chervonohrad (population – 80 thousand, area – 18 km^2), which developed and grew to its present state in parallel with the development of coal mining. State Enterprise "Lvivvughiliya" operates four working mines out of 12 available. Apart from the mines as such, there are subsidiary enterprises and auxiliary infrastructure (heaps, mine water settling ponds, central washhouse, product warehouses, etc.). All of these are in a certain contact with the groundwater and pose a risk of its contamination.

In the San Basin in Ukraine the largest settlements are Mostyska, Yavoriv, Novoyavorivsk, Sudova Vyshnia, villages Nemyriv, Shklo, Nyzhankovychi. The population of cities ranges from 5 to 15 thousand people. The most populous city is Novovolynsk with 30 thousand inhabitants.

In the past there was a sulphur mining enterprise in this region, which was shut down in 2006, but the consequences of its activity have been liquidated up to the present day.

The food, processing, light, woodwork, transport and communal enterprises operate within these territories. Agriculture is also developed contaminating soils and groundwater by using fertilizers, plant protection products and pesticides for the pest control. Within industrial-urban and industrial-rural agglomerations the processes of accumulation of domestic and organic wastes take place, which lead to changes in the biological balance of environment and promotes its pollution.

The study area is distinguished by a diverse and heterogeneous geological structure as well as geomorphology, respectively the aquifers exhibit varying degrees of protection and risks of being polluted. The level of groundwater protection is mainly determined by the thickness and composition of the overlying rocks. Therefore, when designing observation points the vulnerability of groundwater to pollution risks has to be taken into account.

For the Western Bug basin in Ukraine, the main usable transboundary aquifer is the Upper Cretaceous (K_2) one overlain by the Quaternary rocks. The Quaternary sediments in the study area are widespread, characterized by fluctuating thickness and unstable lithological composition. In the elevated areas between the rivers Solokiya, Rata and Western Bug aeolian sediments exist as winnow fluvioglacial sands up to 3 m thick. Alluvial sediments are also common here and include rocks of the first super floodplain terrace, mostly located in the river valleys. The rocks are represented by sands and loams interbedded with sandy loam and peat. The horizon thickness is up to 20 m. The Holocene alluvial sediments are distributed along the river beds and in the floodplain terraces of the rivers Solokia, Rata and Western Bug. The cross-section of modern alluvium of plain rivers is represented by alternating layers of sand, loam with a total thickness of up to 5 m. The Holocene biogenic deposits are developed within the study area and are geomorphologically connected to the floodplain parts, where the thickness of sediments reaches 6-12 m.

In the San River basin in Ukraine, the first undersurface and the main aquifer is located in the alluvial Quaternary sediments (alQ). It is confined to channel and terrace sediments of the Lubachuvka, Steklo, Vyshnya and Ver river valleys. Fluvioglacial sediments are also developed with sporadic groundwater occurrences. The aquifer thickness is low (< 5 m) and is not used for centralized water withdrawal, so it cannot be regarded as a major aquifer.

As the list of overlying rocks shows, these are mainly sands, loamy sands, i.e. rocks with good filtration properties and of moderate thicknesses that are unable to protect the main aquifer from pollution.

The results of the validation with regard to Criterion 2 and Criterion 7 broken down into the Bug and San catchment areas are presented in Fig. 10-13.

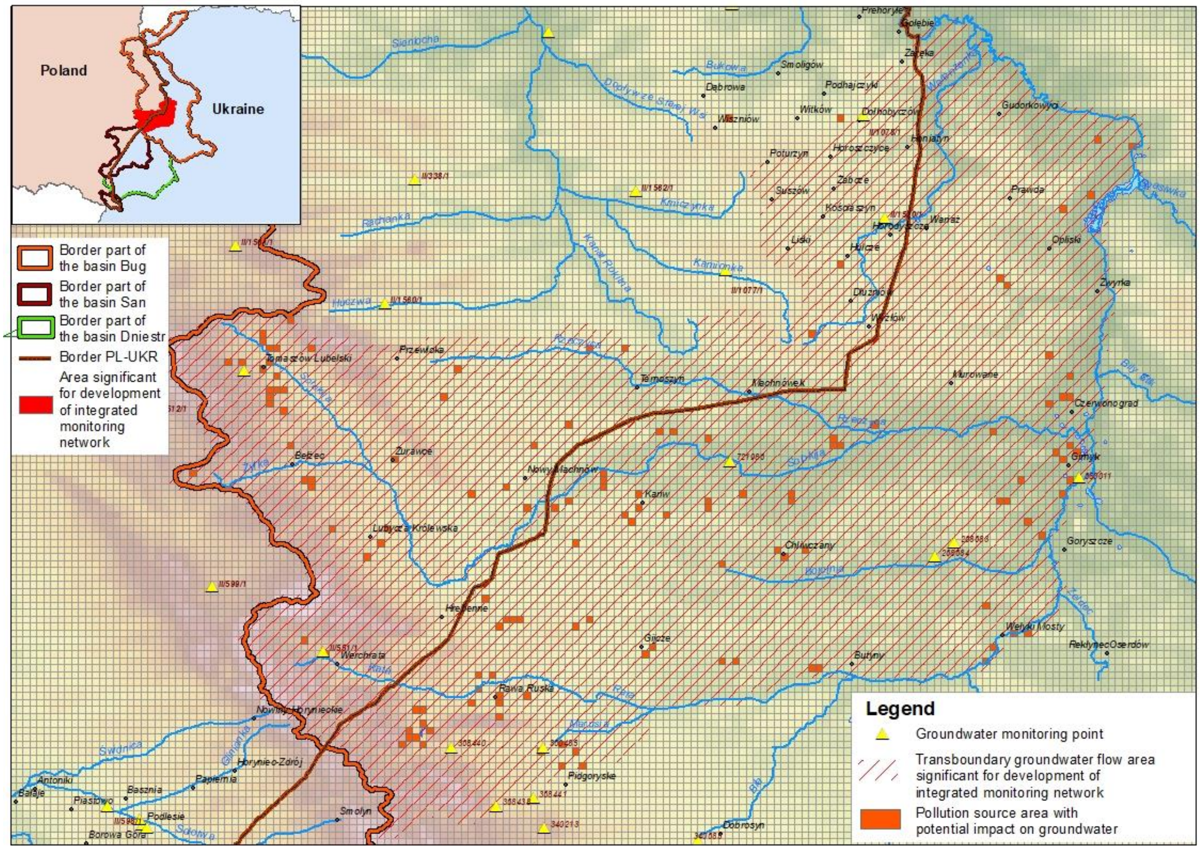


Figure 10 Location of groundwater pollution hotspots (Criterion 2) within the area of transboundary groundwater flows in the Bug river basin (against the background of Criterion 1)

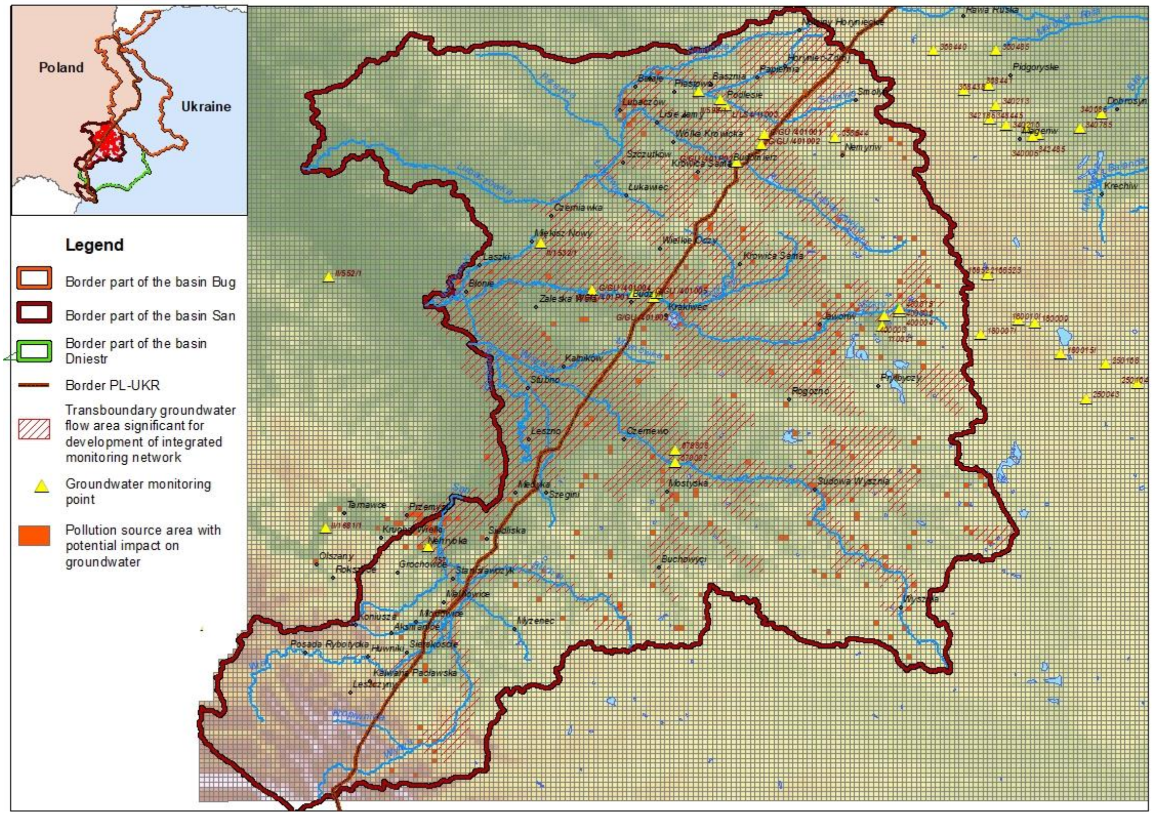


Figure 11 Location of groundwater pollution hotspots (Criterion 2) within the area of transboundary groundwater flows in the San River catchment (against the background of Criterion 1)

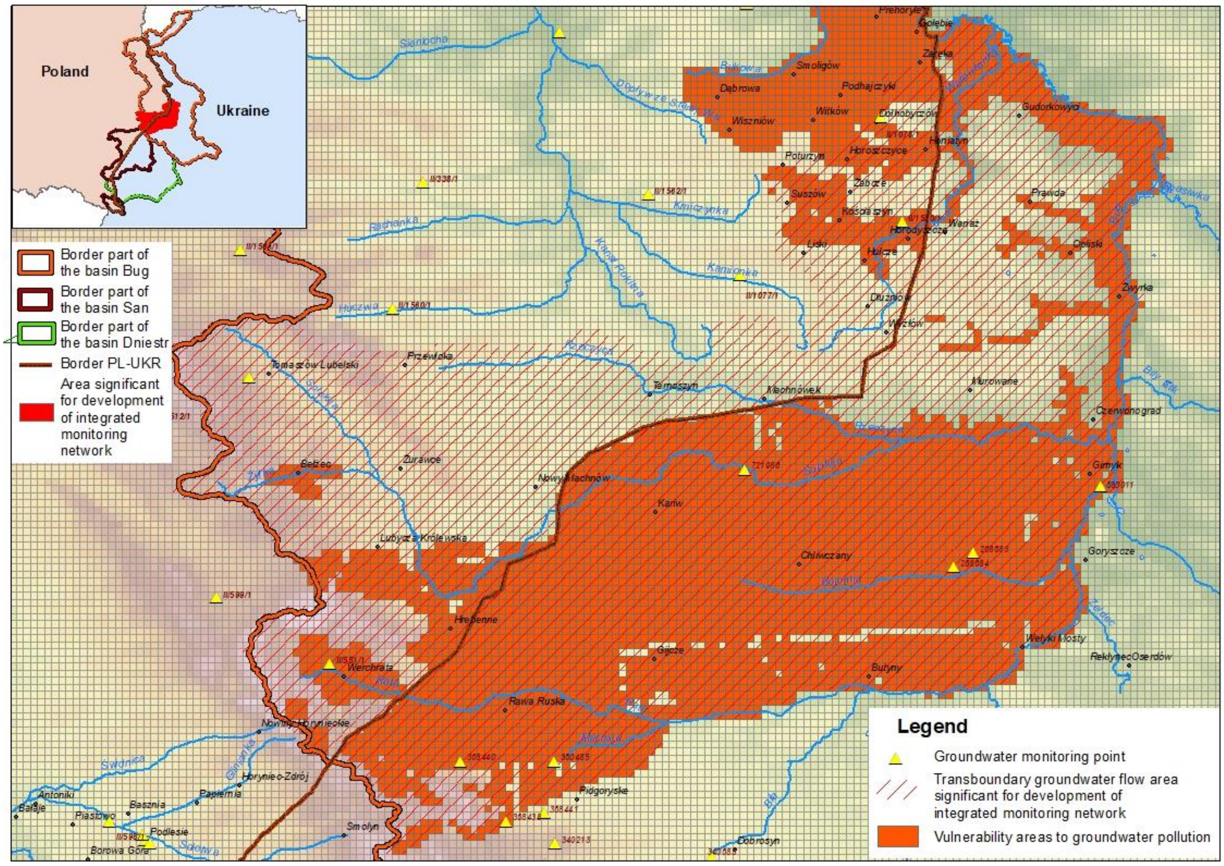


Figure 12 Location of vulnerability areas to groundwater pollution (Criterion 7) within the area of transboundary groundwater flows in the Bug river basin (against the background of Criterion 1)

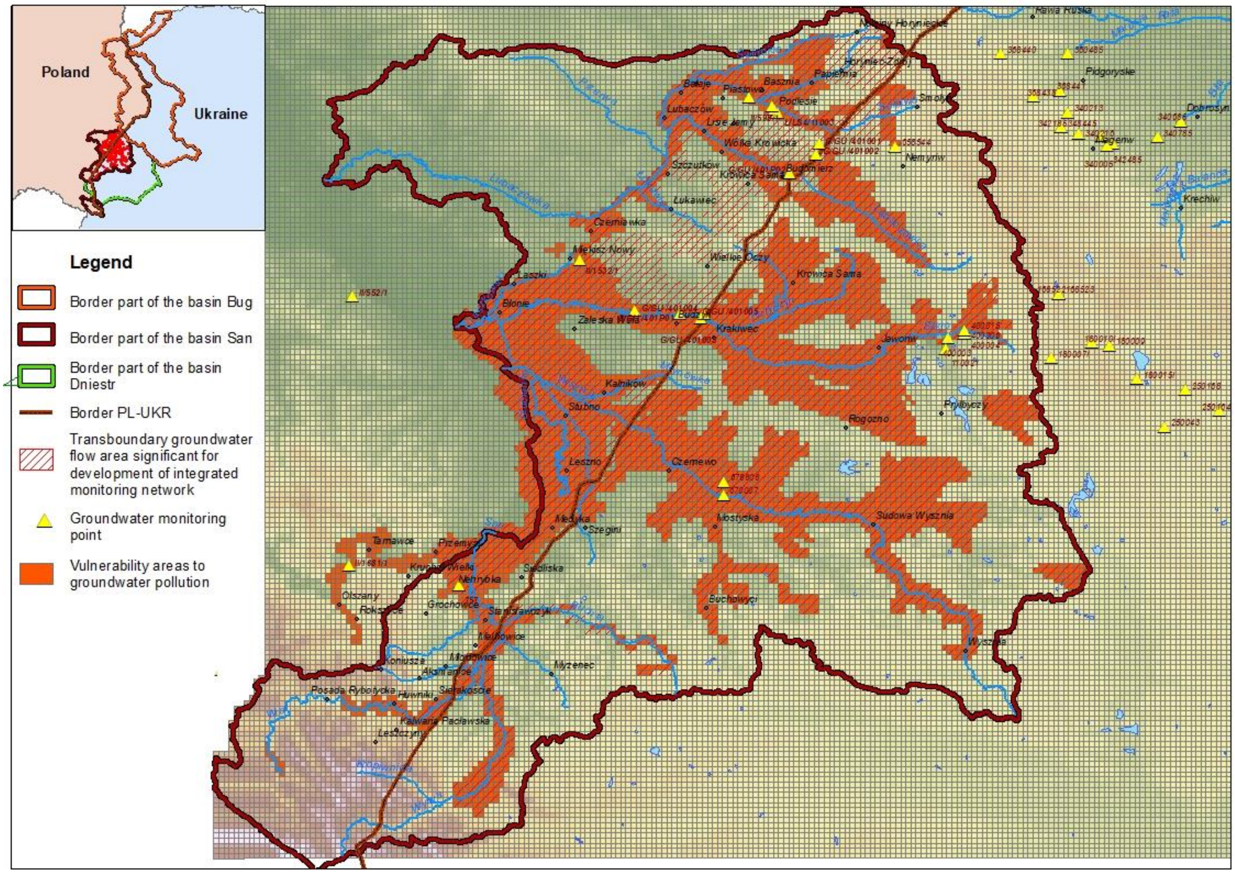


Figure 13 Location of vulnerability areas to groundwater pollution (Criterion 7) within the area of transboundary groundwater flows in the San river basin (against the background of Criterion 1)

- *Criterion 3. Water-dependent ecosystems and Criterion 6. Protected areas*

The parameter of validation of water-dependent ecosystems and the criterion of protected areas were considered both in terms of the location of points where observations can be made, both quantitatively and chemically. Quantitative observation points should be located in protected areas, wetlands, where falling groundwater levels pose a risk to ecosystems. When considering these elements, the type and form of protection should be taken into account, as well as an assessment of potential anthropogenic impacts on changes in ecosystems associated with changes in the groundwater environment.

The low-lying nature of the territory, high level of groundwater (0-5 m), slow river flow due to low flow velocities determine the nature of the water regime and lead to waterlogging of the territory (floodplains of the Western Bug, Solokiya, Bolotnia rivers and, to a lesser extent, the Rata River).

The majority of natural swamps in Ukraine were lost due to the drainage melioration, but a few have been preserved. Within the Bug River basin, between the Rata and the Bolotnia, there is national botanical reserve “Volytskyi”, which covers an area of 150 ha. The reserve area represents a mesotrophic bog dominated by sedge-sphagnum groups of typical flora. It is protected as a habitat for rare and medicinal plant species. The bog functions as a regulator of the water regime throughout the area. Due to dewatering a number of ecosystem functions of bogs are lost, namely moisture maintenance, regulation of hydrological regime, formation of microclimate, preservation of bog flora and fauna diversity. The study area is characterized by a well-developed and extensive river network with a considerable percentage of swampy terrain. The Solokia, Bolotnia and Rata rivers, which are the Western Bug tributaries, feature a flat relief and a wide distribution. In the lowlands, meadows and marshes with a unique ecosystem sensitive to groundwater level fluctuations occur.

In the San Basin in Ukraine, conditions for swamp formation are not very favorable, so there are only small local wetlands in the river and stream plains in this area. A seasonal pattern of this phenomenon can be observed during periods of excessive precipitation.

The arrangement of observation points within protected areas and conservation zones can ensure the monitoring of waters in their natural condition free from anthropogenic pressures. The results received can be treated as a “reference sample” to identify harmful elements or their concentrations in waters under the risk of pollution. However, sometimes elevated concentrations of some components in groundwater are of quite natural origin and are explained by their intensive leaching from water-bearing or overlying rocks.

In Ukraine within the transboundary territories the following nature reserves are located in the Bug River basin:

- the Ukrainian botanical reserve of national significance "Volytskyi". It is located between the rivers of Rata and Bolotnia. The reserve area is 150 hectares. The site encompasses a marshy terrain, dominated by sedge-sphagnum groups of typical flora. It is home to rare and medicinal plant species. The marshland plays an essential role in regulating the water regime here;
- the Prybuzhzhia zoological reserve. It occupies 1,182.1 hectares. Under the protection are pine forests with sporadically birches and black alders (230 ha), wetlands, meadow-shrub meadows, and grasslands (951 ha) in the floodplain of the Western Bug. They provide favorable conditions for breeding of various species of cloven-hoof animals, fur-bearing animals, game birds and water-marsh game;
- the Bug zoological reserve of local significance. The area is 3,556.6 ha. Under the

protection is a part of the floodplain of the Western Bug River with its oxbows, marshes, meadows, floodplain terraces, scrub and forests. Some of rare animal species listed in the Red Book of Ukraine, the European Red List and other international lists of protected species live here, namely the black stork, the crane, the corncrake and the river otter.

- the Roztochchia Nature Reserve. It is located in the north-western part of the Podillia Upland and is a part of the narrow hilly strand of the Ukrainian Roztochchia. The reserve area is 2,084.5 ha, the length of the territory from north to south is 8 km, and 12 km from west to east. The local relief is distinguished by the alternation of river valleys, marshes and hills with cliffs. The Vereshchytsya River and its tributary the Stavchanka River run through the reserve. There are ponds, the biggest of which is Yanivsky (its area is 207 ha). In total 92% of the area is covered with forest, the remaining 8% hosts meadow, marsh and riverine-water vegetation. The flora consists of 1,097 species of vascular plants. Out of them 28 species of higher plants are included into the Red Book of Ukraine. The diverse fauna of the reserve includes 43 species of mammals, 169 bird species, 6 reptile species, 11 amphibian species, and 16 fish species. A total of 18 animal species are listed in the Red Book of Ukraine;
- the Yavorivsky National Nature Park covers an area of 7,078.6 ha. Its territory is a part of the Ukrainian Rastochie, which is a narrow mountain strand, 75 km long. These areas combine features of the Carpathian, the Polissia and the Podillia regions. The southeastern part of the Yavorivsky reserve is crossed by the Main European Watershed. Rivers starting here belong to the basins of the Black Sea and the Baltic Sea. In particular, these are rivers Stavchanka and Stara Rika (left tributaries of the Vereshchitsia), Derevianka and Svynia (basin of the Western Bug); also, the Vereshchitsia runs here and then enters the Dniester River. The territory of Yavorivsky NNP is also rich in forests, among which the hornbeam-oak, pine-oak, pine and low alder stands prevail. There are also more than 200 species of medicinal plants;
- park of Shklo health resort is a monument of landscape architecture of local significance in Ukraine. Its area is 93 hectares. Park is managed by the Shklo health resort administration. Within the park there is a hydrological natural monument – the Naftusia spring of drinking water.

The results of the validation with regard to Criterion 3 and Criterion 6 broken down into the Bug and San catchment areas are presented in Fig. 14-17.

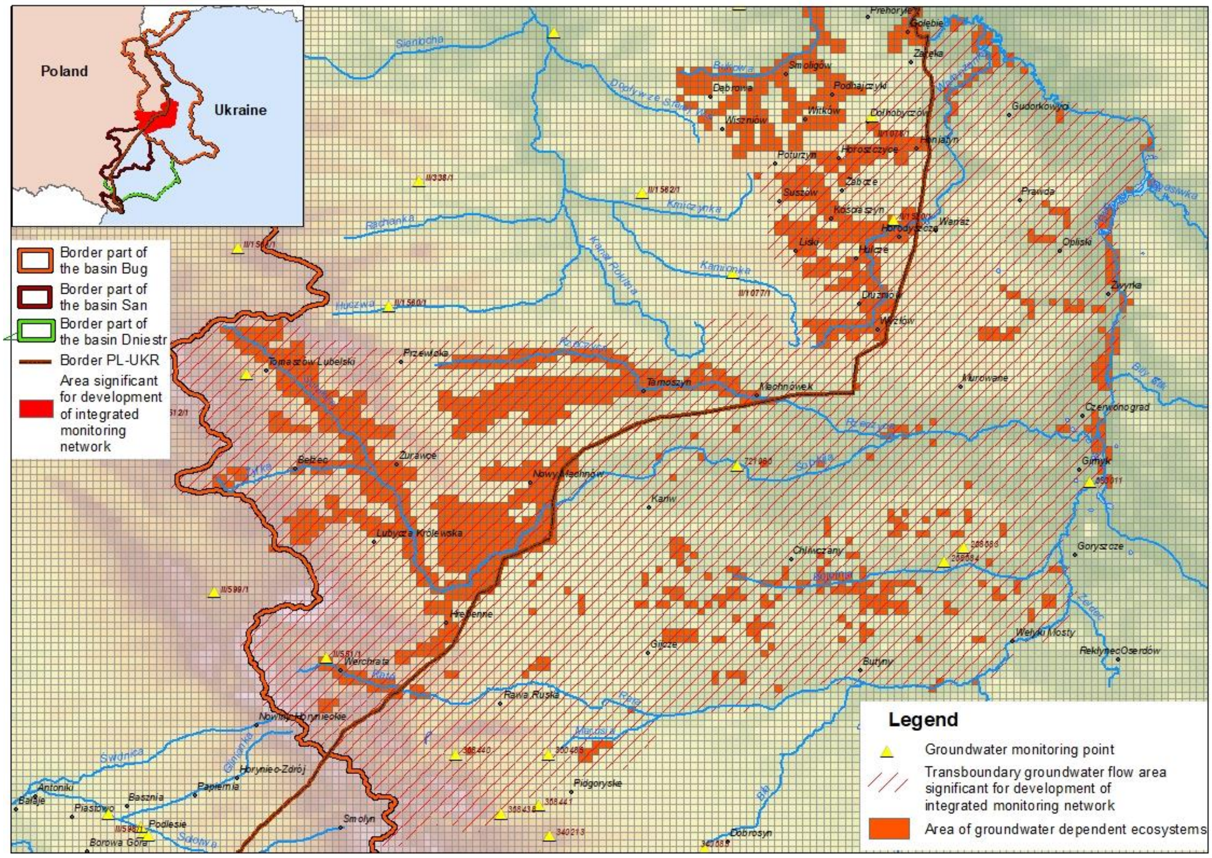


Figure 14 Location of water-dependent ecosystems (Criterion 3) within the area of the occurrence of transboundary groundwater flows in the Bug river basin (against the background Criterion 1)

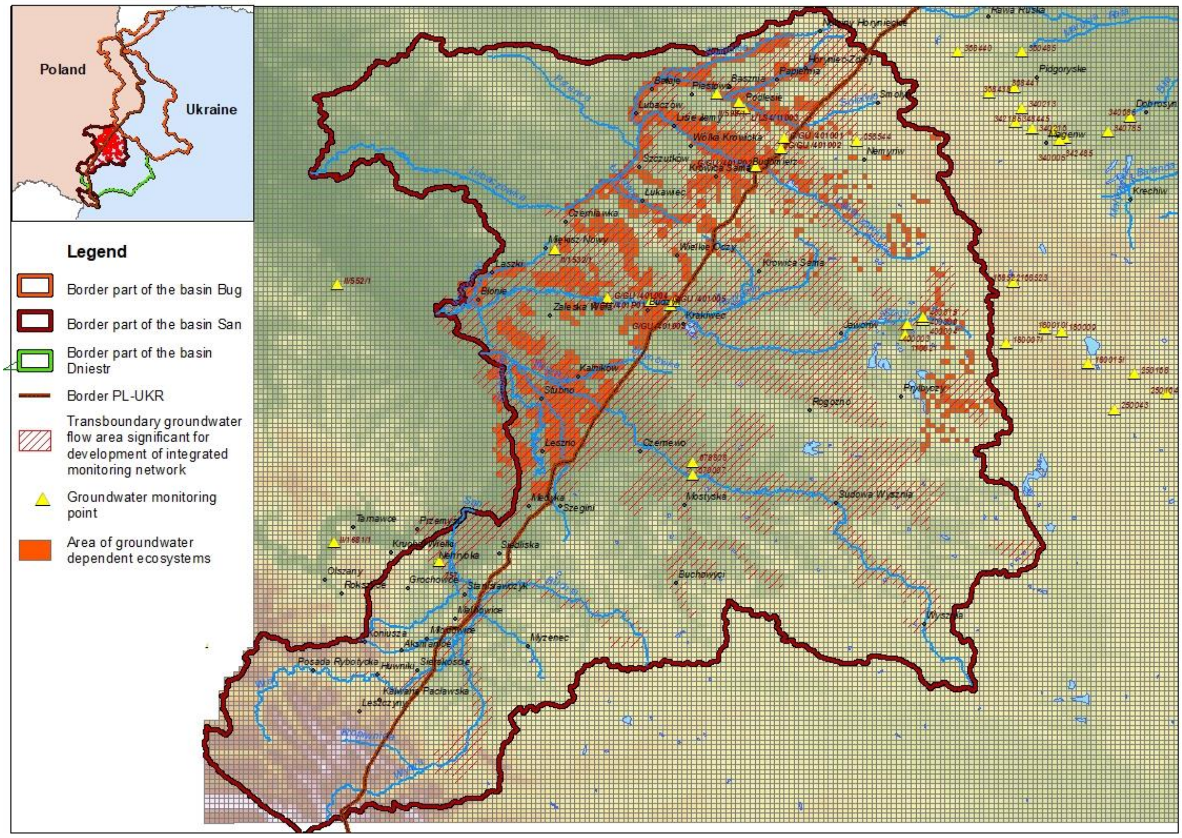


Figure 15 Location of water-dependent ecosystems (Criterion 3) within the area of transboundary groundwater flows in the San River catchment (against the background of Criterion 1)

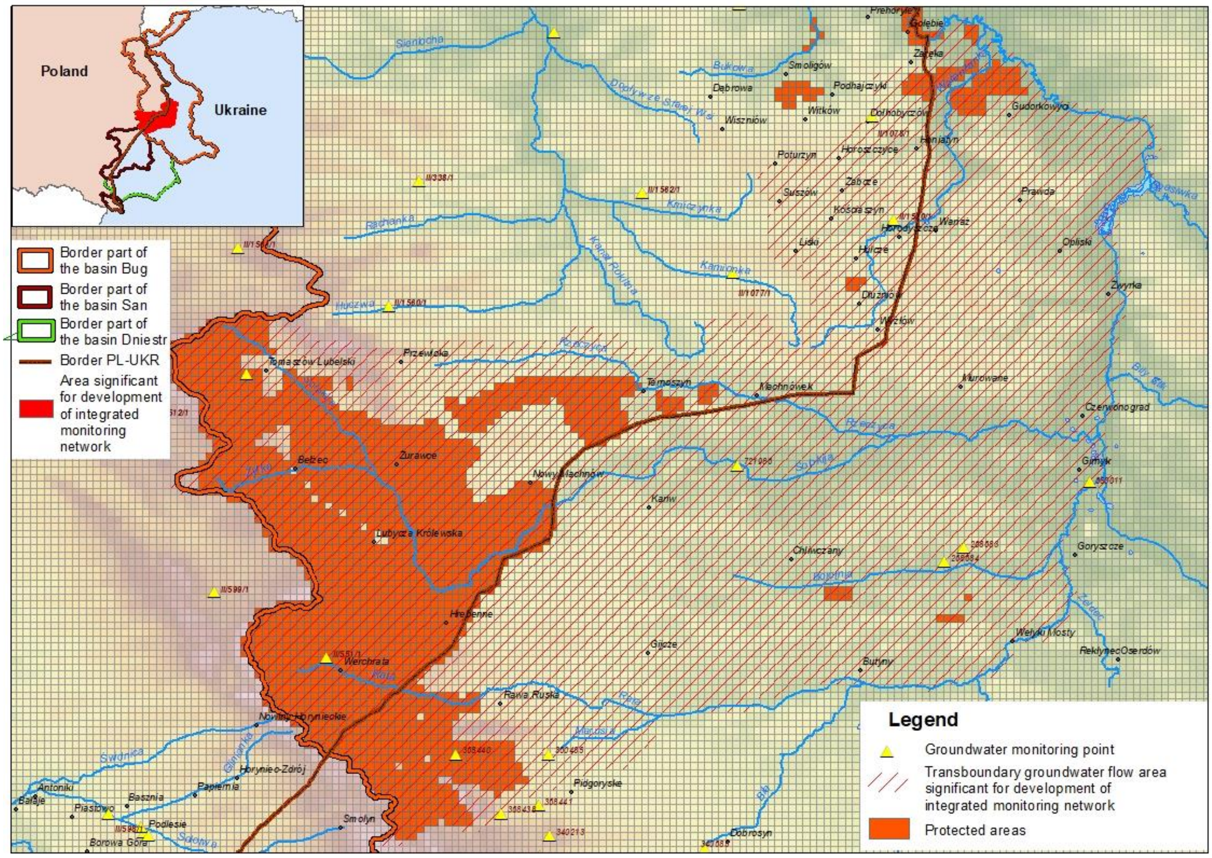


Figure 16 Location of protected areas (Criterion 6) within the area of transboundary groundwater flows in the Bug river basin (against the background of Criterion 1)

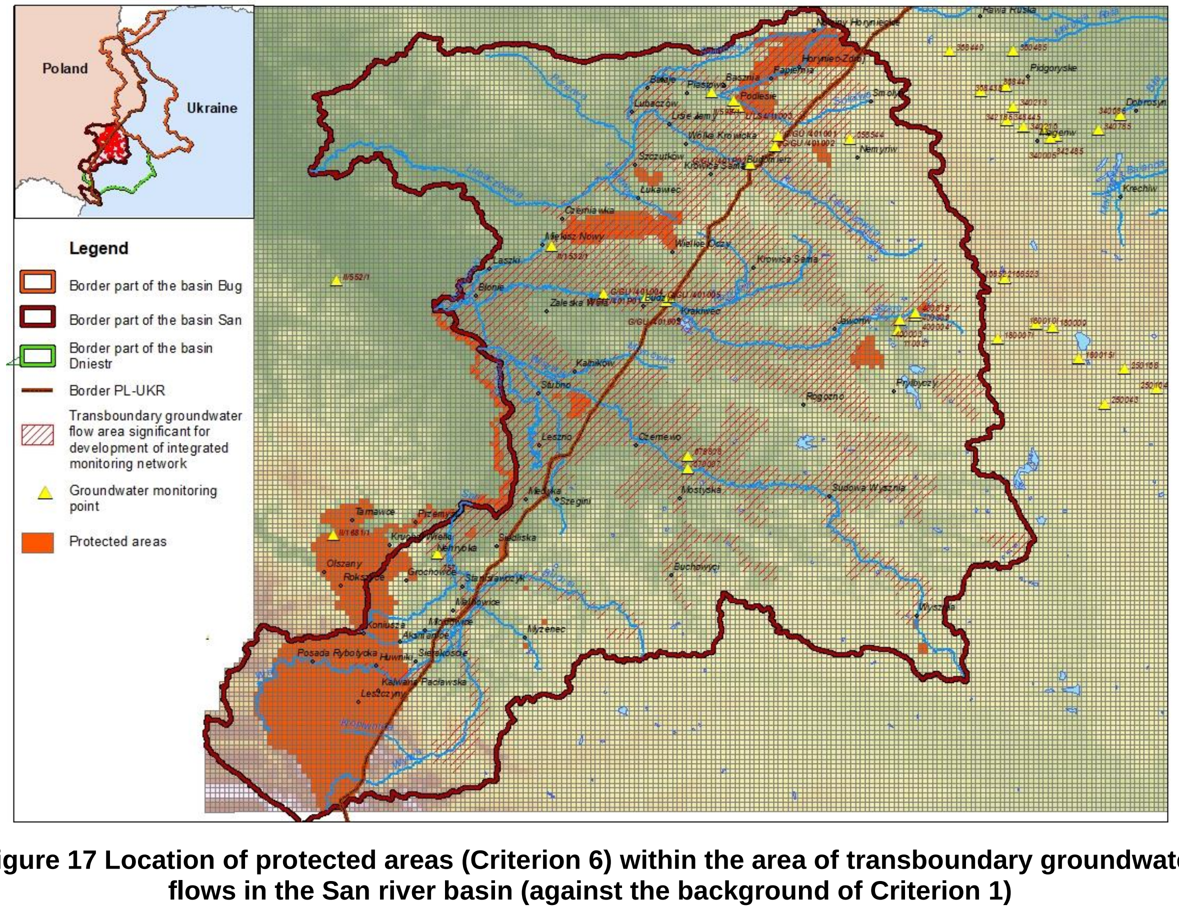


Figure 17 Location of protected areas (Criterion 6) within the area of transboundary groundwater flows in the San river basin (against the background of Criterion 1)

- *Criterion 4. Mining areas and non-recultivated mining areas*

The impact of mining areas and unreclaimed mining areas should be considered as one of the most important both in terms of the pressure on the chemical state and the quantity of groundwater. In terms of monitoring of the chemical status, it may be significantly similar to the pressure exerted by pollution hotspots on groundwater. Obviously, the degree of threat from pressure from mining areas and unreclaimed mining areas directly depends on the nature and type of exploitation, the condition of infrastructure and implemented measures in the field of environmental protection, including water protection. Considering the need to include new observation wells in the above-mentioned areas, it is worth taking into account the existing groundwater monitoring networks located in the areas of mines and post-mining areas, as well as the technical condition of observation points.

The assessment of mining operations impact on the groundwater status is an important parameter for the transboundary monitoring. Within the Bug River basin in Ukraine the Lviv-Volyn coal basin, in particular operating State Enterprise “Lvivvughiliya”, is located. Coal mining activities are accompanied by the export of coal-bearing rocks (about 100 mil. m^3/year) and mine drainage of 6 mil. m^3/year. Mines, waste rock dumps, spoil banks, mine water settling ponds, a washhouse with its infrastructure affect the environment in a number of multi-vector ways, namely it affects surface and ground water, soil, atmosphere (due to spoil banks burning), billions cubic meters of rocks are accumulated in waste rock dumps and spoil banks, land surface subsidence is recorded above mining workings accompanied by flooding and inundation of agricultural lands. The intensity of subsidence has reached 100 mm per year in most parts of Chervonohrad mining area.

The analysis of waste dumps and spoil bank location shows that almost all of them constitute sources of surface and groundwater pollution. Active runoff from all spoil banks and dumps directly into the Western Bug is registered. These flows pollute groundwater used by the population.

Considering the direction of flows, the harmful influence of pollutants transported by the waters from spoil banks, sludge reservoirs and mine water settling ponds does not apply to the transboundary territory.

Within the Bug River basin in Ukraine, rich peat deposits are present and have been extracted from the open-pit mines. Minor peat extraction does not threaten the transboundary groundwater either.

Within the San River basin in Ukraine there are two sulphur deposits, Yazivske and Nemyrivske. The Yazivske deposit is located in the valley of the Shklo River and was developed by state mining-chemical enterprise “Sirka”. The mineral resource was produced by means of open-pit and underground mining. Quarries include mine workings, rock dumps, roads, and buildings. Sulphur extraction ceased almost 20 years ago, the quarry was filled with water and the area has been partially recultivated. Currently, there are no other large mining enterprises in the area. The impact on the environment is minimized. The Neogene aquifer groundwater is naturally high in sulphate content due to its occurrence in gypsum strata.

The results of the validation with regard to Criterion 4 and broken down into the Bug and San catchment areas are presented in Fig. 18-19.

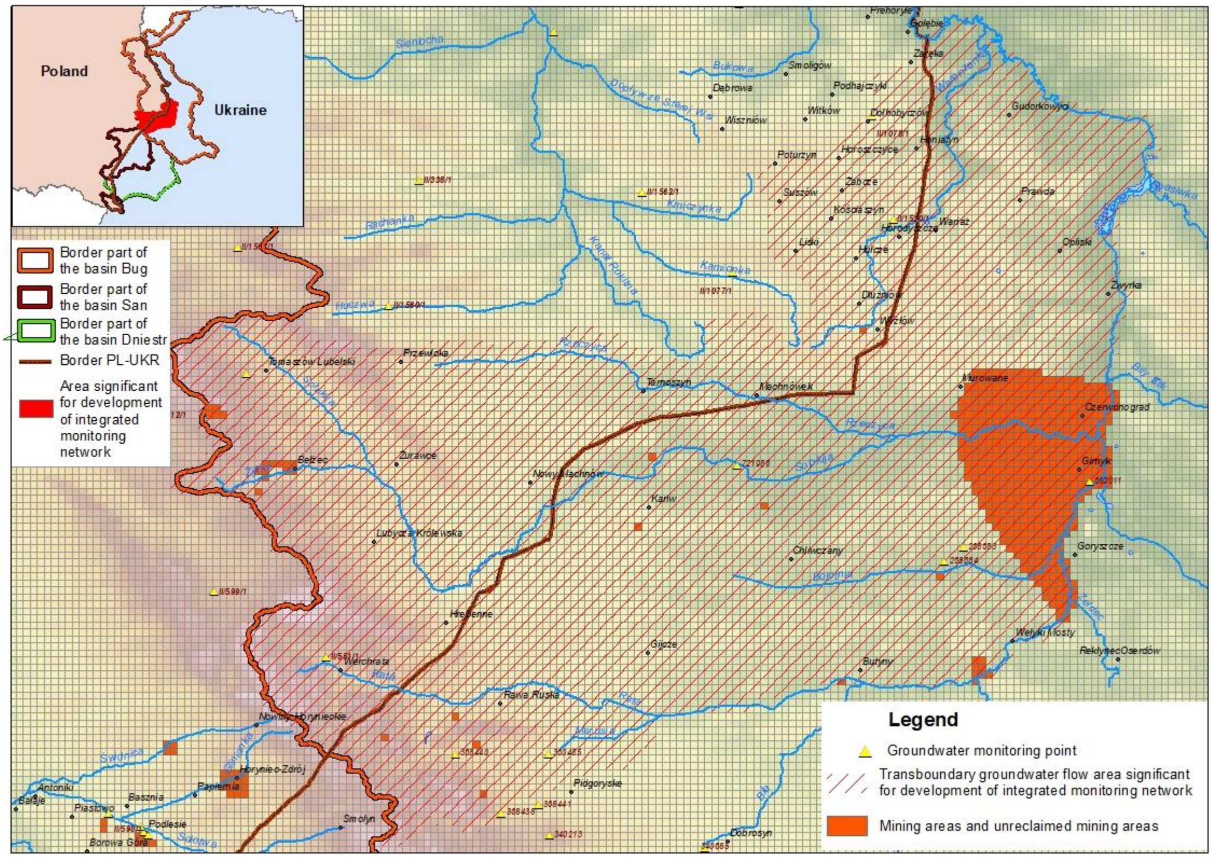


Figure 18 Location of mining areas and non-reclaimed mining areas (Criterion 4) within the area of transboundary groundwater flows in the Bug river basin (against the background of Criterion 1)

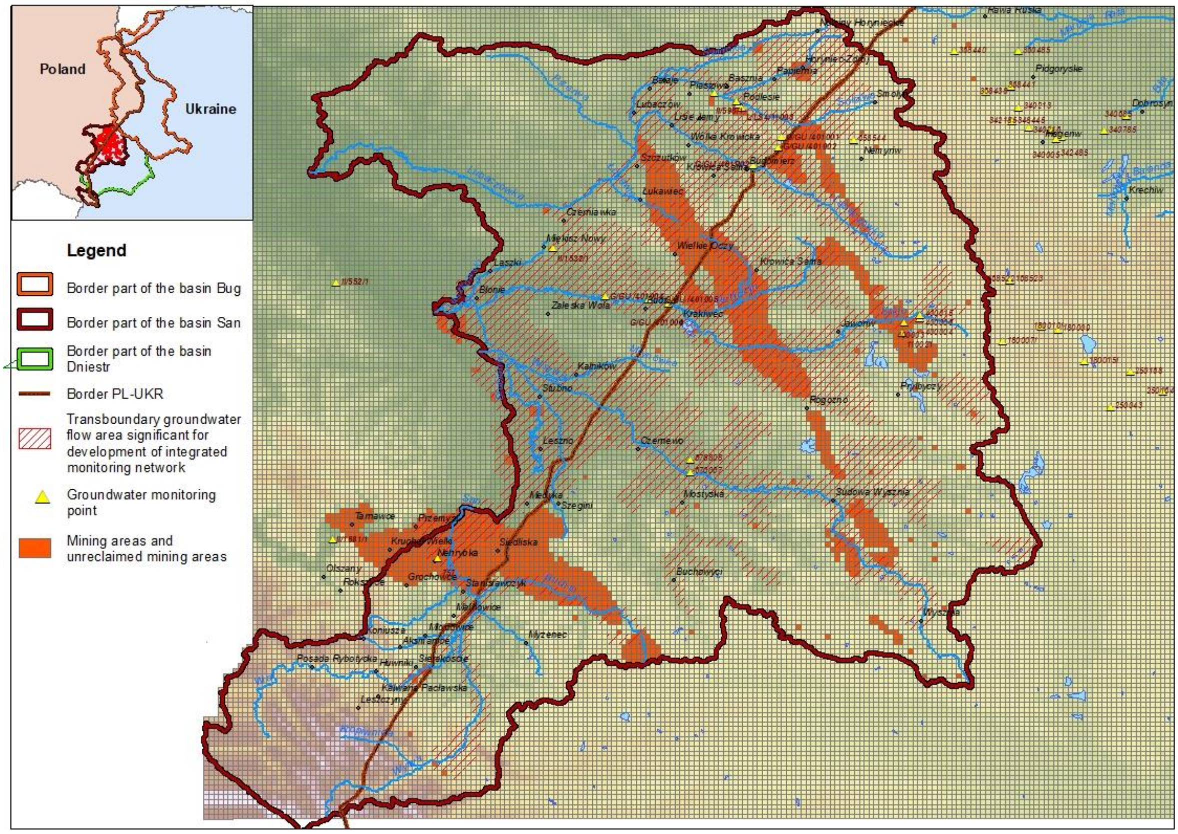


Figure 19 Location of mining areas and non-reclaimed mining areas (Criterion 4) within the area of transboundary groundwater flows in the San river basin (against the background of Criterion 1)

- *Criterion 5. Active groundwater intakes*

The spatial analysis included groundwater intakes located in the border zone, where the average daily water intake was at least 50 m^3/day. The impact of this parameter is important for the location of new quantitative monitoring points in the border area, e.g. in areas where the exploitation of water may affect the level of the water table.

In the Bug basin in Ukraine, there are several water intakes, from which the water intake exceeds 50 m^3/day.

The Rava-Ruska water intake and the Chervonohrad water intakes group are located within the Bug Sub-basin. The Boriatyn water intake is located 1.5 km north of Chervonohrad. Six boreholes were drilled to the Cretaceous aquifer. It is characterized with hydrocarbonate-magnesium-calcium, magnesium-sodium water type and salinity of 0.53-0.56 g/dm^3. The fluorine content varies from 0.57 to 2.06 mg/dm^3; bromine content is 0.2 mg/dm^3; iodine is <0.4 mg/dm^3. The Mezhyrichcha water intake is located in the interfluve of the Western Bug (left bank), Solokia (right bank), the Rata River on the southern outskirts of Chervonohrad. A Cretaceous aquifer is in use. There are four functioning wells at the water intake station. The water content is of hydrocarbonate-calcium-sodium, sodium-calcium type with the mineralization ranging from 0.42–0.65 g/dm^3. Fluoride content averages about 1.89 mg/dm^3 (with some variations varying from 1.65 to 2.16 mg/dm^3). The Pravda water intake is located to the north-west of Chervonohrad. Currently, there are 19 wells at the water intake, located in a zigzag line, with a total length of 7,150 m. The Sokal water intake is located near the town of Sokal. Eight 84 – 100 m deep wells have been drilled to the Cretaceous aquifer. The aquifer is of the pressure-phreatimetric type. Pressures vary from 0 m in watersheds up to 6.7-19.3 m in valleys. Static levels are fixed at depths ranging from 20.1 m in watersheds to +1.2 – 3.3 m in valleys.

Within the San River basin in Ukraine the below water intakes exist:

- Parashka (owned by water services company Yavoriv Vodokanal) is located in the valley of the Vereshchytsia River and the Shklo River. The intake uses a Neogene aquifer consisting of 9 wells and supplies the town of Javoriv and nearby villages;
- Eneria Novoyavorivsk consists of three sections, namely Novoyavorivsk, Starychi and Ivano-Frankovo. The Neogene aquifer is used. It consists of four production wells and supplies the settlements of Shklo, Novoyavorivsk, Starychi, Ivano-Frankovo and Svydnytsia.

Major water intakes (those using the Neogene and Cretaceous aquifers) in Ukraine are located at a considerable distance from the border and do not significantly affect the transboundary aquifers. In most cases the Quaternary groundwater are used by the local people for their individual water supply.

The results of the validation with regard to Criterion 5 and broken down into the Bug and San catchment areas are presented in Fig. 20-21.

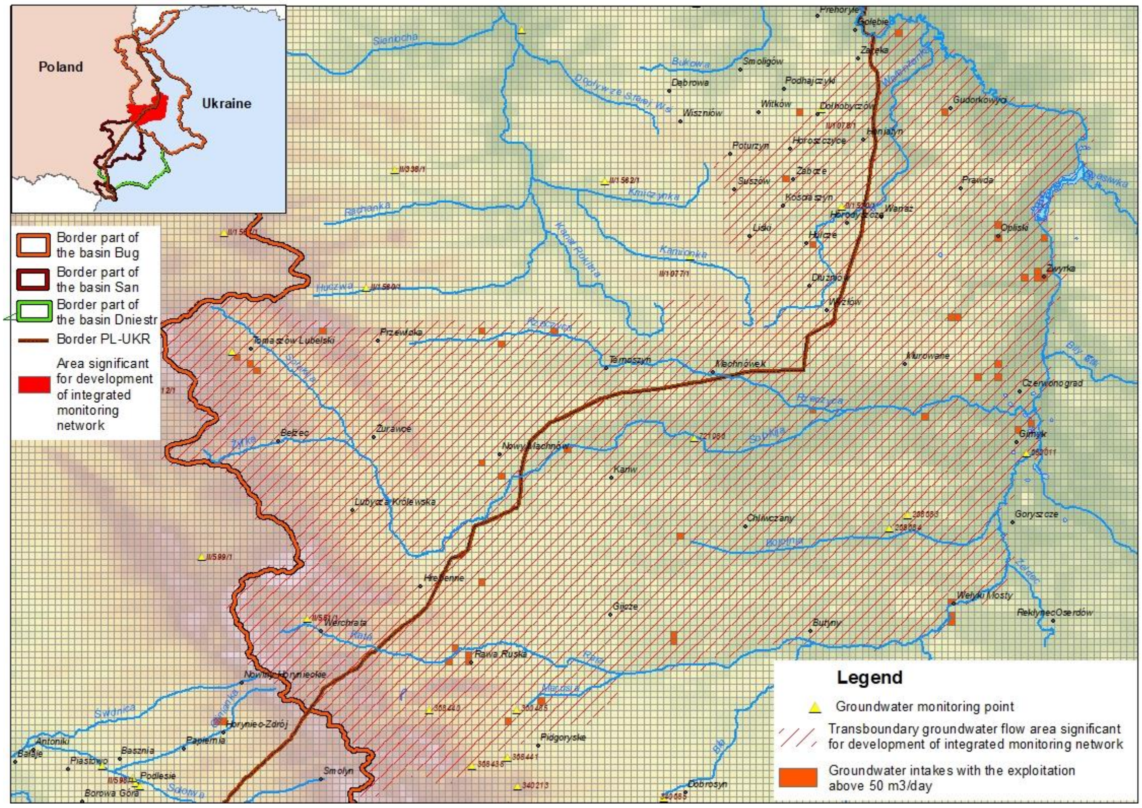


Figure 20 Location of active groundwater intakes with approved exploitation resources exceeding 50 m^3/day, collecting waters of aquifers with a transboundary spread (Criterion 5) in the Bug river basin (against the background of Criterion 1)

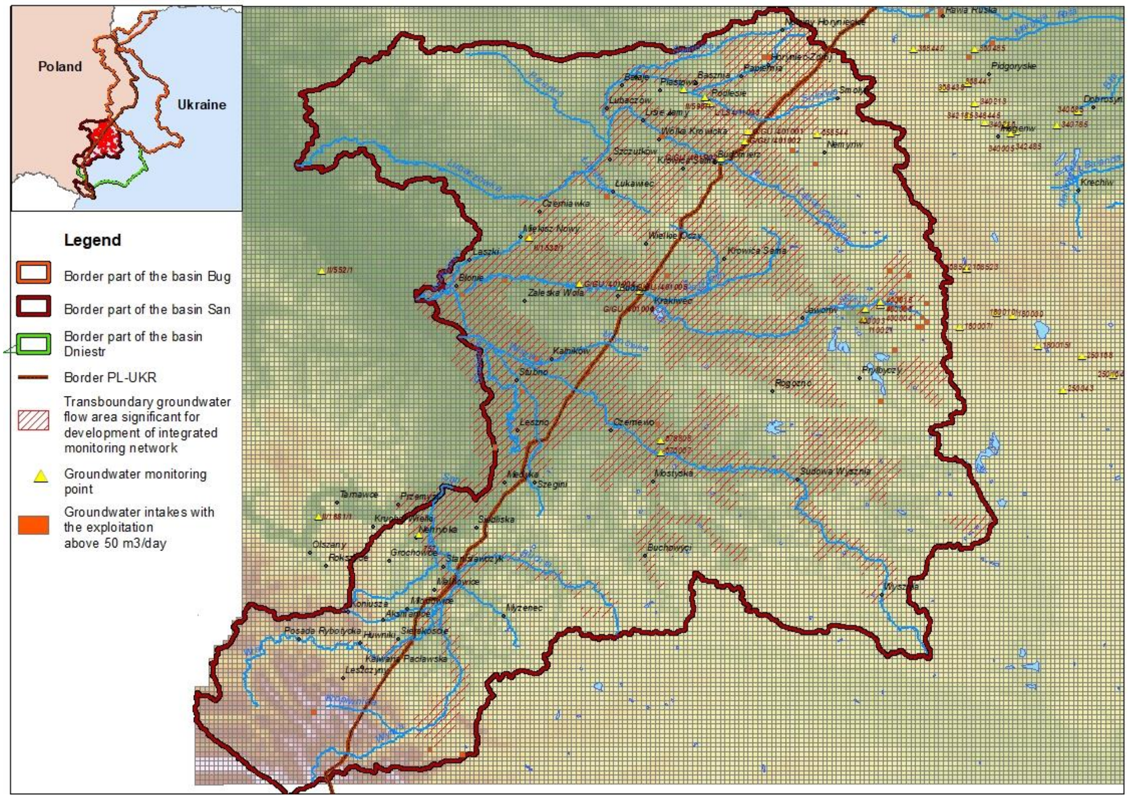


Figure 21 Location of active groundwater intakes with approved exploitation resources exceeding 50 m^3/day, collecting waters of aquifers with a transboundary spread (Criterion 5) in the San river basin (against the background of Criterion 1).

All the above-mentioned validation criteria are very helpful in the process of initial selection of areas that can be considered potentially prospective in terms of the location of new transboundary groundwater monitoring boreholes, but it should be emphasized that the expert decision remains the decisive factor in this process.

In most cases, both quantitative and qualitative observation can be performed at a single point. Important requirements for existing quantitative and qualitative observation points are the availability of complete and accurate geological and technical information on a borehole; the "history", i.e. conducting of observations in previous years; location in a protected settings; relevance to a certain aquifer; the material used to make a well should not significantly change the water composition.

Figures 22-23 show the summary result of the validation for the selection of prospective areas for the establishment of new observation points of the Polish-Ukrainian transboundary groundwater monitoring network.

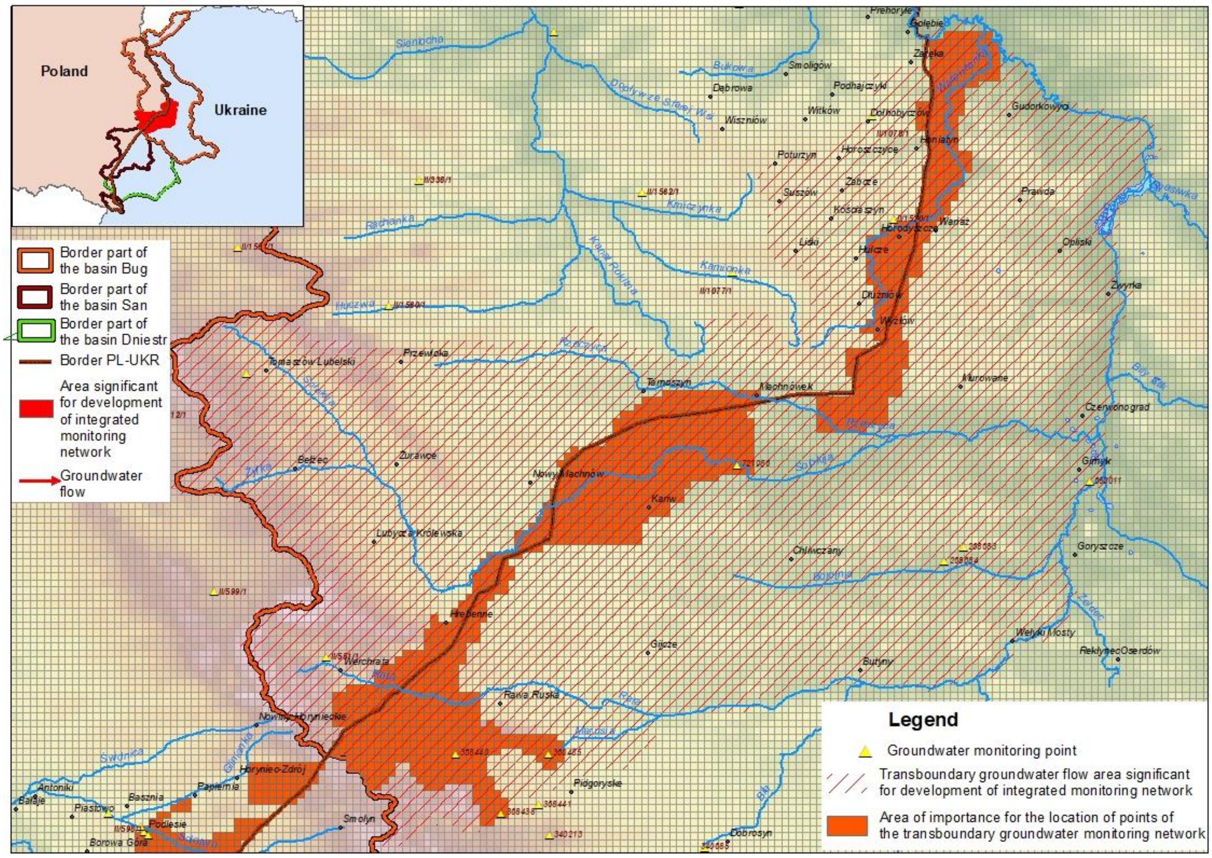


Figure 22 Location of prospective areas for the construction of new observation wells creating a transboundary groundwater monitoring network in the Bug river basin

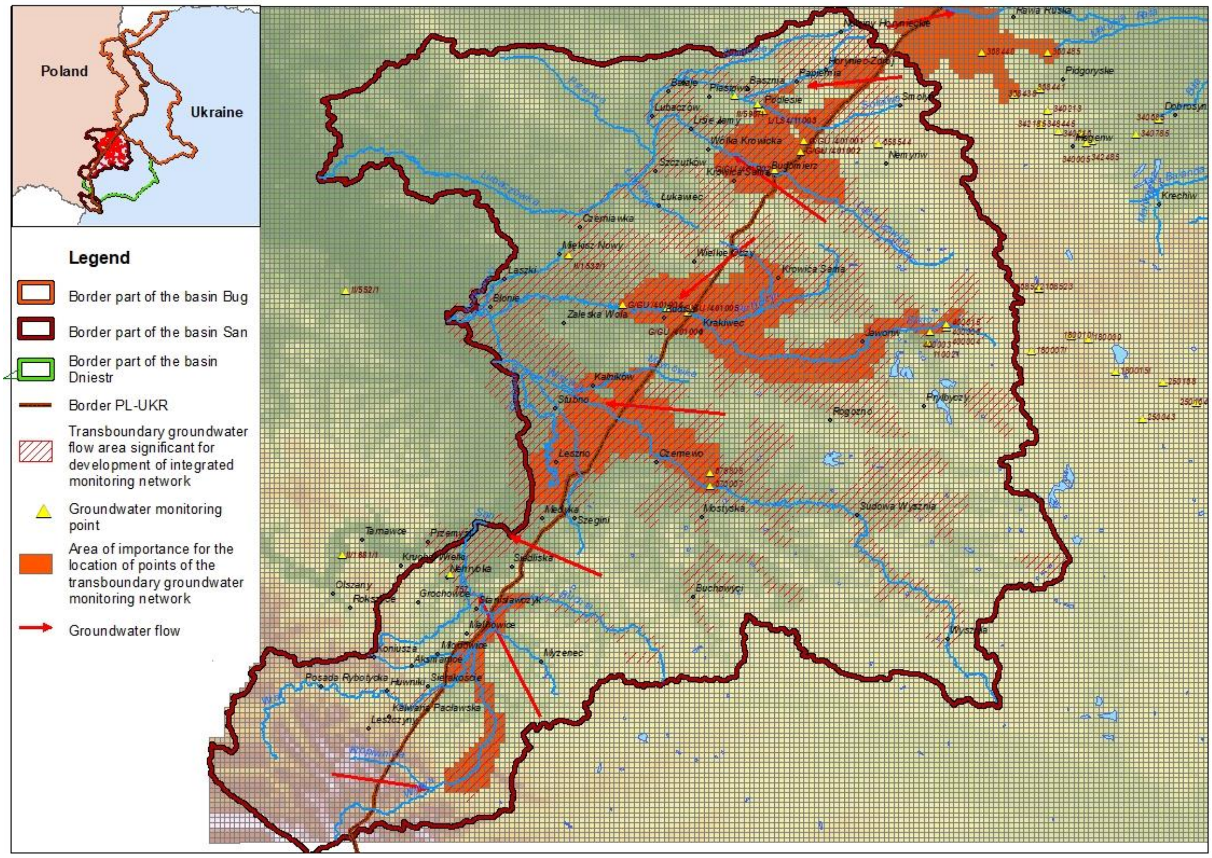


Figure 23 Location of prospective areas for the construction of new observation wells creating a transboundary groundwater monitoring network in the San River catchment

For the border territory of Poland, it was decided to present a proposal for the location of new groundwater monitoring points, which will meet two objectives simultaneously: monitoring in the field of observation of the groundwater table and physicochemical tests of groundwater (Fig. 24). In order to maximize the scope of tasks in relation to the costs incurred, in line with the guidelines of the EU guides, groundwater monitoring networks should be integrated. If possible, groundwater observation points should perform more functions, i.e. simultaneously the function of a chemical status monitoring point and groundwater table level monitoring. It is also recommended to link the groundwater monitoring network with the surface water monitoring network.

Figure 24 Groundwater monitoring points recommended for inclusion in the transboundary groundwater monitoring network

Within the Ukrainian part of the near-border area the impact on groundwater can be caused by intensive water withdrawal, oil and gas extraction, coal mining, now-ceased sulphur production, agricultural activities, municipal wastewater, etc. The impact level depends on the type, intensity and duration of the anthropogenic pressure, the risk of accidents, and the degree of aquifer natural protection.

The project objective consists in assessing the transboundary impacts on the groundwater status in the neighbouring countries. Key sites of the monitoring network were established according to the harmonised criteria (section 3.2), determinative among which were as follows:

- existence of a transboundary flow;
- the intensity of an anthropogenic impact;
- the vulnerability of groundwater to surface pollution (determined by the presence/absence of a confining layer).

The baseline data for determining the eligibility of an area for monitoring purposes were the conceptual hydrogeological and numerical hydrodynamic models developed under this project, which set out the directions and volumes of transboundary flows.

Within Ukraine the area of transboundary flows in the Bug River basin (Lviv region) amounts to 1342.09 km^2 and in the San River basin it is up to 818.73 km^2. Within the Volyn region no clear transboundary flows have been established, which is due to the interception of hydrodynamic vectors by the Bug River. In this area the river channel runs along the state border.

For the Bug TGR within the territory of Lviv region there have been three prospective sites identified for the monitoring purposes. Four sites have been determined for the San TGR (Table 5).

Table 7 Prospective sites for transboundary monitoring

Site number	Monitoring site area, km^2	Transboundary flow direction	River basins	Aquifer vulnerability
TGR of the Bug River				
1	73.36	from Poland to Ukraine	Zhechytsia	alQ – vulnerable K_2 – invulnerable
2	87.32	from Poland to Ukraine	Solokia	alQ – vulnerable K_2 – vulnerable
3	87.34	from Poland to Ukraine	Telytsia Marynka	alQ – vulnerable K_2 – vulnerable
TGR of the San River				
4	25.64	from Ukraine to Poland	Blekh Zavadivka Liubachuvka	alQ– vulnerable N_1– vulnerable
5	142.6	from Ukraine to Poland	Shklo Retychyn	alQ– vulnerable N_1– vulnerable
6	62.24	from Ukraine to Poland	Vyshnia	alQ– vulnerable
7	54.79	from Poland to Ukraine from Ukraine to Poland	Viar Mala Vyrva	alQ– vulnerable

The Bug TGR

Site 1 extends from the Bug River to the Zhechytsia River (left tributary of the Solokia River) (Figure 25). The monitoring site area is 73.36 km^2. Comprehensive (quantitative and qualitative) groundwater monitoring is planned for the alQ and K_2 aquifers. Here the alQ aquifer is sensitive to the surface pollution, while the K_2 aquifer is adequately protected. Given the groundwater flow from Poland to Ukraine, the transboundary impact of the existing coal mining industry is not anticipated. Observation points (boreholes) in respect of the alQ and K_2 aquifers should be designed for the monitoring activities. Where possible, it is advisable to use inactive private or communal water intake facilities upon prior agreement with the owners.

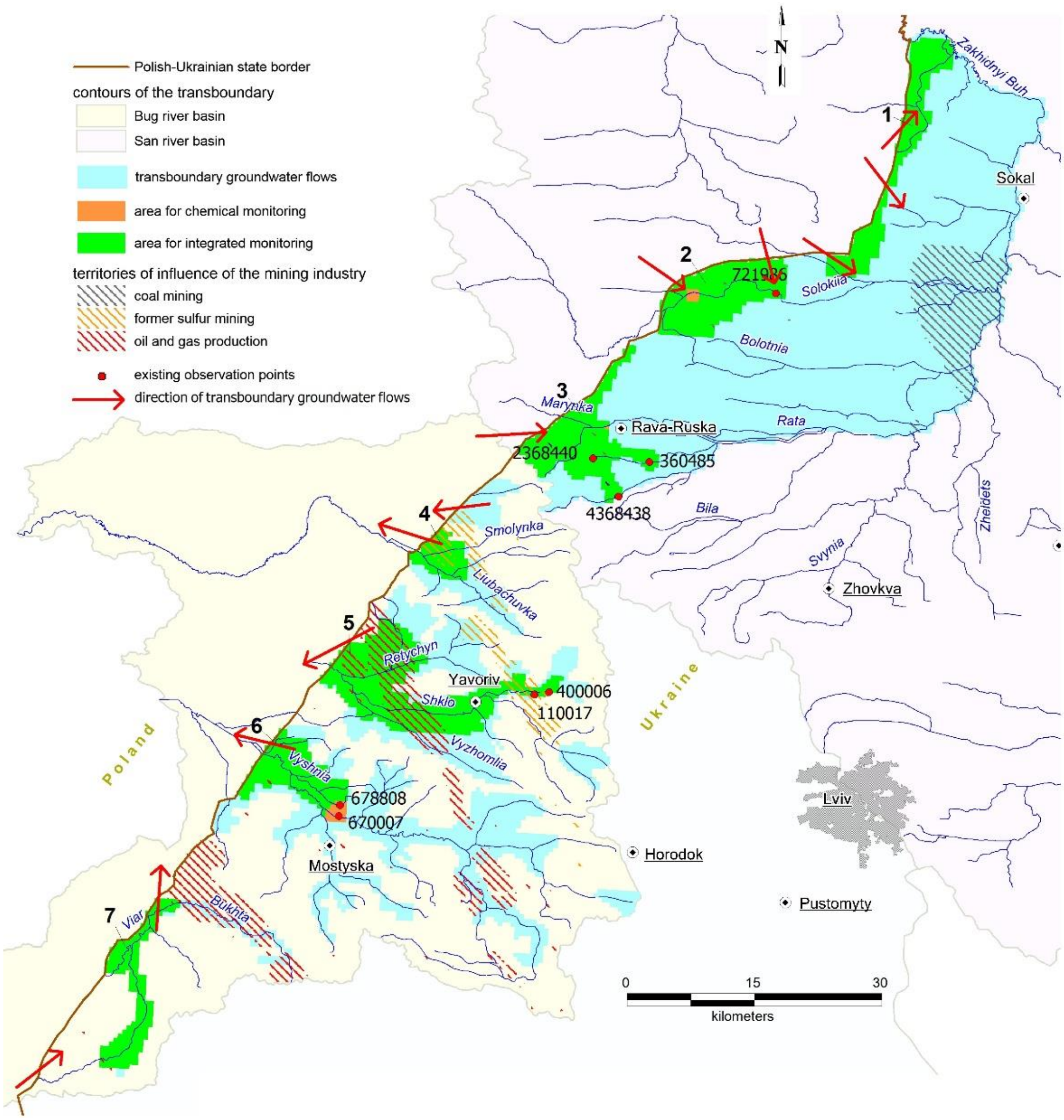


Figure 25 Schematic map of the transboundary monitoring network within Ukraine

The area of Site 2 covers 87.32 km^2. It is confined to the Solokia River valley. The transboundary groundwater flow of the alQ and K_2 aquifers is directed from Poland to Ukraine. Both aquifers are vulnerable to surface pollution. Within this site there is an observation point No. 721986 of the National Monitoring Network, namely a borehole for the K_2 aquifer integrated groundwater monitoring. To monitor the alQ aquifer it is advisable to design an observation borehole within the river terrace and to use inactive water intake facilities where feasible.

Site 3 is located in the interfluve of the Rata and Telytsia rivers and in the valley of the Marynka River (right tributary of the Rata River). The area of the site is 87.34 km^2. The transboundary alQ and K_2 aquifer groundwater flow from Poland to Ukraine. The aquifers are vulnerable to the surface pollution. Within this area there are observation boreholes No. 360485, No. 368440 and No. 368438 used to monitor the K_2 aquifer. It is reasonable to use them for the network of transboundary monitoring of groundwater quantity and quality parameters. To monitor the alQ aquifer the inactive intake facilities can be used.

The San TGR

Site 4 is designed for alQ and N_1 aquifers transboundary monitoring. It covers the area of 25.64 km^2 and is located in the valley of the Blekh, Zavadivka and Liubachuvka rivers. A transboundary flow runs from Ukraine to Poland. The aquifers are vulnerable to the surface pollution. There are no national observation points available within this site; therefore, it is advisable to design observation boreholes for the needs of the transboundary monitoring network and to use inactive water intake facilities where possible.

Prospective Site 4 is located within the areas of the ex-sulphur mining industry facilities (Fig. 19). Presently most of the industrial assets have been reclaimed into impoundments. It is the quantitative and qualitative monitoring of groundwater status of the upper aquifers that will establish the presence or absence of transboundary impact of the abandoned sulphur mining industry facilities.

Site 5 is planned in the valley of the Shklo River and its right tributary Retychyn. It occupies an area of 142.6 km^2. The transboundary flow runs from Ukraine to Poland. The Site is interconnected with the ex-sulphur mining area. It is intended for transboundary monitoring of the alQ aquifer in its western part and the N_1 aquifer in its easternmost part. The aquifers are vulnerable to the surface pollution. For the transboundary groundwater monitoring network of the N_1 aquifer it is suggested to use the existing points of the national network Nos. 400006 and 110017. To monitor the alQ aquifer the inactive intake facilities can be used. If intake facilities related to the fgQ aquifer exist, it would be advisable to use them for monitoring as well taking into account the hydraulic connection between these aquifers.

Site 6 is located in the Vyshnia River valley and is intended for the alQ aquifer monitoring. It extends over an area of 62.24 km^2. The transboundary flow here is directed from Ukraine to Poland. The aquifer is vulnerable to the surface pollution. Within the delimited site, there are observation points of the national network No. 670007 and No. 678808. Since they are located within the impact area of the water intake, they can only be used for quality monitoring. If available, it is also reasonable to additionally engage the inactive water intake facilities for the fgQ aquifer monitoring.

Within the limits of Site 7 transboundary groundwater flows in alluvial sediments (alQ aquifer) first from Poland to Ukraine along the Mala Vyrva River bed and then along the Viar River bed towards Poland. The aquifer is vulnerable to the surface pollution. The site borders with oil and gas extraction grounds to the north and this could affect the status of groundwater of transboundary flows. Actually, this site is designed for the specified purpose. The area of the site is 54.79 km^2. For the purpose of monitoring, it is advisable to design observation boreholes and to use inactive water intake facilities where possible.

Summary

Recently, there has been growing interest in the issues of monitoring and assessment of transboundary groundwater layers / reservoirs. The studies of transboundary groundwater flows in the Polish-Ukrainian borderland as part of the EU-WATERRES project (EU-integrated management system of cross-border groundwater resources and anthropogenic hazards; www.eu-waterres.eu) justify the legitimacy of establishing a transboundary groundwater monitoring network. Currently, a joint monitoring program is carried out on major cross-border rivers.

The aim of this report was to develop the principles of designing the Polish-Ukrainian transboundary groundwater monitoring network in relation to the needs of assessing their quantitative and chemical status. The recommendations were developed taking into account the potential of the existing national networks and the requirement of EU law.

The report presents:

- organization and operation of national measurement networks in the field of chemical and quantitative monitoring of groundwater in Poland and Ukraine;
- review of the legal basis, Polish and EU methodological guides relating to the types and principles of organizing transboundary groundwater monitoring;
- specific objectives of cross-border groundwater monitoring resulting from the specificity of hydrogeological conditions and anthropogenic pressure in the Polish-Ukrainian border area;
- characteristics of the occurrence of areas of particular importance for the transboundary exchange of groundwater in Poland, including the results of anthropogenic pressure analysis in this area constituting the basis for the organization of a transboundary groundwater monitoring network;
- methodology for site validation in terms of suitability for the establishment of a cross-border network in terms of the number and location of monitoring points;
- types of groundwater monitoring provided for in the transboundary network, including chemical status monitoring and quantitative monitoring;
- rules for qualifying points of the national measurement network in the field of monitoring the chemical and quantitative status of groundwater to the transboundary network and assessing the representativeness of these monitoring points;
- prospective areas for the establishment of new points of the transboundary groundwater monitoring network.

The main goal of transboundary groundwater monitoring is to provide the data necessary to perform a cyclical assessment of:

- the direction and intensity of groundwater flow across the state border between Poland and Ukraine;
- tracking groundwater quality of transboundary layers;
- identification and control of cross-border transport of potential pollutants.

The spatial extent of the transboundary layers and groundwater flows identified in the EU-WATERRES project on the basis of a common hydrodynamic model necessitated a new look at the usefulness of national monitoring points in border zones for the purposes of cross-border monitoring. The performed analysis of the representativeness of the existing points showed that only 8 out of 19 border points of the national groundwater monitoring networks of Ukraine meet the requirements of cross-border monitoring. Similarly, in Poland, out of 14 points in the border

area, only 6 qualified for the cross-border network. The insufficient number of points resulted in the identification of places for the location of new facilities. As a result, 7 prospective areas were identified for the development of the cross-border network in Ukraine and 5 - in Poland.

In order to establish new monitoring points in the indicated areas, it will be necessary to undertake activities related to obtaining the possibility of performing physico-chemical tests at approximately 12 additional points in Ukraine and approximately 5 points in Poland dedicated to chemical monitoring, while it is assumed that this type of monitoring will include mainly groundwater intakes. The need to supplement the quantitative monitoring network is estimated at a similar level.

The transboundary groundwater monitoring described in this report will include the measurements and tests of the following groundwater status indicators:

- location of the groundwater table;
- studies of the physicochemical elements of groundwater, characterizing the geogenic and anthropogenic substances present in them.

References

Drinking Water Directive, (1998) Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption

Duchnowski Z., Mieczniki J., (1983) Aneks nr 1 do Projektu podstawowej sieci obserwacyjnej wód podziemnych na obszarze kraju (niepublikowane). [*Annex No. 1 to the Project of the basic groundwater observation network in the territory of the country (unpublished).*] CAG PIG-PIB, Warszawa

European Communities, (2003a) Guidance document Nº 3. Analysis of Pressures and Impacts. European Communities, 2003, Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

European Communities, (2003b) Guidance document Nº 7. Monitoring under the Water Framework Directive, European Communities, 2003, Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

European Communities, (2007a) Guidance Document Nº 15. Guidance on Groundwater Monitoring. European Communities, 2007, Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

European Communities, (2006) Guidance document Nº 16. Guidance on Groundwater in Drinking Water Protected Areas, European Communities, 2006, Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

European Communities, (2007b) Guidance document Nº 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 Water Framework Directive (2000/60/EC)

European Communities, (2009a) Guidance document Nº 18. Guidance on groundwater status and trend assessment, European Communities, 2009, Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

European Communities, (2009b) Guidance document Nº 21. Guidance for reporting under the Water Framework Directive, European Communities, 2009, Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

European Communities, (2010) Guidance document Nº 26. Guidance on risk assessment and the use of conceptual models for groundwater, 2010, Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

European Commission, (2019) Technical report on groundwater quality trend and trend reversal assessment, Common Implementation Strategy for the Water Framework Directive and the Floods Directive, 2019

Groundwater Directive, (2006) Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration

Hordejuk T., Mieczniki J., Pich J., (1994) Projekt sieci krajowej monitoringu zwykłych wód podziemnych (niepubl.). CAG PIG-PIB, Warszawa

Journal of Laws, (2019) Rozporządzenie Ministra Gospodarki Morskiej i Żeglugi Śródlądowej z dnia 11 października 2019 r. w sprawie kryteriów i sposobu oceny stanu jednolitych części wód podziemnych (Regulation of the Minister of Maritime Economy and Inland Navigation of 9

October 2019 on the forms and methods of monitoring of surface water bodies and groundwater bodies) (Dz.U. z 2019 r., poz. 2147)

Journal of Laws, (2020) Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 26 marca 2020 r. w sprawie ogłoszenia jednolitego tekstu ustawy - Prawo geologiczne i górnicze (Announcement of the Marshal of the Sejm of the Republic of Poland of March 26, 2020 on the publication of the uniform text of the Act - Geological and Mining Law) (Ustawa z dnia 9 czerwca 2011 r); (Dz.U. 2020 poz. 1064)

Journal of Laws, (2021) Rozporządzenie Ministra Infrastruktury z dnia 13 lipca 2021 r. w sprawie form i sposobu prowadzenia monitoringu jednolitych części wód powierzchniowych i jednolitych części wód podziemnych (Regulation of the Minister of Infrastructure of 13 July 2021 on the forms and methods of monitoring of surface water bodies and groundwater bodies) (Dz. U. 2021, poz. 1576)

Kazimierski B., Gidziński T., (2011) Koncepcja reorganizacji sieci obserwacyjno-badawczej wód podziemnych. Biuletyn Państwowego Instytutu Geologicznego, 2011 Nr 445 z. 12/2, str. 255-265.

Martyniuk V., Zaleskyi I., Zubkovych I., (2020) The geoecological monitoring of lakes of the zone of potential technogenic impact of the “Khotyslavskyi” quarry (on the example of Sviate Lake, Volyn Polesia). «Colloquium-journal» nr. 21 (73), 2020 / Geographical Sciences, p. 5-13.

Nitrates Directive, (1991) Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources

Pich J., Kazimierski B., (1994) Projekt sieci stacjonarnych obserwacji wód podziemnych na terenie Polski i jej funkcjonowanie (niepublikowane). CAG PIG-PIB. Warszawa

Pich J., Przytuła E., (1993) Aneks nr 2 do Projektu podstawowej sieci obserwacyjnej wód podziemnych na obszarze kraju (niepublikowane). CAG PIG-PIB, Warszawa

UNECE, (2000) UNECE Task Force on Monitoring and Assessment: Guidelines on Monitoring and Assessment of Transboundary Groundwater

UNESCO, (2020) Guidelines for Monitoring Strategies in Transboundary Aquifers: Goals, Methods and Tools. The Case of the DRIN project (ALB-MTN)

Uil, H., van Geer, F.C, Gehrels, J.C., Kloosterman, F.H. (1999). UN/ECE Task Force on Monitoring and Assessment. State of the art monitoring and assessment of groundwaters.

Yatsiuk M., Sydorenko O., Tsvyetova O., Turaieva O., (2021) Monitoring and features of hydrogeological and hydrological conditions of Shatsky Lakes in modern climate conditions, Sciences of Europe nr 67, p. 51-60.

Water Convention, (1992). Convention on the Protection and Use of Transboundary Watercourses and International Lakes. United Nations Economic Commission for Europe (UNECE). February 1992, https://unece.org/fileadmin/DAM/env/water/pdf/watercon.pdf

WFD, (2000) Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy

PART II. Principles of development of a Latvian-Estonian transboundary groundwater monitoring network: methodological foundations and practical solutions

Introduction

Groundwater management is a very comprehensive and complex long-term process, given that this resource is very extensive and not limited by national borders. Changes in the quantity and quality of groundwater are usually slow and the processes most often occur over large areas. In order to identify such changes in groundwater, assess the impacts of pressures, as well as manage groundwater on a national scale more efficiently, it is required to establish a groundwater monitoring network and a monitoring program. The main objective of aquifer management is to control the impacts of groundwater abstraction and pressures, and to monitor this objective, the monitoring of aquifer response and quality trends is key.

If national groundwater management is successfully implemented in most Member States in accordance with the EU requirements, then much more effort and challenges are required for transboundary groundwater management, which requires close cooperation between the countries involved. Cooperation between countries which are sharing water resources plays an important role in establishing transboundary groundwater monitoring. In this context, The Convention of the United Nations Economic Commission for Europe on the Protection and Use of Transboundary Watercourses and international Lakes (Water Convention, 1992) plays important role, by defining a legal and institutional co-operation framework and requires Parties to prevent, control and reduce transboundary impact, use transboundary waters in a reasonable and equitable way and ensure their sustainable management.

According to groundwater monitoring, the main instrument for integrated groundwater management implementation in Latvia and Estonia 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. In both Latvia and Estonia, groundwater monitoring at the national level has been carried out for many years in accordance with EU requirements, by observing the quantity and quality of groundwater and developing monitoring programs. However, no monitoring has been carried out so far in the frame of common transboundary groundwater resources. The EU-WATERRES project is a very important platform to promote cooperation between Latvia and Estonia to improve the common transboundary groundwater management.

In this report, common principles for selecting the transboundary groundwater monitoring points in Latvia and Estonia were developed. Report contains the compliance assessment of the existing monitoring points for the transboundary groundwater monitoring purposes, identifying areas with significant transboundary groundwater flows and intense anthropogenic pressures. Based on the previous, the prospective monitoring site locations in Latvian-Estonian pilot area were identified for improvement of the monitoring network.

1 Analysis of the situation

According to the WFD, the Member States which have identified transboundary groundwater bodies (further – TGWBs) should carry out joint activities to monitor, share data and assess the chemical and quantitative status of these GWBs. According to WFD Annex V 2.2.2. and 2.4.2. requirements, transboundary GWBs should be provided with a sufficient number of monitoring points to assess the direction and the flow rate of the groundwater through the member state boundary, as well as track groundwater quality, timely identify and control transportation of potential pollutants.

Particular attention must be paid to GWBs that have been identified as GWBs at risk, stated or objected to with intense anthropogenic pressure. Member states located in the transboundary area should carry out all the necessary measures (including monitoring network installation) to prevent, limit and reduce any negative transboundary impacts. General requirements for the development of the groundwater monitoring network are mainly determined by WFD "Guidance on Groundwater Monitoring", however more detailed information is available in "Guidelines on monitoring and assessment of transboundary groundwaters" (UNECE, 1999).

1.1 Conditions for the selection of transboundary groundwater monitoring points

To select transboundary monitoring points, firstly it is necessary to identify the hydrogeological conditions (the regime and quality) and potential pollution risks of identified transboundary GWBs. Therefore, the selection/location of representative monitoring points and the selection of appropriate monitoring point density should be based on the conceptual understanding (hydrogeological characteristics and pressures). For transboundary GWBs it is highly recommended that jointly agreed conceptual models are developed using European Commission "Guidance on risk assessment and the use of conceptual models for groundwater" paragraph 3.1.

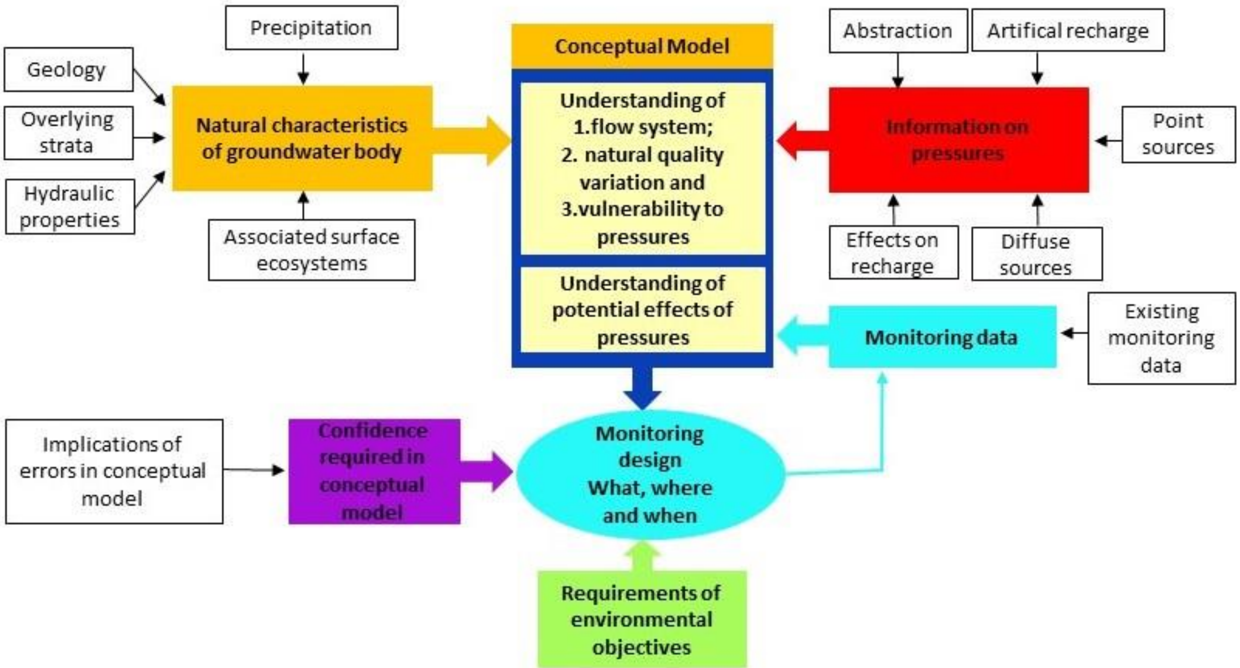


Figure 26 Link between the conceptual model/understanding and monitoring (from CIS WG 2.7 Monitoring Guidance)

Therefore, the design of a monitoring network should take into account the three-dimensional nature of the groundwater system and both spatial and temporal variability, especially when determining the location of monitoring sites and the selection of appropriate monitoring site types. The network should have a spatial and temporal density which considers the natural characteristics of the groundwater body (conceptual understanding) and the pollution risks, to help focus monitoring activities in areas where significant pressures combined with higher vulnerability exist (European Communities, 2007).

1.1.1. Groundwater quality monitoring points

In general, the locations of transboundary groundwater quality monitoring points should be representative for the defined objectives. The aim of the recommended approach is that the positioning of the observation points should be based on the vulnerability of the groundwater flow system, combined with the functions/uses, threats and problems and the core-elements of water management. The various activities for a specification of the location are:

- characterization of the groundwater systems and the geometry of the principal water bearing formations;
- vulnerability assessment, mainly based on the groundwater flow situation (discharge and recharge areas), soil composition and geology;
- identification of the threats to which the groundwater system is exposed (in particular reflected in land use: agriculture, industry, waste sites, military sites, etc.);
- identification of the problems which affect the aquifer (e.g., acidification, nutrients, salinization, pollution, etc.).

The combination of the vulnerability classification with the identified threats and problems gives the opportunity to concentrate the monitoring effort within the most urgent areas. The vertical position of the observation points should be adjusted to the groundwater flow velocity and the eventual movement of pollution fronts, which is generally very slow in porous unconsolidated formations. However, in consolidated formations with secondary permeability, much higher velocities may occur (Uil H. et al, 1999).

1.1.2. Groundwater quantity monitoring points

Probably the most crucial monitoring design aspect of transboundary groundwater quantity monitoring is the specification of the measurement positions in a spatial sense, because this defines an important feature of the observation point, namely its representativity. Technically, the positioning and the number of observation points, which determines the density of the network, is governed by two criteria, namely:

- the specified representativity of the observation points;
- the possibility to determine the spatial trend of the groundwater levels or hydraulic head pressures on the required scale.

The first criterion means in general a specification of the groundwater flow system or unit for which a network should be established. The second depends primarily on the defined technical objectives. For example, for a regional network, a strategic type of monitoring, the objective could be to enable the determination of a regional trend based on the average groundwater levels for a certain period or on the groundwater levels for a specific date. In case of the operational and surveillance type of monitoring, the periods to be considered for trend detection will generally be much shorter and require a higher density of observation points compared to regional monitoring.

Continuous interpretations for describing the groundwater levels and hydraulic pressures in space will also be needed for monitoring of transboundary groundwater systems, which may include strategic as well as operational or surveillance monitoring (Uil H. et al, 1999).

1.1.3. Experience of other countries in selecting transboundary groundwater monitoring points

The conditions of transboundary monitoring points selection in WFD are described very generally. Guidelines developed by the European Commission and UNECE (European Communities, 2007; Uil H. et al, 1999) recommends more detailed criteria for the development of a monitoring network (selection of monitoring points), based mainly on conceptual understanding of the hydrogeological conditions of the transboundary area and potential pollution threats. The selection of transboundary monitoring points is also influenced by the assigned monitoring tasks/objectives, which specify the acquisition of the necessary information for the management of transboundary GWBs and identify the required size of the monitoring network. It should be noted that the existing level of the cooperation between countries and financial consideration may also have an impact on the construction of transboundary groundwater monitoring networks.

An analysis of available materials on the selection of transboundary monitoring points in other countries shows that no country has developed specific methodologies for setting up a groundwater monitoring network or for identification of transboundary monitoring points. It is considered that the groundwater regime or hydrogeological conditions are the basic criteria for creation of a transboundary monitoring network (Uil H. et al, 1999). Furthermore, there should be selected appropriate existing monitoring points, paying particular attention to those areas which are exposed to negative transboundary anthropogenic impacts. To select the monitoring sites, a set of criteria has been applied by the countries, such as aquifer type and characteristics (porous, karst and fissured, confined and unconfined groundwater) and depth of the GWBs. The flow direction was also taken into consideration by some countries, as well as the existence of associated drinking water protected areas or ecosystems (aquatic and/or terrestrial) (ICPDR, 2008).

However, it should be noted that in most cases countries are using existing monitoring networks to assess the initial situation in the transboundary area. Then, after getting more detailed information, for example, risk assessment, the existing monitoring network is extended by installing new monitoring points or by integrating already existing monitoring points. It is noted that for deeper GWBs the flexibility in the design of the monitoring network is very limited, so the effort of obtaining as much knowledge using existing capabilities as possible should be made already at the beginning (ICPDR, 2008; UNESCO, 2020).

In addition, it should be noted that transboundary monitoring in the Estonian-Russian and Latvian-Lithuanian border areas is also provided by monitoring points included in the existing national monitoring network; other methodologies for selecting transboundary monitoring points in both countries have not been developed (Estonian-Russian Cooperation, 2020); B-Solutions, 2018).

2 Transboundary groundwater monitoring point qualification principles (methodology)

Based on the information collected and analyzed in Chapter 1, the initial step in the design of the transboundary monitoring network is the hydrogeological conceptual model. The conceptual model helps to identify the hydrogeological conditions of the transboundary area, the intensity of the anthropogenic pressure, impacts and risks, as well as helps to identify the purpose of the monitoring and the density of the monitoring network in the transboundary area.

For identification of transboundary groundwater quality and quantity monitoring points and designing of new groundwater monitoring points, extent of conceptual model and knowledge base about the transboundary area are two main base factors. The following principles should be taken into account:

- geological structure and main geological units in the transboundary area: geometry, lithology and groundwater flow paths;
- areas with specific interest – places where the most intense pressures are located and identified (prior knowledge base is needed);
- vulnerability;
- practical considerations: financial aspects, long-term access and security.

In order to make the best use of available resources and knowledge, a step-by-step approach initially should be used and all existing monitoring points located in the transboundary area should be included in the transboundary monitoring network. Step-by-step approach could help to form the strongest cooperation between countries in order to organize the management of transboundary groundwater water resources as efficiently as possible in the future. Existing monitoring points (wells, springs) may serve as surveillance monitoring and provide general information on transboundary GWBs status.

The density of transboundary monitoring points may increase in areas where intensive anthropogenic pressures are identified – a chance of GWB not achieving good groundwater status or being at “risk”. The criteria for identifying such areas are given in Table 1. If such chances are low, the density of the transboundary monitoring network can be low while it is still representative of the groundwater body characteristics. Monitoring points that are objected to risk, will already provide operative monitoring. Therefore, the existing monitoring network should be supplemented with the number of strategically located monitoring points (UNESCO, 2020).

Table 8 Criteria for identifying transboundary areas with intense anthropogenic pressures

Selection criteria	Sub-criteria
Geological structure and properties of main geological unit	- groundwater flow path (based on the results of Output 1, identify areas where continuous and significant cross-border flows are possible).
Areas with specific interest	- active groundwater intakes (on the basis of collected materials and cartographic information, identify active groundwater abstraction sites/area with significant groundwater intake >100 m^3/d); - mining areas (on the basis of collected materials and cartographic information, identify active mining areas and quarries that may have an impact on transboundary hydrogeological conditions); - pollution hotspots (on the basis of the collected materials and cartographic information, identify polluted or potentially polluted sites that may have an impact on transboundary groundwater quality).
Vulnerability (is mandatory in cases when a significant pollution pressure has been identified)	- based on available cartographic information identify areas at high risk of pollution

Existing monitoring network may be expanded by installing new monitoring points. But as previously mentioned the flexibility in the design of monitoring networks for deeper GWBs is very limited due to financial aspects, therefore integrated monitoring will contribute significantly to cost-efficient monitoring by making best use of appropriate components of existing monitoring networks serving different objectives. Monitoring points for groundwater level observations can be wells or boreholes that are not substantially affected by groundwater abstraction in the neighboring areas. For groundwater quality networks, use can be made of already existing monitoring or abstraction wells. It should be noted that springs can also be used as monitoring points, in particular for groundwater sampling purposes. With regard to representative data, one spring can replace a number of monitoring wells.

It is necessary to compile the following information on the monitoring points to be identified, integrated or projected, as set out in Annex 1. However, in order to establish a sustainable and efficient transboundary monitoring system, the fontal monitoring network should be reviewed periodically, gaining new knowledge and developing the existing conceptual model (Figure 27).

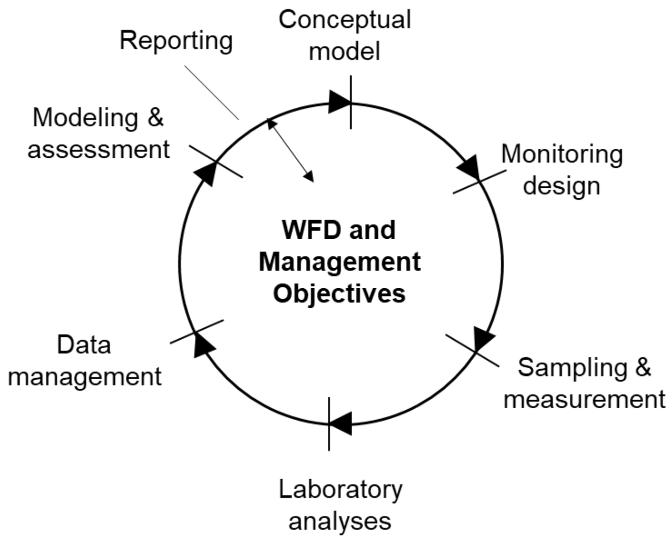


Figure 27 The monitoring cycle adapted for groundwater monitoring (European Communities, 2007)

3 Transboundary groundwater monitoring point qualification

Until now, close transboundary cooperation has not been established in the Latvian-Estonian transboundary area, and transboundary monitoring points in common groundwater bodies have not been identified. Within the framework of this project, it is planned to identify transboundary monitoring points that will be included in the transboundary monitoring plan in the future in order to more effectively manage and monitor the condition of transboundary groundwater bodies.

3.1. Groundwater monitoring in Latvia and Estonia

3.1.1. Groundwater monitoring in Latvia

Regular surveys of groundwater quality in Latvia have been conducted since 1959. The objectives and scope of the groundwater monitoring network varied over time, mainly due to changes in regulatory documents as well as global trends in groundwater monitoring. The groundwater monitoring network was mainly set up between 1959 and 1991, initially to assess the water quality of deep pressurized aquifers and their changes, as these aquifers began to be used intensively for centralized drinking water supply not only in cities during this period, but also in populated rural areas. Gradually, it was supplemented by the addition of "level principle" monitoring stations, which consist of well-placed boreholes with filters at various intervals up to a depth of 200-400 meters, and the installation of "balance stations" with shallow boreholes. From 2004, the groundwater monitoring network also included springs.

Groundwater monitoring in Latvia 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. Groundwater monitoring is primarily performed at the level of GWBs, while integrating the management of the RBD into a common strategy for achieving environmental quality objectives.

The groundwater monitoring program prepared for each period for the RBD management plans helps to monitor the achievement of environmental objectives, assess the impact of human activity and gain reliable data on the actual environmental status of water bodies. The monitoring points that are monitored each year and the parameters to be monitored for groundwater quality may vary according to the annual monitoring plans. The frequency of groundwater monitoring is variable: the frequency of quantitative observations – two times a day (automatic level measurements) up to four times a year, and the frequency of groundwater chemical observations is four times a year, up to once a year (over a six-year period, it changes from one time in six years to one time each year).

Under the constraints of limited funding, the groundwater monitoring program is being adapted to the requirements of the two directives (Nitrates Directive (91/676/EEC) and WFD), which are not equivalent. The WFD requires the identification of the background level of natural chemical composition and trends in the aquifers used in the main water supply of underground water bodies, which in the case of Latvia are deeper confined water. The current groundwater monitoring program is more adapted to fulfill the requirements of the WFD than to fulfill the requirements of the Nitrates Directive (91/676/EEC).

This monitoring program identifies mainly the following types of groundwater monitoring: groundwater quantity monitoring and groundwater quality monitoring (surveillance and operational). The main tasks of the monitoring program are:

1) to assess the quantitative status and chemical quality of groundwater bodies, and the

direction of trends in changes in the relevant status;
2) to ensure observations regarding the condition of groundwater resources in each delineated groundwater body;
3) to determine the status of the quantity and quality of groundwater at the level of groundwater bodies - to determine whether the chemical status of groundwater within the boundaries of the groundwater body is “bad” or “good”;
4) to identify dangerous trends in the quantity or quality of groundwater bodies in a timely manner;
5) to control the regional changes of groundwater of any origin and to provide background data for all types of observations, determining the regularities of changes in the quantity and quality of groundwater;
6) to assess the condition of groundwater bodies at risk, the tendencies of changes in the environmental quality indicators causing the risk;
7) to provide additional information for the preparation of the program of measures of the water management plan.

Currently, the status of groundwater within the framework of monitoring is observed in 311 wells located in 61 stations and 30 springs. Of these, quality (chemical composition) observations are provided at 53 stations - 218 wells and 30 springs, but quantity (water level) observations - at 60 stations, 305 wells. In the 2021-2026 planning period, it is planned to improve the existing groundwater monitoring network in Latvia by installing 25 new groundwater monitoring stations with a total of 70 wells and improving two existing groundwater monitoring stations (it is planned to renovate 1 well and renovate the old station by adding 4 wells). The new wells are planned to be installed at different depths: 0-5 m, 5-15 m, 5-30 m, >30 m (Quaternary aquifer wells) and the deepest groundwater aquifers or pre-Quaternary sedimentary wells. Also, as far as possible, it is planned to improve the technical condition of the existing wells and include them in the current monitoring network. The location of existing and new monitoring points is visually shown in Figure 28.

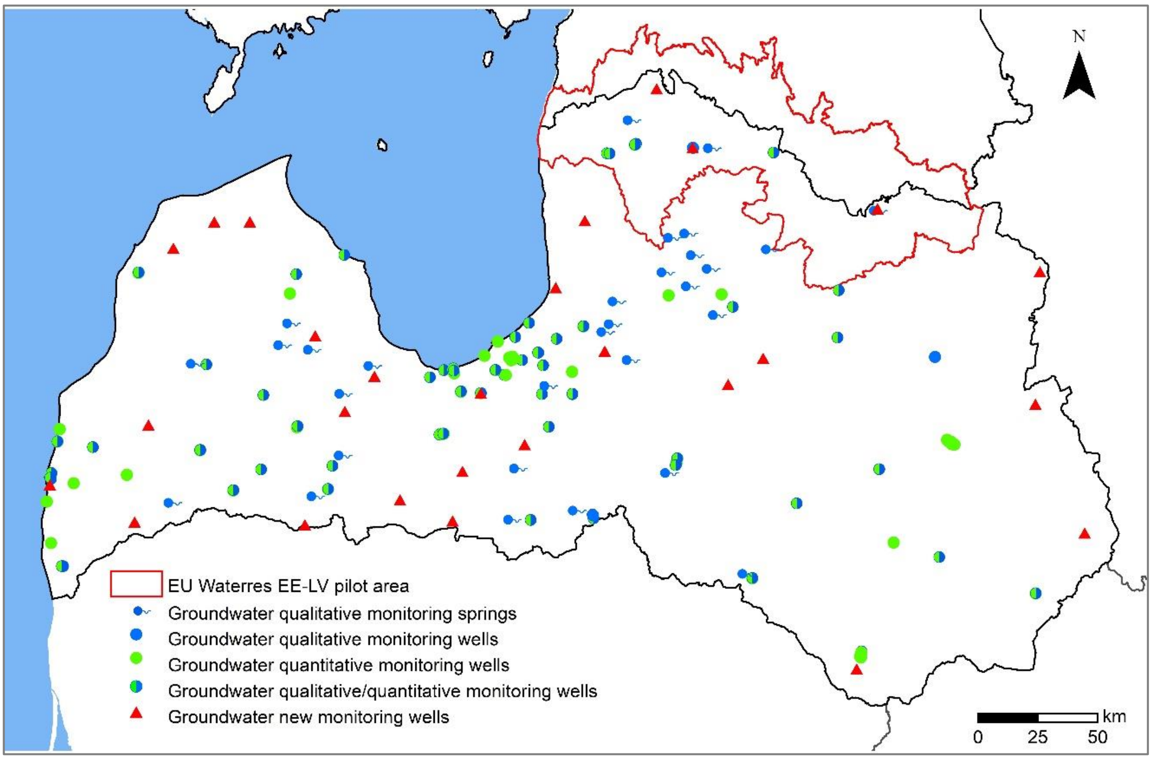


Figure 28 Groundwater monitoring points in Latvia

However, it should be noted that the existing groundwater monitoring network mainly allows the assessment of regional groundwater changes and provides background data on the chemical and quantitative status of groundwater at the level of GWBs, mainly by monitoring aquifers used in water supply. Accordingly, monitoring in protected areas (nitrate vulnerable zone and drinking water protected areas) is only partially provided, as well as additional monitoring of these areas is integrated with other monitoring programs.

3.1.2. Groundwater monitoring in Estonia

The earliest data of groundwater monitoring in Estonia goes back to the 1960-s during the Soviet times. As geological and hydrogeological mapping started in 1958, many new monitoring wells were created in the following decades. In 1995, the Estonian National Monitoring program started, which was the start of groundwater monitoring in its current form. The Geological Survey of Estonia was responsible for it. Since 2018, the monitoring is done by the Estonian Environment Agency, and the Estonian Environmental Research Centre performs the practical activities.

Before implementing the EU WFD, groundwater status changes were observed in seven areas with different hydrogeological and technogenic conditions and pressure (areas with natural conditions, intensive water use conditions, and areas affected by quarries). In 2000, the progress of forming groundwater bodies was started. First groundwater bodies were confirmed in 2004.

The WFD methodology for the assessment of Estonian groundwater bodies and the determination of threshold values was developed in 2013 (supplemented by the GSE in 2019), and based on it, the status of groundwater bodies (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.

The purpose of monitoring groundwater bodies in Estonia is to monitor the chemical and quantitative status (the trends and changes of quality indicators) of the groundwater bodies. Information from monitoring is used for developing the River Basin Management Plans according to the EU WFD.

Groundwater monitoring in Estonia is a part of the environmental monitoring program. It is divided into two parts: monitoring the groundwater bodies and monitoring the Nitrates Vulnerable Zone. The quantitative and qualitative status of 31 groundwater bodies in Estonia are monitored using a network of monitoring wells. The changes in groundwater bodies are described, changes in groundwater flow caused by water level changes are assessed, conclusions are made about salt or other water intrusions into groundwater bodies, and short-term changes are distinguished. Within the assessment of the qualitative status, the pollutants are detected in groundwater, the chemical status class of each groundwater body is determined, and the changes in the chemical composition of groundwater are described and analyzed.

The status of the groundwater body is good if less than 80% of the values of the quality indicators fixed at the monitoring points of the groundwater monitoring program correspond to the values of quality indicators set out in Regulation No. 48 of the Minister of the Environment of Estonia:

1) the concentrations of chlorides, sulphates, and total dissolved solids measured by electrical conductivity do not show an upward trend indicating anthropogenic pollution or saline inflows;
2) pH range 6-9;

3) the content of dissolved oxygen does not indicate a downward trend due to human activity, or the chemical oxygen demand is ≤ 5 mg O_2/l, or if the value of the quality indicator is exceeded, the natural content of dissolved oxygen in the groundwater has been proven;
4) the ammonium content in naturally aerobic groundwater does not exceed 0.5 mg/l or in a naturally anaerobic aquatic environment does not exceed 1.5 mg/l, or if the value of the quality indicator is exceeded, the natural origin of ammonium in groundwater has been proven;
5) the absence of arsenic, cadmium, lead, mercury, trichloroethylene, tetrachlorethylene, synthetic substances, or their concentration does not exceed the groundwater quality limit values for dangerous substances, or the natural origin of these substances in groundwater has been established;
6) the concentration of pollutants does not impede the achievement of the environmental objectives for the surface water associated with the body of groundwater and does not cause significant damage to the ecological or chemical status of the surface water or to terrestrial ecosystems directly dependent on that body of groundwater.

The status of the groundwater body is bad if less than 80% of the values of the quality indicators fixed at the monitoring points of the groundwater monitoring program correspond to the values of quality indicators.

The groundwater level monitoring network in Estonia includes 257 wells. Depending on the well, the monitoring frequency is once a month, or there are automatic water level measurements. The monitoring network for groundwater chemical status includes 225 wells. A groundwater sample is taken once a year during the low water level in summer to determine physical and chemical quality indicators.

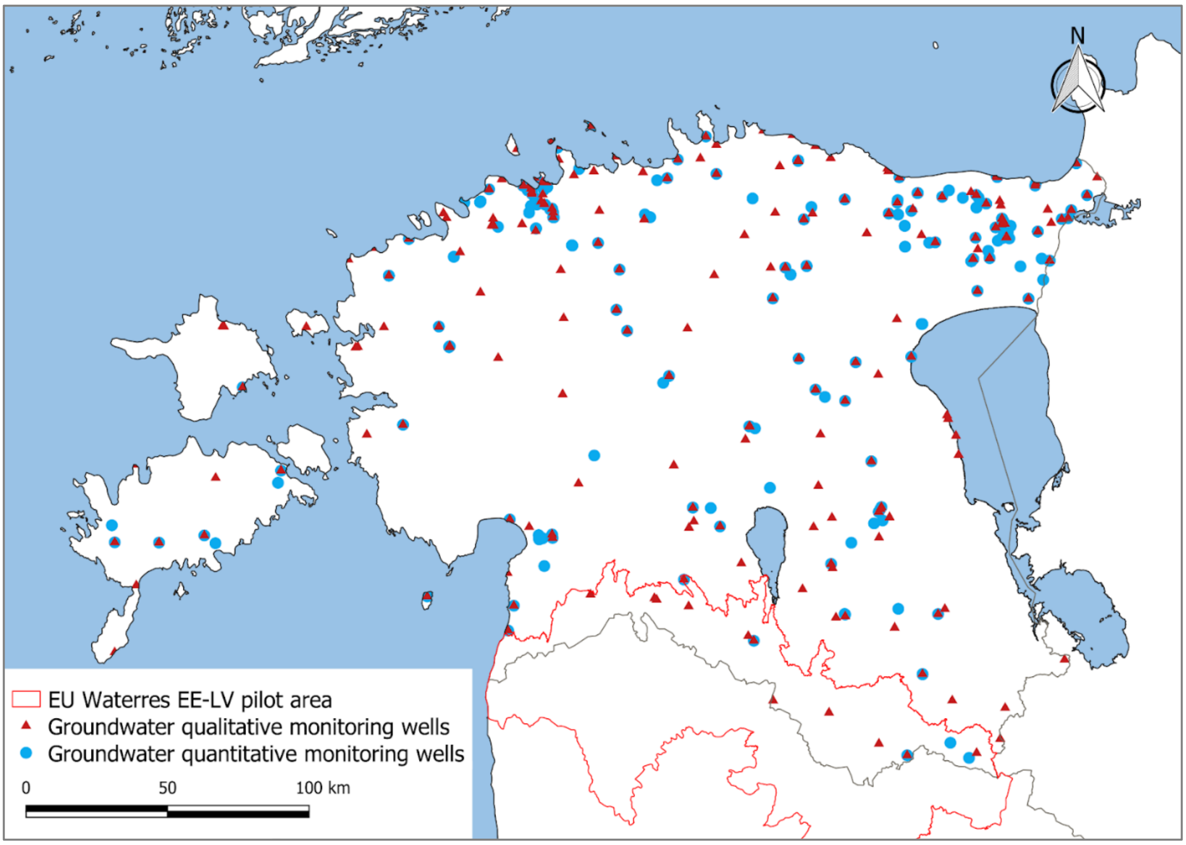


Figure 29 Groundwater monitoring points in Estonia

As a result of the data analysis of the monitoring, in addition to the results of chemical analysis, the following indicators of groundwater status are presented as outputs:

1) natural changes in the chemical composition of groundwater;
2) anthropogenic changes in the chemical composition of groundwater;
3) significant and sustained trends in pollutants;
4) the average NO_3^- content of each groundwater body according to the data from this monitoring;
5) the average concentrations of quality indicators and pollutants in the relevant groundwater bodies and an assessment of the compliance of these concentrations with the threshold value established in the Regulation No. 48 of the Minister of the Environment of Estonia;
6) compliance of the content of hazardous substances with the groundwater quality limit values in Regulation No. 39 of the Minister of the Environment of Estonia;
7) compliance of the content of pollutants with Regulation No. 61 of the Minister of Social Affairs of Estonia;
8) an assessment of long-term anthropogenic changes in the chemical composition of groundwater;
9) an evaluation of the achievement of the environmental objectives.

3.2. Groundwater monitoring point qualification

The Latvian-Estonian cross-border area belongs to the central part of the BAB, where diverse aquifers are found in layers of different ages. The aquifers of the pre-Quaternary sediments are separated from each other by both local and regional aquitards or cage layers – regional Narva aquitard and Silurian-Ordovician layers. Regional aquitards divide the entire sedimentary cover into three practically isolated parts: in the active, slowed-down and stagnant groundwater exchange zone. Water overflow between these zones is possible only in small areas at cracks and fractures. Within the framework of the EU-WATERRES project, only the active water exchange zone up to the Narva regional aquitard is relevant, as it contains freshwater resources in the whole study area, which are exploited and will continue to be exploited in water supply, mainly as drinking water. It should also be taken into account that the largest groundwater flow between national borders has been identified for the aquifer complexes belonging to the active water exchange zone, therefore this part needs increased attention to changes in transboundary groundwater resources.

The active water exchange zone includes two aquifer systems: Pļaviņas-Ogre aquifer system, which characterizes three transboundary groundwater bodies - D6, D8 and 26, as well as the Aruküla-Amata aquifer system, which characterizes four transboundary groundwater bodies - A8, A10, 23, 24 and 25. Quaternary aquifers are included in uppermost groundwater bodies, where they are exposed on the ground surface. It should be noted that the use of Quaternary groundwater as drinking water in the chosen transboundary area is insignificant, so increased attention is paid only to previously mentioned confined aquifer systems. More detailed information on aquifer systems and hydrogeological conditions of the study area can be found in WP3 Output 1 “Assessment of the resources of transboundary groundwater reservoirs for the 2 pilot areas” (Solovey et al., 2021). Further, the data analysis is based on the criteria specified in paragraph 2 and based on the step-by-step principle, as well as the objectives or tasks of cross-border monitoring were taken into account:

1) to provide regional observations on the status of groundwater resources in each transboundary groundwater water body;
2) to assess the initial qualitative and quantitative status of transboundary groundwater,

taking into account the impact/capacity of anthropogenic pressures;
3) to improve cooperation between countries and to establish sustainable management of groundwater resources.

3.2.1. Existing groundwater monitoring points

There are currently 22 monitoring points in the Latvian-Estonian transboundary area, of which 13 monitoring points - wells are located in the territory of Estonia and 9 monitoring points (3 springs and 6 wells in 2 stations) in the territory of Latvia (Figure 30). Monitoring points characterize Pļaviņas-Ogre and Aruküla-Amata aquifer systems or transboundary water bodies - 26, D6, D8 and A8, A10, 23, 24 and 25, and provide mostly continuous quantity and/or quality monitoring. The exception is 4 monitoring points in the territory of Estonia, which are not currently active and have not been monitored in recent years (Figure 30).

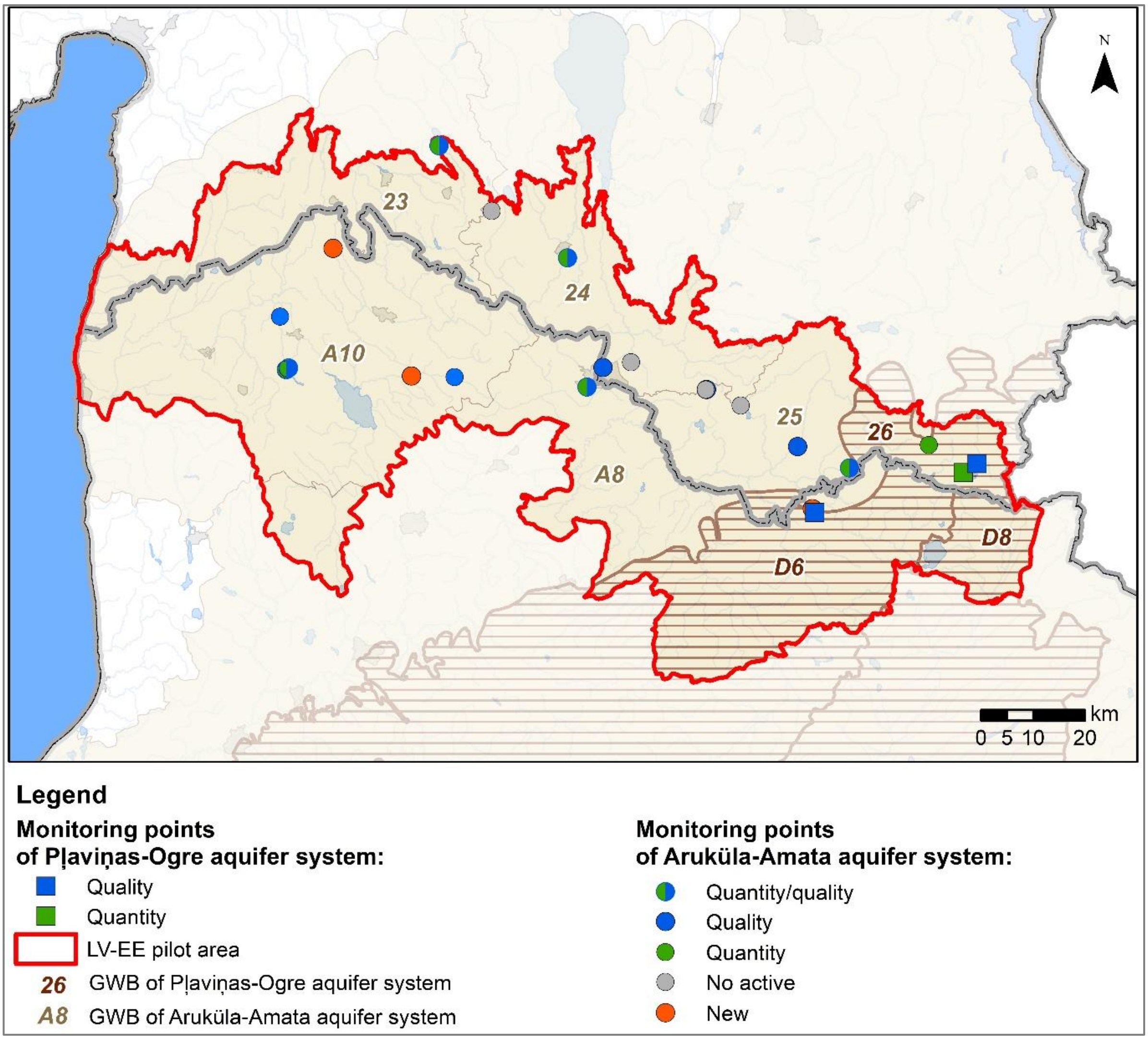


Figure 30 Location of existing monitoring points in the Latvian-Estonian pilot area

It should be noted that by 2027 it is planned to improve the existing groundwater monitoring network in Latvia by installing 3 monitoring stations with 6 wells, which will improve the density of the monitoring network in the Aruküla-Amata aquifer system and further ensure both quantitative and qualitative monitoring. The new wells are planned to be installed at different depths, which would characterize the Quaternary and deeper aquifers. Information on all 22 existing monitoring points and types of monitoring is presented in Table 9, but more detailed information is provided in Annex II.

Table 9 Existing monitoring points in the Latvian-Estonian transboundary area

Aquifer system	GWB	Type of monitoring		Total number of points (springs/wells)
		Qualitative	Quantitative	
Pļaviņas-Ogres	**26**	1	1	3 (1/2)
	D6	1	-	
	D8	-	-	
Aruküla-Amata	**23**	2	1	19 (2/17)
	24	3	2	
	25	5	2	
	A8	1	1	
	A10	5	5	
Total:		**18**	**12**	**22 (3/19)**

It should be noted that the existing monitoring network coverage mainly allows assessing only the qualitative (chemical) status of groundwater, as it is not possible to achieve the quantitative target set by the WFD with the current monitoring network coverage (according to WFD Annex V 2.2.2. requirements, transboundary GWBs should be provided with a sufficient number of monitoring points to assess the direction and flow rate of the groundwater through the Member State boundary).

In order to achieve this goal, it would be necessary to set up a significant number of new monitoring points, which would not be financially adequate. However, in the context of the transboundary area in question, the establishment of such a new and expanded monitoring network would not be adequate and rational, as no significant groundwater intake pressure was identified in the area following data collection and analysis, which could lead to changes in the regional hydrogeological regime (see Chapter 3.3.3) and such an increase is not expected in the future either (the transboundary area is sparsely populated with a declining tendency). Another much more adequate and appropriate solution to assess the direction and flow rate of the groundwater through the Member States boundary would be the establishment of a joint numerical hydrogeological model between the two Member States, through which different scenarios could be modeled, taking into account groundwater intake intensity, which is a key factor in changing the transboundary hydrogeological regime. But, as it was mentioned above, in case of the Estonia-Latvian transboundary groundwater intake pressure is localized and no increase in this pressure is expected.

3.2.2. Groundwater flow path

Based on the calculations made by the University of Latvia (Project partner No. 6), two territories have been identified in the Latvian-Estonian transboundary area, where a relatively significant flow of groundwater between the state borders has been noted: in the eastern part of the transboundary area, in the Gauja-Koiva river basin district, a defined area in which groundwater flows at a relatively high speed; as well as a defined area with a lower groundwater flow between national borders in the central part of the transboundary Salaca-Salatsi river basin district. In the rest of the area, insignificant flows have been identified or not observed at all in some places (Figure 31).

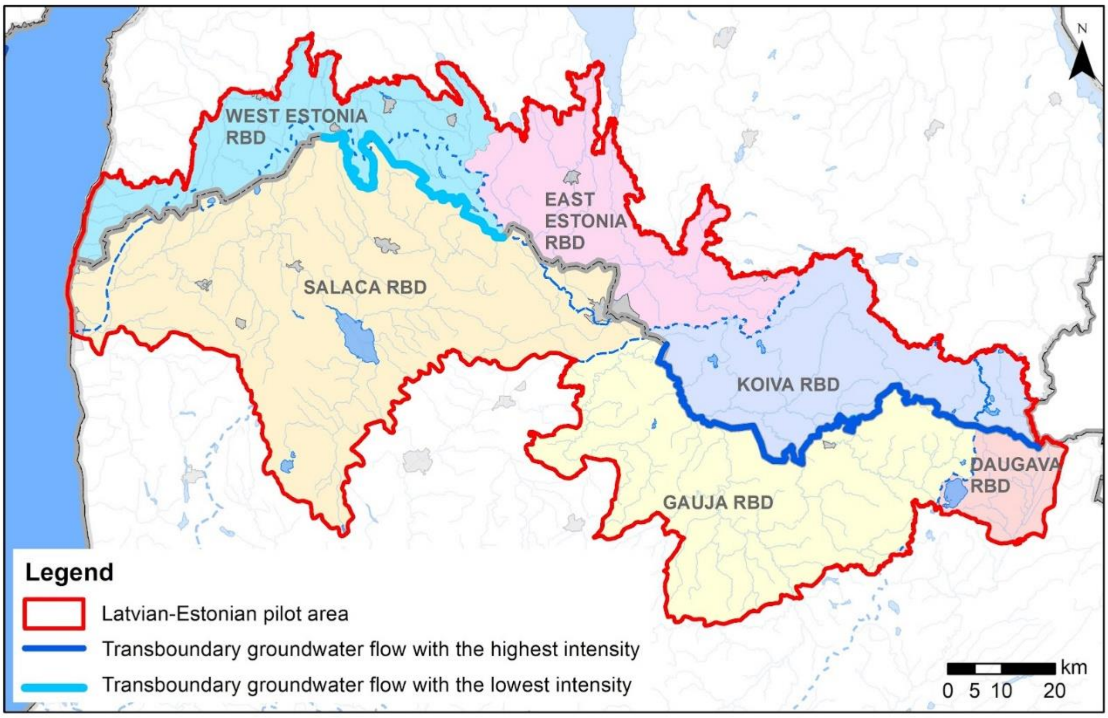


Figure 31 Areas with significant groundwater flows between national borders

However, it should be noted that the intensity of groundwater flow varies not only at the national boundaries, but also at the depth boundaries of the aquifer systems. It can be noted that a higher groundwater flow between national borders has been identified in the eastern part of the Aruküla-Amata aquifer system, where groundwater flows from Latvia to Estonia (in green) with relatively high intensity, while in the central part of the transboundary area waters flow at a lower intensity than in the eastern part of the territory from Estonia to Latvia (in red) and in many parts of the transboundary territory there are no significant groundwater flows across the border - especially in the western part of the territory and in some areas in its central part. (Figure 32).

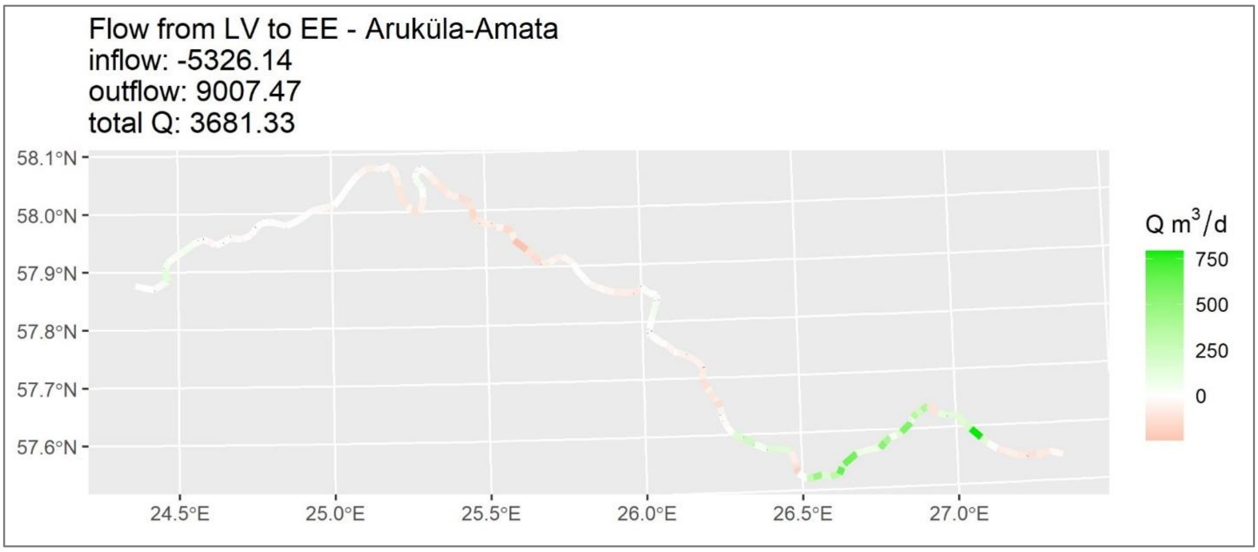


Figure 32 Estimated transboundary groundwater flows across Estonian-Latvian borderline in Aruküla-Amata aquifer system (Solovey et al., 2021)

In the Plavinas-Ogre aquifer system, a lower groundwater flow intensity was observed than in the Aruküla-Amata aquifer system between national borders. Within the distribution range of this aquifer system, two areas with relatively significant groundwater flow intensity between national borders have been identified: in the eastern part the most pronounced groundwater flow from

Estonia to Latvia is identified (in red), and towards the center from the eastern part is identified from Latvia and Estonia (in green), but with a much lower intensity. In the rest of the area, the flow is not observed at all or is insignificant (Figure 33).

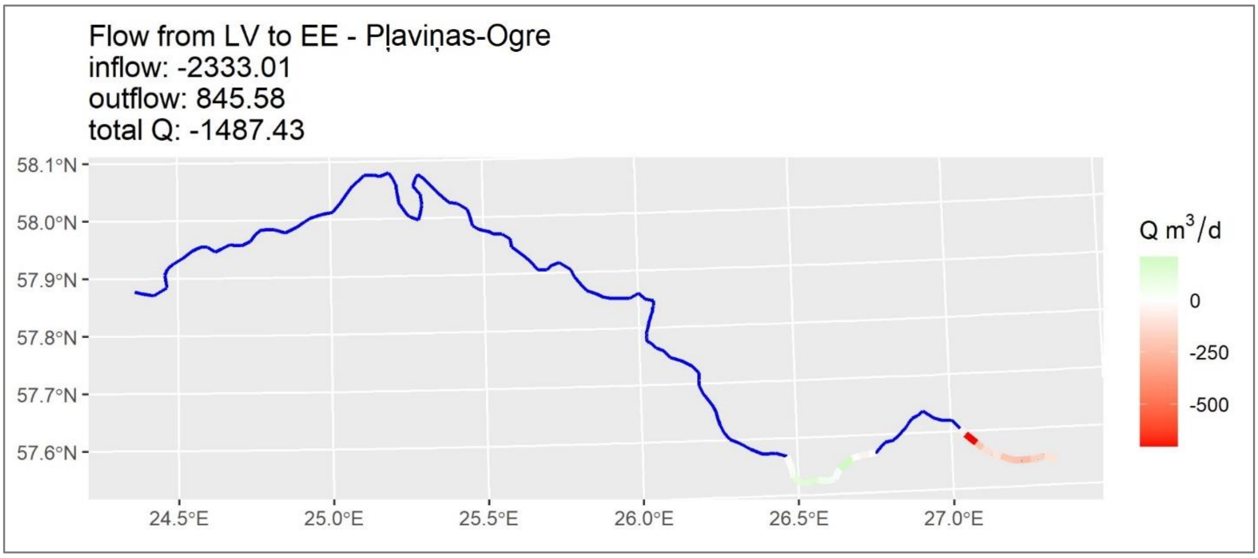


Figure 33 Estimated transboundary groundwater flows across Estonian-Latvian borderline in Pļaviņas-Ogre aquifer system (blue borderline sections - no aquifer system present) (Solovey et al., 2021)

The identified zones/areas mainly determine the priority for the selection of monitoring points, especially in cases where intensive anthropogenic pressures or pollution objects that could affect the quality and/or quantity of groundwater have been identified in these areas. Accordingly, the monitoring points located in these areas will make it possible to identify and control the movement of potential pollutants from one country to another in good time.

3.2.3. Estimation of anthropogenic pressure in EE-LV pilot area

In order to identify regions of the transboundary area where intense anthropogenic pressure have been identified that may endanger the quantitative and/or qualitative status of transboundary GWBs, as a result of which the good status of these GWBs may not be achieved, information was collected for the period 2014-2019 (6-year cycle) from the following information sources:

- Latvian State Geological Fund;
- Latvian Register of Mineral Deposits;
- Latvian state statistical report forms "No.2-Water. Reports on the Use of Water Resources";
- Latvian Environment, Geology and Meteorology Centre, report “3rd cycle Gauja River Basin Management Plans”;
- Estonian Environmental Research Centre, report “Residual Pollution Sites 2014-2015. Compilation and Analysis of Data”;
- Geological Survey of Estonia, “The Status of Estonian Groundwater bodies in 2014-2019”.

In order to estimate the anthropogenic pressure in the Estonian-Latvian transboundary area, the following criteria were considered.

Active groundwater intakes. The Pļaviņas-Ogre aquifer system is distributed only in the eastern part of the pilot area and is mainly operated for decentralized water supply or individual water abstraction needs. In the period from 2014 to 2019, water abstraction from wells in the examined area ranged from 0.1 m^3/d to 65 m^3/d (mainly up to 25 m^3/d), the total groundwater abstraction in the territory was about 200-300 m^3/d. There are no groundwater well fields in the territory with approved groundwater resources and/or active groundwater intake sites with an amount above 100 m^3/d (Figure 34). The largest number of groundwater intake wells has been identified in the vicinity of the city of Alūksne, where an area with total water intake above 100 m^3/d has been identified (maximum total water intake from 4 wells is about 130 m^3/d). However, it should be taken into account that in recent years (2018-2019) groundwater intake was done only from 2 wells, the amount of which did not exceed 40 m^3/d.

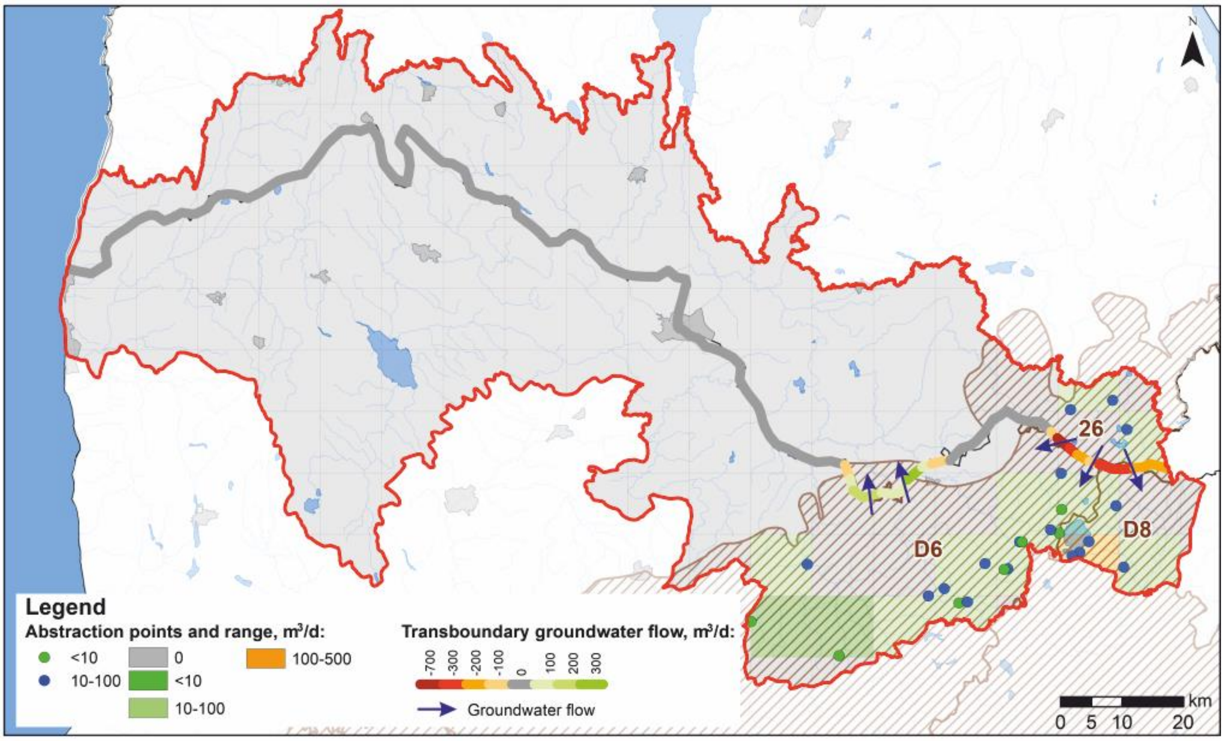


Figure 34 Groundwater intake points in Pļaviņas-Ogre aquifer system and their maximum water intake volumes in the period from 2014 to 2019

The Aruküla-Amata aquifer system is distributed throughout the pilot area and in the eastern part of the territory it lies under the Pļaviņas-Ogre aquifer system. Accordingly, this system is mainly used in those areas where it lies immediately below the Quaternary sediments and is less exploited in the rest of the transboundary area. The Aruküla-Amata aquifer system is intensively operated for both centralized and decentralized groundwater supply, as well as in the individual sector. Areas with intensive groundwater intake pressure were identified in the examined area in those areas where the largest number of intake wells has been identified or intake from wells of groundwater well fields have been observed – groundwater intake in these areas does not exceed 200 m^3/d, and only in Valka-Valga cities it increases up to 4000 m^3/d and in the vicinity of Rūjiena - up to 400 m^3/d (Figure 35). In total, 7 groundwater well fields with approved groundwater resources and only two active groundwater intake sites with intake above 100 m^3/d have been identified in the transboundary area, while no significant water intake has been identified or observed at all in the rest of the transboundary area.

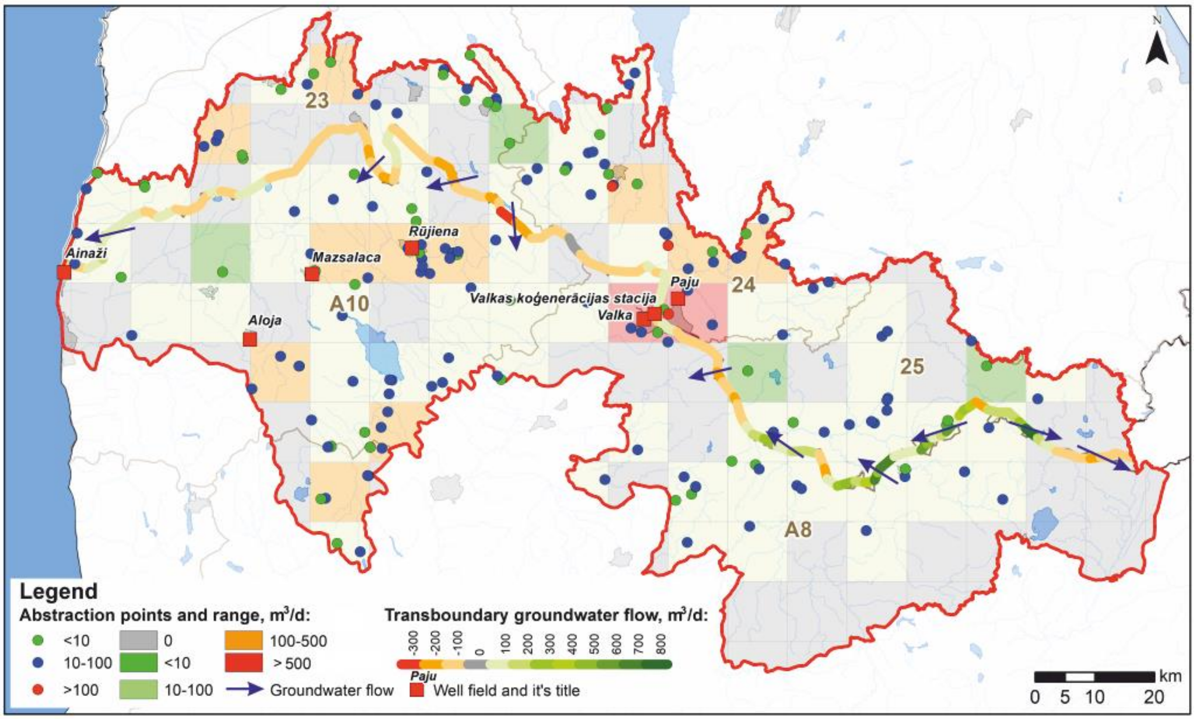


Figure 35 Groundwater intake points in Aruküla-Amata aquifer system and their maximum water intake volumes in the period from 2014 to 2019

Table 10 summarizes information on the most significant groundwater intake sites and their maximum intake volumes in the period from 2014 to 2019.

Table 10 Groundwater well fields with approved resources

Groundwater well fields	Number of wells	Approved resources (m^3/d)	Maximum intake (2014-2019, m^3/d)	Intake (% from approved resources)
Ainaži	1 (2)	480	37.1	7.7
Aloja	1 (1)	200	83.5	41.8
Mazsalaca	1 (2)	432	67.5	15.6
Rūjiena	1 (2)	432	181.7	42.1
Valka	2 (4)	1074	867.6	80.8
Valkas koģenerācijas stacija	1 (1)	600	220.4	36.7
Paju	5	3200	2181.2	68.1
8508	1	-	326	-
10976	1	-	162.8	-
50670	1	-	161	-
	Total:	**6418**	**4300.9**	**56.9**

In the period from 2014 to 2019, groundwater intake from wells in the examined area ranged from 0.1 m^3/d to 100 m^3/d (mainly up to 50 m^3/d), the total intake in the territory was around 5200-6300 m^3/d. In groundwater well fields, a smaller volume of groundwater was abstracted than the approved reserves in them, varying from 7.7% in groundwater well field Ainaži to 80.8% in groundwater well fields Valka (56.9% of the total approved groundwater resources were abstracted from 2014 to 2019).

An in-depth collection of information on the above sites suggests that current groundwater intake volumes cannot change the hydrogeological conditions of the transboundary area. Even if all groundwater well fields would start to intake all the approved groundwater resources, the precautionary principle should be taken into account concerning the surroundings of Valka-Valga cities, taking into account the intake volumes.

Pollution hotspots. In order to assess the potential impact of point pressure sources on transboundary groundwater resources and their quality, previously prepared data from the River Basin Management Plans developed by each country were collected (RBMPs, 2021) and, in addition, materials from available databases and/or fund materials were collected to describe in more detail the origin of point sources and the extent of their impact. The summarized information on identified point source pollution sites in the Latvian-Estonian transboundary area is provided in Figure 36, spatial locations of pollution sites are given in Figure 37.

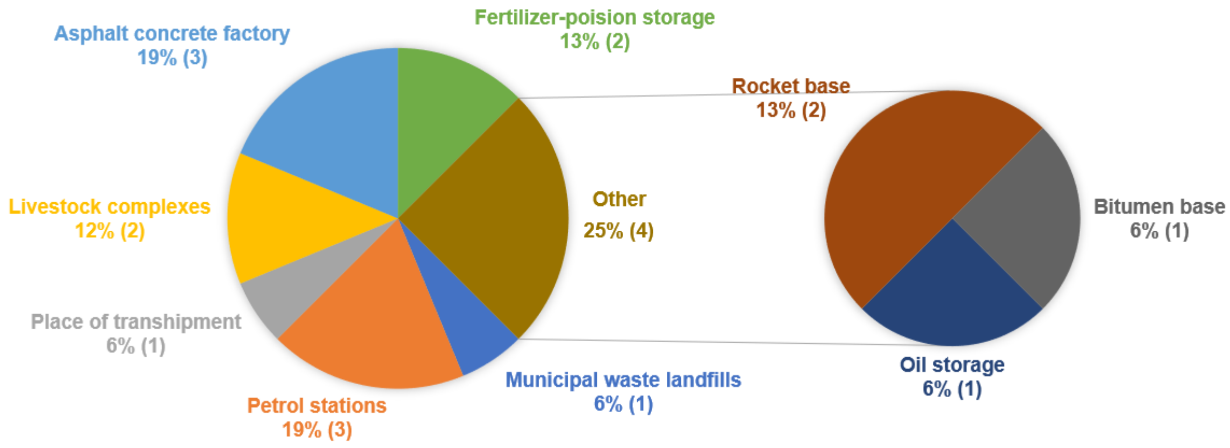


Figure 36 Point source pollution sites in the Estonia-Latvian transboundary area

Pollution sites are mainly concentrated around cities and are mainly petrol stations, asphalt concrete factories, livestock complexes, fertilizer-poison storages and former rocket bases, followed by municipal waste landfills, industrial objects (place of transshipment), oil storages and bitumen bases. A total of 16 point-pollution sites have been identified within the Latvian-Estonian transboundary area, of which 3 sites in the Estonian territory have been identified as pollution site areas (Figure 37).

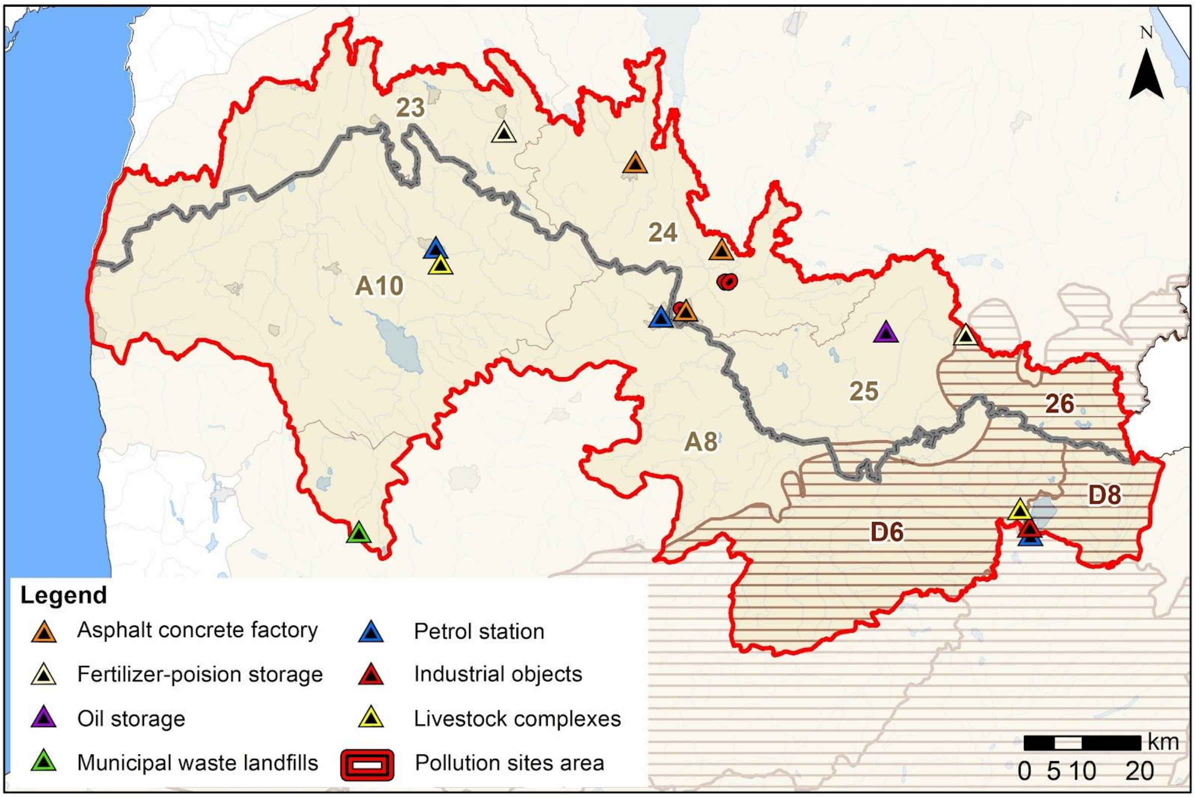


Figure 37 Pollution sites and pollution areas

The type and content of pollution in groundwater is different, it directly depends on the activity profile of the identified pollution sites. The main types of pollutants are petroleum products and nitrogen compounds. More detailed information is available in Table 11.

Table 11 Point source pollution sites in the Estonia-Latvian transboundary

Point pollution source	Type of pollution
Petrol stations	Petroleum products
Municipal waste landfills	N_{tot}, NH_4^+, COD, electrical conductivity, chlorides (Cl^-)
Livestock complexes	N_{tot}, NH_4^+, P_{tot}, COD
Industrial objects	Petroleum products; Heavy metals (Cr, Cu, Zn, Pb, Ni)
Asphalt concrete factory	Petroleum products; Oil shale oil; Polycyclic aromatic hydrocarbons; Phenols
Fertilizer-poison storage	Agricultural poisons; Fertilizers
Oil storage	Motor oil

Studies and observations carried out at the pollution sites in Latvia showed that the pollution is associated with shallow groundwater pollution, which is local and often historical in nature (RBMPs, 2021). In turn, the pollution found in the territory of Estonia is related to the pollution of the Aruküla-Amata aquifer system. The main types of pollution are petroleum products, oil and fertilizers. All of the pollution points are residual pollution points which are mostly eliminated.

The collected data show that the above-mentioned pollution sites cannot significantly affect the quality of transboundary groundwater bodies. In particular, these pollution sites are not located in the areas identified in Chapter 3.2.2 with relatively significant groundwater flows across national borders - accordingly, migration of pollution is not possible.

Mining areas. Based on information from the Estonian Land Board (Web Map of Mineral Deposits) and Latvian Register of Mineral Deposits, a total of 269 mineral deposits have been identified in the transboundary area. According to the available data, most of them (240 mineral deposits or 89% of all cases) are Quaternary mineral deposits and only 11% of all cases (29 mineral deposits) – in pre-Quaternary (D_3*slp*, D_3*pl*, D_3*gj*, D_2*br*) sediments, which, mainly due to intensive mining and lowering of groundwater levels, may affect the hydrogeological regime of the Pļaviņas-Ogre and/or Aruküla-Amata aquifer systems. However, in 192 mineral deposits, no mining or quarrying activities have been carried out in the last 6 years, of which in 151 cases mining was not undertaken after assessment of the mineral resources.

Respectively, in the period from 2014 to 2019, quarrying and extraction of mineral resources were identified in 77 mineral deposits (74 deposits are related to Quaternary sediments, 3 deposits - to pre-Quaternary sediments). In all cases, except for the dolomite deposit in the vicinity of the town of Ape (in Latvia), the extraction of minerals took place without lowering the groundwater levels (Table 12).

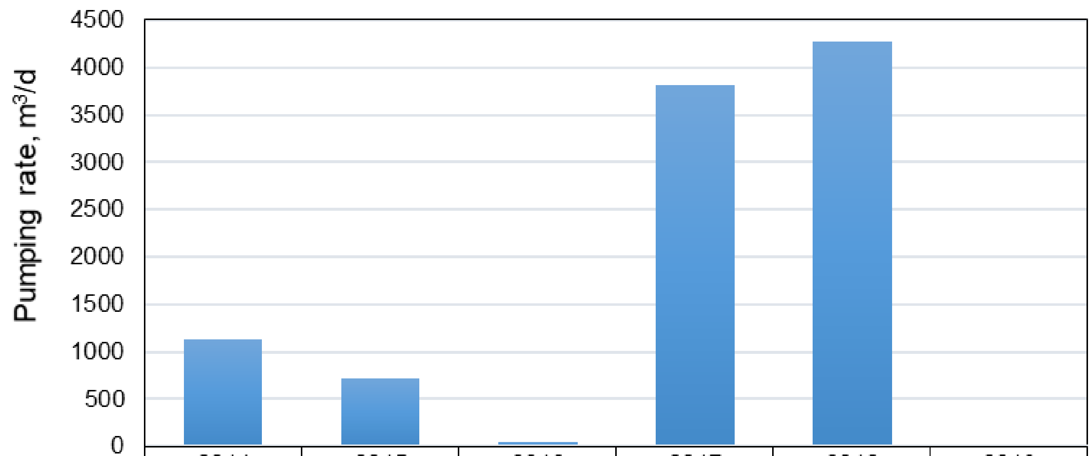
Table 12 Mineral deposits (quarries) in the Estonian-Latvian transboundary area

Aquifer system (GWB)	Country	Number of mineral deposits (active deposits*)			Number of deposits where groundwater levels are lowered
		Q	pre-Q	Total	
Aruküla-Amata (A8, A10, 23, 24, 25)	Latvia	136 (31)	8 (0)	144 (31)	0
	Estonia	43 (27)	0	43 (27)	0
Pļaviņas-Ogre (D6, D8, 26)	Latvia	61 (16)	19 (3)	80 (19)	1
	Estonia	0	2 (0)	2 (0)	0
Total		**240 (74)**	**29 (3)**	**269 (77)**	**1**

*Mining was performed in the period from 2014 to 2019

Dolomite deposit “Ape" is located about 3 km from the Latvian-Estonian border, the layer of minerals to be extracted in the territory of the deposit lies deeper than the groundwater level. Accordingly, the extraction of minerals can only take place by lowering groundwater levels. The main aquifer, that determines the inflow of water into the quarry, is the Pļaviņas (D_3*pl*) aquifer (a permanent Quaternary groundwater aquifer has not been identified in the site and in its immediate vicinity). The results of hydrogeological research, as well as modeling indicate that the radius of the depression cone around the mineral deposit could reach up to 3.2 km at the maximum lowering of the groundwater level in the quarry (final stage of extraction by lowering the water level by 17-18 m). However, it should be noted that in this case a larger depression cone will mainly to form around the quarry itself and only within a radius of 1 km, as a result of which a decrease in groundwater level in the Pļaviņas (D_3*pl*) aquifer by 2 m will be observed. The resulting impact on the transboundary area at regional level will be minimal and localized.

During the last 6 years, the volume of groundwater pumping from the mineral deposit “Ape” ranged from 44.5 m^3/d in 2016 to 4274.22 m^3/d in 2018, while in 2019 no groundwater pumping was performed (Figure 38). According to the research results and calculations – at the end of the quarry exploitation, groundwater pumping can reach up to 10170 m^3/d. According to information from the collected materials, mineral deposit “Ape” is expected to operate intensively in the coming years.



	2014	2015	2016	2017	2018	2019
Pumping rate	1135.07	710.96	44.52	3806.77	4274.22	0

Figure 38 Groundwater pumping volumes (m^3/d) at the dolomite deposit "Ape" in the period from 2014 to 2019

Based on the collected information, it was concluded that at this moment no active mineral deposits (quarries) have been identified in the Estonian-Latvian transboundary area, which could affect the hydrogeological regime on a regional scale – mining at dolomite deposit "Ape" can only cause changes on a local scale (maximum – within a radius of 3.2 km).

However, it should be noted that two dolomite deposits: "Naha" and "Kalkahju" (in Estonia), have been assessed less than a kilometer from the Estonian-Latvian border. They have not yet been accepted to become active deposits, however, in the future, mining can only take place by lowering the groundwater level, which may affect the hydrogeological regime of the Pļaviņas-Ogre aquifer system. Currently in Latvia, in the Estonian-Latvian transboundary area, quarrying mainly takes place without lowering the groundwater levels of confined and unconfined aquifers as the extraction of minerals takes place before reaching it. However, if extraction of all accepted mineral resources will begin in the future, groundwater lowering in confined and unconfined (in some cases) aquifers will be necessary.

Conclusion. The collected materials and cartographic information reflect that no intensive anthropogenic pressure was identified in the transboundary area, which could affect the quality and quantity of groundwater in it - respectively, worsen the condition of transboundary groundwater bodies. No significant groundwater intake was identified in the transboundary area and no regions with mineral deposits (active quarries) that could affect the hydrogeological regime at the regional scale in the transboundary area were identified. Also, no sources of pollution were identified (especially in regions where a relatively significant groundwater flow between the borders of the two countries has been identified) that could affect groundwater quality (Figure 39).

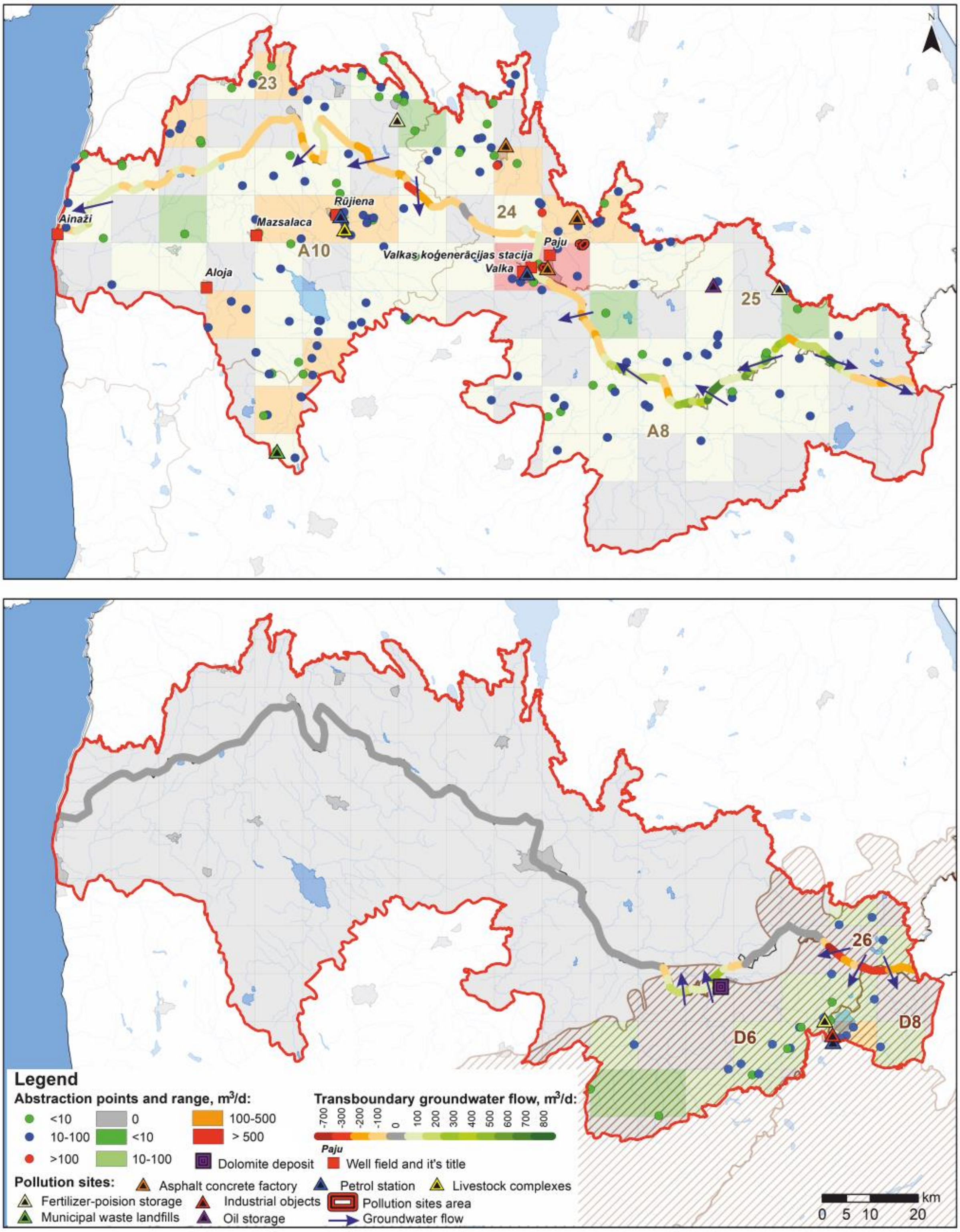


Figure 39 Anthropogenic pressure and transboundary groundwater flow pattern in Latvian-Estonian pilot area

Respectively, for the management of transboundary groundwater bodies D6, D8, 26 (characterizing the Pļaviņas-Ogre aquifer system) and A8, A10, 23, 24, 25 (characterizing the Aruküla-Amata aquifer system) are currently sufficient with the existing monitoring points, which can provide transboundary monitoring at regional level and meet the monitoring objectives set. In the future, more attention should be drawn to the Gauja-Koiva river basin district, which is located in the eastern part of the transboundary area, where the highest intensity of groundwater flow between the two countries in both Pļaviņas-Ogre and Aruküla-Amata aquifer system has been identified.

In the future, additional attention should be paid to the Valka-Valga cross-border area, as the most intensive groundwater abstraction and point sources were identified in this area. Although there is currently no intensive groundwater flow between the two countries, given the local hydrogeological conditions in the area, it may be affected by potential changes in groundwater abstraction.

3.2.4. Integration of other monitoring points or new monitoring points

In order to improve the coverage of the monitoring network in the transboundary area, it is possible to integrate water intake wells as monitoring points in the transboundary monitoring network and/or to include large debit springs in the monitoring network, as well as to install new monitoring wells. Areas that may be prospective for the development of a transboundary groundwater monitoring network have been identified in the Latvian-Estonian transboundary area (Figure 40).

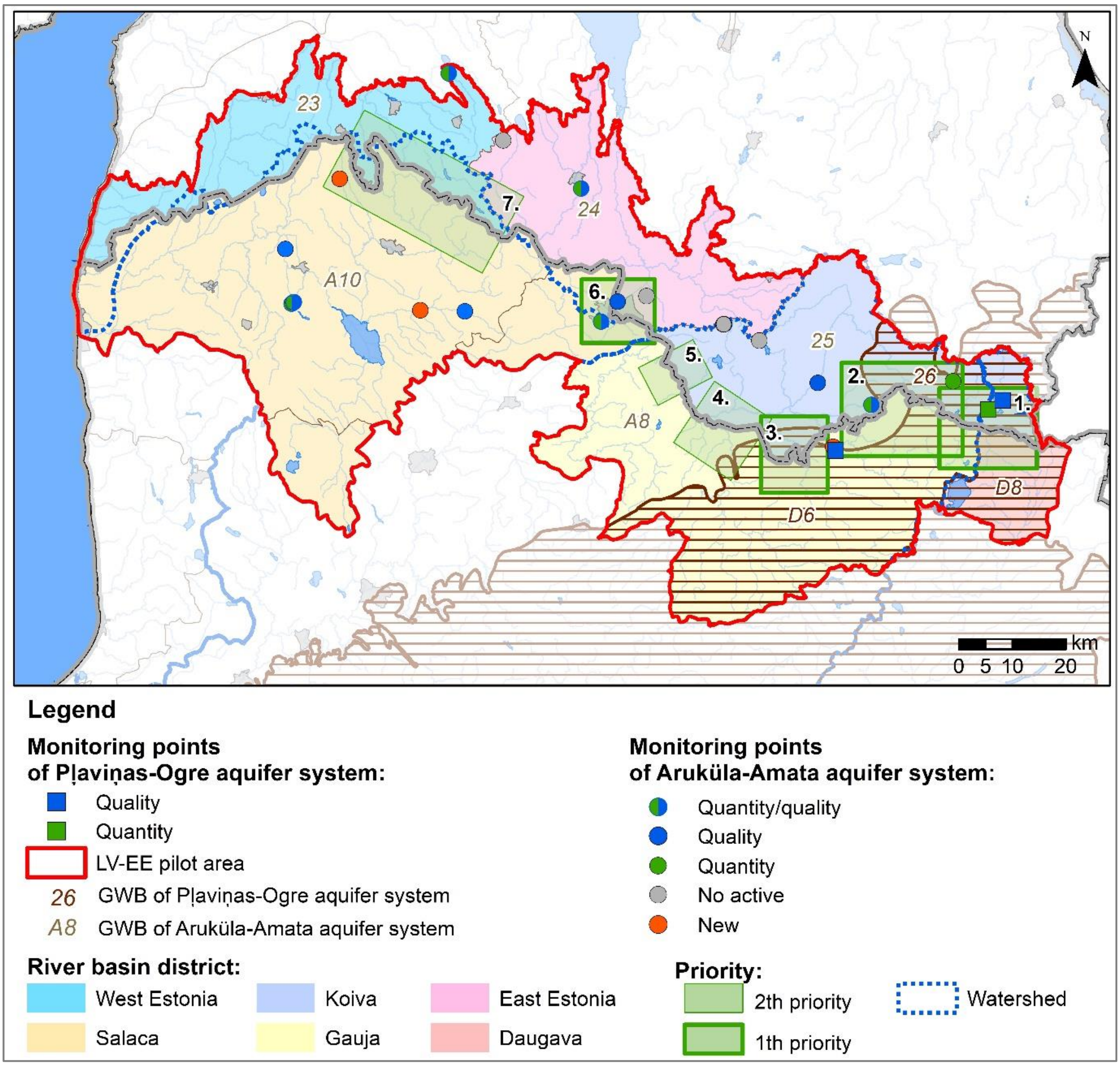


Figure 40 Location of existing monitoring points and perspective areas for improvement of the transboundary monitoring network

The existence and intensity of transboundary flows between the two countries was the key factor in identifying prospective sites for transboundary monitoring, as no significant anthropogenic pressures were identified in the area under review (with the exception of Valka-Valga, where larger water abstractions were mainly identified). The conceptual model developed for the Latvian-Estonian transboundary area and the data analysis performed in Chapters 3.2.1-2.3.3 were used as the basis for the selection of these sites. As a result, 7 perspective areas for the improvement of the transboundary groundwater monitoring network have been identified in the study area, which have been given priority based on the flow intensity (Table 13).

Table 13 Description of perspective territories for Latvian-Estonian transboundary monitoring

Site number	Transboundary flow direction	River basins	Criteria	Aquifer for monitoring*
1.	From Estonia to Latvia	Gauja, Koiva, Daugava	Significant flow, recharge area	D_3*pl-dg*, D_{2-3}*ar-am*
2.	From Latvia to Estonia	Gauja, Koiva	Significant flow, recharge area	D_{2-3}*ar-am*
3.	From Latvia to Estonia	Gauja, Koiva	Significant flow,	D_3*pl-dg*, D_{2-3}*ar-am*
4.	From Latvia to Estonia	Gauja, Koiva	Less significant flow	D_{2-3}*ar-am*
5.	From Estonia to Latvia	Gauja, Koiva	Less significant flow	D_{2-3}*ar-am*
6.	Now significant flow	Salaca, East Estonia	Significant water abstraction rate	D_2*ar+br*
7.	From Estonia to Latvia	Salaca, West Estonia	Less significant flow	D_2*ar+br*

* Ideally, observations should also be performed in the Quaternary aquifer, especially in areas, where more permeable and vulnerable layers are distributed (3. - 6. site).

However, it should be noted that no significant anthropogenic pressure has been identified in the transboundary area, indicating that the installation of new monitoring wells and the integration of other monitoring networks would be financially unjustified. But it should be kept in mind, that based on the fact that there are not many existing monitoring points in the Latvian-Estonian transboundary area that could be representative in terms of transboundary aquifer research, it is recommended to use the identified areas for further investigations.

Also, the initially identified areas can be specified after new data have been obtained (once a harmonized vulnerability map has been developed, all groundwater-related ecosystems have been identified etc.) for the study area and a new knowledge base has been originated by developing a hydrodynamical numerical model.

Summary

The aim of this report was to form common principles for selecting the transboundary monitoring points in Estonia and Latvia in the need of assessing quantitative and chemical status of groundwater in the Estonian-Latvian transboundary area. As a result, prospective monitoring site locations in the Estonian-Latvian transboundary area were identified for the improvement of the monitoring network taking into account EU requirements.

The report presents:

- analysis and review of the current EU requirements for the selection of transboundary groundwater monitoring points and experiences of other countries in selecting transboundary groundwater monitoring points;
- methodology of the transboundary groundwater monitoring point qualification in accordance with EU requirements;
- procedure of the transboundary groundwater monitoring point qualification in the Estonian-Latvian transboundary area, including depiction of already existing groundwater monitoring principles and network in both – Estonia and Latvia; as well as qualification of the transboundary groundwater points, which included analysis and review of the existing groundwater monitoring points, groundwater flow path and estimation of anthropogenic pressure in the Estonian-Latvian transboundary area;
- and finally, identification of seven prospective areas for the research needs for the establishment of new transboundary groundwater monitoring points.

An existing monitoring network coverage in the Estonian-Latvian transboundary area mainly allows assessing only the qualitative (chemical) status of groundwater, but it is not possible to achieve the quantitative target set by the WFD with the current monitoring network coverage. It would be necessary to set up a significant number of new monitoring points, which would not be financially adequate. However, the establishment of such a monitoring network would not be adequate and rational, as no significant groundwater intake pressure was identified in the area, which could lead to changes in the regional hydrogeological regime and such an increase is not expected in the future either.

During the analysis, also no intensive anthropogenic pressure was identified in the Estonian-Latvian transboundary area, which could affect the quality and quantity of transboundary groundwater aquifers – no significant groundwater intakes and no regions with active quarries were identified that could affect the hydrogeological regime at the regional scale. Also, no point pollution sources (especially in regions where a relatively significant groundwater flow has been identified) were identified that could affect groundwater quality. Additional attention in the future should be paid to only to the Valka-Valga transboundary area, as the most intensive groundwater abstraction and point pollution sources were identified in this area. Although there is currently no intensive groundwater flow between the two countries, given the local hydrogeological conditions in the area, it may be affected by potential changes in groundwater abstraction.

In total, seven prospective areas for the improvement of the transboundary groundwater monitoring network were identified, which have been given priority based on the transboundary groundwater flow intensity. Based on the fact that there are not many existing monitoring points in the Latvian-Estonian transboundary area, it was recommended to use the identified areas for further investigations. The initially identified areas should be specified after new data have been obtained for the study area and a new knowledge base has been created by developing a hydrodynamical numerical model.

References

B-Solutions, (2018) B-solutions initiative's pilot action "Lithuanian Geological Survey and Latvian Environment, Geology and Meteorology Centre institutional cooperation on cross-border groundwater management". Available: https://www.meteo.lv/lapas/projekta-b-solutions-informacija?&id=2459&nid=1176

Estonian-Russian Cooperation, (2020) Estonian-Russian Joint Commission for the Protection and Sustainable Use of Transboundary waters (26.11.2020) *Minutes of the Estonian-Russian Joint Commission for the Protection and Sustainable Use of Transboundary waters XXIII meeting.* https://envir.ee/media/1478/download

European Communities, (2003). Guidance Document No.7. Monitoring under the Water Framework Directive.

European Communities, (2007) Guidance Document Nº 15. Guidance on Groundwater Monitoring. European Communities, 2007, Common Implementation Strategy for the Water Framework Directive (2000/60/EC)

European Communities, (2010). Guidance Document No.26. Guidance on risk assessment and the conceptual model for groundwater.

ICPDR, (2008). Groundwater guidance. International Commission for the Protection of the Danube River, www.icpdr.org

ICPDR, (2016) Groundwater Guidance. International Commission for the Protection of the Danube River. Final Draft of 3rd Edition of 2016. https://www.icpdr.org/flowpaper/viewer/default/files/nodes/documents/groundwater_guidance.pdf

RBMPs, (2021) River Basin Management Plans, LEGMC. Available: https://videscentrs.lvgmc.lv/lapas/udens-apsaimniekosana-un-pludu-parvaldiba#58821703

Solovey, T., Rafał, J., Małgorzata, P., [...] M., Piasecka, A. (2021) Assessment of the resources of transboundary groundwater reservoirs for the 2 pilot areas. EU-WATERRES project WP3-Harmonization of transboundary groundwater monitoring, pp 97. http://eu-waterres.eu/news-resources/resources/

Uil, H., van Geer, F.C, Gehrels, J.C., Kloosterman, F.H. (1999). UN/ECE Task Force on Monitoring and Assessment. State of the art monitoring and assessment of groundwaters.

UNESCO, (2020). Guidelines for Monitoring Strategies in Transboundary Aquifers: Goals, Methods and Tools. The Case of the DRIN project (ALB-MTN)

Water Convention, (1992). Convention on the Protection and Use of Transboundary Watercourses and International Lakes. United Nations Economic Commission for Europe (UNECE). February 1992, https://unece.org/fileadmin/DAM/env/water/pdf/watercon.pdf

Annex I. **Required information of transboundary monitoring points**

Factor	Chemical monitoring points	Quantitative monitoring points
GW station name	E	E
International code for the GW station	E	E
National code for the GW station	E	E
Location – longitude and latitude	E	E
Groundwater body	E	E
Monitored aquifer(s)	E	E
Filter interval, m	E	E
Site type – well or spring	E	E
Type of monitoring point – national monitoring, additional monitoring, drinking water supply monitoring and any other usage	E	E
Purpose (s) of monitoring site – surveillance, operational or any other	E	E
Vulnerability	E	D
Visual materials (including land use and pressures, potential sources or point pressures)	E	D
Start of observation	D	D
Construction details	D	D

E - Essential, D - Desirable

Annex II**. Groundwater monitoring points in Latvian- Estonian transboundary pilot area**

Nr.	Country	Station name	National code	Database	International code	GWB	Y	X	Type	Monitoring type	Aquifer	Screen interval, from	Screen interval, to	Start of monitoring	Quality	Quantity	Purpose	Location type**
1.	EST	Tõrva pk, Valga-Jõgeveste ristmikust 800 m loodes	SJA9243000	7588	EESJA9243000	24	614650	428657	well	National	D2ar+br	48.3	133.5	1995	YES	YES	Surveillance	Forest and seminatural areas
2.	EST	Misso suurfarm	SJA6773000	10722	EESJA6773000	26	693403	389028	well	National	D3	44	70	2008	YES	NO	Surveillance	Forest and seminatural areas
3.	EST	Õisust 0,8 km kagus	SJA7121000	7592	EESJA7121000	23	589928	450231	well	National	D2	16.6	18.5	1995	YES	YES	Surveillance	Agricultural areas
4.	EST	Valga, Transporditn 1	SJA2670000	8485	EESJA2670000	24	621469	407529	well	National	D2ar+br	50	80	2007	YES	NO	Surveillance	Artificial surfaces
5.	EST	Varstu alevik	SJA9725000	10890	EESJA9725000	25	658874	392320	well	National	D2	83	123	2008	YES	NO	Surveillance	Artificial surfaces
6.	EST	Lüllemäe	SJB3122000	11890	EESJB3122000	25	641363	403306	well	National	D2tr	74.2	90	2018	YES	NO	Surveillance	Artificial surfaces
7.	EST	Krabi põhikooli puurkaev	SJA8742000	13376	EESJA8742000	25	668863	388200	well	National	D2; gQIII	9.6	15.5	2014	YES	YES	Surveillance	Agricultural areas
8.	EST	not applicable	SJB1928000	10656	EESJB1928000	25	684137	392623	well	National	D2	153.1	189.3	2018	NO	YES	-	Agricultural areas
9.	EST	Misso vald, Kaubi küla, Vetevana kinnistu	SJB1843000	24521	EESJB1843000	26	690736	387283	well	National	D3	42	70	2018	NO	YES	-	Forest and seminatural areas
10	EST	Lillemäe	SJA7579000	11495	EESJA7579000	25	641226	403275	well	National	D2tr	75.5	100	2014	YES	NO	Surveillance	Artificial surfaces
.11.	EST	Ahero-Alakonnu talu, Mähkli küla, Antsla vald, Võrumaa	SJA9623000	-	EESJA9623000	25	647952	400223	well	National	D2	-	-	2014	YES	NO	Surveillance	Agricultural areas
12.	EST	Paanikse kordonelamu	SJA7613000	15122*	EESJA7613000	-	600085	437668	well	National	Q	10.3	30.8	2013	YES	NO	Surveillance	Agricultural areas
13.	EST	Reemniku, Valgast 6 km kagus	SJA1400000	7598	EESJA1400000	24	626876	408539	well	National	D2ar	24.53	40.06	1995	YES	YES	Surveillance	Agricultural areas
14.	LAT	Zīļu avots	914	24563	LV914D6_24563	D6	662194	379621	spring	National	D3pl	-	-	2006	YES	NO	Surveillance	Forest and seminatural areas
15.	LAT	Spiģu avots	912	24554	LV912A10_24561	A10	559401	417349	spring	National	D2br	-	-	2004	YES	NO	Surveillance	Forest and seminatural areas
16.	LAT	Govs avots	905	24561	LV905A10_24554	A10	592941	405687	spring	National	D2br	-	-	2005	YES	NO	Surveillance	Forest and seminatural areas
17.	LAT	Rimeikas	391RIM	22652	LV391RIMA10_22652	A10	560544	407112	well	National	gQ3ltv	3.7	5.7	2010	YES	YES	Surveillance	Agricultural areas
18.	LAT	Rimeikas	391RIM	9601	LV391RIMA10_9601	A10	560984	407442	well	National	gQ3ltv	3.2	5.6	1973	YES	YES	Surveillance	Forest and seminatural areas
19.	LAT	Rimeikas	391RIM	9600	LV391RIMA10_9600	A10	560985	407436	well	National	D2br	35.8	40.2	1973	YES	YES	Surveillance	Forest and seminatural areas
20.	LAT	Rimeikas	391RIM	9602	LV391RIMA10_9602	A10	560544	407111	well	National	D2br	23.3	28.2	1973	NO	YES	-	Agricultural areas
21.	LAT	Rimeikas	391RIM	22653	LV391RIMA10_22653	A10	560818	407312	well	National	gQ3ltv	3.5	5.8	2008	NO	YES	-	Agricultural areas
22.	LAT	Valka	240SED	9637	LV290VLKD5_9637	A8	618372	403774	well	National	D2ar	97.5	122	1980	YES	YES	Surveillance	Artificial surfaces

Annotations:

* The monitoring point is linked to GWB 23

** Based on CORINE Land Cover 2018 data

No active monitoring point