Transboundary Aquifers in the Eastern Borders of The European Union

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Transboundary Aquifers in the Eastern Borders of The European Union

Regional Cooperation for Effective Management of Water Resources

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Preface

The present paper is a continuation and, at the same time, an expansion of the publication entitled "Groundwater Management in the East of the EU", which appeared in the NATO SPS series in 2010 and was mainly dedicated to the presentation of the principles of groundwater management in the countries which participated in the NATO Pilot Project "Sustainable Use and Protection of Groundwater Resources – Transboundary Water Management". This time another the set of independent articles is presented, but all of them indicate the importance of aquifers not only as a source of clean and safe drinking water, but also because of social, economic and safety reasons. In accordance with the book's title the authors focus on the issues related to transboundary aquifers on both sides of the eastern EU border to emphasize their importance form the regional water management point of view. This publication indicates a wide range of real problems related to the management of groundwater, which are characteristic of most countries situated in the East European (EE) region. It also presents potential threats which may materialise in the absence of integrated measures in the whole area of a transboundary aquifers and which, due to the application of rational management mechanisms and the pursuit of the appropriate water policy, can be minimised through arrangements and cooperation among the countries which share the water resources.

The seminar which was held in Kiev on 10–12 November 2010 on "Regional cooperation for solving transboundary issues East of UE" demonstrated that the approach to the problems related to transboundary waters on the eastern EU border must not be limited only to Belarus, Lithuania, Poland and Ukraine, and that it was necessary to address this issue in a much broader manner by adopting comprehensive solutions in the scope of the management of transboundary groundwater aquifers in the EE region. Very similar problems in this respect occur in all the countries of the European Union which lie in its eastern part. Certainly, each of the countries had had its individual experiences in this scope; however, the conclusions presented during the seminar were unambiguous. Just as the Water Framework Directive (2000) made it possible to order the water management issues within the European Union, so analogous measures should be taken on the eastern EU border. Still, when implementing the experiences of the EU countries in the scope of water management, we should also remember the solutions used by our eastern neighbours, which in many cases deserve to be considered and, certainly, they should be utilised at the stage of preparing an integrated transboundary water resources management system in the region.

Irrespective of the positive actions to implement the Water Framework Directive, the problems related to the quality of water resources continue to be topical and in certain countries, particularly in Africa and Asia, affected by the water crisis, they are becoming a primary issue. One should be aware that – given the dramatically growing population size – in the future, indeed in a not so distant future, modest drinking water resources will be of large importance for the shaping of the global policy. Not only the policy which is directly related to the natural environment, but also in a much wider, indeed an international, context. The deteriorating water quality in the world not only worsens the state of the environment, but primarily has a directly adverse impact on humans. At the first stage of the implementation of the WFD, River Basin Management Plans were drawn up in all the EU Member States. At present, work is underway on the implementation of the Water Quality Management Strategy, which aims at providing reliable information and ensuring appropriate tools for water quality assessment. These measures are extremely important, not only from the point of view of the development of national programmes, but they should also be considered in much wider terms, both in time and space. There is no doubt that the care for water quality should take the transboundary aspects into account, while the monitoring of transboundary groundwater aquifers should be a priority element of the national water resources management systems. The implementation of the tasks sets out in the River Basin Management Plans and also the preparation of reliable forecasts and analyses of water status require the integration of the monitoring of groundwater and surface waters in a river basin-based system. As indicated by the results of surface water quality surveys in the Ukrainian part of the Bug River basin, the state of waters is far from one which would meet the required standards. It is also important to note the impact of these pollutants on the transboundary areas in the neighbouring countries – indeed, their contribution to the deterioration of the quality of Vistula River and in the end the Baltic Sea waters. The specific character of the Bug River valley, a large part of which is a wetland where groundwater-dependant ecosystems occur and, hence, mutual interactions occur between ground and surface water, is another piece of evidence indicating the need to carry out integrated monitoring surveys covering surface waters and groundwater. The systematic approach addressing the Integrated Water Resources Management (IWRM) principles is needed to propose a sustainable solution taking into a account groundwater and surface water issues.

The condition of water management in Eastern Europe is not so tragic as in many regions of Africa or Southeast Asia, but, certainly, this does not mean that there are no problems which should be addressed here. Water is, and in the future it will increasingly be, a strategic raw material. As demonstrated by the lessons learned from water crises taking place in the different parts of the world, there is a very thin line between a dispute and an open conflict which may emerge from it. All the more so, on the basis of observations on the actions launched in connection with water conflicts which have taken place to date, the long-term water policy for transboundary areas should be meticulously planned. At present, many independent factors affect water management and potential water supply scenarios indicate another very important element related to climate variability and change in the near future. Thus, in order to ensure healthy and safe water, it will be necessary to take national measures and to pursue long-term policy. Therefore, the use of experts and scientists' knowledge should provide the basic guidelines for persons who make strategic decisions, particularly in the case where decisions must be made at regional level in several different places, given the international specificity of the region. This objective is served, inter alia, by the presentation of the measures carried out in the Narew River Basin with the framework of the SCENES Project, aimed at developing and analysing a set of comprehensive scenarios of Europe's freshwater in the timeframe until 2025. An integrated approach to river basin management seems to be the most appropriate and promising way to achieve sustainable development of the large river catchment.

The pursuit of a rational international water policy requires not only the preparation of international water management plans, but also appropriate agreements at the level of the countries which share international waters. For many years this issue has been an important problem in water management planning, particularly in respect of groundwater. For many years as well, the existing international legal acts have defined to a slight extent the issues related to groundwater management and its consequences. The existing regulations have rather tended to address the issues related to surface waters, since for many years they have been the main source of systemic water supply. This situation should change as a result of the adoption of the draft "Law of Transboundary Aquifers" by the United Nations General Assembly in 2008. This is a collection of articles concerning the scientific and hydrogeological issues, and the socio-economic, institutional and environmental conditions in the areas of transboundary groundwater. Most importantly, this is also a collection of regulations which can be directly implemented into regional agreements concluded between states.

The atlas of transboundary groundwater prepared by the UNESCO within the framework of the international project called "International Shared Aquifer Resources Management" (ISARM) indicates the existence of several transboundary groundwater aquifers along the line of the eastern EU border, extending from the Baltic Sea to the Black Sea. Certainly, the information presented in this study is of very general nature and only constitutes an inventory of transboundary resources at the scale of the whole planet. Nevertheless, it shows the areas where such aquifers occur and it is a signal for institutions in the individual countries that detailed research in this scope should be carried out. The identification of the situation in transboundary areas should give rise to solutions in the scope of integrated water management.

Repeatedly, in the course of the NATO Pilot Project "Sustainable Use and Protection of Groundwater Resources – Transboundary Water Management" it was emphasised that the aim of the expert work group was to develop an Integrated Monitoring System in the areas where transboundary groundwater aquifers occurred.

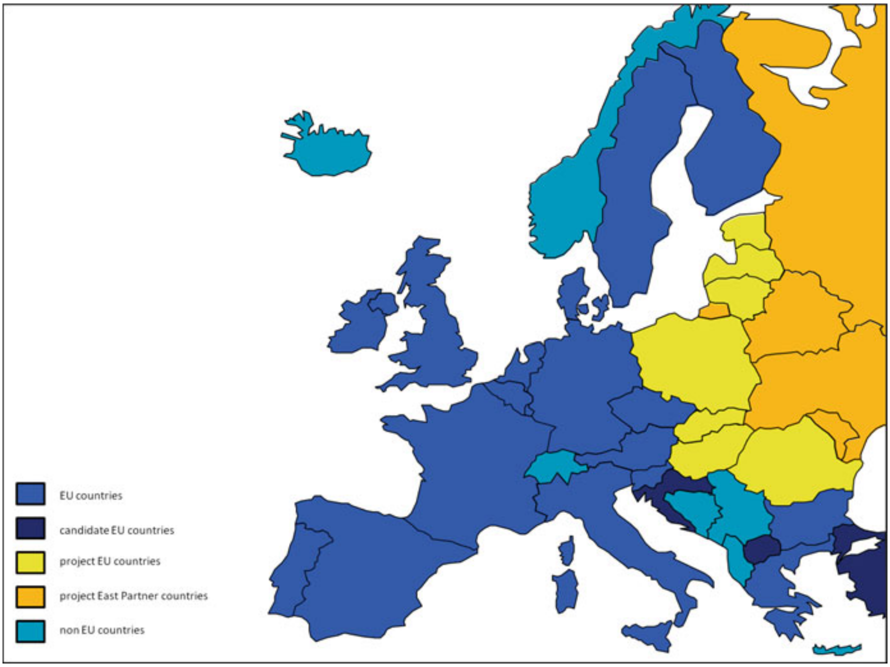

Fig. 1 EU and East Partner countries involved in transboundary project

The initially performed work was limited to the three countries sharing the Bug River basin, i.e. Belarus, Poland and Ukraine. In the course of talks and analyses, it was found that a much wider, regional approach to groundwater management was needed. Certainly, a basin-based water management system should be the determinant, but a political dimension is also a very important element, which determines the chances of a success of the future international project. Indeed, the construction of a system for managing and monitoring groundwater using only the Bug River basin as an example would be a local solution. Certainly, it would be valuable for both the European Union and the Eastern European countries, but it would not fully resolve the transboundary problems in a regional context. For Ukraine, which has several transboundary aquifers at the interface with the EU, it would be a signal encouraging possible measures. The situation may be assessed in a similar way from the point of view of the EU. As a result of such reflections, regional cooperation was the main message of the Kiev seminar. The representatives of all the EU countries which constitute the eastern border of the Community (Estonia, Latvia, Lithuania, Poland, Slovakia, Hungary and Romania) were invited to cooperate. Apart from the representatives of Ukraine and Belarus which had participated in the Project from its start, the Eastern Partners were also represented by Russia and Moldova (Fig. 1).

It turned out that the regional approach to the issue of transboundary groundwater flows, covering Central and Eastern Europe, met with a large interest and also enabled a much broader look at the problems; which will certainly generate more in-depth conclusions. The lessons learned from the project carried out by colleagues in Slovakia and Hungary, which are presented in this publication, indicate the need to perform detailed studies on the characteristics of transboundary flows. Among other things, the absence of coordinated work in the neighbouring countries prevents the development of joint scenarios on groundwater abstraction ensuing from the growing water demand in a given region. Similarly, only cooperation based on rational data enables the launch of quick and correct measures in critical situations related e.g. to the propagation of pollutants in the aquifer.

One should be fully aware that transboundary resources ensure a drinking water source on both sides of the border and constitute a system of communicating vessels. Interference at one point of the system will cause a reaction at another point. Therefore, the cooperation of all the interested parties seems to be the only reasonable solution. In spite of appearances, the launch of far-reaching cooperation can save time and money and contribute to ensuring safe and healthy water in the future. A positive example of the launch of integrated measures in the scope of international water management are the water commissions established in most large basins of European rivers. Apart from the EU states, the Danube Commission also includes the representatives of Ukraine or Moldova as well as Bosnia-Hercegovina, Croatia, Montenegro and Serbia. Good practices in groundwater management between the Czech Republic, Germany and Poland are illustrated with the example of the work done within the framework of the International Commission for the Protection of the Odra River against Pollution (ICPO).

Within the Framework of the project called the "South-Eastern Europe (SEE) Transboundary Aquifers Inventory", which was part of ISARM, 63 transboundary groundwater aquifers were inventoried and described. Another measure taken in this region to improve the issues related to groundwater and to facilitate its efficient and sustainable use was the project called the "Dinaric Krast Aquifer System" (DIKTAS). These examples indicated the need to investigate transboundary groundwater and its significance for the public and the economy. The question "Are there transboundary aquifers in Belarus?" asked in one of the presented articles and supported by detailed characteristics of groundwater in the territory of this country is absolutely justified. The analysis performed indicates that a global inventory of groundwater aquifers needs to be specified in the Eastern European region (just as was the case in SEE), since some of the resources were not included here. Similar conclusions can be drawn from the articles presenting transboundary issues in Russia, Moldova or Lithuania. Unfortunately, we still continue to have too scarce information resources in this field, which greatly impedes the performance of reliable studies and the support for decision-making processes.

Many experts in the field of hydrogeology point out the need to assess the hydrogeological regional conditions in the zones where transboundary aquifers occur and to develop joint recommendations on this basis, which would be applied not only within the individual countries, but would also be a uniform solution for the whole region. Such measures should be based on detailed surveys carried out in the areas where groundwater aquifers occur in the border zone extending from the Baltic Sea as far as the Black Sea. The conclusions drawn from such surveys would provide the basis for developing a uniform strategy. In this way, the decision-makers would receive uniform information, which could serve to prepare appropriate, uniform legal provisions and procedures related to the water management system. Thus, due to integrated measures in the whole region, e.g. Ukraine, which shares transboundary waters with several countries, could avoid the need to create separate management systems with every neighbour as well as at the same time present a clear message to all organisations involved in the process. At the same time, the countries of the European Union would also obtain a system, which could easily be consolidated with the Water Framework Directive. In the course of the NATO SPS Project, we tried to collect as much information as possible concerning the principles of water management and legal systems in this field in the individual countries. In parallel, we presented various international projects which were carried out in the region in the field of water management. However, taking into account previous achievements, we are fully aware that scientific research should certainly be complemented with the further detailed exploration in these fields, which would be the basis for working out a uniform solution and its presentation as recommendations for governments.

The lessons learned from numerous projects carried out in Eastern Europe indicate that the Integrated Transboundary Water Resources Management System should focus on five basic elements:

- field measurements (monitoring)
- data management
- analyses (hydrogeological models)
- interpretation of results
- support for the decision-making system (effects dissemination)

The system prepared in this way would, inter alia, enable the testing of various scenarios concerning groundwater abstraction depending on the demand and a quick response if the conditions change in one of the neighbouring countries. The assessment of the hydrogeological conditions by international teams would meet another important research objective; specifically, it would guarantee a safe water use by all the parties, while ensuring the care for the sustainable development of the natural environment.

The publication of this book coincided in time with the session of the Eastern Partnership Summit in Warsaw on 29–30 September 2011. This initiative, which had been proposed by Poland and Sweden, started in May 2009 in Prague. The Eastern Partnership is a programme to build a common and stable Europe. The current summit is also a platform for a discussion on the support for the reforms in the six countries participating in the programme (Armenia, Azerbaijan, Belarus, Georgia, Moldova and Ukraine) and the strengthening of the relations between these countries and the EU. The actions within the Eastern Partnership should also be used to promote the sustainable management of transboundary water resources, inter alia, through the integration of legal solutions in the scope of water management.

The issues considered within the framework of the NATO SPS Pilot Project also correspond to the priorities of the Global Environmental Facility (GEF). "*The goal of the International Waters focal area is the promotion of collective management for* *transboundary water systems and subsequent implementation of the full range of policy, legal, and institutional reforms and investments contributing to sustainable use and maintenance of ecosystem services*". The long-term GEF strategy is base on building national and regional capacity and knowledge generation for global environmental benefits.

From the point of view of experts, the project called "Sustainable Use and Protection of Groundwater Resources – Transboundary Water Management" met its basic task; specifically, it became a platform for an exchange of knowledge and experiences at the scientific level. In the course of the 5 years of the implementation of the project, a number of seminars were held, in the course of which the representatives of the countries in the region could discuss the rational groundwater resources management in transboundary areas, their monitoring and protection. As a results of the work done, a number of very valuable materials and reflections were collected. In the future, they should become the basis for the preparation of the Integrated Transboundary Groundwater Management System in the Eastern European region. In order to supplement the work, it seems justified to involve in the project actions the potential decision-makers representing the institutions which would use the data provided by international expert teams to implement their tasks in the future.

The detailed elaboration of the Integrated Transboundary Groundwater Management System in the Eastern European region needs the establishment of a new project which would expand the issues identified by experts within the framework of the NATO SPS Project. I hope the new project will be organized in the near future and became the significant contribution to solving transboundary water management issues in East Europe region as well as support building local and regional decision making scenarios.

Tomasz Nałęcz

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I would like to express my gratitude to all experts from more than 15 countries who supported our project since the beginning in 2006. By this period, I hope we created a small, but strong enough community, which will be continually work for dissemination of transboundary aquifer research idea. It is our success to gather together so many people with powerful determination to tackle transboundary environmental issues and develop international cooperation in the East Europe region. I hope that project is only the first, initial step for further detail research and safe, sustainable usage of transboundary aquifers along the east border of European Union.

I want to thank the representatives of NATO Science for Peace and Security Committee for financial support for scientific expert platform. During the project I have met very kind and at the same time professional approach of the SPS NATO staff.

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A special thanks to my colleagues from the Polish Geological Institute team, who despite many adversities supported my activities, step by step developing the transboundary initiative. I want thank them for all their help, support, interest and valuable hints.

For my Son,
A little things, can build the great ideas

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Chapter 1
Implementation of Legal Mechanisms to Strengthen the Process of Transboundary Aquifer Resources Management

Tomasz Nałęcz and Shaminder Puri

Abstract In recent decades, the importance of groundwater for the economy and in particular for its supply to the population grew significantly. The management of water resources requires multi disciplinary and multi functional approaches. The situation becomes even more complex when a river basin or an aquifer is of a transboundary nature. Until 2009 there have been no suitable provisions of international law nor adequate guidelines which would set out sound principles for the management of such resources. Certainly, individual countries conclude bilateral agreements where they incorporate joint aquifer resource management, although until most recently their provisions mainly address surface waters, drawing on the UN 1997 Convention, leaving aquifers in the background.

The work carried out within the framework of the International Shared Aquifer Resources Management Project (ISARM) has resulted in the elaboration of Draft Articles of the UN International Law Commission, that give foundation to "The Law on the Use of Transboundary Aquifers" as adopted by the United Nations General Assembly (UNGA) in 2009. The UNGA Resolution that promotes these regulations encourages Member States to implement these regulations and to incorporate them into bilateral agreements. At the same time, further elaboration of the guidelines for the incorporation of the principles of aquifer management into sustainable environmental management is strongly recommended.

Keywords Hydrogeology • Transboundary aquifers • Sustainable environmental management

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1.1 Introduction

The challenge to the practical management of transboundary water resources is derived from the need to adopt and implement multi disciplinary & multi functional approached [1]. There is a relatively short history, for coordinated activities in this domain and it has been carried out for only several dozen years [2, 3]. Some of the driving forces affecting the development of research in this field and the actions at the policy level were some examples of conflicts connected primarily to the abstraction of shrinking natural resources [4]. Grounds for conflict included pollution of waters (e.g. the Rhine Basin) or their perceived excessive exploitation by one of the interested parties [5, 6]. Conflicts arise at a local level, but – as history has shown – they can elevate themselves to wider issues, which involve actors across the government. Intensification of the utilisation of water resources and the coming climate variability have raised the concern on transboundary water resources at a global level [7].

The transboundary management of water resources extends far beyond the natural aspects and, for this reason, it poses a challenge for politicians, planners and scientists, since different political and administrative systems are involved in the decision-making and management processes. At the time of unlimited access to information from each, arbitrarily chosen place in the environment, the absence of adequate knowledge concerning water resources on the other side of the border seems to be completely anachronistic. Particularly when considering the fact that such knowledge is necessary for each party and can be of great importance in decision-making processes.

1.2 The Significance of Groundwater Resources

Most of the now available freshwater resources which sustain human life and are necessary for the sound functioning of many sectors of the economy can be found in aquifers. At present, on the global scale, aquifers provide about 50% of drinking water supply, and 1.1 billion people in Asia and 175 million in Latin America rely directly on aquifer resources. At country scale the range is quite wide. e.g. in Poland 70% of drinking water comes from groundwater and since the early 1980s this share has been seen to grow; 12 of the worlds 23 megacities are fully reliant on aquifers. At a time when human activities cause an increasingly large pollution of surface waters the resources available in aquifer gain even greater significance and therefore require protection and special public care. Along with the degradation of water quality, the demand for clean water grows, as in recent decades the world population has dramatically increased and is expected to continue to grow.

Although in the circulation system groundwater combines with the waters present on the surface, it has completely different characteristics. On the one hand, these resources are protected by the aeration zone, where infiltration into the aquifer takes place. However, on the other hand, the pollution of groundwater causes much greater impacts than those in the case of surface waters. Given the complexity of the geological structure, it is much more difficult to track the pollution propagation process in the rock medium and, in consequence, to use effective remedial measures. The cleanup of a river can take several or a dozen or so years, whereas in the case of groundwater the duration of this process becomes significantly longer, mostly due to the complexity of the processes which determine the water flow in the rock formations. From the economic point of view, the costs of the cleanup of groundwater aquifers is significantly higher than those in the case of surface waters.

The establishment of administrative borders is of no consequence for the groundwater flow processes and the whole water exchange cycle in nature. Just as most natural processes, groundwater knows no borders. Despite this, borders indirectly affect water resources, since the character of water management pursued by individual states is important. Only the rational management of water resources and their protection can ensure that clean waters will be available for many decades. If an aquifer is situated in the territory of more than one country and, as the global inventory [8, 9] indicates, a substantial part of the resources is of a transboundary character, it is extremely important for all the parties to be involved in the joint management of transboundary waters through the establishment of joint teams, the unification of procedures and an exchange of information.

1.3 Mechanisms to Manage Transboundary Waters

The pursuit of rational water management and the management of water resources in transboundary areas are much more difficult than within the territory of one state, since they require the involvement of at least two parties and their cooperation based on relevant agreements. Experience shows that much time is needed to reach such a situation and that sometimes it takes many years to do so. Policy formulation for transboundary waters requires appropriate mechanisms of international law. These regulations can be of a twofold character. International conventions are characterised by long-term, general goals and cover a large territorial range. The current matters between individual countries are resolved through bilateral agreements. Poland, which has a number of transboundary aquifers, has signed a number of such documents in the field of water management [10] though none are specific to shared aquifers. One of the mechanisms to regulate the international cooperation in the management of transboundary waters are bilateral commissions which organise the current cooperation among experts.

Although the needs of the water management in transboundary areas had been known for many years, it was only the adoption of the Water Framework Directive (200/60/EC) [11] in 2000 by the European Commission that provided the basis for taking action in the river basin districts shared by two and more states. In Poland, the WFD provisions were transposed into the national law [12]. Another step was the adoption of the Directive on the protection of groundwater (2006/118/EC) [13]. These acts made it possible to take integrated measures in river basin districts within the EU Member States.

Both of the abovementioned legal acts defined much more exactly the scope related to groundwater than the United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses [14] did. Despite the fact that the EU Directives were milestones in the introduction of modern mechanisms to manage waters, they involved two important limitations. Specifically, they were limited to the territory of the European Union and it was only in general terms that they addressed the management of transboundary groundwater.

In general, it can be said that the transboundary groundwater management issues are supported and regulated to a limited extent in international law. Moreover, it should be noted that water management regulations are rather adapted to the properties of surface waters and take into account the specificity of groundwater aquifers to a slight degree only. Considering that most bilateral agreements use higher-rank acts to define local solutions, there is a need to prepare appropriate international regulations which would set out schemes for managing groundwater in cross-border areas. In 2002, the United Nations International Law Commission responded to the needs defined in this way from the assessments carried out by the IAH Commission on Transboundary Aquifers. The UNESCO's International Hydrological Program (IHP) took a very active part in this process [15]. Within its framework, work was launched on the International Shared Aquifer Resources Management Project (ISARM). This Project defined the basic objectives in the scientific, hydrogeological, socioeconomic, institutional and environmental scope. The lessons learned from the implementation of the ISARM Project provided the basis for the United Nations International Law Commission to Draft Articles of "The Law on the Use of Transboundary Aquifers" [16] adopted by the United Nations General Assembly in 2008. This document is consistent with the recommendations contained in the *Rio Declaration on Environment and Development* and in *Agenda 21*. This set of Draft Articles constitutes a recommendation for the states which conclude bilateral or regional agreements (international agreements) concerning the management of transboundary groundwater.

The document lays down the principles of equitable and reasonable utilisation of transboundary aquifers by the states in whose territory they are situated, taking into account a number of factors:

- an assessment of the population dependent on the aquifer or the aquifer system;
- the social, economic and other needs, present and future;
- the natural characteristics of the aquifer or the aquifer system;
- the contribution to the formation and recharge of the aquifer or the aquifer system;
- the existing and potential effects of the utilisation of the aquifer or the aquifer system;
- the actual and potential effects of the utilisation of the aquifer or the aquifer system in one aquifer in one country on the other aquifers in other states;
- the availability of alternatives to the present or planned utilisation of the aquifer or the aquifer system;

- the development, protection and conservation of the aquifer or the aquifer system and the estimated cost of the measures to be taken to that effect;
- the impact of the aquifer or the aquifer system on the related ecosystems.

Article 6 provides for an important obligation of the states which utilise transboundary aquifers to take all appropriate measures to prevent the causing of damage which may ensue from activities threatening aquifers and their users in the discharge zone, in each state in whose territory this zone is situated. The document also notes the significance of the cooperation of all the interested states and the creation of joint mechanisms of cooperation for the management of transboundary waters. The cooperation should be based on a regular exchange of geological, hydrogeological, hydrological, meteorological and ecological data. In order to emphasise the importance of this element, it is indicated that if one of the states has not the relevant data it should employ experts to prepare such information, taking into account the best practices and standards in these fields. The data should be prepared in a manner which facilitates their utilisation by other partners.

The countries which share transboundary aquifers are obliged to protect them and the related ecosystems. Large attention is also paid to the protection and the minimisation of detrimental effects (pollutants) in the recharge and discharge zones. Joint monitoring of the groundwater in the areas of transboundary aquifers is recommended as one of the basic protection mechanisms through establishing harmonised standards and survey methodology. All these activities should be covered by the transboundary aquifer management plan.

In its Article 16, the document also provides for the capacity building of developing countries in scientific, technical and legal fields.

1.4 Conclusion

Efficient aquifer management in transboundary areas and their protection requires all the countries which share an aquifer to implement uniform cooperation principles. This requires the introduction of appropriate legal mechanisms which would regulate in a legible manner the rights and duties of the particular states and provide the basis for the relevant bilateral or regional agreements.

“The Law on the Use of Transboundary Aquifers” prepared by the United Nations International Law Commission was the first document to comprehensively address the issue of transboundary groundwater and the problems which occur in these areas. At present, this document has a Draft status, though it has been adopted through a Member State Resolution, it is subject to the next round of consultations in 2011 of the General Assembly that it is expected to function as an international convention which should be respected by all the signatories. In the interim period, this document can be treated as a set of good practices and used in international cooperation.

The provisions concerning cooperation and support for developing countries are very important for Poland and the countries which border on it from the east and which are not EU Member States. The Draft Articles should stimulate the development of closer cooperation and support for new technologies and an exchange of information in the field of the management and protection of transboundary groundwater resources occurring between our states.

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Chapter 2
Water Quality Management as a Stage of WFD Implementation

Andrzej Sadurski

Abstract Groundwater quality management is a task of the EU Water framework Directive, that has to be elaborated for river basin management plans. It should be treated together with surface water resources as an integrated management system and refers to the statutes, state of the environment of river basins and also past and present activity in these areas. The results of groundwater monitoring are the basis for groundwater quality assessment and trends calculation. The range of monitoring is gradually extended; new chemical compounds and microbiological species should be checked. Nowadays groundwater quality management is one of the serious problems for national and river basins water management planes.

Keywords Groundwater management • Water framework directive implementation • Groundwater monitoring • River basin management plans

2.1 Introduction

The most important tool in water management strategies and programmes is water quality monitoring. It provides information about patterns and trends in surface and groundwater quality and also about pollution sources. The Polish hydrogeological survey (PHS) monitors the groundwater bodies delineated within the watersheds (Fig. 2.1). The survey performs monitoring and reporting required by such statutes as the Water Act, Environmental Protection Act, and also other regulations and consents or approvals are required for groundwater exploitation, wastewater discharges to the ground or watercourses and surface water reservoirs.

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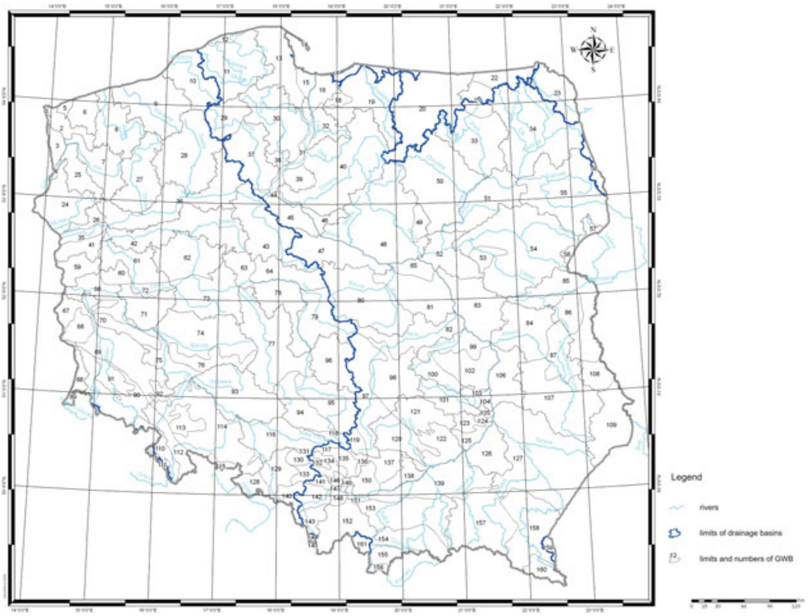

Fig. 2.1 Distribution of GWB in Poland on the background of river net

Although nitrate concentrations in surface water are relatively low, some groundwater wells on farms contain relatively high concentrations in water used for family supply.

In response to a rapidly urbanizing community and heightened awareness of public health issues related to drinking water, PHS has developed its monitoring net and programme to include testing of all groundwater bodies and a greater number of potential pollutants in springs and wells (Fig. 2.2). Wells and springs are sampled once per year, usually during the summer in conjunction with the pump procedure of observation wells. PHS as a part of Polish Geological Institute has its own analytical laboratory, which is certified by the state.

Poland joined the European Union in 2004 and this year the implementation of the EU directives commenced. The first stage of the implementation consists of the years 2004–2010. Tasks achieved during this stage of Water framework directive implementation were as follows:

- delineation of GWBs and their characteristics;
- analyses of pressures and impacts on groundwater
- defining groundwater monitoring network;
- GWB's status assessment;
- preparation of River Basin Management Plans;
- implementation of integrated water management plans within river basins.

Fig. 2.2 Observation wells for groundwater monitoring in Poland

The water management plans are oriented towards the sustainability concept of the environment, as is apparent in new EU countries [1, 2].

Sustainable groundwater management consists of two issues; one refers to the quantity requirements and the second one to quality of water [3]. The first was explained by Kinzelbach et al. [4] that abstraction for water supply should be limited to a fraction of recharge in order to guarantee a minimum availability of water downstream. As a rule water quality is relevant to water table decline due to overexploitation of aquifers.

2.2 Framework of Groundwater Quality Management

The legal framework of groundwater monitoring programmes, the scope of observations and the frequency of measurements constitute statutes and Ministers' regulations in effect in the Poland. The basic documents include water management strategies and policies [5].

The strategy sets out the basic objectives, directions and principles of actions enabling the implementation of the concept of sustainable development in the management of water resources in Poland, taking into account the expected climate change. The overriding objective of the strategy is to define the legal, organisational, financial and technical solutions in water management.

Water Quality Management Strategy should provide information and tools to help communities manage their water resources to meet current and future needs. It provides policies and guidelines for water quality management, which includes a step-by-step approach for planning, implementing and managing water quality locally, plus information about common environmental stressors.

The strategic objectives include:

- the achievement and maintenance of good status and potential of waters and the related ecosystems,
- the satisfaction of the needs of the population in the scope of potable water supply and sanitation purposes,
- the satisfaction of the socially justified and economically viable water requirements of the country,
- the improvement of the efficiency of the protection of the population and the economy in crisis conditions.

The strategy is based on balances of water resources available for utilisation, the use of water and the demand for water in river basins – water economy regions. It also takes into account the opportunities provided by water saving policy, the possible changes in spatial development in the context of the limitation of resources in space in the areas of nature reserves, national parks and NATURA 2000 sites, and the need to adapt to climate change and the growing risk of the occurrence of extreme weather phenomena.

The more general statute defines policy. Water quality policy consists of:

- objectives and directions of future water use demands water quality management,
- strategic action plans (with calculation of social and economic cost of impaired water),
- identification of national priorities – guide for investments,
- plans for developing cost-effective programmes,
- establishing data standards, which realistically reflect needs and capabilities of citizens,
- water monitoring networks at river catchment area and at community levels,
- regulatory framework including a combination of water quality objectives and effluent controls.

The national water quality programmes consist of goals and priorities of:

- protection of potable water resources;
- limitation of water acidification;
- limitation of eutrophication of water bodies;
- limitation of chemical or/and bacteriological water contamination;
- water shortages control; and
- increase of water retention in river basin.

The principal objective of the programmes is sufficient water resources for the community and the environment in the future. The parts of programmes refer to political basis, action plans, measures and their guidelines [6].

2.3 Fundament Statutes in Water Management

Up to 2010 the European Union directives were implemented in the Polish legal system, mainly the following are considered:

- POLISH PARLIAMENT WATER ACT – of the 27th of April 2001, Edit. In 2006. Journal of Laws No. 129, entry 2019 with later amendments
- NITRATE DIRECTIVE 91/676/EEC of the 12th of December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. EU Official Journal from 31.12.1991 L 275
- DIRECTIVE 2000/60/EC [7] of 23 October 2000, establishing a framework for Community action in the field of water policy. Official Journal. EC
- DIRECTIVE 2006/118/EC [8] and EP of the 12th of December 2006, of groundwater protection and against groundwater pollution degradation of their condition. Official Journal. 2006 in EC L 372/19
- DIRECTIVE (2007/60/EC) on the assessment and management of flood risks – valid from the 26th of November 2007. Official Journal of the 6th of November 2007

2.4 Background

Water crisis is mainly understood as a water quantity question. Serious degradation of water quality in large areas contributes to loss of potable water. Mortality and morbidity from water-borne diseases are common worldwide. Fresh water contamination by toxic chemicals from municipal and industrial wastes, acidic mine water effluents, expansion of agro-chemicals and agricultural runoff to provide food security causes increased toxic contamination of the coastal and marine environment. Water quality problems are more and more often recognised in large areas as major factors contributing to water crisis.

The chemical state and quantity of groundwater water resources have been examined by PHS and reported in 2010 [9, 10]. The groundwater in Poland is generally in good condition (Fig. 2.3).

However formerly, bad water quality was associated with human health issues and transfer of water-borne diseases. Currently, degraded water contributes to loss of beneficial human use, e.g.: loss in agricultural production, loss of habitats and loss in tourism revenues, loss of commercial fish species, increased costs of water treatment facilities because alternative potable water sources are limited. The lack of water resources of good quality is also a barrier for developing regional strategies.

These problems were considered during the XXXVIIII Congress of the International Association of Hydrogeologists (IAH) in September 2010 in Krakow (Poland). Over 600 scientists gathered for this congress and elaborated the Krakow Declaration on the Protection of Groundwater Quality. It was stated that the global deterioration in water quality, the degradation of lands, and the consequent impact

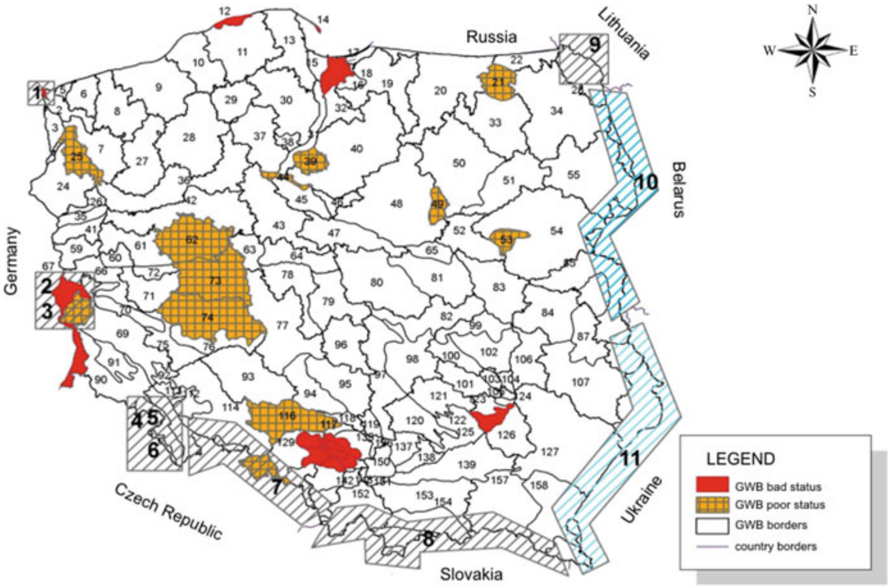

Fig. 2.3 GWB's distribution and transboundary monitoring zones along the Polish border

on human health as well as on human and environmental security should be a worldwide concern and shall require increased global efforts to assess the current situation and identify appropriate measures. The Krakow Declaration calls the attention of decision makers to the fact that policies on water resources management on national and regional levels should recognise the important role of groundwater in water quality management. In many regions existing activities may cause deterioration of groundwater quality that would be difficult to reverse. Land management policies must be developed to minimise risks to long-term water quality. This recognition would prevent groundwater contamination and groundwater quality deterioration in a less cost-intensive manner than later high cost remedial action.

2.5 Water Quality Monitoring (WQM)

The promise of WQM is that well designed programmes can satisfy most requirements regarding water quality issues. It is a so-called data-rich or data-driven approach, whose objective is to gather monitoring data. As a result, WQM should enable answering the question whether water quality is improving or deteriorating. These mainly chemistry-focused programmes are very expensive. However, until now, there was no better solution for a cheaper and more effective method.

Fig. 2.4 Distribution of observation points in Poland

Poland is a hydrogeological data-rich country and with a well documented environment.

Water quality assessments require long term data, gathered in a data base, which for practical and scientific reasons should contain data recorded over 15 years. PHS started with groundwater monitoring in the middle of the 1970s, that is almost 40 years ago. Distribution of the national monitoring network is presented on Fig. 2.4.

According to Directive 2006/118/EC [8] there is now a need for innovations in water monitoring techniques:

- biological, especially microbiological assessments, assays for toxicity,
- enzymatic indicators among organisms e.g. algae,
- use of sediments in river or lake bed as a chemical indicator of water quality,

The PHS Monitoring database gathering data specific to public health, such as pathogens, chemical compounds, toxic elements etc. This data bank is comprised of descriptive data – used for reports, planning and public information, data of status and trends of GWB's. There are also files of transboundary observation results, issues, according to bilateral treaty or agreement obligation (Fig. 2.3).

Monitoring for research purpose, organised locally is operated from other monitoring programmes. Data from national monitoring programmes are usually not sufficiently rigorous to produce the type of data required for research programmes. These data are used for deterministic finite element flow and transport simulation model or stochastic optimisation combined with flow and transport simulation for optimal decision-making Quality Assurance and Quality Control is a basis of monitoring in operation [11, 12].

(QA/QC) – is essential to data programmes and is inexpensive, but on the other hand is difficult to find donors for it. One possible method of funding is to signed agreements with water suppliers and large water treatment concerns that tackle the problems of water quality [13].

The bad chemical status of GWB, stated on the basis of the monitoring results, leaves no course of action other than commencing a very expensive and long-term task. The economic justification for this activity is on the urban area. The experiences of remedial project implementation are that it is not rational and based in poor forestry regions, where the natural attenuation is usually planned. Natural attenuation includes all natural metabolisation and adsorption processes in the unsaturated and saturated zones e.g. in the vicinity of landfills or industrial sites (also in the past). For water quality management plans, are needed for the following: evaluation of the efficiency in the selected area, detection of decrease of emission (pollution) concentration downstream the source, separation of the dilution from adsorption and metabolisation effects by biological methods, groundwater sampling especially for microbiological and molecular examination and creation of long-term monitoring concept of natural attenuation efficiency.

The growth in complex remedial requirements in many regions would merit the introduction of an extensive multi-disciplinary, educational process within large programmes.

2.6 Conclusions

The groundwater quality management programme is formulated on statutes, strategies and policies. During the previous 5 years water authorities identified some deficiencies in the management. Measures and directions of sustainable water management are not specified (e.g. sector measures in the scope of water management are not harmonised and the water factors, in particular the phenomena related to floods and droughts, are not already taken into account at the stage of spatial planning). There is no modern water management system in place (combining the management of water resources and the administration of water management assets with an efficient system of economic and financial instruments).

Now the implementation of water management strategy for sustainability involves political and economic questions and thus is urgent.

In turn, there is a groundwater monitoring system managed by the state hydrogeological service, which provides a base for developing groundwater quality management programmes. The quantitative and chemical status of groundwater bodies is known and water management plans are developed for economic water regions. This creates the need to improve groundwater tests and observations, which are partly used in prediction models on pollutant transport in groundwater streams and to prepare remediation plans for GWBs with unsatisfactory chemical status. Water quality management needs the elaboration of a steady state, mass-balance water quality model to predict water quality in the conditions of the aquifers.

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Chapter 3
Lessons Learned from the Water Conflicts Are a Warning for the Water Policy Makers in the 21st Century

Tomasz Nałęcz

Water is the blood of the Earth

—Jennifer Green

Abstract The analysis of the history of water conflicts which have inseparably accompanied the development of our civilisation indicates many interesting trends. Most countries have transboundary waters in their territory, which gave rise to various conflicts at a smaller or greater scale in the past. Observations and analyses of examples from Middle East, Africa or Southeast and Central Asia should lead to conclusions and activities to prevent water conflicts which may occur practically everywhere in the world. This is particularly important at the time of a dramatic population growth, the extreme natural phenomena and climatic variability. Different scenarios indicate that water resources will be one of the most desired raw materials in the twenty-first century, which can give rise to intensifying conflicts in the areas of transboundary waters.

At the time of shrinking unpolluted surface water resources, groundwater can also be the cause of conflicts. Therefore, the prevention of water conflicts should be a strategic and priority direction of actions by states which share transboundary waters, while the lessons learned from the water conflicts known to date should contribute to the building of a compromise and rational water management between the neighbouring countries.

Keywords Water conflict • Transboundary waters • Water management

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3.1 Introduction

Political systems changed over the centuries, different religious movements developed, some communities fell, to be replaced by new ones. At the same time, one element did not change in the history of both modern and ancient civilizations, specifically the demand for a source of life which is water. A raw material which was inseparably connected and will be connected with mankind. Given the significance of this raw material, it could never be separated from politics. Politics which was very often related to numerous conflicts.

The first records showing the use of water as a dangerous element against humans can be in the Old Testament, where in Chap. 6 there is a description of the flood which God sent to the Earth to punish mankind for its immorality. God only warned Noah, who saved himself in the Ark. A similar tale can be found among Sumerian legends, where the god Ea punished humans with a 6-day storm and a flood. Water was also included in the Code of Hammurabi, which featured several provisions concerning irrigation and also specified penalties for neglect in the execution of these activities and for water theft. Over the centuries, the most intense water conflicts could be observed between the seventh and third centuries BC [1]. Those times saw e.g. the damage to the irrigation system and the destruction wrought by the Assyrian King Sargon II in the Armenian lands; in the course of Peloponnesian war, the Spartans poisoned water cisterns in Piraeus and similar measures were taken by the Assyrian King Assurbanipal who drained the wells of his enemies. Many examples indicate that water was intensely used over the centuries as a strategic element and that it was also the cause of many conflicts. Unfortunately, the most intensive conflicts came in modern times after World War Two.

In view of the dramatically growing world population, water resources will always be insufficient, especially because their distribution is asymmetric with respect to the population density in the particular regions of the Earth. It should be emphasised that while the world population grew by a factor of three in the twentieth century the use of this raw resource increased by as much as a factor of 7. When addressing the issues related to water conflicts, one should be fully aware of the distribution of the drinking water resources in the world, specifically that 60% of them are controlled by nine states only (Canada, Russia, China, India, Brazil, Indonesia, Congo, Columbia and USA). This demonstrates a significantly unbalanced access to drinking water in the particular parts of the Earth.

According to the UNESCO estimates, it is assumed that the annual precipitation level all over the world is 577,000 km^3 and that this value has been relatively constant over the years. This indicates that while the amount of water per one inhabitant in the 1930s was 300,000 m^3 now this amount has decreased by a factor of more than three and is barely 90,000 m^3 [2]. However, not all the precipitation water resources can be used, since most of them can be found in the oceans. Only 3% of water resources are freshwater which can be utilised. Taking into account the statistical data and bearing in mind the fact that the amount of 1,700 m^3/person/year is taken to represent the minimum needed supply, it would seem that these resources

Fig. 3.1 National and transboundary River Basin Districts in the European continent

are sufficient. However, there are a number of countries where this amount is less than 200 m^3/person/year. And in many cases this generates various conflicts.

At present, 40% of the population of our planet lives in International River Basin Districts. Just in Europe there are more than 492 million people and transboundary areas can be found in the territories of the majority of the states in this continent (Fig. 3.1). Just in the territories of 13 European states, there are first-order catchments within one state and they represent a small fraction of the surface area of the whole continent. In nature, rivers do not create borders, but administrative and state borders should not be designated along them, either [3]. A border river usually gives rise to problems rather than benefits and in many cases such a border is the cause of various conflicts. Many of the water conflicts which occurred in the twentieth century were those caused by a desire to gain control of increasingly large water resources.

3.2 The Best Known Water Conflicts

One should be fully aware that all over the world there are 268 large rivers which cross the territory of one or more countries. In certain cases, this may involve a dozen or so countries. Such a situation may be the cause of conflicts. The reasons may be greatly different, from border disputes, the excessive water abstraction by one of the parties, through the discharge of pollutants into the water system, to terrorist acts and international blackmail. Fortunately, in most cases, conflicts are resolved by peaceful means through negotiations and mediations [4]. However, there is always a certain fraction of events where means of a military character are used. The most dramatic events included the disputes between Turkey, Iran and Syria in the Tigris-Euphrates river basin, between India and Bangladesh concerning the Ganges River and the probably best known conflict, with military operations in the background, in the Jordan River Valley. Ryszard Kapuściński [5], a well-known Polish reporter, considered that while the twentieth century was dominated by conflicts related to oil the new millennium may bring about a number of clashes where water will be at the centre of attention.

Water can also be and has already been an element of international blackmail. In 1986, Chun Doo-hwan, President of North Korea, announced a "water attack" on South Korea. It involved a plan to build a dam and reservoir on the Bukhan River (the Upper Han River) – the *Imnam Dam,* which could directly pose a threat of flooding Seoul (South Korea).

3.2.1 The Ganges: India–Bangladesh

Both countries are situated in the humid climate zone (Fig. 3.2), but despite this water became there the cause of wide-scale conflict. For India the water problem

Fig. 3.2 Transboundary area of the Ganges River between India and Bangladesh (Source: [6])

is a crucial one, since this dynamically developing country, whose population represents 16% of the total global population, has only 4% of the world sources of drinking water. Until 1947, under the British rule, Bangladesh had been part of India. After the British had gone the territory was divided, with Bangladesh becoming part of Pakistan. The sources of the Ganges are situated in the Himalayas in northern India. The river then flows through the Ganges Plain entering Bangladesh, where it joins the Brahmaputra, creating the largest delta in the world the waters of which drain into the Bay of Bengal.

The direct cause of the conflict between the neighbouring countries was the construction of the Farakka Dam located at a distance of 16 km from the border with Bangladesh. The main purpose of this huge investment project was to divert waters to the Hooghly River and, as a result, to ensure its navigability to the port in Calcutta, at the same time, ensuring water for the city and causing the removal of the silt accumulating in the river channel [7]. The construction works lasted for more than 10 years and the investment project was commissioned in 1975 [8]. Pakistan repeatedly protested against the construction of the dam (at that time the present-day Bangladesh was situated within the borders of Pakistan). In the 1970s, numerous talks were conducted to resolve this conflict; however, they were unsuccessful and in the course of a dry season still only about 280 m^3/s of water reached Bangladesh. The situation of Bangladesh was all the more complicated as India was the main country which supported in military and economic terms the movement for the liberation of this country from the Pakistani rule. At that time, the mediators for the agreement were both the World Bank and the United Nations.

A breakthrough in the negotiations came in the 1990s and, as a result of the government-level talks, on 12 December 1996 a comprehensive agreement was signed on the sharing of the Ganges waters between India and Bangladesh [8]. Under this agreement India undertook to ensure, in the period from 1 January and 1 May, a flow rate in the Ganges of at least 990 m^3/s to Bangladesh. The agreement was signed for a period of 30 years and entered into force in 2001, ending an almost 40 years long transboundary dispute.

3.2.2 The Ganges: India–Pakistan

Because of its situation and a shortage of water resources with respect to the growing demand on the part of its dynamically increasing population and economy, India is exposed to conflicts with its neighbours on issues related to the sharing of water resources. Along with the conflict about the Ganges waters, the first stage of the dispute with the Pakistani government involved a conflict about the Indus waters.

Demographic problems affect not only India but also Pakistan; in addition, given its climatic conditions, this state depends on water supply from the Indus River and its tributaries. The Indus waters are intensively used for agricultural purposes, mainly for the irrigation of arable lands (the largest irrigation system in the world). At present, the water resources which were sufficient to supply a state with 34 million inhabitants at the time when Pakistan gained independence are far from adequate for a population of 176 million.

The background to the water problems between India and Pakistan was a political crisis which originated from the times of the declaration of independence by these states. The area under dispute is the Province of Kashmir situated in the North between the competing states (Fig. 3.3). At the end of 1947, under the Instrument of Accession, Kashmir was annexed to India, which led to Pakistani protests and was the direct cause of the war between these two countries. In subsequent years, there were two armed conflicts and, despite the armistice signed in 1971, border clashes have continued until the present day.

Although the water problems were only a marginal issue of the overall territorial dispute and ensued directly from the Pakistani concern that the water system in the

Fig. 3.3 A network of surface waters in the disputed border region between India and Pakistan (Source: [6])

Indian territory (where the sources of the Indus are situated) would be expanded, they were more often than not utilised as an additional argument in the main conflict. There is no doubt that the expansion of the network of irrigation canals in the Indian territory caused a reduction of the flow in the river and direct losses in agriculture on the other side of the border. On 19 September 1960, the treaty on the partition and the joint use of the Indus waters (the Indus Waters Treaty) was signed in Karachi. It provided that India cannot build any water storage reservoirs on the Indus, Chenab and Jhelum Rivers. At the same time, the agreement allowed India to abstract a fixed amount of water from the Pakistani tributaries of the river.

It should be emphasised that in general the lands in Southeast and Central Asia, including such countries as China, India, Cambodia, Laos, Bangladesh, Thailand and Vietnam, face the onset of a great water crisis. Even today, it is predicted that the melting glaciers in the Himalayas may deprive hundreds of thousands of persons of access to water. At the first stage, disastrous floods are expected, to be followed by a drought, which can be tragic for the overpopulated regions of Asia.

In addition it is worth emphasizing that the region of Southeast Asia can be the scene of a great water conflict, since China is working on a project to reverse the course of the Brahmaputra, which flows through India and Bangladesh after it leaves the Chinese Tibet.

3.2.3 The Euphrates/Tigris: Turkey–Syria–Iran

Another hotspot in the map of water conflicts is the region of Middle East. For centuries water used for irrigation purposes in these areas has been an element which supported the civilisational development. The Euphrates, which is one of the larger rivers in this region and has its sources in the Turkish territory, also flows through the lands of Syria and Iraq, just as does the Tigris which drains into this river (Fig. 3.4). For centuries the waters of these rivers were utilised mainly in Mesopotamia in Iraq, while they flowed freely through the lands of Syria and Turkey because of their low population density.

The conflict in the transboundary Tigris – Euphrates basin is a very good example of relations and dependences between countries lying in the upper course of a river and their neighbours managing the waters in its lower course. The problems and disputes concerning water resources in this area began in the 1970s and ensued from a project initiated by Turkey as early as in the 1960s. The Lower Euphrates Project provided for the construction of a number of dams in the Turkish part of the basin in order to enhance the capability to generate power and develop irrigation [10]. In successive years, the project was substantially extended, since 21 dams and 19 hydropower plants were to be built as a result of it [11].

Two hydro-engineering investment projects had a significant effect on the relations between the neighbouring countries: the construction of the Ataturk Dam and Reservoir by Turkey (1990) and the analogous site in Syria – Madinat as – Saura [2]. In this way, still other countries situated in the upper course of the rivers cut off access to waters for the countries downstream. It should be stated unambiguously that the water projects implemented in the individual countries were not coordinated in any way and aimed only at meeting the needs of only the country which carried out the project.

Certainly, although the water problem was important in economic terms it was not the only issue that caused the tense relations in the region. Turkey accused Syria of supporting terrorist movements, which significantly affected the tensions in the border strip between the countries. The greatest intensity of the conflict between these countries came in 1980–1990 [10].

(1) Dukan Dam
(2) Bekhme Dam (unfinished)
(3) Mosul Dam
(4) Cizre Dam (planned)
(5) Ilisu Dam (planned)
(6) Batman Dam
(7) Kralkizi Dam
(8) Haditha Dam
(9) Al Baath Dam
(10) Tabqa Dam
(11) Tishreen Dam
(12) Karkamis Dam
(13 Birecik Dam
(14) Ataturk Dam
(15) Karakaya Dam
(16) Keban Dam

Fig. 3.4 The hydrographic network in the Tigris–Euphrates basin, along with hydro-engineering facilities (After Kibaroglu and Scheumann [9])

The history of the water conflict in this area was also a long process of attempts to regulate the water relations through diplomatic actions. The first such action was the establishment of the Joint Economic Commission between Iraq and Turkey in 1980, which was joined by Syria 3 years later [10]. However, subsequent meetings did not bring a solution which would satisfy all the parties. After the end of the Gulf War, representatives of the USA also took part in the negotiations as mediators.

Despite the warming up of the relations among the countries in the region and their conspicuous willingness to cooperate and resolve the water management problems, these issues are certainly likely to remain for some time to come a challenge for the neighbouring countries. Some opportunity to resolve it may be offered by the establishment of a group of scientists to prepare expert studies in the field of the management of transboundary waters within the framework of the epistemic community (EPIC).

3.2.4 The Jordan: Jordan–Israel–Lebanon–Syria

The basin of this small river situated in Middle East is an example of inconsistency between hydrographic borders and political ones. This area, which is situated in an arid zone and is naturally poor in waters, became the venue of possibly the best known water conflict in the contemporary world (although water disputes in this area date back to the biblical times), involving Israel, Jordan, Lebanon, the Palestinian Autonomy and Syria. The causes of the dispute include both the excessive utilisation of the Jordan waters and the enhanced groundwater abstraction.

The Jordan is supplied with water through its tributaries called the Hasbani, the Dan and the Banias, the sources of which are situated in the lands neighbouring on Israel, Lebanon and Syria. The largest water reservoir in the Jordan basin is Lake of Genessaret below which the Yarmuk River, flowing through the territories of Jordan and Syria, drains into the Jordan. In its farther course, the Jordan River constitutes a natural border between Israel and Jordan, to drain into the Dead Sea.

For many centuries the political situation in the Middle East region repeatedly caused armed conflicts and in the twentieth century it was the cause of continuous tensions and fighting. According to Kowalczak [3], in the background to all the five Arab-Israeli wars which took place after Israel had won its independence (1948) there was a hidden water conflict. In a different manner and on a different scale, each of the countries in the region tried to utilise the Jordan waters for its own purposes.

In the early 1950s, Jordan and Syria carried out a number of measures to irrigate the lands in the Jordan River Valley (the East Ghar Project, the construction of the Margain Dam). These measures caused a substantial abstraction of the waters of the Yarmuk River and practically cut off the flow to the Jordan. On the other hand, Israel launched works to drain the Hulleh wetlands (on its border with Syria), which caused armed conflicts between Israel and Syria [12].

The decisions of the summit of Arab states in 1964 and the financing of the dam on the Yarmuk River confirmed by Syria and Lebanon and a number of other measures related to water management were in contradiction with Israeli plans. In fact, they were the causes of the military conflict in 1967, known as the Six-Day War [13]. During the military operations the Israeli forces took over e.g. the Golan Heights, which were of strategic significance from the point of view of water supply to the Jordan River Valley. This prevented Syria from reducing the flow in the Jordan in the future [14].

Subsequent armed operations in this region included the destruction of the water facilities in the East Ghor Canal (Jordan) by Israel in 1969 and its attacks on Lebanon in 1978 and 1982 (the takeover of the areas along the Litani River).

The process of development of the eastern part of Israel and the construction of settlements in this area caused a greater water demand. As a result of the excessive water abstraction, the mouth part of the Jordan nearly dried out, which caused a substantial lowering of the water level in the Dead Sea and many environmental problems which emerged in direct consequence of these activities. These activities were directly related to the political crisis which arose with the Palestinian Autonomy, since the Jordan waters were practically the only source of water for the growing population in the region. On the other hand, this issue became a priority from the point of view of Israel's national security, in view of the maintenance of the settlement process. In consequence, for many years the water problem was the crux of the dispute between the parties [2].

The water problems and the attempts to resolve them in the Middle East region also involved many mediation efforts undertaken by the USA, the United Nations or the World Bank. Here, it is important to mention the first attempts made under the so-called Johnston Plan already in the 1950s and the mediations by the United States in 1993, the direct effect of which was the signing of the Declaration of Principles between Israel and Palestine [15].

Indeed, the water problem in the Middle East is extremely complicated, mainly given the insufficient resources in the Jordan River Valley in the context of the growing population and economic growth. There is no doubt that the preservation of peace in this area is directly related to the water management, which should be characterised by cooperation among all the interested parties to the conflict. It is also extremely important to look at the resources of both surface waters and groundwater in a comprehensive manner. The establishment of the International Jordan Commission suggested by Kowalczak [3] would certainly contribute to the resolution of many problems in this hotspot region.

3.2.5 Darfur

The conflict in this Central African Province of Sudan is an example of the bloodiest dispute about water in the twentieth century. Over the 50 years of the confrontation it led to more than two million victims, while more than 4.5 million persons were forced to emigrate (www.wikipedia.org).

The fighting in Darfur was probably the first case of a war caused by global warming and climate change (Salopek 2009). The cause of the conflict was the southward movement of the humid zone of Sahel and the progressive drying of water sources which sustained the life of nomad peoples inhabiting these lands. Certainly, as in the case of many other disputes regarding water resources, political, ethnical and religious disputes between the population seeking new places to stay and the tribes inhabiting these lands also superimposed themselves on the problems related to a water deficit .

3.2.6 Europe

Europe seems to be free from water conflicts or they are well resolved at the negotiation level. Certainly, the Water Framework Directive [16] and the international commissions which implement its provisions play an essential role here.

In fact, these are only appearances and from time to time grounds for conflicts emerge in the old continent. It seems sufficient to mention the dispute between Slovakia and Hungary (the Gabčíkovo-Nagymaros Project) or the growing tension between Slovakia and Austria caused by the construction of the Odra – Morava – Danube water link.

The problems of a water shortage also affect Spain, where following two winters (2006/2007 and 2007/2008) the retention reservoirs situated round Barcelona were empty, while those located in the mountains nearby were filled only to the extent of 20%.

Just as in the case of most European countries, Poland cannot "boast" of spectacular water disputes. Although the situations where water was used during armed conflicts were known in the past, when e.g. the residents of Gdańsk who defended their city in 1734 caused a controlled flooding of Żuławy in order to impede the attack of Russian troops.

3.3 Groundwater

In recent decades, groundwater gained increasing significance for the economy and can have an important effect on the civilisational development in the twenty-first century [17]. Apart from the generally known fact that the largest freshwater resources can be found exactly in hydrogeological structures, it can be noted that, given the growing pollution of surface waters, this can be a basic source of drinking water supply to the population in the future. Unfortunately, in the history of the civilisation the twentieth century turned out to be a period of an enormous degradation of the natural environment, including the pollution of surface waters, which have been for centuries the main, most easily accessible source of water for the inhabitants of the particular regions. The Huang He, the largest Chinese river, which has been excessively exploited for many years, mainly by industry, vanishes in its lower course. Another factor which has an adverse effect on accessibility of water resources is climate variability and change which are manifested by the occurrence of the extreme weather events, including those related to the desertification of many areas. Simulations indicate that climate warming will cause enhanced evaporation from the surface of oceans and the precipitation distribution mainly at higher latitudes.

Such a pattern will aggravate the water related situation which is already tragic today in many countries in Africa and Southeast Asia and it can also affect the countries in Southern Europe. These conditions can only worsen the already tense relations among the countries in these regions.

The extreme precipitation levels in the belt of higher latitudes will not have a positive effect on water management, either. It is predicted that by the middle of the present century China will lose even two-thirds of its glaciers, which can have a direct impact on more than 300 million people. Given the so dramatic predictions and bearing in mind the substantial pollution of surface waters, groundwater will become the key resource. Already today in many regions it is the basic source of drinking water supply to the population. Such developments can lead to many potential conflicts about these underground riches, particularly at places where transboundary aquifers accessible to two or more countries are situated.

In the 1980s, Libya prepared the project to build a pipeline to carry water from the rich groundwater resources at Al-Kufrah to the north of the country – the Great Man-Made River (GMR). About 2 million m^3 of water a day is abstracted here from 450 m depth. Water is used mainly for irrigation purposes. Unfortunately, the robber water management leads to excessive depletion of the resources. It is important to note that the aquifers which Libya uses are of a transboundary character and also belong to other countries (Chad, Egypt, Sudan). Zenetti (2005) predicts that despite the absence of the neighbours' reaction to the Libyan activities a conflict is only a matter of time. In the future, the excessive depletion of groundwater resources may have an adverse impact on the flow in the Nile, which can cause Egypt's reaction.

In the Hebei Province in China, an increased demand for groundwater caused the excessive exploitation of the resources and a substantial lowering of the water level [18]. As a result, unproductive intakes were abandoned (36,000 wells) and another 55,000 intakes were drilled, reaching out for increasingly deep resources. In this area, the groundwater table has been seen to lower by 1.5 m a year, which can lead to a regional disaster.

Another example of the problems which can ensue from a shortage of groundwater resources is Lvov in Ukraine. The city lies on a watershed and groundwater resources are its only source of drinking water. Unfortunately, they are not sufficient and a restrictive water policy has been pursued for a dozen or so years. The very bad situation is aggravated by the disastrous condition of the transmission network, where the water losses are estimated at more than 40%. This situation forces the authorities to ration water, which is only available at set hours. All this is done to protect the city from the situation where there would be no water at all.

In Poland, in the last decade of the twentieth century, as a result of the mining investment projects at Bełchatów (an open-pit lignite mine) the drainage of a lignite deposit at the Bełchatów Lignite Mine caused the emergence of a regional groundwater depression cone and the related change in the water regime in an area extending over tens of kilometres. In the future, similar effects can be caused by the planned mine in the area of Lubin and Głogów. Such situations give rise to numerous protests of the residents who suffer directly from the absence of water.

Just as surface basins, groundwater aquifers are very often shared by several states. An example of the transboundary problems caused by the drainage of open-pit mines located in the German territory directly across the Nysa Łużycka border river is the lowering of the groundwater level [19]. As a result of the operation of a lignite mine (Jänschwalde), an anti-filtration screen was created to limit the flow of surface waters and groundwater from Quaternary and Tertiary aquifers to the drainage system. Monitoring surveys have indicated that the operation of the mine has caused the emergence of a deep depression cone in Tertiary formations and a lowering of the water levels by 50 m over 20 years. This situation should be the subject matter of talks between the neighbouring parties in order to prevent the adverse impacts of the mining operations underway.

3.4 Conclusion

The problems related to water management are seldom covered by the world media except for the cases of disastrous events such as floods. At present, it is estimated that today about 20% of the global population has no access to clean water and that half of the world population is not connected to wastewater collecting systems. According to the IPCC report, in 2080 water will not be available for 1.1–3.2 billion people [20]. There is no doubt that this situation must cause concern and that in the nearest time the absence of systemic solutions may lead to an escalation of many conflicts ensuing from a struggle for water resources.

It might seem, in accordance with the analyses performed by Keegen [21], that water problems are mainly connected with the subtropical and tropical zones, i.e. they do not affect the belt between 9° and 55° North and 90° and 135° West. However, a look at the map of the history of water conflicts (Fig. 3.5) shows that this is a substantial simplification and that these problems have a much wide range.

Considering different scenarios of the development of our civilisation, it seems that the water problem will certainly not vanish and that, quite on the contrary, its range will cover increasingly large areas. Particularly in the case of the observed climate change and the increasingly often recorded extreme events.

These examples of water disputes, which more often than not turned in their later stage into open armed conflicts, indicate how important it is to ensure correct water management, particularly in the context of transboundary issues. There is no doubt that unless rational measures are taken at the level of the whole world these problems can only grow in the nearest future. In particular, considering that as estimated the demand for water will grow by 70% in 2025.

It may seem that Europe and the developed countries located within it are free from water problems. Unfortunately, the reality is much worse and 41 million people in this continent have not free access to water. Therefore, the water problem applies practically to all the inhabitants of our planet – of course, to a lesser or greater extent.

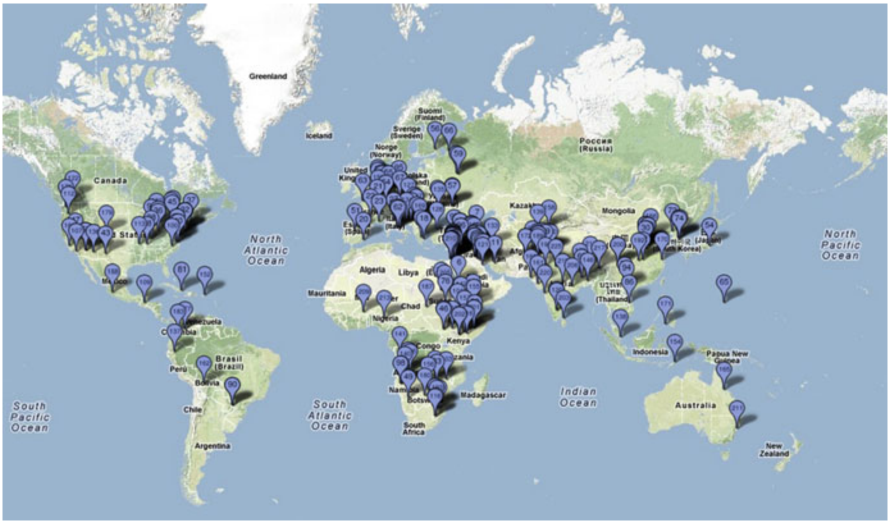

Fig. 3.5 A map of water conflicts in the world [22]

In connection with the depletion of surface waters which are suitable for drinking, we reach out for increasingly deep resources, but we should be fully aware that they are limited, too. Rational water management in the areas of transboundary aquifers should be a priority for countries neighbouring on each other, since in the nearest future they can be the basic resources to be used by the population to satisfy its fundamental needs. Abstraction must be controlled according to preset rules and protection against potential pollutants must be ensured. Groundwater shared by several states is an extremely sensitive issue, since it is very easy to damage a fragile consensus which more often than not it has been worked out for a long time.

Water management in transboundary areas needs an interdisciplinary approach. There is no doubt that in this case expert groups assisted by scientists have a very important role to play. Their task should be an in-depth exploration of the problem, which is characterised by local specificity in most cases, and to present solutions which would be acceptable to all the parties. Certainly, the success of such a process needs political involvement and financial support for related research. In the future, such a scenario of preventive measures may prevent the emergence of many potential water conflicts.

The water problems and the prevention of conflicts also become greatly important due to the strategic position of water resources. It is well known that the construction of water facilities can be (as history has shown) a means of political blackmail. At the time when terrorism has become one of the forms of policy implementation, one can also imagine that in the future extremist groups can target broadly understood water resources. Bearing in mind the public security, water must be treated as a priceless raw material and care must be taken to ensure its broadly understood protection.

It is important to analyse the water disputes known to date and draw on the experience which they afford in order to contribute to the building of a compromise and rational water management between the neighbouring countries which share water resources. The prevention of water conflicts should be a strategic and priority objective in the field of environmental protection.

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Chapter 4
Cooperation in the Protection of Transboundary Groundwater in the Case of the Odra River Basin

Bogusław Kazimierski and Tomasz Gidziński

Abstract The main task of groundwater monitoring system in Poland is to monitor and assess condition of groundwater bodies (including GroundWater Bodies (GWB) in the border area), pertains to the qualitative and quantitative status, in order to plan water management in river basin districts and achieve required environmental goals. In this article were presented groundwater monitoring networks focused on assessment of pressures from the territory of the neighboring country, which can influence groundwater chemical, as well as quantitative status in the border area of Poland. The surveys in groundwater monitoring networks are aimed at assessment of changes in groundwater quantity and quality to provide with data, which allow to prepare reports and plans of water management and water protection.

Good practices in the domain of water protection, related to international cooperation were worked out on the level of the International Commission for the Protection of the Odra River against Pollution. The experiences and solutions applied in working groups of the International Commission for the Protection of the Odra River against Pollution can be implemented in international commissions, whose range covers other international river basin districts.

Keywords Hydrogeology • Transboundary aquifers • Monitoring • Groundwater status assessment

4.1 Introduction

In Poland, waters are managed in a division into basins and sub-basins, while the groundwater status is carried out for groundwater bodies (GWBs), including the border-area GWBs.

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The Polish Hydrogeological Survey (PHS) participates in international and intergovernmental cooperation in the framework of the implementation of the national policy in the field of the management and protection of groundwater. Some activities of the PHS are related to the direct implementation of tasks coordinated by the Minister of the Environment, the National Water Management Authority, the Chief Inspectorate for Environmental Protection and the Government Plenipotentiary for Cooperation in Border Waters. They are carried out in the following commissions to which the staff of the Polish Geological Institute – National Research Institute were seconded as delegates or experts:

- the International Commission for the Protection of the Odra River against Pollution,
- the Commissions for Border Waters: the Polish-German Commission, Polish-Czech Commission, the Polish-Slovak Commission, the Polish-Ukrainian Commission and the Polish-Lithuanian Commission established in 2010.

The cooperation in border waters, including groundwater monitoring, is based on guidelines: agreements and memorandums of understanding concluded at the level of government institutions (the International Commissions for Border Waters) and self-government and sectoral ones, e.g. with the representatives of the border-area Land of Mecklenburg-Vorpommern.

In the scope of hydrogeology, the Commissions for Border Waters focus on the resolution of current problems related to the protection of resources and quality of groundwater. Within the Commissions, working groups and expert teams are appointed to solve the particular problems set for them.

The Polish-German Commission for the Border Waters mainly deals with the problem of the impact of the drainage of lignite mines in the territory of the neighbouring state and the coordination of water supplies from groundwater intakes in the border areas.

The Polish-Czech Commission for the Border Waters mainly deals with the issues of the coordination of water abstraction in border areas, the impact of mining drainage and the impoundment of waters in surface reservoirs on groundwater [3].

4.2 The Network for Investigative Monitoring of Groundwater Along the Western and South-Western Borders of Poland

Surveys and cyclical monitoring observations of groundwater in the Polish border zone are carried out in survey networks in the following border areas:

- with Germany – within the Polish island of Uznam and in the area under the impact of the drainage of the German Jänschwalde, Nochten and Reichwalde lignite mines on groundwater in the border area of Gubin and Łęknica;
- with the Czech Republic – in the Central Sudety Basin and along the state border, within the limits of Śląskie and Opolskie Provinces (Fig. 4.1).

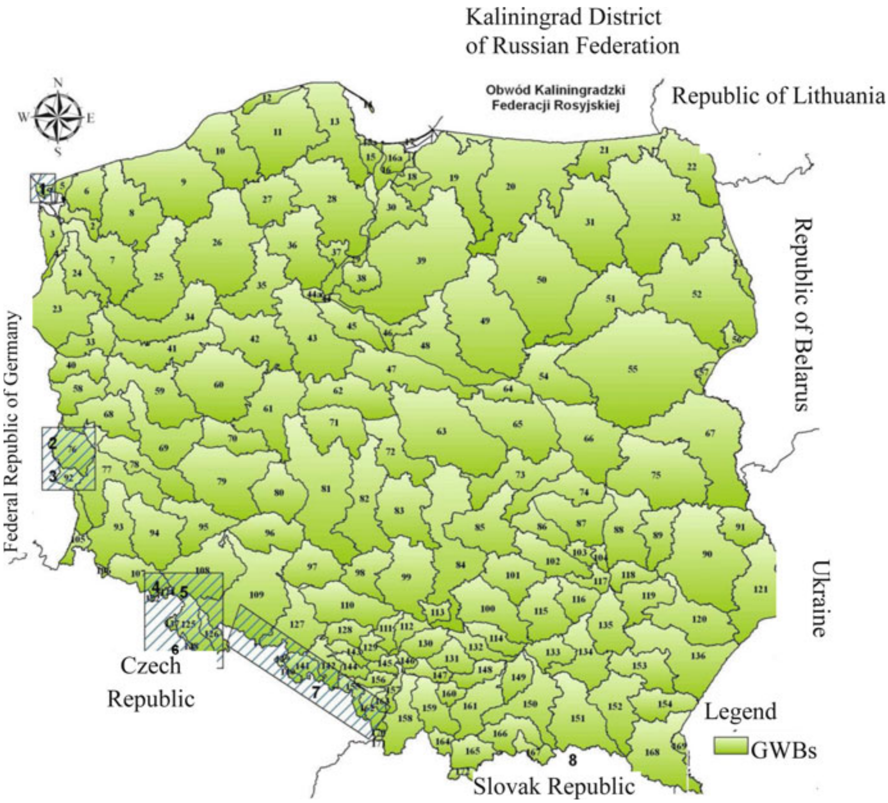

Fig. 4.1 The distribution of the border-area groundwater monitoring networks along the western and south-western borders of Poland. *Explanatory notes*: 1 – the area of the Polish Uznam Island, 2 – the area of Gubin (the impact of the German Jänschwalde lignite mine on groundwater on the Polish side of the border), 3 – the border with the Federal Republic of Germany – the area of Łęknica (the impact of the German Nochten and Reichwalde lignite mines on groundwater on the Polish side of the border), 4 – the border with the Czech Republic – the area of Krzeszów-Ardšpach, 5 – the area of the Górna Ścinawka basin, 6 – the area of Kudowa and Police, 7 – the border area along the state border in Śląskie and Opolskie Provinces [3].

4.3 Groundwater Monitoring in the Area Under the Impact of German Lignite Mines on Groundwater in the Area of Gubin and Łęknica

For the purposes of this article, this section presents the characteristics of the groundwater monitoring networks in the area under the anthropogenic impacts of the mining operations at the German Jänschwalde, Nochten and Reichwalde lignite mines on the status of groundwater in the Polish border zone (Fig. 4.2).

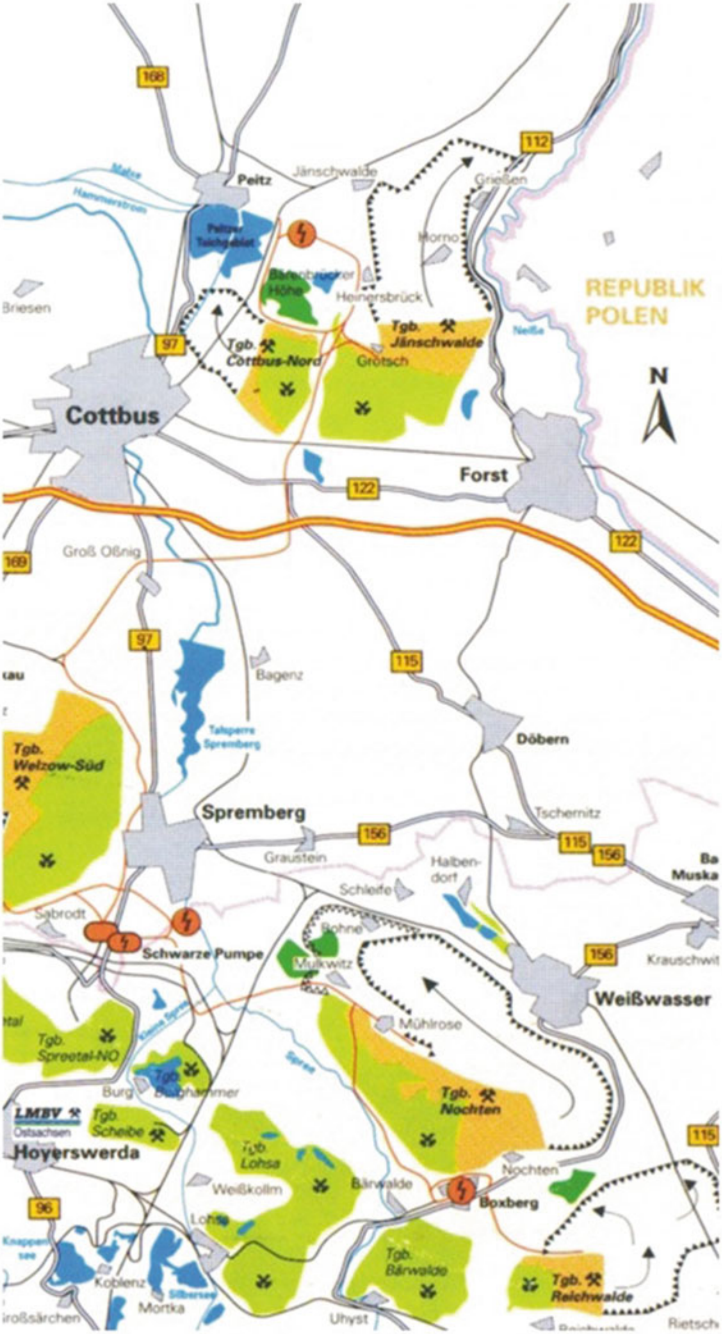

Fig. 4.2 Detail of a review map with the locations of German lignite mines situated in the border zone with Poland [4]

4.3.1 Groundwater Monitoring in the Area of Gubin

The groundwater monitoring network in the area of Gubin covers the area under the impact of the German Jänschwalde lignite mine. The drainage of this mine has caused the emergence of an extensive depression cone also extending to the Polish territory and can ultimately lead to difficulties in water supply to the communes adjacent to the mine. The line of operations is parallel to the Nysa Łużycka River, northwards. Monitoring observations in the border-area monitoring network in question include measurements of the Quaternary and Tertiary groundwater levels. The results of these observations provide the basis for identifying the impact of the drainage carried out at the German open-pit lignite mine on the groundwater in the area of Gubin.

The border-area groundwater monitoring network in the area of Gubin consists of 27 survey boreholes, of which 23 are piezometers and the other 4 are dug-up wells. 11 of the group of the survey stations in question were incorporated into the national groundwater research-observation network of the Polish Geological Institute – National Research Institute (with a weeklong measurement cycle). The monitoring network extends from the locality of Polanowice in the north to the locality of Strzegów in the south.

4.3.2 Groundwater Monitoring in the Area of Łęknica

The groundwater monitoring in the border area of Łęknica is carried out to assess the effect of the impact of the drainage at the German Nochten and Reichwalde lignite mines. The mining drainage has caused the emergence of an extensive depression cone in the German territory, reaching the Nysa Łużycka border river. The groundwater monitoring network in the area of Łęknica consists of 19 survey stations – 7 piezometers and 12 wells – and extends from the area of the locality of Przewoźniki in the north to the locality of Sobolice in the south. Five piezometers of the border-area monitoring network were incorporated into the groundwater research-observation network. Similarly to the area of Gubin, the purpose of the monitoring within the network is to measure the Quaternary and Tertiary groundwater levels in relation to the exploitation of the open-pit lignite mines, situated in the border areas of Germany. The Nochten and Reichwalde mines are situated at a distance of about 10 and 18 km from the Polish-German border at the latitude of the localities of Potok and Sobolice. The measurements in this observation network were started in 1998 [2].

4.4 The Characteristics of the Impact of Anthropopressures in the Area Under the Impact of the Jänschwalde Lignite Mine on Groundwater in the Polish Border Zone

Near the border with Poland, in the German territory the open-pit Jänschwalde lignite mine is in operation. The drainage of the open pit has caused the emergence of an extensive depression cone, also reaching the Polish territory, despite the existence of the Nysa Łużycka border river. The monitoring of the impact of the drainage started in 1975 and has continued until the present time. Modelling and monitoring research conducted to date have indicated that the range of the drainage of the Jänschwalde mine is substantial only within the Paleogene and Neogene aquifers, where lignite deposits are situated. The maximum depression range within the Paleogene and Neogene aquifers is about 60 m, while its range, determined in 2010 from the Nysa Łużycka border river, was about 10 km into the Polish territory (Fig. 4.3).

Within the Quaternary aquifers the effects of the drainage can largely be seen only in the sub-till aquifer. Within the groundwater aquifer it is difficult to distinguish the effects of natural changes in the water level from those caused by the drainage. The reason for this is the effect of the Nysa Łużycka, which stabilizes the groundwater table and the dense network of land amelioration canals.

The Paleogene and Neogene aquifer system is directly drained by the mine. The quaternary multiaquifer formation is drained indirectly through the zones of facilitated vertical groundwater flows (in the erosion troughs and hydrogeological windows). As a result of the period of more than 35 years when the mine was drained, the stabilizing effect of the Nysa Łużycka and other watercourses and the existence of the isolation screen, the process of the water groundwater-table lowering in Quaternary aquifers only just revealed itself. It can be expected that over the next dozen or so years it will become more intense. However, in order to confirm this assumption it would be necessary to perform further observations and tests.

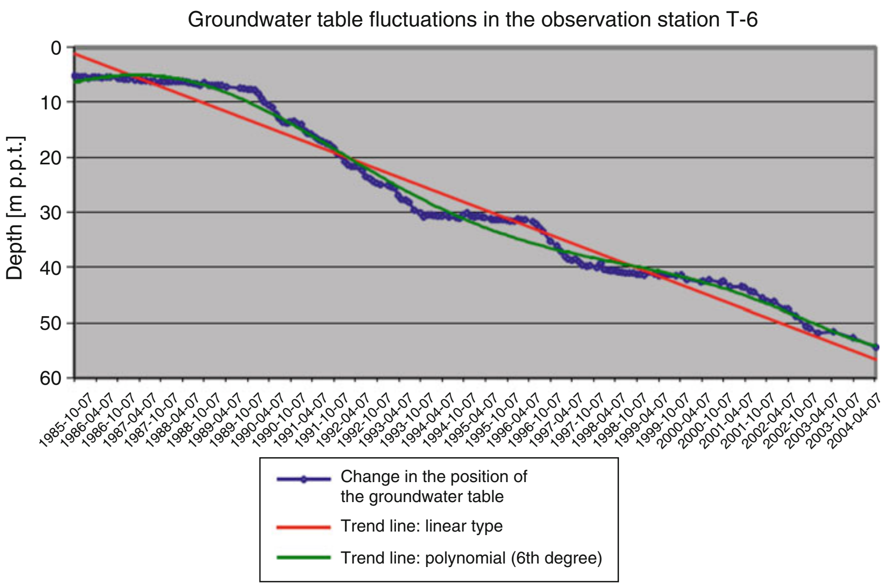

Fig. 4.3 The results of the observations of the groundwater level lowering in the Polish territory as a result of the drainage of the German Jänschwalde lignite mine

However, there is no doubt that there are transboundary flows from the Polish territory into Germany within the Paleogene-Neogene useful multiaquifer formation (i.e. the one utilized in the Polish territory or one that may serve to supply water to the population). For this reason, this area, which is part of the groundwater body GWB No. 76, should be regarded as a transboundary one, while GWB No. 76 should be considered to be transboundary with all the related implications.

4.5 The Activity of the International Commission for the Protection of the Odra River Against Pollution

4.5.1 The Characteristics of the Odra River Basin

The total surface area of the Odra River Basin is 124,049 km^2, 86% of which belongs to Poland, almost 6% to the Czech Republic and 7.7% to Germany. For the purposes of the characteristics of the waters status in the whole basin, its area was divided into sub-areas including: the Upper Odra (18,019 km^2), the Middle Odra (31,231 km^2) and Lower Odra (10,915 km^2), the Szczecin Lagoon (5,009 km^2), the Nysa Łużycka (4,395 km^2) and the Warta (54,489 km^2). Within the boundaries of the Odra River Basin, a total of 103 groundwater bodies (GWBs) were delineated, including 27 GWBs in the Upper Odra area, 18 GWBs in the Middle Odra area, 11 GWBs in the Lower Odra area, 10 GWBs in the sub-region of the Szczecin Lagoon, 16 within the Nysa Łużycka River Basin and 21 GWBs within the Warta River Basin.

The boundaries of the transboundary GWBs have not been designated so far.

4.5.2 The Legal Grounds for the Establishment of the International Commission for the Protection of the Odra River from Pollution

The International Commission for the Protection of the Odra River against Pollution was established under the provisions of the *Agreement on the International Commission for the Protection of the Odra River against Pollution* of 11 April 1996, signed between the Government of Poland, the Government of the Federal Republic of Germany, the Government of the Czech Republic and the European Union. The agreement came into effect after its ratification on 26 April 1999.

4.5.3 The Main Objectives of the International Commission for the Protection of the Odra River Against Pollution

The objectives of the work of the Commission include:

- Prevention and permanent reduction of the pollution of the Odra River and the Baltic Sea with harmful substances,
- Ensuring that water and costal ecosystems are as close as possible to natural ones, with their specific biodiversity of species,
- Ensuring the use of the Odra River above all for obtaining drinking water from infiltration coastal intakes, for agricultural use of water and sediments,
- Prevention and permanent reduction of the risk of flood damage
- Coordinating the implementation of the Water Framework Directive in the Odra River Basin [1].

The decisions of the International Commission for the Protection of the Odra River against Pollution are taken at its sessions by the delegations of the individual countries – Signatories to the Agreement.

The work of the Commission is carried out in working groups, consisting of experts from the particular countries. The particular working groups prepare action plans to determine their objectives in a given field.

The aim of the work of the GM Monitoring Group is to identify and present the quantitative and qualitative status of groundwater bodies, in accordance with the requirements of the Water Framework Directive (WFD), to identify the shortages with respect to the achievement of the WFD assumptions and to determine long-term trends. The tasks of the GM Monitoring Group also include the elaboration of a system for surface water and groundwater monitoring in the Odra River Basin, based on: the observation points of the national monitoring networks and the results of monitoring surveys. The activities of the GM Monitoring Group aim at achieving good status of the waters in the Odra River Basin, including good groundwater chemical status. The countries participating in the work of the Commission agreed to prepare a joint plan, based on the national water management plans, which would take into account the specific problems of water management in each of the countries situated in the Odra River Basin.

The assessments of groundwater quantitative and chemical status for groundwater bodies were elaborated on the basis of the results of measurements and surveys from national monitoring systems (Fig. 4.4). Poland has the lowest number of groundwater monitoring points in relation to the surface area of the individual GWBs, i.e. 0.27 monitoring point per 100 km^2. In Germany, the density of groundwater monitoring stations is 8.9 monitoring stations per 100 km^2. In the Czech Republic, the density of the monitoring points, where observations of first (shallow) aquifer are carried out is 2 stations per 100 km^2, while the density of the monitoring points where the main aquifer is monitor is 0.64 monitoring point per 100 km^2 [1].

Since all the states lying in the Odra River Basin District are Member States of the European Community, the main methodological guidelines for water status

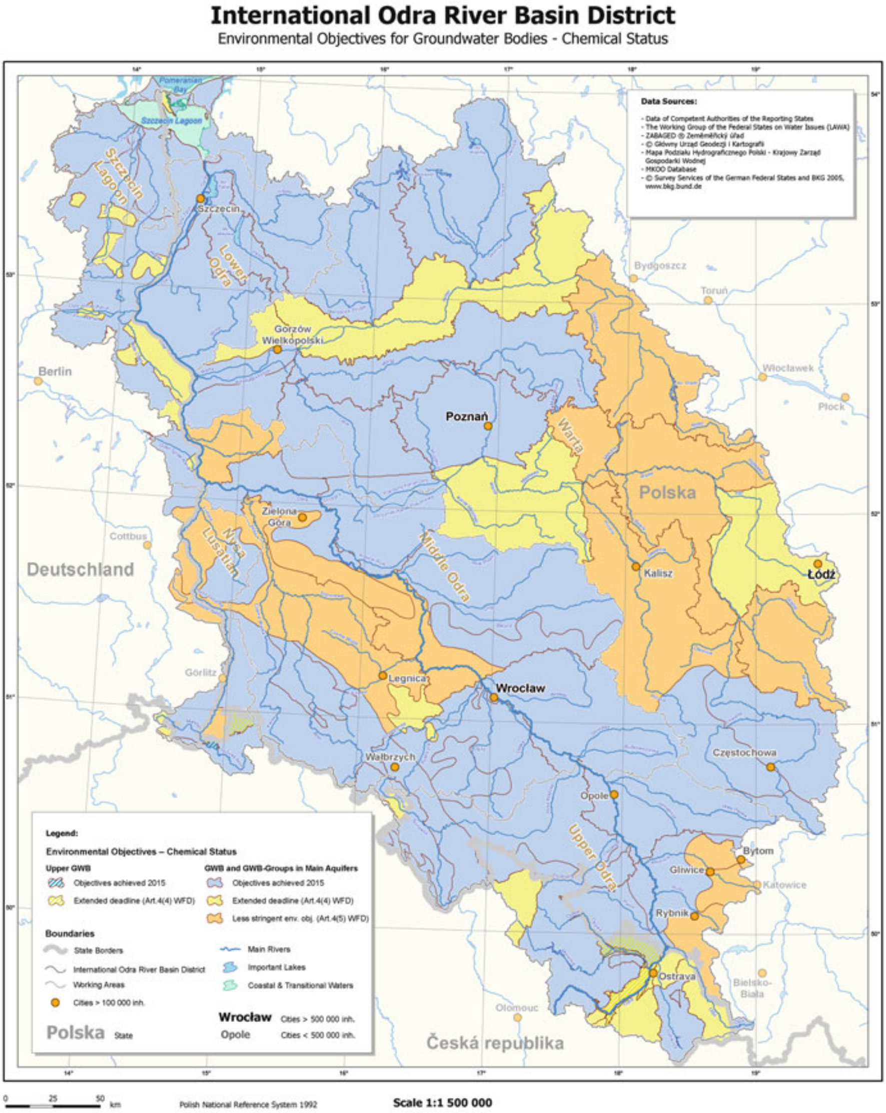

Fig. 4.4 The assessment of the chemical status of groundwater bodies in the International Odra River Basin District [1]

assessments are governed by the relevant requirements of the Water Framework Directive. However, for the purposes of the implementation of the project in question it is necessary to harmonise the national methodologies and criteria for the assessment of groundwater status.

From the point of view of the assessment of quantitative and qualitative status, it is very important to create transboundary measurement and survey courses, which would allow for the specification of the impact of anthropogenic pressures on groundwater in a neighbouring country (e.g. the impact of the drainage at the Jänschwalde, Nochten and Reichwalde lignite mines in Germany on the border areas in Poland).

On the basis of the results of monitoring surveys in 2007, good chemical status was found in 68 GWBs encompassing the main aquifer, whereas poor chemical status was identified in 29 of them. Additionally, at all the six GWBs characterising the first aquifer bad chemical status was found.

On the basis of the results of monitoring surveys in 2007, good quantitative status was found in 80 GWBs, 4 of which characterise the first aquifer. Poor quantitative state was identified in 23 GWBs, including 2 encompassing the first aquifer.

The major factors contributing to the deterioration of GWBs starus in the Odra River Basin District included:

- area pollution of agricultural origin (plant protection agents and nutrients) and the pollution related to mining operations,
- point pollution sources, e.g. poorly controlled waste landfills,
- groundwater abstraction intakes, particularly in mining areas, including the drainage areas at the mines located in the border areas,
- other anthropogenic impacts, e.g. those related to intensive development of mining [1].

4.6 Conclusion

The experiences and solutions applied both within the structure of the International Commission for the Protection of the Odra River against Pollution and the results of the work done by the particular working groups can be implemented in newly established commissions, whose range covers other international river basin districts. In the case of the states bordering on Poland from the east, i.e. Ukraine and Belarus, to date pilot projects have been implemented covering issues in the scope of the assessment of surface water status and, to a lesser extent, that of groundwater. Good practices worked out at the level of the work done by the experts of the International Commission for the Protection of the Odra River against Pollution, e.g. in the harmonisation of areas, ranges and forms of observations and surveys, as well as the methods and criteria for the assessment of groundwater status can prove to be very useful in the process of identifying the characteristics of groundwater status in the International River Basin District of the Bug or the Vistula.

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Chapter 5
Natural Conditions and Man-Made Influence upon Surface Waters Quality in the Western Bug River Basins

Stefan Tatukh, Petro Chalyi, Orest Mukha, and Andrij Mykhnovych

Abstract The problems of unsatisfactory state of water resources and imperfections of water management in the Western Bug river basin are most urgent in the region. These problems are not national but international because of transboundary status of this river. In the presented paper the natural and man-made factors of hydro-ecological situation forming in the catchment are considered. Much attention is paid to the analysis of water quality in the rivers as well as the trends and scales of long-term water runoff changes in the Western Bug river basin.

Keywords Water pollution • Water runoff changes • Man-made effects • Western Bug river basin

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5.1 Introduction

In the Lviv region, surface water is the most polluted natural resource. The state of surface water is caused by a wide spectrum of interconnected factors such as land and air pollution, land use and landscape structure changes, technical processes, low effectiveness of the treatment plants, unauthorised municipal, industrial and agricultural waste waters, ignoring water protection zones and coastal vegetations belts in the settled areas.

An effective monitoring system is an important precondition of scientific research and water management Water monitoring is a part of the state environmental monitoring system of Ukraine. Water monitoring consists of two aspects — qualitative and quantitative.

The Western Bug is the biggest river of the flat part of the Lviv region. It is the right tributary of the River Vistula. There are 25 observation points in the Western Bug basin within the Lviv region. Most of them (17) are located along the Western Bug riverbed and the rest of them on the tributaries.

The objectives of the investigation include analysis of the river water quality determining factors. The main tasks are:

1. evaluation of the natural preconditions of river water quality forming;
2. assessment of the river water quality in the transboundary areas;
3. analysis of the anthropogenous factors of the water quality deterioration;
4. analysis of the wastewaters purification effectiveness.

The informational base of the investigations are the monitoring data of the laboratories of State environmental inspection in the Lviv region, of the Volynian regional centre of hydrometeorology, Lviv regional sanitary-epidemiological station and Lviv regional water management authority.

5.2 Study Site and Natural Factors

The Western Bug is a part of the Vistula River basin. The investigated upper part of the catchment area is located in Ukraine within the Lviv and Volyn' administrative regions. The length of the river within Ukraine is 392 km [1]. Width of the catchment area is about 70–100 km. The studied part of the basin was formed during the last few millions years and according to geological research this part of the catchment area was part of the Black Sea basin within the catchment of the River Dnister [2].

According to the physical-geographic zoning scheme of Ukraine [1] the upper part of the Western Bug catchment area is located within the following physical-geographic regions: Podillia Highland, Male Polissia, Volyn' Highland and Polissia Lowland. Podillia and Volyn' Highlands belong to the Western Ukrainian forest-steppe province of bedded and bedded-tier erosional plains, Male Polissia and Polissia lowlands belong to the Polissia flat-undulating low mixed forest province. Both provinces are part of the Eastern-European Plain [3, 4].

According to the tectonic maps the catchment area is situated on the south-western side of the *East-European Platform* where the Precambrian base foundation is covered by 2,500–3,000 m of sediments. In the central lower part of the catchment area the deposits of the Cretaceous period (upper division K_2) dominate. They are indicated by light-grey and white soft marls and limestones. After the Paleogene era the dry land of the studied area was covered by a shallow sea in the Miocene period. So higher areas are shown by Medium Miocene deposits (sand, sandstones, clay and limestones) [5]. The tops of hills and ridges are composed of limestone, marls and sands of the Upper Miocene age. Pleistocene aeolithic and deluvial deposits are represented mostly by loesses, loams and sands as well as eluvial-deluvial deposits (fragments of limestones, sandstones and marls) within the higher parts and watershed borders. The slopes are composed by holocene and modern deluvial debris cones and trains. The lower part of the catchment area and river valley are covered by modern alluvial sands and loams and early pleistocene fluvio-glacial sands [5].

The River Bug or Western Bug rises from a spring in Verkhobuzh village (about 311 m above sea level). The Western Bug headwaters are located within the part of Podillia Highland named Voroniaky Hills or Upper-Bug Ridge with absolute altitudes about 300–400 m and significantly elevated above Male Polissia lowland (200–250 m above sea level). Spring water here comes from the fissures in the limestones of the Neogene period (Dombrowski et al.). Downstream from the village the riverbed was straightened and became a part of the drainage system of the Koltiv valley. The upper part of the River Bug valley is 1–3 km width, has terraces and a boggy floodplain with former riverbeds.

The river valley leaves the Podillia Highland near Bilyi Kamin' village and is only 1 km wide here. Then the river passes Male Polissia — an area with many meadows and bogs as well as hills covered by loesses. Here the river meanders in north-westwards. Here the river is characterised by slight fall, great meandering and furcation, great canalsation, water-divide lines are feebly marked and often are crossed by drainage canals. In the central and lower parts the river valley width is 40–75 m, locally up to 100 m [1].

The river valley is formed in the marls of the Cretaceous period (K_2m), limestones, sandstones and sands of the Miocene era (N_2op), in glacial and fluvio-glacial detritus-gravel-clay and sand sediments of the Lower Pleistocene era (g, fg P_1sl). The relief forms are composed by the sediments of the medium and upper Pleistocene and Holocene eras. The river valley crosses three geomorphological subregions of the Volyn'-Podillia highland: the Podillia structural-denudational plateau; the Male Polissia aeolian-denudational plain and the Volyn' denudational-loess highland [6].

The natural history of relief forming in the Upper Bug headwaters was disturbed by human impact especially in second half of the twentieth century — the period of intensive melioration systems construction and "kolhoz" [large scale state farm unit] agricultural land use with deforestation. During this period the small rivers and streams received 200–500 t/ha sediments annually. In consequence many streams and ponds were silted, the thickness of riverbed and floodplain alluvium increased 0.5–1.5 m [7]. At the beginning of the twentieth century drainage systems construction was started by straightening and deepening of the River Bugbed. In the Soviet

Table 5.1 Average air temperatures in the investigated region [5]

Station	Months												Year	Amplitude
	1	2	3	4	5	6	7	8	9	10	11	12		
Brody	–4.3	–3.2	1.2	7.6	14.2	17.0	18.7	17.7	13.5	8.7	1.8	–2.2	7.5	23
Bus'k	–3.9	–3.2	1.6	7.7	13.8	16.6	18.2	17.1	13.2	8.2	2.4	–2.1	7.5	22.1

Absolute minimum of air temperature is –27.9°C and maximum 34.3°C [8]

Table 5.2 Average precipitation in the investigated region [5]

Station	Months												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
Brody	36	34	42	53	74	106	106	80	59	53	55	44	742
Bus'k	25	23	30	50	69	99	99	79	55	45	38	29	641

Table 5.3 Average, average maximal and average minimal temperature of the soil surface in Brody meteo-station [8]

Parameter	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Average	–4.3	–3.4	2.2	8.2	15.8	19.2	20.5	19.6	14.3	7.9	1.8	–2.9
Average maximum	0.4	0.9	9.8	21.1	29.9	33.5	34.5	33.7	25.6	16.5	16.4	1.9
Average minimum	–7.5	–7.2	–3.2	1.5	6.5	10.2	12.5	11.6	7.4	2.9	–2.6	–5.8

period drainage systems were constructed on the terraces. Drainage became the main factor of other environmental components' changes in the catchment area — the so-called "chain reaction" of unforeseen ecosystems' changes has been started [7].

The climate of study area is temperate and characterised by mild winters, small differences between winter and summer temperatures, high precipitation. The moisture coefficient is 1.1. The total solar radiation is approx. 92 kkal/cm^2 (the highest parameter in July (16.6), the lowest in December (1.1)). The radiation balance is negative in November – February and positive in March – October [5]. Temperate zone polar air predominates here. In all seasons the sea polar air is typical. Continental polar air usually comes in spring and summer. In the winter-spring period the continental arctic air comes quite often and causes frosts of down to –30°C. In the summer-autumn period cold and wet weather is caused by the Arctic Sea air. In summer the hot and dry weather is the consequence of continental tropical air invasions. Most often wind velocity is 0–5 m/s (70–90% per year). The coldest month is January (–4.3°C), the warmest one is July (+18.7°C) (Table 5.1).

The average annual sum of precipitation is about 700 mm (Table 5.2).

Temperature regime of the soil surface is presented in the Table 5.3.

The Western Bug is a relatively full-flowing river. The width of the riverbed is from 1 to 10 m in the upper part to 80–100 m in the lower part within the Polissia lowland. The depth changes between 1.0 and 6.5 m. Average water discharge is 10–15 m^3/s (near Kamianka Buz'ka) and 25–30 m^3/s (near Lytovezh); absolute maximal discharges are 222 m^3/s (Kamianka Buz'ka) and 230 m^3/s (Lytovezh). The flow velocity fluctuates from 0.5 to 0.8 m/s within the highlands to 01–0.2 m/s within the Polissia Lowland. The average river network density is 0.3–0.5 km/km^2 ([1, 5, 9]; Main hydrological…, 1985).

Alimentation of the river is mixed (rain, snow and subterranean). Three water discharge peaks may be defined: spring flood, summer rain floods and winter floods due to thaws. Spring water levels are highest and reach 5 m. In the central and lower parts the floods are slightly marked with water level peaks up to 1 m [5, 10].

According to the geo-botanical zoning of Ukraine the study area is located in the European deciduous region, Eastern-European province, Holohory-Voroniaky district. This district of beech forests occupies the narrow belt corresponding to the *Holohory Hills* and *Voroniaky Hills*. This region is relative to other neighbouring areas less tilled. Forests occupy about 40% of the land area. Among forest species *Fageta sylvaticae* dominates [11]. They are spread in the middle and upper parts of the hills. A characteristic feature of these communities is the existence of Carpathian mountain elements (*Aconitum moldavicum, Astrantia major, Veronica montana*). Below the beech forests there are oak-hornbeam forests, which are more widely spread. hornbeam-beech forests are less spread here. Small areas are occupied by pine and oak-pine forests. Swamps are seldom seen — in the river valley they are classed as eutrophic herbaceous. Meadow vegetation is spread on the floodplains of small rivers (true meadows) as well as on the hill slopes of southern, western and northern exposure.

On the slopes the communities of *Poeta angustifoliae, Cariceta montanae* dominate [11]. Boggy vegetation in Voroniaky has islands of distribution and an eutrophic-mesotrophic character. Bog parts are at different phases of post-meliorational transformation [12]. The massive area of western-European carbonaceous bogs is between the villages Verkhobuzh, Koltiv, and Kruhiv in the boggy part of upper Bug river floodplain. There are communities with *Cladium mariscus* domination (between Verkhobuzh and Kruhiv) with area of 0.5 ha [12]. The Upper-Bug floodplain-bog mass is protected now.

Agricultural land use was formed on the sites of former natural forests. Cultivated lands are cropped between grain crops (40%), fodder crops (35%), potatoes and vegetable (15%), technical crops (10%).

5.3 River Water Quality

River water quality in the Western Bug basin is formed by combination of natural and man-made factors. The main factor of pollutions is the wastewaters of the Lviv treatment plant as well as industrial plants along the riverbeds of the Bug and its tributaries.

Due to the laboratory analyses it has been ascertained that the water quality in the upper part of Western Bug is characterised as “bad” and “very bad”. This is caused by inflowing polluted water of the Dumna, Rata, Solokia, Kamyanka and Poltva rivers. The Poltva receives the wastewaters of the Lviv treatment plant so it is the most polluted in the basin.

Negative effects of water pollution are observed downstream to Dobrotvir reservoir. In the reservoir water quality becomes better due to more intensive biological self-purification processes. It is facilitated by high plants and animals factors in the water of the reservoir as well as the factor of mixing with high volumes of water. Downstream from the reservoir the water quality is satisfactory.

The most pollution is caused by untreated wastewaters and inefficient functioning of sewerage systems and wastewater treatment plants in the basin as well as unauthorised domestic and industrial wastes disposal directly in the riverbeds.

Most of characterised aspects are typical for the Poltva – most polluted river from headwaters to the mouth, the Solokia – transboundary river affected by diffusion pollution caused by lack of coastal water protection zones as well as high proportion of agricultural fields and settlements (so the major part of pollutants comes to the river bed from agricultural fields due to erosion) and the River Rata which is mostly polluted by wastes.

The main object – sources of pollutions are:

- Municipal enterprise “Lvivvodokanal”
- State Enterprise “Chervonohradvodokanal” (in Hirnyk urban area);
- Urban water supply and sewerage system of Zhovkva;
- Urban water supply and sewerage system of Rava-Rus’ka;
- Urban water supply and sewerage system of Velyki Mosty;
- State enterprise “Rava-Rus’ka crosstie production plant”;
- Rava-Ruska customs wastes treatment plant.

Wastewaters flowing into the riverbeds are an important parameter of human pressure upon water resources. Usually volumes of wastewaters are equal to 15–30% of water intake for use, but in the Solokia and Poltva rivers this parameter reach 100% of water use in the catchment area. In the River Poltva the volume of wastewaters is equal to the water runoff of this river for 75% of the year. Purification treatment of wastewaters is not efficient so it is one of most important factor of water resources deterioration in the Western Bug basin. Another important factor of river waters pollution is unauthorised domestic wastes disposal in the private sector. So increasing water supply to the villages is correlated to increasing unauthorised wastes draining directly into the riverbeds.

There are about 85 waste treatment plants of settlements and enterprises. Most of the treatment plants were constructed before 1990 using technical solutions of 1970–1980. Many of them are typified by depreciation greater than 50%. Technical equipment is in an unsatisfactory state. Sewerage systems are characterised by exigent conditions. All these factors cause inefficient wastes purification (Fig. 5.1).

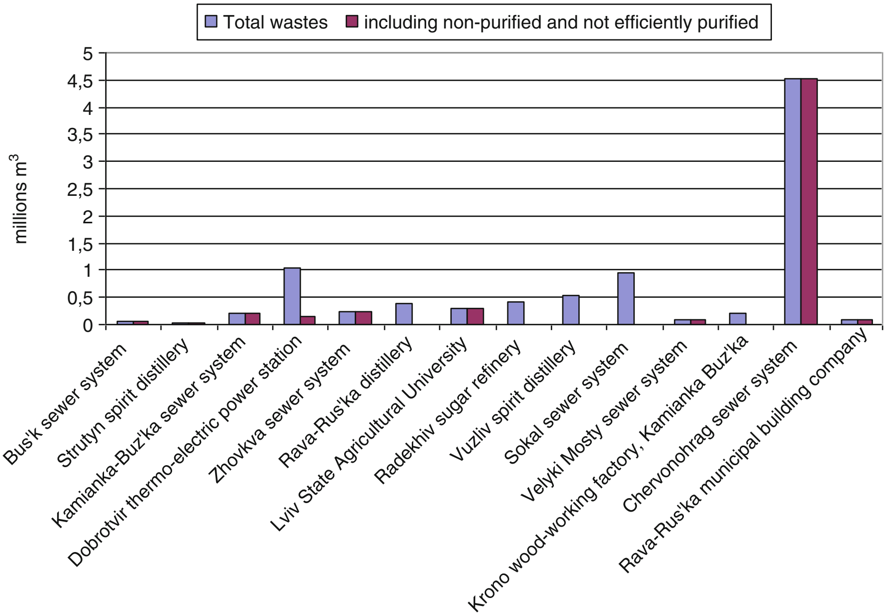

Fig. 5.1 Quality of waste waters purification in 2009 by different treatment plants (*blue colour* total volume of wastes, millions of m^3, *red colour* including non-purified and not efficiently purified)

Disregard of regulations in water protected zones also influences the ecological state of the rivers. Many riverbeds in the settlements are the places for accumulating domestic dust. According to the water legal code every river should have a water protection zone with limited economic activity. But observance of these laws is delayed by lack of money in the regions. According to the laws water protection activity should be carried out by water users and enterprises, which damage water resources.

Control of the ecological state of the river systems in the Western Bug basin is performed by the state monitoring system. Laboratory investigations are undertaken every 3 months. In the Western Bug river basin the water quality is monitored at approx. 50 points. The overall results of monitoring testify that water quality of almost all river systems can be characterised as unsatisfactory. River waters are typified by high levels of biological consumption of oxygen and chemical consumption of oxygen and high contents of Fe, Cu, Mn, Cr, compounds of nitrogen, phosphates and sulphates.

5.4 Long-Term Runoff Changes

Before World War II there were 27 gauging stations in the Western Bug basin. Now only nine gauging stations provide hydrological data for research. The longest data sets are in Poltva (Bus'k), Bug (Sasiv), Rata (Mezhyrichia), Svynia (Zhovkva). Based on the observation information the hydrological databases were created for 16 gauging stations for the period 1963–2000 (Table 5.4).

By observation of results the long-term average discharges (MMQ), average minimal (MNQ) and average maximal (MHQ) discharges were calculated for the periods 1965–1987, 1980–2000 and 1963–2000.

The results obtained testify that average water discharges have increased in the upper part of the river basin and have decreased in the catchments of the Rata, Solokia and Svynia rivers. Such trends can be explained by the drainage systems declines, because the minimal water runoff has increased everywhere.

Average yearly water runoff is characterized by different trends. Increasing is characteristic for Bug (Sasiv) and Bug (Kamyanka Buz'ka), Poltva (Bus'k) (Figs. 5.2, 5.3 and 5.4). Decreasing run-off is observed in the river basins of the Svynia, Rata, Solokia (Figs. 5.5, 5.6 and 5.7). Determined long-term changes are not greater than 30% for the previous 40 years.

Table 5.4 Gauging stations in the Western Bug river basin

River	Station	Kilometre from the mouth	Area (km^2)	Altitude (m)	Period
Bug	Verkhobuzh	772	–	314.72	1980–1988
Bug	Sasiv	758	107	261.04	1963–2000
Bug	KB	689	2,350	201.79	1963–2000
Bug	Sokal	632	6,250	183.42	1963–1988
Bug	Litovezh	602	6,740	180.92	1979–2000
Zolochivka	Zolochivka	10	90	255.37	1971–1975
Poltva	Poltva	20	725	214.02	1963–1970
Poltva	Busk	0.2	1,440	208.34	1963–2000
Kamianka	KB	1.1	141	202.15	1963–1975
Kholoivka	Byrok	1.3	46	no data	1962–1964
Rata	Volytsia	22	1,140	198.23	1963–2000
Rata	Mezhyrichia	3.5	1,740	187.64	1963–2000
Svynia	Zhovkva	28	98.6	223.11	1963–2000
Zheldets'	Luhove	3	246	195.49	1963–1988
Solokia	Chervonohrad	1.5	931	186.32	1963–2000
Luha	Volodymyr-Vol.	20	1,270	182.05	1965–2000

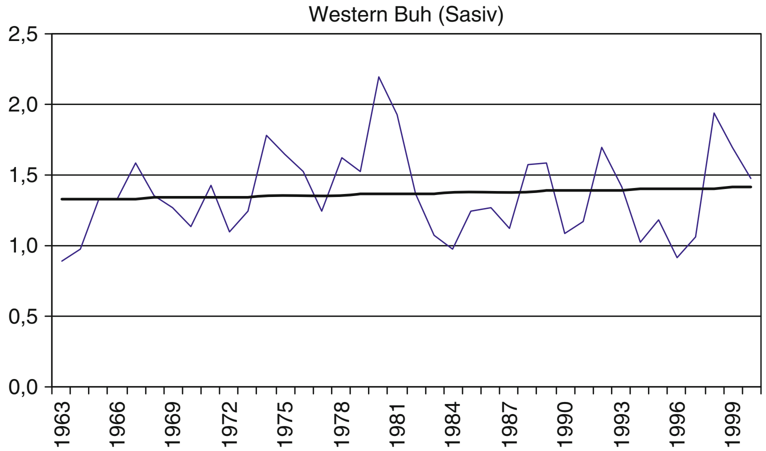

Fig. 5.2 Average water run-off (m^3/s) changes in the Bug (Sasiv)

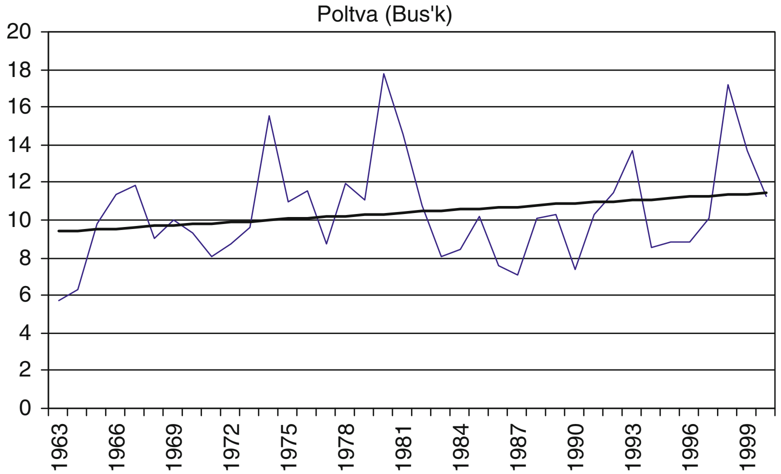

Fig. 5.3 Average water run-off (m^3/s) changes in the Poltva (Bus'k)

Average maximal water discharges have decreased everywhere (some places by half and more) (Figs. 5.8, 5.9 and 5.10). Minimal water discharges have increased everywhere in the basin. Increases are some higher in the upper parts of the basin and lower in the tributaries catchments, reader's left to right (Figs. 5.11, 5.12 and 5.13)

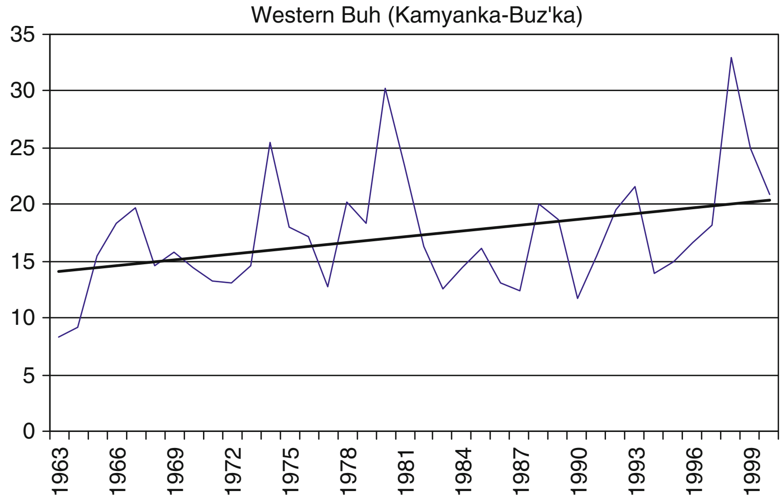

Fig. 5.4 Average water run-off (m^3/s) changes in the Bug (Kamyanka Buz'ka)

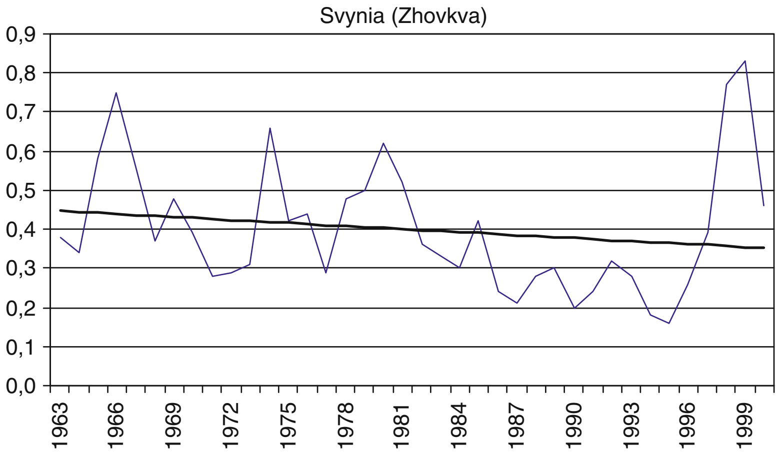

Fig. 5.5 Average water run-off (m^3/s) changes in the Svynia (Zhovkva)

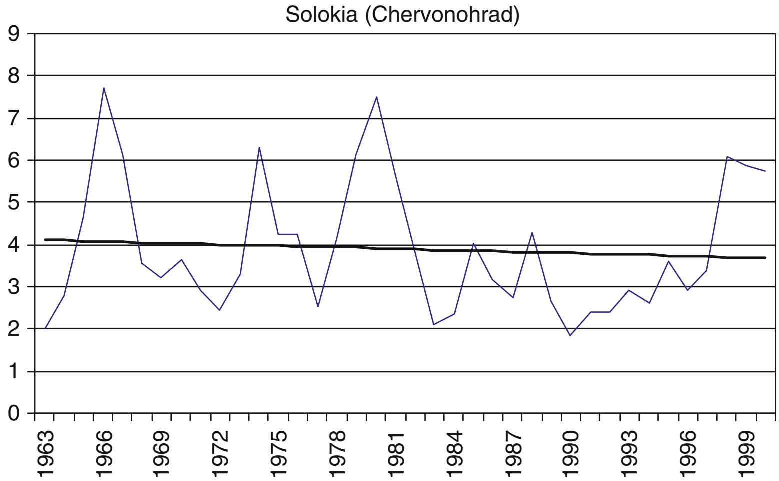

Fig. 5.6 Average water run-off (m^3/s) changes in the Solokia (Chervonohrad)

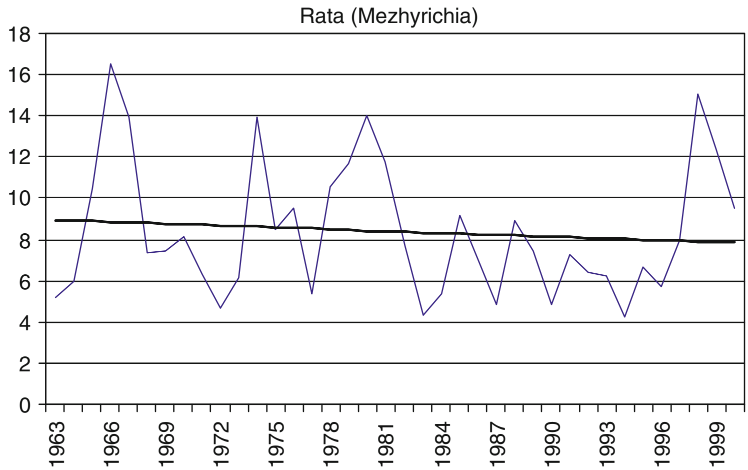

Fig. 5.7 Average water run-off (m^3/s) changes in the Rata (Mezhyrichia)

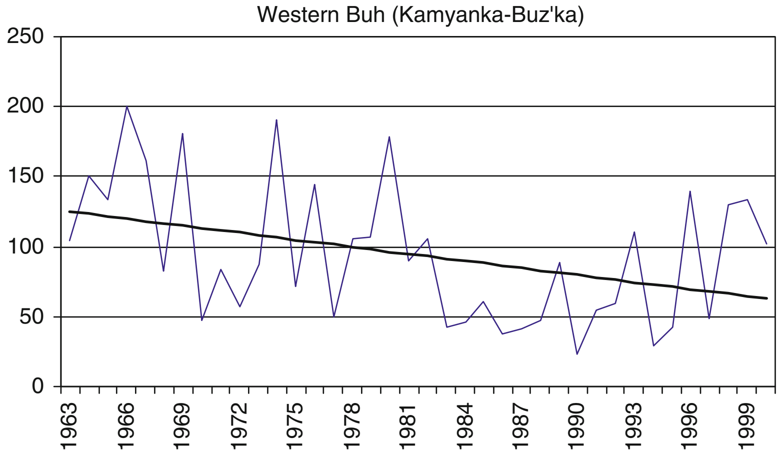

Fig. 5.8 Average maximal water run-off (m^3/s) changes in the Bug (Kamyanka Buz'ka)

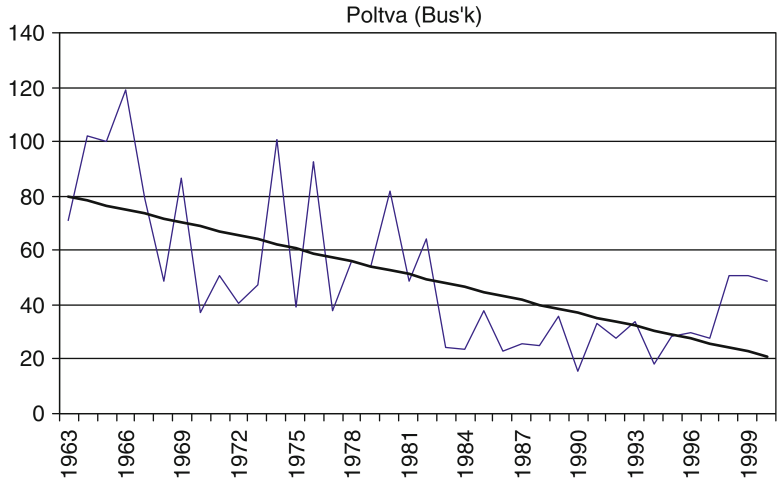

Fig. 5.9 Average maximal water run-off (m^3/s) changes in the Poltva (Bus'k)

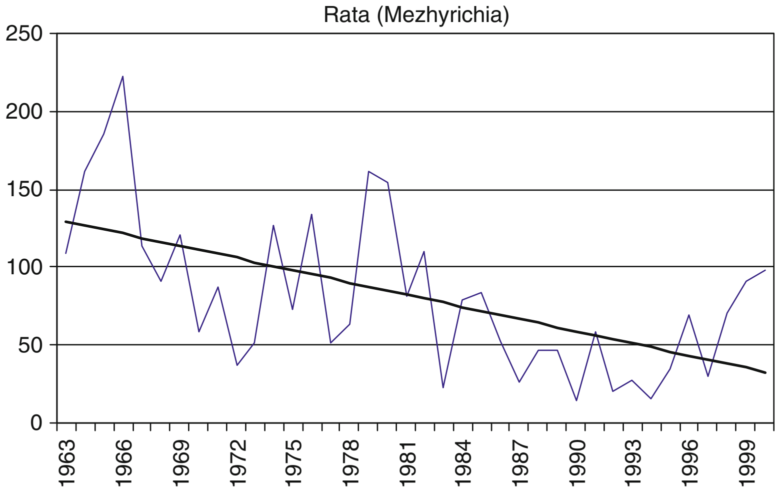

Fig. 5.10 Average maximal water run-off (m^3/s) changes in the Rata (Mezhyrichia)

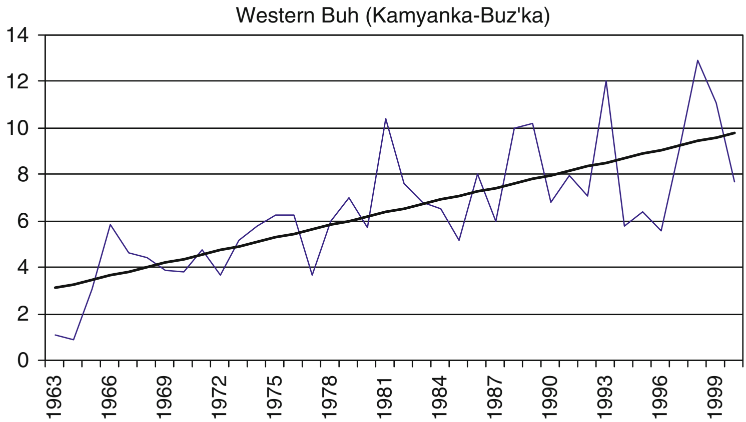

Fig. 5.11 Average minimal water run-off (m^3/s) changes in the Bug (Kamyanka Buz'ka)

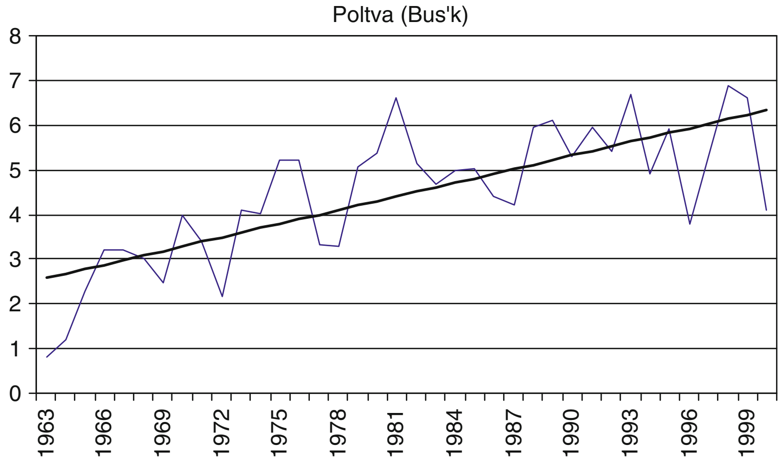

Fig. 5.12 Average minimal water run-off (m^3/s) changes in the Poltva (Bus'k)

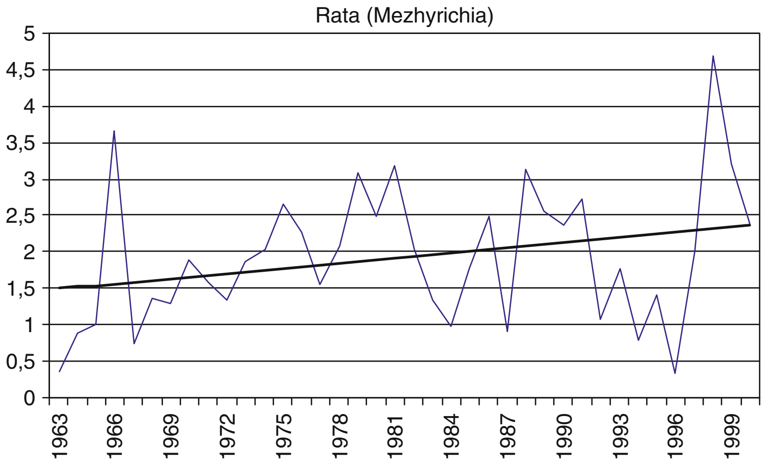

Fig. 5.13 Average minimal water run-off (m^3/s) changes in the Rata (Mezhyrichia)

5.5 Conclusions

- Too few gauging stations and controlled parameters are the main causes of monitoring system imperfection.
- All river systems in the Western Bug basin are characterised by different changes in quantitative and qualitative parameters of their condition.
- The main causes of the unsatisfactory ecological state of the river systems are economic activity in the basin, unsatisfactory state of wastewaters treatment plants and disregard of the water legal code.

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Chapter 6
Integrated Water Resources Management: Approach to Improve River Water Quality in the Western Bug River Basin

Jens Tränckner, Bjoern Helm, Frank Blumensaat, and Tatyana Terekhanova

Abstract The Western Bug is a transboundary river with relevant environmental impact on the Vistula and the Baltic Sea. On entering the EU it must comply with the European Water Framework Directive, which demands an integrated water resources management (IWRM) on river basin scale. In this paper a systematic approach addressing the IWRM principles is proposed and applied for the upper part of the Western Bug. The existing pollution regime in the W.Bug catchment area to the gauge W.Bug – Kamianka Buska is assessed by application of a five step methodology including system screening, compilation of pressures, comparison with biological status, detailed process analysis of relevant interactions, definition of response measures based on a multi-criteria evaluation. Survey of previous studies, analysis of regional monitoring data, MFA modelling with MONERIS tool and carried measurements campaigns have shown, that in a row with extremely high point source input load on a watershed border (Lviv WWTP), such diffuse sources of nutrients as tile drained areas, rural areas without waste water treatment and erosion compose a nutrients input over an entire basin (approx. 2,500 km^2) comparable to the mentioned point source. Moreover, the emission patterns partitioning is different for DIN and TP. During the measurements campaign the results of MFA modelling were supported and other deficits, such as extinction of the natural Poltva river ecosystem and nitrate pollution of the uppermost aquifers were found. Therefore, for detailed process analysis two main subsystems have been identified: (i) River Poltva and River Bug downstream from the confluence with the River Poltva, (ii) the uppermost aquifers. Already at this stage of study it was found that water quality formation in W.Bug is subject to acute deficits in the settlements sanitation systems in the basin while diffuse pollution due to agricultural activities is (under the current socio-economic conditions) of lower relevance.

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Keywords Integrated water resources management • Water quality • Material flow analysis (MFA) • Western bug • MONERIS

6.1 Motivation

With a catchment area of almost 40,000 km² the River Bug or Western Bug is the biggest tributary of the River Vistula which flows directly into the Baltic Sea. The Western Bug may be regarded as good reference for a transboundary river entering the European Union. It is situated in Ukraine, Belarus and Poland and has a significant environmental relevance within Europe.

Currently, the river is one of the major sources of pollution and threats to the Warsaw drinking water supply [1] and accounts for 15% of the pollution in the Vistula [2, 3]. However, the existing studies of the pollution sources are not consistent. While TACIS [4] refers to urban and rural wastewater as main sources for river water pollution, UNECE [5] found that 84% of nitrogen and 68% of phosphorous pollution are caused by diffuse sources. According to HELCOM [2] the wastewater system of the city of Lviv is among the 20 biggest single polluters in the Baltic Sea catchment area. Besides, the Western Bug is heavily contaminated with heavy metals and pesticides [6] but the input pathways for micro pollutants are not quantified, yet.

The River Bug when passing the border should comply with the European Water Framework Directive (EWFD) and achieve a good ecological status by 2015. According to the EWFD all members of the European Union are obliged to perform their activities, related to water resources, according to the principles of Integrated Water Resource Management. For transboundary rivers, environmental objectives, established under the mentioned directive, should be coordinated for an entire river basin area [7].

The concept of Integrated Water Resources Management (IWRM) is based on an overall consideration of the water cycle, its compartments and interrelated processes. It is seen as a promising solution for minimising harmful anthropogenic influences on water resources and securing sustainable water management [8]. Implementation of this concept in practice requires appropriate knowledge about the water cycle and its interrelations with other parts of the geosphere within spatial entities. Hence, there is an increasing necessity for a quantitative and qualitative description of the cycle of water resources and its mutual relationship with environmental and socio-economic conditions.

In this paper a systematic phased approach to analyse and improve water management according to the IWRM principles is presented and applied for the upper part of the Western Bug basin. So far only results of the analysis and first conclusion for management options may be shown.

6.2 Method

The proposed approach [11, 24] is closely linked to the DPSIR framework [9]. The key idea is to reduce complexity by a graduated differentiation of **m** relevant pressures within **n** subsystems. The method may be separated into five major steps: (i) Screening, (ii) Compilation of pressures, (iii) Comparison with biological status, (iv) Detailed process analysis of relevant interactions, (v) Definition of response measures based on a multi-criteria evaluation (Fig. 6.1).

6.2.1 Screening

Starting point is a preliminary river systems analysis. It sets the systems boundary, compiles obvious deficits (e.g. water quality problems, morphological deficits) and identifies the main drivers (e.g. urban settlements, intense agricultural activities) and potentially affected subsystems.

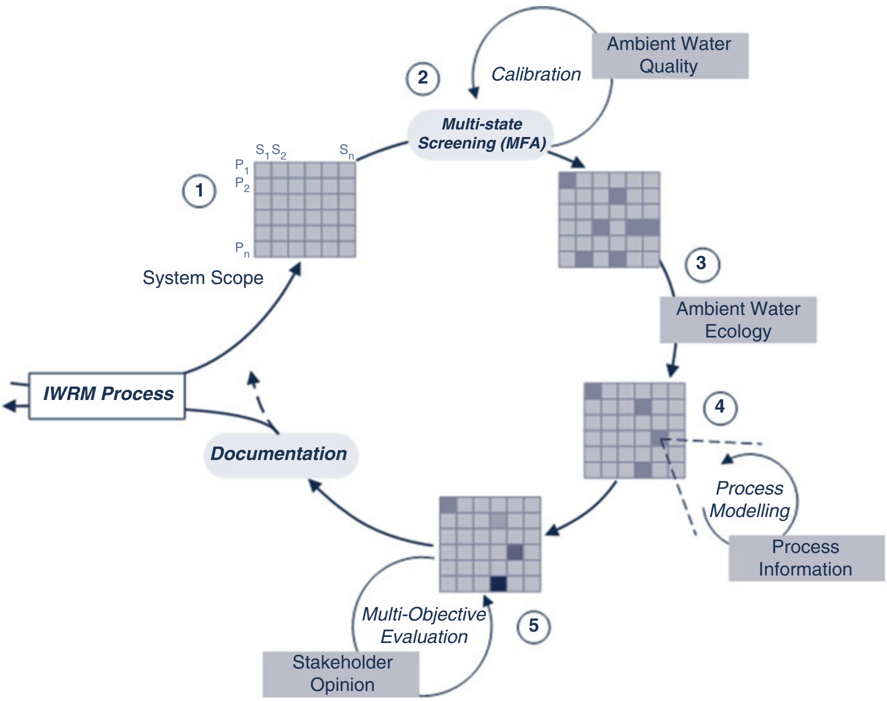

Fig. 6.1 Overview on the methodology [11, 24]

6.2.2 Compilation of Pressures

The foremost objective of this step is the identification of relevant pressures, i.e. pressures that could potentially lead to environmental deficits. The mass flow analysis (MFA) concept provides the global framework for the quantification of the pressures in the system [10]. On the river basin scale the quantification of matter loads originating from different sources enables primary driver identification of water quality deficits.

The MFA concept is used to link flows estimated using conceptual, deterministic or stochastic approaches. GIS based applications should be applied to handle complex spatial problems. The validation of MFA results should be performed based on available water quality data. If available data on quality and flow often do not fulfil requirements of sound load balancing at the desired spatial and temporal resolution, additional field measurements may need to be initiated.

MFA tools are generally not intended to describe highly dynamic processes. In case those processes cannot 'a priori' be excluded from the compilation of likely pressures (e.g. short term toxicity, hydraulic stress, etc.) and cannot be described otherwise, they must be investigated in step 4 ("detailed process analysis").

Generally it cannot be expected that the MFA results and the measured loads at the river system entirely agree. This may be due to different reasons: uncertain or missing input or measurement data, imprecise or poorly parameterised model approaches, e.g. through additional processes, which are so far not considered. The identification of so far unexplainable deviations between calculated emissions and measured loads might often be a more valuable fact than a closed balance. The final result of this step is a differentiated matrix of affected subsystems and potential pressures.

6.2.3 Ecological Impact Assessment

Identified pressures are opposed to biological indicator data that typically reflect the ecological state at the chosen spatial aggregation units. Ecological assessment typically follows biological indicators, e.g. water flora, benthic invertebrates, fish fauna as is required for an assessment according to the European Water Framework Directive [7]. Based on this comparison relevant cause-effect relationships are qualitatively identified, that is specific pressures are allocated to certain impacts. Pressures of upstream-located aggregation units must be included (superposition). As a result of this impact analysis an identification of the most relevant interactions is achieved.

6.2.4 Detailed Process Analysis

For the identification of suitable and efficient measures to improve the system status (ecological status), the unclear pressures must be quantified and cause-effect relationships between relevant pressures and impacts need to be further investigated.

Due to the a priori reduction of system complexity (only relevant pressures and subsystems remain) the list of potentially suitable measures is in most cases clear. However their efficiency is case specific. This quantitative assessment is supported by detailed process models addressing just the relevant processes and parameters.

6.2.5 Multi-criteria Evaluation and Design of Response Measures

The results of process models are in most cases the time series of physical-chemical parameters in a predefined spatial and temporal resolution, but not the ecological status itself. The assessment of the ecological status is obtained by transforming these data based on available guidelines (particularly developed with regard to urban drainage pressures [12, 13]) into characteristic evaluation criteria (e.g. after [14]). The results for the different evaluation criteria must be compiled in a consistent scheme. Although different mathematical methods for multi-objective decision making exist [15] this process has a subjective nature. For water projects different approaches for a multi-objective benefit analysis have been proposed (e.g. [16, 17]). It is indispensable that all stakeholders, namely those who are directly concerned by the identified measures, actively participate in the design of the multi-objective benefit analysis. This participative process (actually being a substantial demand of the IWRM concept) ultimately leads to a ranked list of potential response measures that ideally reflect the interest of all stakeholders.

6.3 Investigation Area

The described method was applied in the upper part of the Western Bug catchment (from source to hydrological gauge Kamianka Buska) within an area of 2,550 sq. km. This basin is completely situated in the Lviv oblast [province] of the Ukraine (Fig. 6.2).

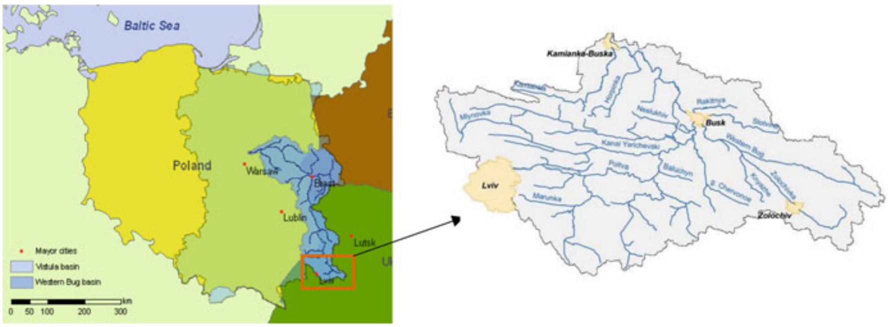

Fig. 6.2 Investigation catchment of W.Bug basin

The relief of the catchment is characterised as undulating plain with altitudes variation from 60 m in the northern part to 400 m on the southern watershed boundary. The climate of the Western Bug basin is characterised as temperate with mean annual temperature of 8°C (extremes: +38; −39) and 650–800 mm precipitation (65–75% of which is in the warm season).

The population density in the basin is relatively high, but the population distribution is extremely uneven. So, 80% of the total number of inhabitants (ca. 950, 000) live in the city of Lviv. The other 20% are distributed more or less equally over the area. Settlements cover around 5% of the total basin area (Fig. 6.2).

Major economic activities in the basin are agriculture (sugar beet, vegetables, poultry breeding) and related industries (food processing). Nearly 70% of the area is used for agricultural purposes: arable land (43.7%) and grassland (29.6%).

6.4 Results

6.4.1 Screening

6.4.1.1 Previous Studies

Poor water quality in the Western Bug is emphasised in several studies, which also identify different and partly contradictive types and sources of water pollution [2–6]. With regard to nutrients pollution, in most of the reviewed literature the River Poltva is defined as one of the main sources.

In order to verify water quality estimations in different literature sources, the analysis of four data sets from different authorities for the period of 1980–2009 was performed [18].

- An extensive water quality monitoring campaign in the 1980s, mainly to support the development of a river water quality model (RM80) for the Western Bug (observation period 1977–1990);
- The Lviv Regional Water Management Authority (WMA) (observation period 1993–2001);
- State Environmental Inspectorate (EnvInsp) with observations in 2003, 2007, 2008;
- Western Bug River Basin Council (WBRC) observation period 2002–2008.

During the examined period the concentration of nitrogen compounds (NH_4–N, NO_3–N, NO_2–N) was stable at a high level (around 10 mg/l DIN) in the 1980s, decreased in the 1990s to around 4 mg/l DIN, since 2003 a new increase and strong variability can be observed (Fig. 6.3), in contrast orthophosphate concentration is fairly stable throughout the period and ranges around 0.6 mg/l in W.Bug at gauge Kamianka Buska and around 1 mg/l in Poltva. Concentrations indicating organic pollution and nutrients in the Poltva are generally about one order of magnitude higher than in the Western Bug.

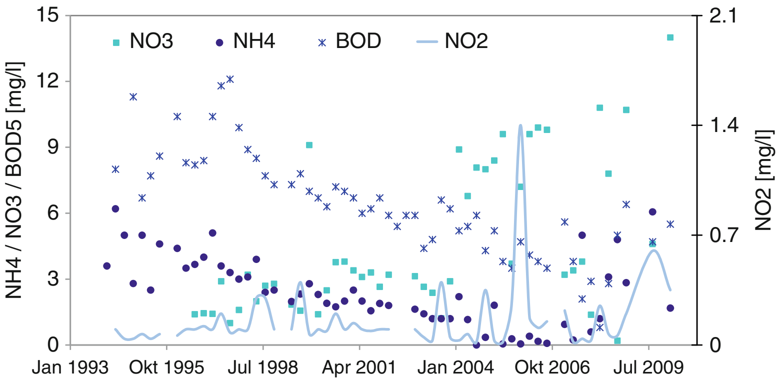

Fig. 6.3 Nutrient and organic pollution at Kamianka Buska gauge [17]

Despite all the compared data sources providing information at gauge W. Bug – Kamianka-Buska it seems insufficient to perform an analysis for the entire catchment area. As data on matter concentrations and water discharges is available only integratively at the catchment area outlet, the contribution of different subsystems cannot be assessed in coherently.

Measurements Campaigns

River System

In order to fill the gaps in the data and to compose a complete overview on water quality as well as the current status of the basin system, measurement campaigns were conducted in the framework of the project IWAS-Ukraine, funded by the German federal ministry of education and research (BMBF). Investigations included river water quality sampling (hourly analysis) throughout the basin, hydrological measurements (discharge, meteorological characteristics), river sediments analysis, hydro biological investigation, and assessment of the river ecosystem quality according to the German LAWA-guidelines.

The main findings of the measurements campaign are the following:

– The upper catchment of the W.Bug river due to observed water quality may be divided into three parts: (i) from source to confluence with the Poltva river, (ii) the sub-catchment of Poltva and (iii) basin part from Poltva confluence up to gauge Kamianka Buska (Fig. 6.2, right).
– In the headwaters of Western Bug (0–40 km in Fig. 6.4), water quality is in compliance with standards (except nitrate).
– In the River Poltva consistently increased pollution, nutrient concentration and diminished oxygen content (less than 2 mg/l) were observed. Particularly high

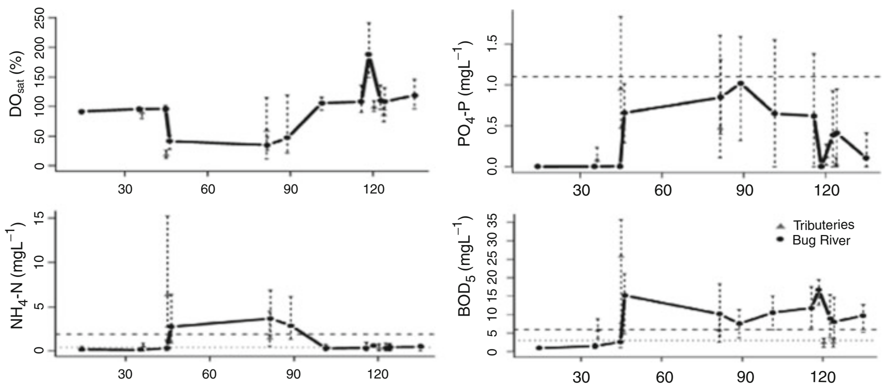

Fig. 6.4 Water quality along River W.Bug due to field survey 2009 [22]

concentrations of ammonia reach toxic levels (NH3 – N mean concentration: 0.18 mg/l), dry weather COD levels range around 100 mg/l. The concentrations clearly exceed the concentrations recorded in adjacent tributaries by a factor of 10.

– Concentration of nutrients and COD observed in the Poltva tributaries are significantly lower (except NO3-N) and comparable to concentration in the upper stream of the W.Bug. Hence, it may be concluded that the River Poltva, originated from Lviv WWTP, is the main polluter of the W. Bug during dry weather conditions.
– Downstream the confluence of the Poltva and Western Bug in Busk (40–80 km in Fig. 6.4), the mixing processes of the relatively pure headwaters of the Western Bug water and extremely polluted River Poltva lead to deteriorated water quality in the main river.

Aquifer

Water supply of approximately 180,000 rural inhabitants is almost exclusively limited to the uppermost quaternary groundwater horizon, except some public wells that extend to the Miocene layer or use of artesian sources.

Currently, hydrogeological monitoring stations mainly observe deeper lying aquifers, which are used or could be used for industrial purposes or centralised water supply. Controversial opinions were stated on the water quality of the quaternary aquifer. Results of emission mass flow analysis indicated that a significant portion of riverine pollution enters via the groundwater path. Hence a screening of groundwater quality was performed in the measurement campaign in May 2010.

In order to reach a process- and gradient oriented sampling density private and public wells were focused on for the campaign. Figure 6.5 gives an overview on provided locations. During the campaign a set of 81 samples was taken, fulfilling the inner 5 × 5 km² sampling schedule by 73% and additionally eight samples at the

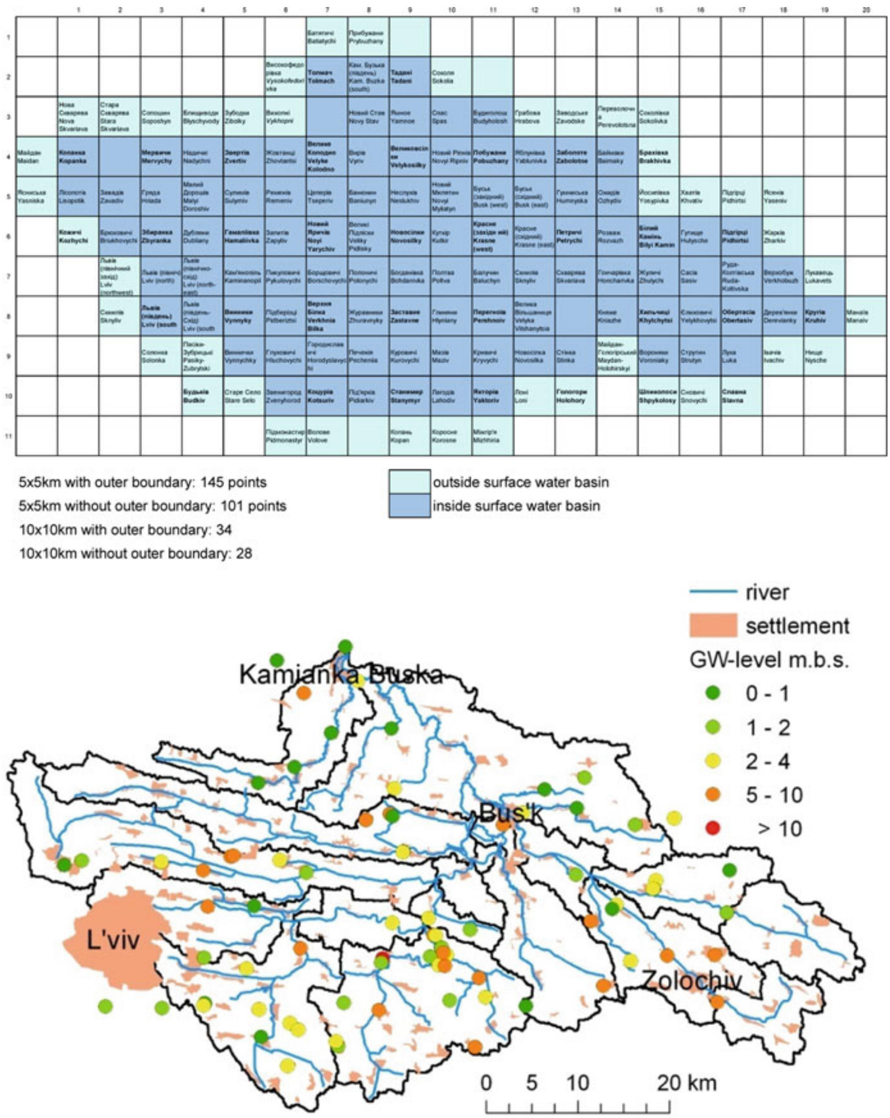

Fig. 6.5 Groundwater sampling sites in the upper Western Bug basin in May 2010

estimated groundwater divide. Samples were taken as grab samples with a bucket sampler, which was estimated as acceptable for the analysis of non-volatile, solute, inorganic substances. They were filtered and cooled for conservation.

As shown in Fig. 6.5 groundwater levels are generally high in the region, for most wells levels less than four meters below surface are observed. This promotes the strong interaction between surface and uppermost groundwater.

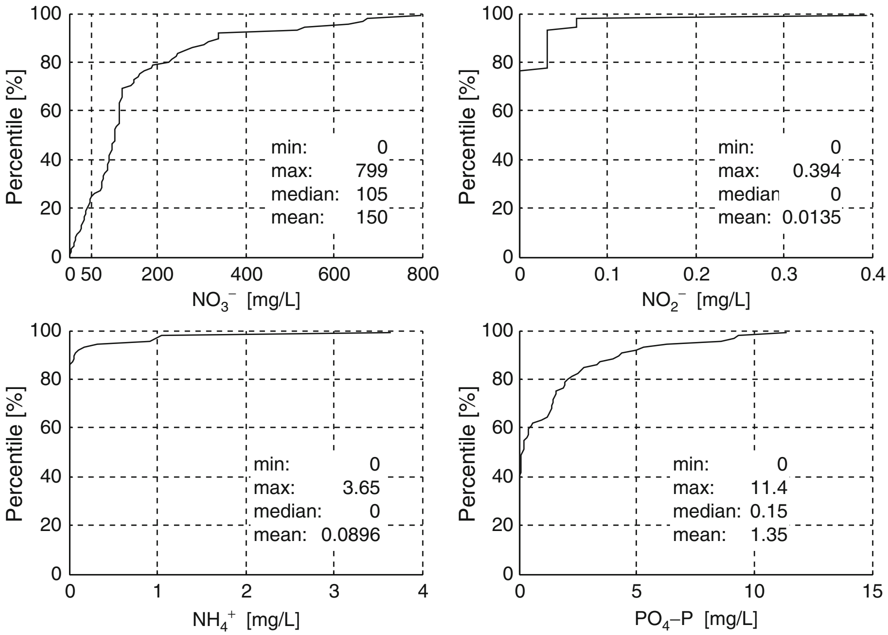

Fig. 6.6 Cumulative distribution of nitrate, nitrite, ammonia and phosphateconcentrations in the groundwater samples

Figure 6.6 shows the range of concentrations for dissolved inorganic nitrogen species and phosphate. Nitrite values are low, ammonium shows some values clearly above 1 mg/l, the variable can be interpreted as a proxy for surface water or infiltration water influence as ammonium fades rapidly in the unsaturated zone. Hence wells with increased ammonium concentration deserve further attention e.g. for analysis of faecal contamination.

Nitrate concentrations are elevated in the whole area. Less than 25% of the sampled wells are below the WHO recommended limit value for consumption of 50 mg/l. Mean concentration is 150 mg/l, the 5–95% interval is 11–553 mg/l. The numerous values above the 95% probability indicate a distorted distribution of concentrations, which is confirmed by the empirical frequency distribution (Fig. 6.7). Concentrations of 100–150 mg/l are most frequent but tailing is much more pronounced for higher concentrations than for lower ones.

A second measurement campaign with a less representive sampling size of 20 samples was additionally analysed for the faecal indicator *E. coli*. Here, only 25% met the standard of zero counts per 100 ml, with median: 7 counts and 75% quantile: 50 counts per 100 ml.

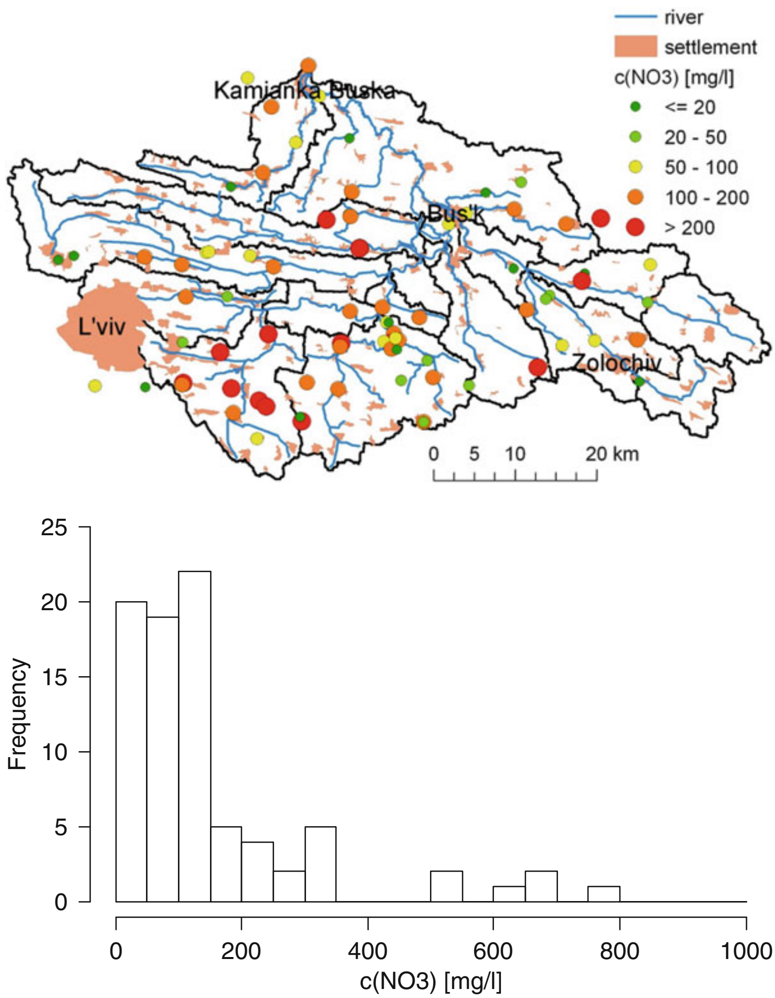

Fig. 6.7 Nitrate concentration in groundwater samples in the upper Western Bug basin

6.4.2 Compilation of Pressures

In an initial step an MFA for the W.Bug catchment area was set up with the MONERIS tool [19] to estimate pollution flows based on existing data. This tool was chosen for application because of its relatively low input data requirements, implication of static ordinary equations describing main relevant emissions pathways (groundwater, point sources, surface runoff, tile drainage, settlements, point sources, atmospheric deposition) and widely application across European river basins [19].

The investigated catchment was divided into 18 sub-basins regarding morphological, topological and water management criteria. To close data gaps the results of

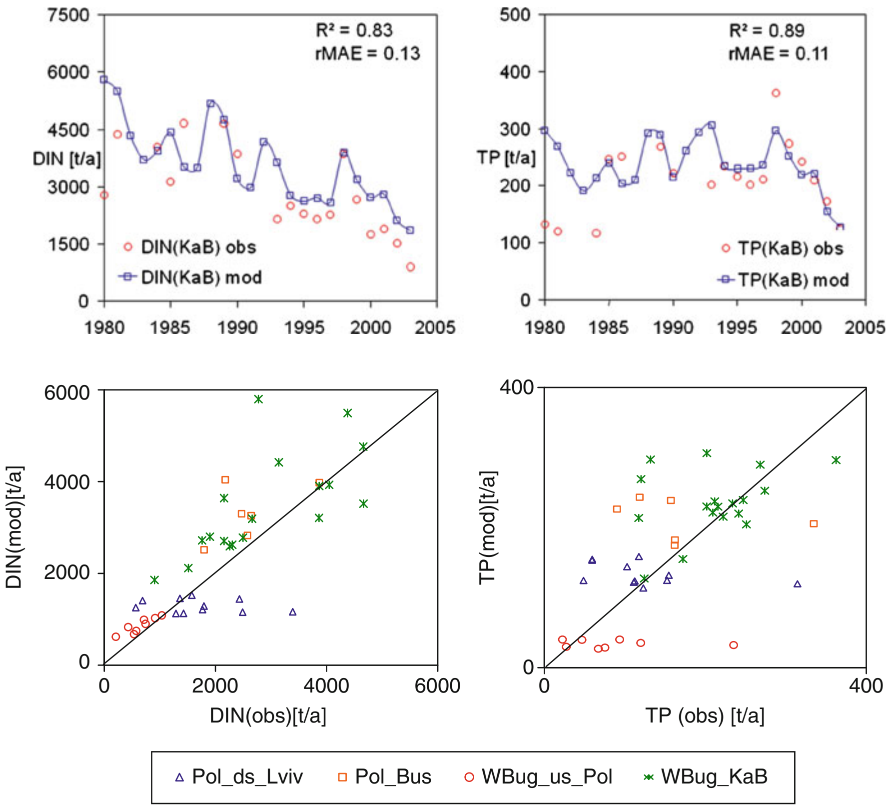

Fig. 6.8 Temporal and spatial validation of MONERIS model for the Western Bug for 1980–2003. (*Pol_ds_Lviv*: Poltva, downstream Lviv, *Pol_Bus*: Poltva in Busk; *WBug_us_Pol*: Western Bug, upstream of Poltva confluence, *WBug_KaB*: Western Bug in Kamianka-Buska)

own field surveys (2009, 2010) and remote data were used. The model was set up for the period of 1980–2003 and validated on water quality and discharge data for Western Bug – Kamianka Buska gauge (Fig. 6.8).

The results of modelling show that in last 20 years nutrients sources partitioning in the basin has been changing, especially significant for DIN. Due to the reduction almost to fivefold of the DIN load transported via groundwater and tile drainage path to the years of the 2000s, the major part of DIN is accounted to originate from WWTP and settlements. This reduction of load from groundwater and tile drainage could be explained by the fact of reduced fertilizer application in the 1990s due to abrupt changes in economic conditions in Ukrainian agriculture [20]. Tile drainage areas are especially vulnerable to fertilizer surplus, as underground retention is short-circuited [21]. Therefore, currently stated sources of nitrogen compounds in the basin are effluent from communal WWTP and settlements, which includes input from sealed areas and inhabitants not connected to WWTP. In spite of input from WWTP is prevailing, the larger part of total load is observed from not connected inhabitants (normally using a

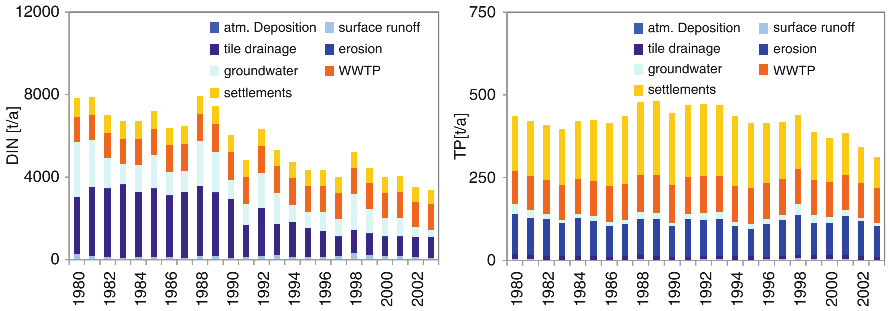

Fig. 6.9 Dissolved Inorganic Nitrogen (*DIN*) and Total Phosphor (*TP*) pathways partitioning in W.Bug basin in 1980–2003

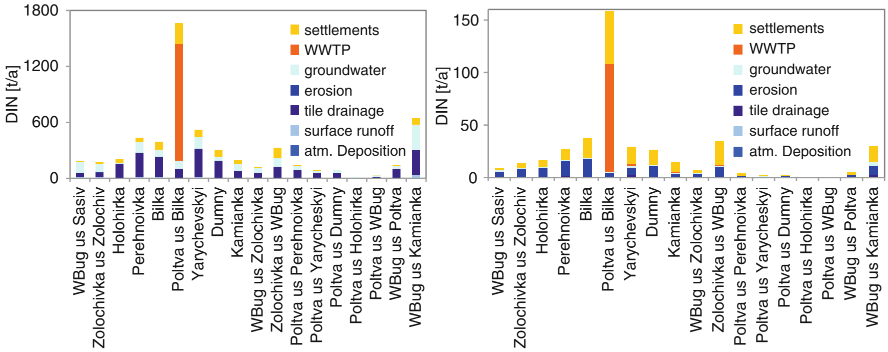

Fig. 6.10 Distribution of calculated loads among sub-catchments (average for 1980–2003)

pit latrine for sanitation), tile drainage (which is constructed for dewatering purposes, i.e. deterioration of groundwater level) and groundwater (Fig. 6.9). Although in the model these pathways are not connected to each other computationally, this finding indicates probable deficit in the groundwater subsystem.

The dynamic of phosphorous sources partitioning is less variable than that of DIN. In the 1990s a moderate decrease in total load, mainly caused by the reduced input from settlements is observed, which until the middle of the 1990s was a main source of TP. At the same time the inputs from other main sources (erosion and WWTP) have not been changed significantly (Fig. 6.9). The spatial distribution of modelled loads among sub-basin shows that approximately 29% of DIN and more than 42% of TP is an input from the upper River Poltva, where the city of Lviv with the largest communal WWTP in the basin and highest population density is situated (Fig. 6.10). This confirms the findings of previous studies. At the same time for other sub-basins tile drainage, groundwater and settlements are of more importance as delivery pathways of nutrients (Fig. 6.11).

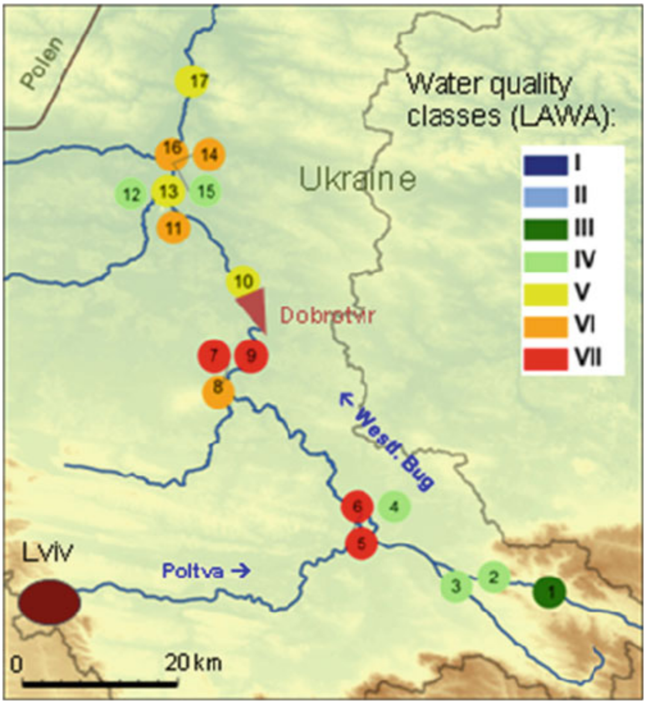

Fig. 6.11 Water quality classes of the sampling stations according to the German hydrochemical classification [22] (PS1-PS4 are the sampling sites in the upper part of the basin, PS5 is the sampling point in River Poltva, PS6-PS7 are the sampling sites below the confluence of the Poltva and W.Bug)

6.4.3 Ecological Impact Assessment

The investigation of the biology in the river system was performed by the Institute for Hydrobiology of TU Dresden. It is based on field investigation of chemical water quality criteria and microbiological indicators in the W. Bug river and its tributaries in 2010 [22].

The results of this investigation show a significant deterioration of the hydrochemical and ecological status after confluence of Poltva and W.Bug rivers (on Fig. 6.11 after PS4).

The same trend was found for the bacterial concentration, which gradually increased with flow length and showed a peak at station 5. About 50% of total vital cells (TVC) were detected as coliforms. *E. coli* a characteristic faecal indicator made up approx. 50% of the total coliforms. *E. coli* and coliforms found significantly correlated to typical wastewater parameters (BOD COD), [22].

These observations support the results of MFA, in which the urban system of the city of Lviv (in the Poltva river system) is quantified as the main pollutants emitter, as well as the results of the measurements campaign on water quality in the upper Western Bug and Poltva.

The pressures leading to the high nitrate concentration are not completely identified, yet. Mass Flow Analysis is of limited value, here. Long term accumulated nitrogen loads from earlier intensive agriculture are not regarded with the MFA tool used. The finding of *E. coli* indicate also very local (husbandry, latrines) sources, leading to an additional pathogenic risk. Sources and processes of groundwater contamination and must therefore be subject to a much more detailed analysis.

6.4.4 Detailed Process Analysis

Based on the results of MFA supported by biological indicators and investigation results of regional scientists [3, 6], two subsystems of the basin were prioritised for process analysis: Poltva river system (including Lviv urban system with WWTP) and the Groundwater subsystem.

The urban drainage system and the wastewater treatment plants are already described by numerical models and currently under detailed investigation. A great challenge in this context was the establishment of a realistic a sewer network model. Since data of the existing infrastructure are scarce a good guess must be dared. Based on a combination open source data processing and design guidelines for sewers a nearly realistic hydrodynamic sewer model could be developed [23]. The River Poltva will be described by a hydrodynamic pollutant transport and transformation model under the software environment SWMM (http://www.epa.gov/athens/wwqtsc/html/swmm.html) coupled with Simba (http://simba.ifak.eu/simba/). Transformation of pollutants will be described as River Water Quality No.1 [24]. This however will not be sufficient, due to the impact of organic sediments and the high particle load at the overflow structures and the effluent of the WWTP. Therefore additional investigation is necessary to describe sedimentation, erosion and transport of sediments as well as the processes inside the sediment and diffusion exchange with the bulk water.

So far not tackled is the process analysis of the groundwater system. But, there is a great need to understand the responsible sources and processes for intolerably high contamination with nitrate and (partly) pathogenic germs.

6.5 Conclusions

1. The analysis of existing water quality data in the W.Bug basin has shown a vital necessity of changes in regional institutional data management as well as extension of environmental monitoring density and frequency.

2. The method presented in this paper follows the concept of IWRM to account all compartments of the water cycle and supports consistent system analysis, which allows identification of main deficits in the studied system:

Deficit	Affected system	Pressure
Surface water quality	Poltva, Bug	Waste water system (diffuse Nitrogen emissions)
Faecal contamination of groundwater	Quaternary aquifer	Rural waste water disposal, husbandry
Nitrate contamination of groundwater	Quaternary aquifer	Surplus nitrogen from agriculture Rural waste water disposal, husbandry

   Based on these preliminary results a detailed process analysis aimed at designing effective mitigation measures shall be performed as next step. The analysis shall focus on the identified Systems, deficit, pressures and potential measures.
3. Material flow analysis indicates different patterns of emission sources for P and DIN in W.Bug basin. It is assessed that surface water quality is currently extremely influenced by TP and DIN load of one point source (Lviv WWTP) and, additionally, on a basin scale by diffuse input from tile drainage (DIN), urban areas and untreated sewage (DIN, TP) and erosion (TP). Although input from untreated sewage is not computationally linked to the groundwater pathway, predominant disposal in the area is by pit latrines. Together with the assumed input via agricultural groundwater and the significant portion of base flow in river discharge it is expected that groundwater plays a major role in the nitrogen transport of the basin. To quantify this interaction further research on water and nutrients transport in the uppermost aquifer in the W.Bug basin is required.
4. Elevated nitrogen contamination in the uppermost aquifer is suspiciously influenced by sanitation facilities (pit latrines), which are normally situated near to sample point (drinking water well). With regard to elevated ammonia concentration in some samples this link must be justified via investigation of nitrogen origin source (isotope analysis) with study of samples from natural site (not in a settlement) and matter transport processes in un- and saturated zone on sample sites. And if the assumptions are confirmed, the concept of rural water management in the basin should be changed.
5. Findings in water quality formation in W.Bug address acute deficits in the sanitation systems in the basin, which as detailed process monitoring has shown lead to overall deterioration of ecosystem quality.
6. Moreover, significant nutrients inputs from tile drainage and erosion point to regional changes in land management and implementation of erosion prevention measures in relevant areas.

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Chapter 7
Investigation of Transboundary Aquifers in Russia: Modern State and Main Tasks

Igor S. Zektser

Abstract Transboundary problems of groundwater development are very significant for Russia as it has land boundaries with 13 countries. The main research line concerning this problem is to develop principles and criteria of acceptable groundwater withdrawal by neighbouring countries with compliance with environmental limitations. This includes groundwater protection from depletion and contamination, development of constant groundwater deposit models applied in border regions of neighbouring countries in order to determine groundwater balance elements of certain hydrodynamic flows, their internal interaction and interaction with surface water. Estimation of potential groundwater shared use based on large scale assessment and mapping of its sustained yield with regard to groundwater protection from contamination is also of importance.

Determination of prospects for groundwater use and withdrawal management is always connected with the problems of exploitation restrictions in accordance with different criteria. The latter may be both internal and external. Among internal criteria are limitations of hydrogeological and hydrodynamic operation conditions, such as groundwater recharge rate, tolerance dynamic level lowering throughout estimated period, risk of non-standard groundwater being drawn up to a water intake, and others. The external criteria that can restrict groundwater use are related to possible impacts of a planned water extraction upon different environmental components including river run-off, suppression or death of vegetation due to excessive lowering of shallow groundwater level in the upper unconfined aquifer; activisation of karst and suffusion processes; earth surface subsidence, etc.

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The main tasks of hydrogeological investigations are the following:

- Determination of admissible limits of groundwater extraction in each of boundary countries in order to prevent water reserves depletion in neighbouring countries.
- Regional evaluation of natural groundwater resources of an exploited aquifer.
- Assessment of a groundwater pollution hazard in transboundary aquifers and development of joint recommendations preventing such pollution.

Specific examples of transboundary groundwater use perspective assessment in particular adjacent zone regions of Russia are presented.

Keywords Transboundary aquifers • Groundwater discharge • Natural resources • Vulnerability • Core of depression

In recent years the problem of transboundary waters use has become actual in many countries. This concerns not only the interstate boundaries where the use of marginal or transboundary rivers (rivers that cross boundaries) in many cases is regulated by special international agreements. The problem of transboundary water use regulation is also acute inside some countries (e.g. USA, Australia, Russia, India and others), where particular administrative regions (states, regions, federal divisions) have a constitutional independence and solve many problems of natural resources use independently, coordinating basic legislative acts only with neighbouring countries or federal organs.

In Russia the principle of the superiority of international right to the state right in the field of the environmental protection and natural resources use is legislated by Federal Law [1].

The basic principles of international agreements in the field of natural resources use and environmental protection include the sovereignty of a country over the natural resources of its territory; impossibility of reaching safe environmental situation in one country while the environment of another country is being damaged; and settling of environmental and legal disputes by peaceful means, etc.

Without mentioning the legal and juridical problems of natural resources use in boundary regions, we would like to note that presently the cost of liquidation of adverse consequences from human activity impacts on the environment (for example, pollution of water resources) is known to considerably exceed the cost of predictive and warning measures.

It should be noted that the problem of assessment of possible and perspective groundwater use in transboundary areas is of great importance for many countries in the world. Moreover, this problem is one of the least studied in hydrology and hydrogeology. The specialists must answer several important questions, such as: what is the mutual hydrodynamic influence of existing water intakes on groundwater; how much water can be withdrawn from transboundary aquifer by each country without depletion of groundwater resources; is there a danger of aquifer contamination; what are the perspectives of groundwater use in boundary areas of each country etc.

The careful analysis of hydrogeologic and hydrodynamic conditions in a given boundary zone by specialists from both sides is necessary for solving these problems.

Basic problems concerning transboundary aquifers study and use are often closely interconnected. These problems are the following [2]:

1. Quantitative assessment of natural and exploitable groundwater resources of boundary and transboundary aquifers. The method of such regional estimation is sufficiently well developed. It is based chiefly on hydrodynamic calculations, including regional models of groundwater discharges and possible productivity of aquifers and large groundwater well fields;
2. Determination of chemical, biological and radionuclide compositions of groundwater and an allowable level of its changes;
3. Estimation of fresh groundwater vulnerability in transboundary aquifers to anthropogenic contamination penetrating from the earth's surface;
4. Scientific and methodical substantiation of inter-country agreements on allowable limits of groundwater use from transboundary aquifers, including, geo-environmental aspects, permissible levels of groundwater extraction, risk of aquifer contamination and depletion;
5. Development of joint interstate monitoring of transboundary aquifers groundwater use and its protection.

Currently the main problem of hydrogeologic investigations in Russia is to develop scientific bases for the rational use and forecasting of groundwater resources from transboundary aquifers. The main tasks concerning these problems are the following: to analyse the peculiarities of fresh groundwater formation and distribution in boundary regions of Russia; to develop methodologies for forecasting the rational use of groundwater from transboundary aquifers; to develop principles and criteria of permissible joint groundwater withdrawal from transboundary aquifers considering groundwater protection from contamination and depletion; to develop constant-working mathematical models of groundwater deposits distributed in boundary areas of neighbouring states, intended to determine conditions and values of hydrodynamic flows recharge and discharge; to approbate the models for specific examples in boundary areas between Russia and neighbouring countries of the former USSR.

The main tasks of hydrogeological investigations are the following:

- Determination of admissible limits of groundwater extraction in each of the boundary countries in order to prevent water resources depletion in neighbouring countries.
- Regional estimation of natural groundwater resources of an exploited aquifer.
- Assessment of a groundwater pollution hazard in transboundary aquifers and development of joint recommendations preventing such pollution.

Below the basic tasks of hydrogeological investigations in boundary regions are briefly considered.

7.1 Determination of Permissible Limits of Groundwater Extraction in Each of the Boundary Countries in Order to Prevent Water Reserves Depletion in Neighbouring Countries

In most cases the given matter concerns usually two neighbouring countries exploiting the same aquifer for water supply or irrigation. Here, the most important task is to determine the position (sizes) of the depression cone at the current stage of water extraction and at the predicted stage of water withdrawal, taking into account an admissible (by hydrogeological criteria and criteria of environmental protection) level decrease in the aquifer for 25 or 50 years of exploitation.

7.2 Regional Estimation of Natural Groundwater Resources of an Exploited Aquifer

Natural resources characterise the volume of water, which is continuously being renewed during general water circulation at the expense of, infiltrated precipitation, absorbed river run-off and water seepage from other aquifers. Average multi-year groundwater recharge excluding evaporation is equal to a groundwater flow value. Therefore in regional evaluations the natural groundwater resources are often expressed in average annual or minimal groundwater flow modules. Natural groundwater resources represent the upper limit, which determines the productivity of continuously functioning water well fields. The productivity is provided by their natural recharge during an unlimited exploitation period (except water well fields where the yields of which are formed from additional reserves involved during exploitation). The methods for regional estimation of average multi-year values of natural groundwater resources are sufficiently well developed and described. These methods are the following: genetic separation of hydrographs of rivers draining groundwater from basic aquifers for a multi-year period; hydrodynamic calculations of flow rates, including modelling; analysis of low water run-off of rivers draining groundwater; water balance and calculation of infiltration recharge of groundwater, etc. Each of these methods has certain advantages and disadvantages. The possibility of using a particular method depends on the geological and hydrogeological conditions of a studied territory and availability of reliable factual data. However, all the above-mentioned methods have a certain advantage. Using these methods it is possible to carry out regional estimation of natural groundwater resources by means of analysis. Also available information can be obtained without conducting special expensive drilling, experimental and filtration works. To determine the prospects of groundwater use, it is important to estimate not only the average annual, but also seasonal (especially minimal) values of groundwater renewal. This can be done by analysing the multi-year observations of groundwater level regime.

7.3 Assessment of a Hazard of Groundwater Pollution in Transboundary Aquifers and Development of Joint Recommendations Preventing Such Pollution

Numerous facts show that groundwater pollution is often of a regional character. It restricts the possibility and prospects of practical use of fresh groundwater including fresh groundwater in boundary regions. Therefore, the regional assessment and mapping of groundwater protection against pollution in transboundary aquifers has become of great importance in conditions of existing and possible hazards of pollution to groundwater as a source of domestic and drinking water supply. Under "groundwater protection" one should understand the environmental possibility to preserve the composition and quality of groundwater during a predicted period (25 or 50 years), meeting the appropriate requirements of practical water use. The concept opposite to the given one is "groundwater vulnerability" to pollution. This term is widely used in foreign literature. The higher (better) the protection of groundwater is, the lower is its vulnerability and vice versa.

Two different approaches can be distinguished. The first one is assessment and mapping of groundwater vulnerability in any territory without taking into account the characteristics and properties of particular pollutants. The second one is assessment and mapping of a natural system applied to a particular type of pollution.

The majority of methodologies are based either on qualitative or quantitative analyses of different factors affecting groundwater vulnerability. Usually the degree to which unconfined groundwater or groundwater in the upper confined aquifer is protected is being assessed.

Results of quantitative assessment and mapping of groundwater vulnerability to pollution may be used in the following concepts: development of a strategy for groundwater use and protection in areas with different natural vulnerability; substantiation of plans for location and development of large industrial and agricultural objects with hazardous liquid and hard wastes; hydrogeological substantiation of different water-protective measures; selection of places for accumulation and storage of wastes.

One of the most important practical results of assessment and mapping of groundwater protection is the possibility to compare different territories concerning groundwater protection against pollution and decide which territory is better protected. Assessment and mapping enables discovery of where a high risk of pollution of water well fields exploiting groundwater for water supply exists, as well as to learn where water protective measures are primarily necessary.

Geofiltrational models of Russian and Estonian, and Russian and Ukrainian border regions have been developed in recent years in Russia to determine the prospects of transboundary aquifers use. Modelling results are briefly stated below.

7.4 Russian and Estonian Border

Teamwork of Russian and Estonian hydrogeologists resulted in an integrated Russian-Estonian geofiltrational model of the Lomonosovskiy-Voronkovskiy aquifer. The model is based on the analysis of available hydro-geological information on the Estonian Republic territories, the Leningrad and Pskov regions of Russia. Water containing formations of this aquifer are indicated by quartz sandstones with interbedded clays with total thickness of 30 m. The thick stratum of Loptovskiy clays serves as their upper aquiclude and clays of upper Proterozoic appear as their bottom. This aquifer is a subartesian one with pressure value of approx. 100 m. Water levels in wells are established at depths of 15–45 m. The aquifer is maintained in border regions of Russia and Estonia. Three possible variants of development of the hydrodynamic situation in the Russian and Estonian border area have been considered in the regional model: They are the following: (1) the new water intake in Ivangorod with productivity of 3,000 m^3 per day is added to the already operating water intakes with existing productivity; (2) water withdrawal from all water intakes on the Russian territory, including the new one in Ivangorod, has increased twice, and Estonian water intakes yields remain constant; (3) Estonian water intakes yields are decreasing for the second time. As a result the groundwater overflow through the Russian-Estonian border under the influence of water withdrawal has been determined to be much lower than their natural discharge through it. Even double decrease in water withdrawal from this aquifer on the Estonian territory shall not change the current hydrodynamic conditions. Only the high increase in water intake on Russian territories can change the hydrodynamic situation until the complete inversion of the natural flow.

Researches of Russian and Estonian transboundary aquifers were the first and almost the only joint work of experts from neighbouring countries concerning transboundary groundwater studying. These researches could be an example of international cooperation on this challenge [3].

7.5 Russian and Ukrainian Border

The integrated base of cartographic and factual data for the general mathematical model of transboundary aquifers of the Dneprovo-Donetsk artesian basin is created. The model covers territory of 248 × 276 km, a grid step is 1 km. The northern part of the model includes the Belgorod region of Russia; the southern part comprises the Kharkov region of Ukraine. Four aquifers and three relatively impermeable layers are considered vertically. The basic regional water intake is coincidental with the second one, which consists of Maastriht-turonskiy and Alb-senomanskiy aquifers.

On model live conditions the specifications of existence of regional hydrodynamic flow for undisturbed filtration regime have been reproduced. Hydro- and pezoizogips maps for four aquifers and a water exchange map between them have been constructed as well. Also the data on balance components have been obtained. Besides, graphic representation of groundwater flows for simulated aquifers concerning state borer has been received.

To reproduce the disturbed filtration conditions all existing water intakes of the Belgorod region for the periods of 1970, 1980 and 1990 have been set with prolongation of 10% increase in water withdrawal till 2009.

Maps of levels decrease in exploited aquifers and also tables of certain hydrodynamic balance components on calculated time steps are received.

The analysis of structure of groundwater resistance indicators and their quality for transboundary aquifers of the Dnepr and Don river basins showed that the Dneprovsko-Donetskiy basin is characterised by a high resistance indicator, and the Donetsk basin has extremely low groundwater resistance indicator to anthropogenic impact [4].

In conclusion, it should be noted that transboundary problems of groundwater development are very significant for Russia as it has land boundaries with 13 countries. Basic tasks concerning solution of these problems at the current stage are the following:

– development of principles and criteria for acceptable groundwater extraction by the neighbouring countries regarding nature protection restrictions, including groundwater protection against depletion and pollution;
– development of constantly functioning models of groundwater fields in boundary regions of neighbouring countries in order to determine groundwater balance elements in particular hydrodynamic flows and their interaction with each other and with surface waters both in natural and anthropogenically disturbed conditions;
– determination of prospects for joint use of groundwater on the basis of large-scale assessment and mapping of groundwater safe yield taking into account its protection against pollution.

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Chapter 8
Are There Any Transboundary Aquifers in Belarus?

Mikhail Kalinin

Abstract In 2008 the UNESCO International Hydrological Programme (IHP) introduced the map of transboundary aquifers. The map gives the general view where transboundary aquifer occur, unfortunately not all aquifers were identified. Further efforts are needed to extend the knowledge in this field.

In the paper the main aquifers and aquifers systems in Belarus were charcterised. There are five main water pressurized systems in the national territory of Belarus that are widely used for the purpose of general water supply: Quaternary, Palaeogene, Albian-Cenomanian, Devonian and the Upper Proterozoic. Base on the available information the attempt to identify regions of transboundary groundwater flow occurrence were taken. Because of the lack of sufficient date in that field the detailed study of hydrogeological condition in indicated areas are recommended to achieve bilateral cooperation and sustainable use of aquifers.

Keywords Aquifers • Transboundary groundwater • Hydrogeology

8.1 Introduction

In the recent decade, the issue of correct usage of natural resources are in the global focus and that is not limited only to surface waters, but includes groundwater, as well. The groundwater water-bearing horizons (aquifers) account for almost 96% of the global fresh water resources, with those being 100 times as much as that of the surface fresh water total. In the arid and semi-arid zones, those are often one of only few sources of water supplies, yet sometimes the only one.

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In 2000, the Intergovernmental Council of the IHP launched the ISARM – Internationally Shared Aquifer Resources Management initiative, the objective of which was to draw up the worldwide inventory of the transboundary groundwater aquifers and to formulate the relevant recommendations for sustainable management of these resources.

In 2006, the International Law Commission adopted on first reading a set of 19 draft articles on the law of transboundary aquifers with comments thereto and presented them to the Governments for their further comments and observations to be made.

In 2008, at the 60th session, the Commission considered various comments presented by the Governments and adopted on the second reading the revised set of 19 draft articles on the law of the transboundary aquifers.

Since the Governments' opinions regarding the final form of the draft articles differed, the Commission decided to propose a two-step approach to the UN General Assembly, i.e.: (a) to take note of the draft articles through their attachment to its resolution and recommending that the relevant bilateral and regional agreements be signed by the respective States aiming at efficient management of their transboundary aquifers, while based on the principles set forth in the aforementioned draft articles; and (b) to consider the opportunity to enter at a later stage a Convention based on the said draft articles. Since the decision making process concerning the second step will take some time, the Commission determined to refrain from development of the draft article on relation between the mentioned draft articles and the other international agreements, as well as it refrained from development of drafting the article on the disputes possible to settling once after the second step is started only.

The UNO, UNESCO, FAO and ECE experts, and the International Association of Hydrogeologists (IAH) made significant efforts in this filed. Thus, in 2008, the UNESCO International Hydrological Programme (IHP) produced their first specific map of the transboundary aquifers the number in 2010 was more than 270 worldwide, including 73 in the North and South Americas, 38 in Africa, 65 in the Eastern Europe, 90 in the Western Europe and 12 in Asia. The UNESCO IHP is the only UNO programme which involves surveying these issues of water resource management, including training on water resources use.

However, the map showing the transboundary waterborne horizons fails to show all of those in Belarus, and it has been confined to a part of them only (i.e. in the south-western transboundary areas at the Polish and the Ukrainian borderland).

The major regularities of Belarusian hydrological setting, including possible occurrence of the transboundary aquifers at all the adjacent State borderlands (i.e. Poland, Latvia, Lithuania, Ukraine and Russia) are presented below.

8.2 The Major Aquifers and the Aquifer Systems

Natural circumstances in Belarus are favourable to preservation and restoration of considerable part of groundwater resources. Natural fresh groundwater resources are estimated at 43.56 million m^3/day [2]. Its forecasted usable resources make up

49.6 million m^3/day. At the country scale, there are more than 60 aquifers and aquifer systems in sedimentary strata and in fractured zone of the crystalline basement that distinguish by the groundwater certain stratigraphic peculiarities, lithological composition, spatial structure, water saturation and permeability and chemical composition [1, 4–8]. Some of these aquifers are the transboundary ones.

The Quaternary water bearing horizons and systems feature by notable variety of their lithological composition, fragmentation and spreading, frequent pinches and washouts of water logged rocks. A lot of water bearing horizons and aquifer systems can be found within super moraine, intermoraine and moraine (waterproof comparable to poorly permeable rocks) separating the first two ones, the hydrodynamic and hydro geochemical uniformity, and the interrelation of which provides for their combination into one hydrogeological level. About 30% of all usable fresh groundwater horizons in Belarus are embedded in the Quaternary aquifers and the aquifer systems. Just these Quaternary water bearing horizons are utilised by many major central- and local water-supply systems [2, 3, 6–8].

Covering deposits, which are mainly the Upper-Quaternary deposits and modern alluvial (*aIII pz* and *aIV),* lake-alluvial (*aIII pz*) and boggy-lake (*l,bIV*) deposits, as well as fluvioglacial super moraine deposits of the Poozyorye, Sozh and Dnieper glaciation periods (*fIII* pz^s, *fII* sz^s and *fII* d^s), include free (water-table) aquifers featuring by a close hydraulic interrelationship which provides to consider them as a single groundwater complex. The aquifer thickness ranges from some centimetres to 20–30 m, being 10–15 m, at the mean. A water yield of the rocks can vary mostly. The well specific yield varies from 0.01 to 5.0 dm^3/s, the filtration factor can be from 0.001 to 35 m/day. The groundwater depth level ranges between centimetres (in river floodplains and water-logged areas) and 15–16 m (within ash and kame deposits), being 2–4 m at the mean. The groundwater level surface reflects the ground-terrain featuring. The surface of the local heads up to 2–3 m is possible in the areas with lenses and loamy, clayey or clay-sandy bands. Seasonal amplitude of the groundwater level is usually below 1.5–2.0 m. Its minima (0.1–0.5 m) can be found in bog massifs, and maxima (up to 3–4 m) – in large rivers valleys. Groundwater recharge occurs principally through effective infiltration of rainfall waters, whereas in river valleys – through head water inflow from underlying aquifers and aquifer systems. Groundwater discharge occurs into rivers and drainage canals, lakes and bogs. Overflow into underlying aquifers can be noted on watersheds.

Both, scattered groundwater in moraine and end-moraine deposits of the Poozyorye and Sozh glaciation periods (*g, gtIII pz* and *g,gtIII sz*) and those of moraine deposits of the Dnieper glaciation period (*g,gtII d*), on the sites in which the deposits mentioned are close to the ground surface, have been largely used through a number of wells and small holes as the basic water intakes for water supply to villages and towns in Belarus.

The Sozh-Poozyorye (*f,lgII sz-IIIpz*), the Dnieper-Sozh (*f,lgII d-sz*), and the Berezinsky-Dnieper (*f,lgII br-d*) water bearing horizons are the most important Quaternary aquifer subsystems containing underground head waters.

The Sozh-Poozeiye Aquifer (*f,lgII sz-III pz*) prevails over the northern part of the national territory. Its southern boundary almost coincides with that of the

Poozyorye glacier. The confining bed depth ranges between few meters and 90 m, and the thickness of water-bearing deposits ranges between 3 and 50 m, and makes up to 10–20 m at the mean. The piezometric surfaces are at the depth of 1 and 55 m (in river valleys those can jut out 15 m over the ground level). The head can be 80 m over the confining bed. The filtration factors of the aquifer rocks are 3–10 m/day at the mean, and the well specific yield varies between 0.02 and 3.5 dm^3/s.

The Dnieper-Sozh Aquifer (*f,lgII d-sz*) covers the major part of the national territory except for the Polesye. The southern boundary of the aquifer is close to the Sozh glacier boundary. The confining bed depth ranges from 2 to 40 m in river valleys and it can reach 100 m and more in watershed areas. The thickness of water-bearing deposits can be from 2 to 74 m, and makes up 15–30 m at the mean. The piezometric surfaces are at the depth of 1–6 m in the river valleys up to 30–53 m in the watershed areas. Heads vary from 1 to 90 m, being the lower in the close-to-river areas. Water yield and filtration characteristics of rocks rather vary. The filtration factors of water-bearing rocks are from 0.2 to 50, being 5–15 m/day at the mean. The well specific yield is between 0.01 and 9.5 dm^3/s.

The Berezinsky-Dnieper Aquifer (*f,lgII br-d*) spreads over almost everywhere. The water-bearing rocks depth ranges from few meters to 170 m, their thickness is from 2–10 m to 100–170 m and even more (in ancient buried valleys). The piezometric surfaces are at the depth of 1–78 m (in river valleys it can sometimes be up to 2.5 m above the ground level). The head ranges from 1 to 134 m. the water yield is rather high; well specific yields are from 0.01 to 4.3 dm^3/s and the filtration factor of the rocks is between 0.2 and 26 m/day.

In addition to these three important Quaternary pressure aquifers, in the South of Belarus there is a system of aqueoglacial, alluvial, lake and boggy deposits, which are under the Berezinsky moraine. (*f,lgII* br^i). As a rule, the water-bearing deposits are associated with the ancient valleys and erosion depressions; their thickness ranges from few meters to 25–30 m. the filtration factors are from 0.1 m to 10–12 m/day, and the well specific yield is from 0.3 to 6.0 dm^3/s.

The aquifers mentioned are separated by moraines of the Poozyorye, Sozh, Dnieper and Berezinsky glaciation periods. The moraines thickness is 10–30 m at the mean, but in preglacial valleys, it reaches 50–60 m and even 100–120 m. The moraine deposits are mainly represented by loamy and clayey sands (often with rubble), where water-bearing seams, lenses and pockets (inclusions) with consertal (varigrained) sands, sand-and-gravel and gravel-pebble materials occur. They do not form independent aquifers and are defined as *scattered groundwater of comparatively waterproof moraine (and end-moraine) deposits* of Poozyorye (*g,gtIII pz)*, Sozh *(g,gtII sz)*, Dnieper *(g,gtII d)* and Berezinsky (*gII br*) glaciation periods.

The area of confined intermoraine aquifers is uneven. In river valleys, where moraine deposits are often washed out, and in the areas, where facies replacement of loam and clay-sands with sands take place, so called "hydrological windows" are formed, through which a hydraulic connection between intermoraine aquifers and their links with groundwater and surface waters occur. The piezometric surfaces of such aquifer systems in watersheds have absolute maximum elevations, but they are lower than the groundwater levels. Towards the river valleys, the confined water level of Quaternary deposits regularly goes down; within floodplains and the first fluvial terraces, the waters are deposited at the minimum elevations, which exceed, as a rule, the levels of groundwater and surface waters. This fact means that the recharge of confined aquifers mainly occurs in watersheds elevations through infiltration of atmospheric precipitates and due to the inflow from shallow aquifers. The discharge takes place in river valleys. The interfluvial areas may be considered the areas hydro dynamically independent on the formation, and the discharge of not only shallow groundwater, but also confined Quaternary groundwater occurs, while the whole mass of these deposits may be considered a single hydrodynamic system, where the groundwater of all the aquifers and the aquifer systems form an integrated flow with characteristic properties strictly corresponding to the "interfluvial flow".

The overlaying Quaternary deposits feature by rather high permeability. This feature causes formation of considerable storage of fresh groundwater therein. The total natural fresh groundwater resources in Belarus are estimated at 10.3 km^3/year and the average modulus of the underground discharge out of these deposits makes up 1.6 $dm^3/s/km^2$.

The Quaternary deposits strata are in the upper zone of active water exchange. This position evokes formation of mainly hydrocarbonate and calcium-magnesium fresh and ultra fresh waters. Their mineralization ranges between 15 and 700 mg/dm^3 and yet more, thus making up 200–400 mg/dm^3 at the mean.

In Neogene-Palaeogene aquifers, the horizontal hydro geochemical zoning can be well perceived, which appears through a regular increase of water mineralization from watersheds towards river valleys. The minimum mineralization (30–150 mg/dm^3) is recorded in watersheds, the maximum one (up to 400–600 mg/dm^3) – within river valleys and mainly in floodplain areas. One can also observe discharge areas of deep mineralized waters there. The total mineralization of such waters can reach 2.0–6.7 g/dm^3.

The aquifer system is widely used for the centralized water-supply to the localities of Stolin, Luninets, Vasilevichy, Mozyr, Kalinkovichy, Rechitsa, Gomel, Zhitkovichi, Petrikov, Loyev, Khoyniky, Narovlya, Yelsk, etc., and water is also utilised through a number of single wells for water supply purpose to villages and farms. There are no evidences of anthropogenic pollution in the aquifer system, except for some areas featuring by extremely high anthropogenic load (Soligorsk, Gomel, etc.).

The Upper Cretaceous Aquifer System spreads over a notable part of Belarus. It does not occur in the areas of deep erosion cuts in the large rivers valleys.

Fractured and karst chalk, marl and limestone with rare bands of the Maastricht, Turonian, Campanian, Coniacian, Santonian clay and sands are water-bearing, as are the marly-chalk formations of the upper and medium sub layers of the Cenomanian. The confining bed depth ranges between 0–60 m in the East and 70–150 m in the Pripyat River Basin, and 110–240 m in the West and the Southwestern part of the national territory. The total thickness of the marly-chalk formations towards the northern and south-western parts of the spread area makes up 40–60 m, and reaches 200–290 m in the Brest and Pripyat River hydrogeological basins. The thickness of the most fractured and water-reach part of this section does not exceed 30–50 m.

The piezometric surfaces are in 10–50 m depth. The heads over the water-bearing confining bed can reach 160–230 m, while the 15–75 m heads prevail.

The water yield of the Upper Cretaceous deposits is mainly high, and it depends on the fracturing and karstification of the marly-chalk rocks. The specific well discharge ranges between 0.002–0.9 and 10–12 dm^3/s, with the filtration factor of water-bearing rocks ranging from 0.1 to 1.0 m/day. The transmissibility makes up 50–100 m^2/day.

The water is fresh and its mineralization seldom exceeds 0.5 g/dm^3, as featuring by frequent hydrocarbonate-calcium and calcium-magnesium contents.

The Albian-Cenomanian Aquifers are spread over the South of Belarus. The water-bearing deposits are represented by the lower sub layers of the Cenomanian upper chalk and the Albian lower chalk. Quartz-glauconitic sand, carbonate sandstone and arenaceous chalk are the water-bearing rocks. The confining bed depth ranges from 5–100 m in the East of the national territory to 315–375 m in the Pripyat River basin.

The thickness of water-saturated rocks can vary from 0.3–5.0 m in the northern to 10–25 m in the central part, and 30–50 m in the south-eastern and western part of the aquifer spread area. The piezometric surfaces of the groundwater are 37 m below the surface level and can reach 18.8 m above the surface level (the absolute elevation being 77.8–263.0 m). The head over the confining bed can vary from 23–95 m (within the Belarusian hydrogeological massif) to 170–280 m (within the Brest and Pripyat River hydrogeological basins). The well specific yield falls within 0.001–8 dm^3/s and the filtration coefficients of the water-bearing rocks can be between 0.02 and 62 m/day, mainly making up 1–20 m/day.

The water is fresh and its mineralization seldom exceeds 0.5 g/dm^3. Its composition includes hydrocarbonate calcium-sodium, sodium, calcium or calcium-magnesium. The cases were found there with opening of chloride-sodium waters with mineralization up to 12 g/dm^3 (a well near village of Slutsk/Poblin), which apparently come out of deeper Palaeozoic deposits.

The Lower Cretaceous (Valanginian-Aptian) Aquifer System spreads over the south-eastern part of Belarus. The water-bearing rocks are mainly varigrained sands, often clayey sands, somewhere with layers of semi consolidated sands, siltstone and clay. The confining bed depth of the system ranges from 100–120 m in the North-East to 240–420 m in the South-East. The water-bearing sediments thickness ranges between 2–7 m in the North of the system and 10–70 m in the Pripyat hydrological basin. The waters occur under pressure and the piezometric surfaces are at the depth of 5–10 m; single well-springs have been noted. The head over the aquifer confining bed can reach 25–260 m.

The mineralization of the groundwater in the Pripyat River hydrogeological basin is within 0.1–0.5 g/dm^3 and is of hydrocarbonate calcium and hydrocarbonate calcium-sodium composition. However, the mineralization of the Lower Cretaceous waters can reach 6 g/dm^3 in areas of discontinuous faults.

The Upper Jurassic Aquifer System spreads over the south-eastern part of Belarus within the Pripyat River hydrogeological basin, the Zhlobin hydrogeological zone, and in the western part of the Brest hydrogeological massif. The water-bearing rocks are cavernous and fractured limestone and marl, as well as semi consolidated carbonate sands and the Callovian and the Oxford sands of the Upper Jurassic.

The confining bed ranges from 140–250 m in the East of the system spread area and 150–300 m in the West of the national territory to 450 m (in the Zhlobin Saddle and in the South-East of the Pripyat River hydrogeological basin). The water-bearing bed thickness reaches 45–104 m. The waters are pressurised, the piezometric surfaces are at the depth of 2.5–66 m, the head can reach 117–301 m over the confining bed; well-springs are detected in the river valleys. In the Neman River valley, the water heads reaching 10–20 m above the ground level were found.

The specific well discharge in the East of the system spread area does not exceed 0.2–0.3 dm^3/s, in the West they are 0.3–3.3 dm^3/s and more. The groundwater is fresh, and features by mineralization amounting to 0.5–0.9 g/dm^3 and more, and by the hydrocarbonate-calcium composition.

The Middle-Upper Jurassic Aquifer System spreads over within the Brest and the Pripyat River hydrogeological basins, including the western part of the Belarusian hydrogeological massif, the southern part of the Orshansk hydrogeological basin, and the hydrogeological area of the Zhlobin Saddle. The system is represented by two water-bearing layers: the upper marly-limestone layer (the Oxford stage of the Upper Jurassic) and the lower sandy-argillaceous layer (the Callovian, Bath, Bajocian stages of the Middle Jurassic). The water-bearing rocks are cavernous and fractured limestone and marl, as well as varigrained sands, and sandstone somewhere.

The confining bed depth ranges between 30–100 m (in the East of the national territory) and 70–100 m (in roof deposits), up to 350–470 m (in the Pripyat River and the Orshansk basins). The thickness of the water-bearing rocks does not exceed 22 m in the West of Belarus and is over 195 m in the Pripyat River basin.

The waters occur under pressure. The piezometric surfaces are in 4–22 m depth. The head can be from 80 to 240 m, and the well specific yield does not exceed 0.25 dm^3/s. The filtration coefficient is usually within 0.1–1.0 m/day. The groundwater mineralization varies from 0.3 to 0.8 g/dm^3, but waters with higher mineralization amounting to 1.1–2.1 g/dm^3 were found in deeper strata. The waters feature by their hydrocarbonate calcium and hydrocarbonate calcium-magnesium composition.

In the Orshansk and Pripyat River basins, the aquifer system is mainly represented by clays with their thickness ranging between 12 and 85 m. Within these hydrogeological structures, the clays perform as a confining layer separating the aquifers with fresh and mineralized groundwater.

The Aquifer and the saline water-bearing system of the Permian and Triassic deposits is mostly developed within the Prityat River basin and fragmentarily in the Brest hydrogeological basin.

The Triassic deposits are represented by interchanging variegated sandy and clayey rocks in the Prityat River hydrogeological basin. The water-bearing rocks are sands and sandrocks with interbeds of pudding rocks and chalk-stones. The occurrence depth of the upper boundary of aquifer sandy rocks of the Induan Stage ranges from 120 to 600–700 m. The groundwater occurs under pressure, the static levels are established at the depth of 15–100 m under the surface level. The water recharge in deposits varies within 10–45 m^3/day at a decrease of the water level in wells by

35–200 m. The groundwater mineralization is from 10–13 to 16–78 g/dm^3. The composition of the mineralized water and saline water is sodium chloride, with relatively high level of ammonium, strontium and bromine.

Sandy interbeds 2–14 m thick are the aquifers in the Brest hydrogeological basin, in the mostly clayey Triassic section.

The Permian deposits of the Pripyat River basin are represented by sandy and clayey formations interbedded by pudding rocks, chalk-stones and sulphate rocks of the Asselian and Tatarian Stages. The inequigranular sands are most water-encroached, as well as the cracky and loose sand-rocks of the upper section of the Permian system are. The Low Permian deposits are mostly represented by clays. The groundwater of the Upper Permian deposits is pressurised, the static levels are established at the depths of 15–50 m below the ground level. The water recharge in rocks varies within 30–150 m^3/day at decreases in 5–100 m. Mineralization of water and saline water increases in line with their depth, and ranges between 25 and 285 g/dm^3, the water composition being sodium chloride, and also sodium calcic somewhere.

The Aquifer and the saline water-bearing system of the Carboniferous deposits are broadly developed in the Pripyat River hydrogeological basin and fragmentarily within the Volyn Monocline. The groundwater is connected with thin insufficiently aged interbeds of sands, sandrocks and chalk-stones. The occurrence depth of the upper boundary of water-bearing deposits ranges between 60–80 m (in the western and north-western parts of the Pripyat River basin) and 1,000 m and more (in its eastern, south-eastern and central parts).

The groundwater occurs under pressure; the static levels are established in 5–100 m depth from the daily surface. Recharge of the wells vary within 50–450 m^3/day at the decreases of the level by 36–400 m. Mineralization of groundwater and saline water depends on the depth of their occurrence and ranges from 12 to 185–281 g/dm^3 (in below 1,200 m depth).

The Devonian Famennian Aquifer and the saline water-bearing system developed in the South-East of Belarus (the Pripyat River hydrogeological basin), restrictedly spread over in its outer north-eastern part and include separate areas at the bents of the Zhlobin and Polesye saddles.

The Devonian Upper Famennian groundwater and saline water do not form aquifers sufficiently aged according to both the area and the thickness, in the Pripyat River hydrogeological basin, but are deposited as water-bearing lenses and interbeds in the depth of clays, sodium-chloride and chalky clays, which are united into aquifer and the saline water-bearing subsystems.

The Supra-Salt Devonian Aquifer and the saline water-bearing system are connected with the upper part of the Streshyn and the Polesye horizons of the Pripyat River basin. The hydrophilous rocks are carbonate-argillaceous non-sulphate deposits in the West (the Starobin and the Turov drawdowns), and terrigenic deposits in the south-east. The occurrence depth of the upper boundary of hydrophilous rocks ranges from 70–150 m (West of the Pripyat River hydrogeological basin) and 170 m (north-east) to 700–2,000 m (in the main part of the basin area). The total thickness of the supra-salt layer can reach 1,000 m.

The groundwater and saline waters are highly pressured. The static levels are established in 140–150 m depth, in the western part of the basin; 40–135 m in its north-eastern part, and up to 30 m in its central and southern parts. The pressure head grows from the West and North-West towards the South and South-East. It also depends on the occurrence depth of the water-bearing deposits. The recharge volumes in wells and specific yields increase towards the same direction (from 0.006 to 3–5 m^3/day).

The mineralization of groundwater and saline water varies from 0.3–2.0 g/dm^3 (at the depth of 300–400 m) in the North-West of the Pripyat River basin to 132–367 g/dm^3 in the South-East of its area. The supra-salt Devonian deposits feature by saline waters their with mineralization amounting to 117–330 g/dm^3.

The Upper-Salt Aquifer and the saline water-bearing rocks are coincided with the Lebedyan, the Oresa and the low part of the Streshyn horizon. The upper salt rock system is represented by carbonate interbeds and sandy clayey rocks.

The upper boundary of the occurrence depth of water-bearing deposits ranges from 300 m (Soligorsk, Starobin) to 3,000 m and more (in the south-eastern part of the Pripyat River basin). The total thickness of the upper salt deposits ranges from 70 to 3,250 m, and 40–75% of the whole thickness is shared by non-salty layer in separate sections.

The saline water of non-salty deposits of the upper salt-bearing depth is under pressure. The piezometric surfaces are established at the marks over the daily surface and to 1,000–1,450 m depth. During wells testing, the recharge volumes amounting to 14–230 m^3/day were obtained. An Artesian well with 1,560–1,730 m^3/day yield is noted within the Yelsk area.

The mineralization of the saline water varies from 100 to 390 g/dm^3, and mineralization of 484 g/dm^3 is observed in mine openings of the Starobin potash salts deposits. The saline water is chloride sodium and calciferous. The upper salt stratum can generally be considered a regional water confining layer influencing significantly the formation of hydrodynamic situation in the Pripyat River hydrogeological basin.

The intersalt aquifer and the saline water-bearing stratum, according to its scope, correspond to the Zadon, Yelsk and Petrikov lithologic and stratigraphic horizons. The water and the saline water-bearing deposits are represented by carbonate (chalk-stones, dolomites), sand and clay and volcanic formations of low Famennian Age. The occurrence depth of the upper boundary of the hydrophilous rocks ranges from 236 to 3,870 m, with their total thickness ranging from 300 to 950 m, and can reach 1,820 m in areas of volcanic deposits development. The intersalt deposits are blended out in separate areas adjacent to those of sublatitudinal splits.

The Devonian Frasnian Aquifer and the saline water-bearing system spreads over in the south-East of Belarus and within the Pripyat River hydrogeological basin, in the north-eastern slopes of the Belarusian Anticline and the Zhlobin Saddle, as well as within the Orshan hydrogeological basin.

The north-eastern regions of Belarus. The occurrence depth of the upper boundary of the Frasnian deposits (the Semiluki, Sargaya, and Lan horizons) ranges from 5 to 180 m. The cracky, non-karstified chalk-stones and dolomites are the hydrophilous deposits, with their total thickness being 137 m, and the thickness of a water-saturated part of the deposits amounting to 50–75 m at the mean. The water is pressurized. The water piezometric surfaces in wells made in the river valleys sometimes exceed the ground level mark. The pressure over the upper boundary of hydrophilous rocks is 120 m. The discharge rates of individual wells are 47–125 dm^3/s at decreases amounting to 1.5–35 m. In the valleys of the Dnieper River (near the City of Orsha), the Zapadnaya Dvina River (eastwards of the City of Vitebsk), the cities of Saryanka and Vitba, there are outcrops of the system rocks. Newly-appearing springs are found there.

The water is mainly fresh with its mineralization not exceeding 0.1–0,5 g/dm^3. The water is hydrocarbonate calciferous and hydrocarbonate magnesium calciferous.

The south-eastern regions of Belarus. The Frasnian deposits are represented by the Evlanov and the Livny salt-bearing stratum, and mostly carbonate formations of the Lan, Sargaya, Semiluki, Rechitsa, Voronezh and Evlanov horizons. The low salt stratum is a water confining layer with thickness thereof up to 500 m and more that developed within the territory of the Pripyat River basin.

The undersalt carbonate deposits form a water-bearing stratum having the same name. The thickness of the undersalty carbonate system is 60–250 m, but seldom more (up to 490 m). The mineralization of the saline water amounts to 453 g/dm^3.

The Devonian Starooskol and the Lan Aquifer and the saline water-bearing system spreads over in the Pripyat and Orsha hydrogeological basins and partially in the North and East of the Belarus hydrogeological massif.

The hydrophilous rocks are mostly represented by fine-graded sands and semi-consolidated sand rocks, up to 200 m thick. The occurrence depth of the upper boundary of hydrophilous deposits is 15–165 m in the North-East of the national territory, 270–540 m in the West and up to 1,200–3,000 m and more in the Pripyat River hydrogeological basin.

The water is pressurized. The piezometric surfaces are 7–35 m in the Orsha basin; they can seldom reach 200 m and more. In the north-eastern part of Belarus, specific wells discharges amount to 0.001–3.6 $dm^3/s/m$, while 0.5–1.0 values prevail.

In the western part of the national territory, the groundwater is not considerably mineralized (0.4–0.5 g/dm^3) and it features by hydrocarbonate calcic and magnesium composition. In the northern areas of the national territory, water mineralization increases up to 0.7–1.5 g/dm^3, and turns into chloride and hydrocarbonate, magnesium and calcic, or chloride and sodium composition. In line with deepening of water bearing rocks towards the north-eastern direction, water mineralization amounts to 2.5–3.0 g/dm^3 at 200–300 m the depth with respective change in its ionic composition.

The Devonian Eifelian Pyarnu and Narov aquifer and the saline water-bearing system spread over within the Belarus hydrogeological massif, in the Pripyat River and the Orsha hydrogeological basins.

The water bearing deposits are represented by cracky dolomites and chalk-stones, seldom chalky clays with interbeds of clays, sands and hydrous sulphate of limes. The occurrence depth of the upper boundary of hydrophilous deposits ranges between 70–300 m within the Belarus hydrogeological massif, up to 300–400 m and more in the Orsha, and 60–3,500 m in the Pripyat River hydrogeological basin. The total thickness of the aquifer and the saline water-bearing part of the deposits ranges from several meters to 200 m in the central part of Belarus, and to 100 m in its south-eastern part.

The water is pressurized. The piezometric surfaces in wells are established at the depths of 0.2–60 m. The cases of the Artesian wells are noted in the river valleys. The specific flows of the wells vary within 0.003–0.7 $dm^3/s/m$ in the territory of the Belarus hydrogeological massif and in the Orsha basin. The specific discharge of the wells in the Pripyat River basin vary from 0.0007 to 0.04 $dm^3/s/m$.

The groundwater mineralization in the northern part of the system spreading is 0.3–0.6 g/dm^3; the fresh water changes to weak and strong brackish water (1.4–5.2 g/dm^3) featuring by sulphate magnesium and calcic and chloride and sulphate calcic composition. In the immersed parts of the horizon, the saline water and salt brines of chloride sodium composition appear with 15–65 g/dm^3 mineralization.

In the Pripyat River hydrogeological basin, the Eifelian Stage is represented by sedimentary formations of the Vitebsk, Pyarnu and Narov horizons (subsalt terrigenic saline water-bearing system). The total thickness of the system is 120–340 m.

The Ordovician and Silurian Aquifer System develops in the north-western and the south-western regions of Belarus within the north-western end of the Belarus hydrogeological massif, and in the Brest hydrogeological basin. Hydrophilous rocks are cracky chalk-stones and dolomites with the interbeds of chalky clays. The occurrence depth of the upper boundary of the hydrophilous deposits is 70–340 m in the North-West and 200–450 m in the South-West of the national territory, with their thickness ranging between 5–160 and 85–630 m, respectively.

The aquifer system includes pressurized water; the piezometric surfaces are established at the depths of 2–50 m, seldom over the ground level, up to 20 m. The pressure values above the upper boundary of the hydrophilous deposits are 150–240 m. The specific discharges the wells are 0.01–3.3 $dm^3/s/m$. The concentration of the dissolved substances in the water ranges from 0.2–0.6 g/dm^3 (hydrocarbonate calcic and calcic magnesium contents) to 43.3 g/dm^3 (chloride sodium, sulphate chloride contents).

The Low and Medium Cambrian Aquifer System spreads over in the North-West and the South-West of Belarus. The hydrophilous rocks are fine- and medium graded, and anisometric sand rocks, seldom sands. The occurrence depth of the upper boundary of hydrophilous deposits ranges within 160–190 to 620–730 m and more, with thickness of deposits being from 3–30 to 50–130 m.

The water is pressurized. In the North-West, the piezometric surfaces are recorded in up to 21.2 m depth and marks 0.5–4 m above the ground level; the pressure height is up to 470 m.

The specific discharges of the wells during the system testing are 0.4–13.3 dm^3/s, with decreases being 22–33 m. The groundwater mineralization varies from fresh calcic hydrocarbonate (0.15 g/dm^3) to mineralized sodium chloride (6.3 g/dm^3 and more).

The Upper Proterozoic Aquifer and the saline water-bearing system widely spread over the Belarusian territory and occupy around 85% of its area.

The occurrence depth of the upper boundary of the aquifer and the saline water-bearing rocks ranges from 10–100 m at the Mikashevichi and the Zhytkovichi projection to 550–700 m in the Brest Basin, 10–1,000 m within the Belarus Anticline and the Latvian Saddle and achieves 1,000–4,500 m in the Pripyat River basin. The thickness of the aquifer and the saline water-bearing deposits varies within a wide range from 10–100 to 500–1,000 m.

Hydrogeological and hydro geochemical conditions of the Upper Proterozoic deposits depend on their location in the open cut of geological structures. Due to that fact, the general characteristics of the Upper Proterozoic Aquifer and the saline water-bearing deposits is described according to the scheme of geological and structural and hydrogeological classification and nomenclature of geological and hydrogeological taxonomic units, commonly approved and used domestically, as follows.

The Belarusian Hydrogeological Massif. The groundwater is fresh and ultra fresh. The thickness of the fresh water area in the open cut of the sedimentary cover is 200–450 m. The mineralization varies from 0.2 to 1.0 g/dm^3, with its 0.3–0.8 g/dm^3 values prevailing. According to its chemical composition, the water is hydrocarbonated calcic, sodium calcic and calcic-sodium [7].

The water is pressurized within the major part of the massif. The piezometric surfaces are established in 1–12 m depth; there are some cases of exceeding static levels of water over the surface level. The discharge rates of the wells are 90–170 m^3/day [3].

Let us consider the Upper Proterozoic deposits in Belarus. ***Orsha hydrogeological basin*,** which includes the Riphean and Vendian water bearing horizons in the open cut of the Upper Proterozoic deposits.

The Riphean Aquifer and the saline water-bearing horizon spread over almost everywhere. The occurrence depth of the upper boundary of hydrophilous deposits ranges from 200 to 470 m in the South and West of the basin area and reaches 1,100–1,300 m in the North-East. The thickness ranges between 30 m in the outskirts and 1,000 m in the central part of the hydrogeological structure. The bearing rocks are mostly represented by sand rocks of different granulity, openness and cleavage, determining the water inflow in the horizon. The specific discharge rates of the wells vary from 5 to 50 m^3/day/m. The piezometric surfaces are established in 18–120 m depth; the artesian wells are often noted.

The groundwater is mostly mineralized, with available salts volume being within 35–50 g/dm^3 in the central and south-western parts and 100–150 g/dm^3 in the north-eastern part of the basin.

The Vendian Aquifer and the saline water-bearing horizon are widely spread in the whole territory of the Orsha hydrogeological basin. The occurrence depth of the upper boundary of bearing rocks is 120–200 m in the West of the structure and up to 800 m in its North-East. The specific discharge rates of the wells vary from 5–9 to 90–172 m^3/day/m. The piezometric surfaces are established at the depths of 1.3

to 130–140 m related to the ground level. In separate cases, the static levels exceed marks of the surface level by 4–8.5 m.

The mineralization and chemical composition of the Vendian deposit groundwater vary from the fresh (up to 1 g/dm^3) calcium hydrocarbonate to sodium chloride saline water with its mineralization up to 150 g/dm^3 in the North-East of the basin.

In the Vendian open cut, mostly water-proof Volyn, Vilcha and Valday rocks developed which form regionally sustained confining layer up to 300–400 m thick that separates the hydrogeological systems of the Upper Proterozoic and the Palaeozoic.

The Brest Hydrogeological Basin. The Upper Proterozoic deposits are represented by the Vendaian Valday and the Volyn formations. The rocks of the Volyn series in the structure of tuffogenic and sediment rocks form a regional confining layer for the whole basin area. The hydrophilous rocks are sand rocks and rock clays of the Valday series. The occurrence depth of the upper boundary of the hydrophilous rocks ranges from 150 to 630 m, with its thickness reaching 220 m.

The groundwater is mostly fresh and low mineralized (up to 1–3 g/dm^3); the mineralization can be 15–20 g/dm^3 only in the sunk parts of the water bearing horizons. Chemical composition of fresh water is sodium hydrocarbonate or calcic, and the composition of mineralized water features by sodium chloride. The water is mostly pressurized; the piezometric surfaces related to the surface level are established at the marks of 0–45 m [8].

The Pripyat Hydrogeological Basin. The Upper Proterozoic deposits rest on a crystalline basement, with the occurrence depth of the latter ranging from 2 to 200 m within the Mikashevichi and the Zhytkovichi projection up to 5,800–6,200 m in the Yelsk trough fault and at the Malodushin-Chernoslobodska stage.

The hydrophilous rocks are anisomerous sand rocks with the interbeds of siltstones and Riphean clays, as well as palaeoglaciogenic sand and clay rocks of the Vilcha series and calc-sinter, sand rocks and siltstones of the Vendian Volyn series. The total thickness of the Upper Proterozoic deposits reaches 800 m.

The aquifer area of cracky Archean-Lowproterozoic rocks of the crystalline basement is developed throughout the whole Belarusian national territory. The occurrence depth of the upper boundary of the basement ranges from 80–250 m (in the crest of the Belarus anticline) to 1,500–1,700 m (in the Brest and Orsha basins) and 6,200 m (in the Pripyat River basin). The hydrophilous rocks are cracky and eroded kinds of metamorphic and intrusive rocks (gneiss, shale rocks, granite, syenite, gabbro). The water related to them is pressurized; the piezometric surfaces are recorded in 0.7–38.0 m depths and more; the well springs have been observed in individual wells. The water recharge in the deposits depends on cleavage and weathering conditions of the hydrophilous rocks. The discharge rates of the wells vary from 0.03 to 8.3 dm^3/s, with decreases being 14–54 m.

Groundwater is fresh (its mineralization amounts to 0.16–0.4 g/dm^3) on the sites where the basement depth is not too low, however, as the depth increases, fresh water gradually becomes more and more mineralized and salty (14–51 g/dm^3) in the Brest and the Orsha basins.

8.3 The Transboundary Aquifers

The Brest Basin and the structures adjacent to it are of specific transboundary interest to Belarus, Ukraine and Poland [2]. The complex geological setting appears the result of the block tectonics of the crystalline basement. The accretions of sediments and the underlying rocks till the Silurian development have been disrupted into blocks by ruptual tectonic leaps. The blocks feature by their varying displacement amplitudes. The Jurassic sediments covering them and the overlying formations dip smoothly in the Western direction and are not touched by splits [8].

The main features of geological setting of the Brest Basin became known in result of the deep drilling survey and the geophysical exploration carried out there in the 1950s through 1960s. Pilot exploration works for coal and oil were conducted in that period. However, no positive results were attained. All the basin sediments appeared washed out by infiltration waters and the local low amplitude structures (Kustinskaya and Pribugskaya) were water cut.

During deep drilling on various sites of the Brest Basin, the mineral water of different chemical composition was found, and the available fresh water in the Cambrian sand rocks at considerably big depth (940–1,090 m) was detected, as well.

At the Pribugskaya structure, four structural wells (26 k, 28 k, 29 k, 31 k) 1,202–1,762 m deep were drilled in 1971–1972. During 1976–1997, the total of 106 wells 550–1,600 m deep were drilled, as situated in relatively confined 9×3 km^2 area. All the wells undergone a set of comprehensive tests for their hydrogeological parameters and water quality of three horizons of the Cambrian sand rocks. Those delivered material qualitatively sufficient on groundwater bearing horizons ranging between 930 and 1,240 m.

Geological cross-section of the Brest Basin could be presented as a powerful two-layer sediment stratum laid on a crystalline basement. The lower strata includes formations of the Riphean and Venda system of the Upper Proterozoic, Cambrian, Ordovician, Silurian, and sometimes Permian and Triassic periods, filling along with the basement from the East (Belarus) to the West (Poland), with a big drift. The upper stratum which combines sediments of the Upper Jurassic, Cretaceous, Palaeogenic, Neogenic, and Anthropogenic periods, with a smaller gradient in the same direction covers the older formations everywhere.

A large water drive system formed during geological development process of the region in question. This system is called the Brest Artesian Basin. The Basin relates to the eastern, mostly pitched part of the second Class Podlyassye-Brest Artesian Basin which, in turn, falls in the larger first class Mazovian-Lublin Artesian Basin, with the most part of which being located in Poland.

In the open cut of the sediment stratum of the Brest Artesian Basin, a set of regionally spread water bearing horizons and systems separated by low penetrating strata could be distinguished. The main feeding and recharge of the groundwater resources occurs in the internal basin territory due to infiltration of the atmospheric condensation and water from surface watercourses and water reservoirs.

The groundwater flow from the pitched feeding areas, reflects in both the terrain features and the buried tectonic structures of the crystalline basement (the Belarus anticline, Polesye saddle, the Ratnovsky Projection) to areas of local loading-out: such rivers as the Zapadniy Bug, Mukhavets, Lesnaya, etc., as well as to the West to the Podlyasskiy Basin, in the form of the deep run-off.

The proximity of the areas with permanent atmospheric feeding, transit and deep run-off under conditions of a long-term continental break in sedimentation (around 300 million years) and active penetration of infiltration water caused a deep wash and freshness of the sedimentary cover water. Therefore, in the deepest part of the Brest Basin, a powerful area of fresh hydrocarbonate water (mineralization of 1 g/dm^3) formed with this area exceeding 1,000 m altitude. Near the City of Brest, this area comprises sediments from the Anthropogenic to Cambrian period, inclusive.

The severe regional confining layer is formed by the Volyn volcanic units of the Upper Proterozoic period consisting of basalt, andesite, calc-sinters and tuff sand rocks. These deposits divide the sedimentary cover into the areas featuring by intensive and slow groundwater flows. The clay horizons within the Cambrian sand rocks, as well as sufficiently compact clay chalk stones and chalky clays of the Ordovician and the Silurian period do not impact the conditions of fresh infiltrating water circulation and are considered, in the centre and in the circumferential direction of the basin, as the penetrating ones, in the single stratum of hydrophilous rocks of the Cambrian, Ordovician and Silurian periods. The mineralized chloride sodium water links to the Volyn volcanic rocks and sand rocks of the Pinsk series of the Upper Proterozoic period laying under it, as well as cracky rocks of the crystalline basement. Obviously, the solid volcanic rocks play a significant role in prevention of water filtration and increase the groundwater total mineralization not only at big depths of the Brest Basin. At significantly smaller depths of 350–650 m, these rocks and the Pinsk sand rocks are linked with saline water (3–18 g/dm^3) at the Ratnovo projection and the slopes of the Polesye Saddle.

Thus, the deep penetration of infiltration water in the major part of the Brest Basin prevails to a volcanogenic regional confining layer. The hydraulic connection between all the water bearing horizons and their demineralization is revealed there. The continuous groundwater flow of the atmospheric genesis from the eastern raised feeding areas to the Podlyasskiy Basin contributed to their active intrusion into ancient strata. Formation of hydrostatic stratified pressures in the upper area of the fresh water is caused by a difference between the absolute and the relative terrain heights and the aquifer layers, in the field of feeding and transit. The groundwater pressure in the deep area of fresh and more mineralized water is also caused by the geostatic pressure of consolidating rocks and it depends on their hydraulic and ductile properties. In the lower area, the high geostatic layer pressures are often connected with water squeezing from the clay to sand collectors. A comparison of the piezometric surfaces of the Cambrian and overlying water bearing horizons in the deep part of the basin shows that the absolute values of the deep water pressures in the discharge areas are exceeded by the values of the upper horizons. This fact provides for groundwater flow from the bottom upwards and, obviously, the partial groundwater discharge in erosion channels of the river valleys.

8.4 Conclusions

There are five main water pressurized systems in the national territory of Belarus that are widely used for the purpose of general water supply: Quaternary, Palaeogene, Albian-Cenomanian, Devonian and the Upper Proterozoic. As of the date, scale 1:500,000 hydro geochemical maps are produced for the Palaeogenic, Albian-Cenomanian and Devonian systems; with the maps being the basis for the future drawing up the international maps of transboundary aquifers.

In view of the fact that the current management of the transboundary water resources is carried out within the river basin systems, the Author listed below both the transboundary aquifers identified in specific river basins and the groundwater flow directions.

The Zapadnaya Dvina River Basin
Belarus, Latvia and Russia occupy this river basin area.
The transboundary groundwater aquifers are following:

– The Quaternary deposit aquifers (systems),
– The Middle and Upper Devonian Starooskolsky and Lansky terrigenic aquifer system,
– The Upper Devonian terrigenic carbonate aquifer system.

Prevailing direction of the groundwater flows is from Belarus to Latvia.
The Upper Devonian terrigenic carbonate aquifer system is common for Belarus and Russia. Prevailing direction of the groundwater flows is from Russia to Belarus.

The Neman River Basin
Belarus, Latvia and Poland occupy this river basin area.
The transboundary groundwater aquifers are following:

– The Quaternary deposit aquifers (systems),
– The Albian-Cenomanian carbonate terrigenic aquifers,
– The Ordovician and Silurian carbonate aquifer system.

Prevailing direction of the groundwater flows is from Belarus to Latvia.

The Bug River Basin
Belarus and Poland occupy this river basin area.
The transboundary groundwater aquifers are following:

– The Quaternary deposit aquifers (systems),
– The Palaeogene-Neogene terrigenic aquifer system,
– The Oxford and Cenomanian carbonate terrigenic aquifer.

Prevailing direction of the groundwater flows is from Belarus to Poland.

The Dnieper River Basin and the Pripyat River Sub-basin
Belarus, Ukraine and Russia occupy these river basin areas.

The transboundary groundwater aquifers are following:

- The Palaeogene-Neogene terrigenic aquifer system. Prevailing direction of the groundwater flows is from Belarus to Ukraine,
- The Cenomanian carbonate terrigenic aquifer. Prevailing direction of the groundwater flows is from Belarus to Ukraine,
- The Upper Proterozoic terrigenic aquifer system. Prevailing direction of the groundwater flows is from Ukraine to Belarus,
- The (Dnieper River basin) Upper Devonian terrigenic carbonate aquifer system. Prevailing direction of the groundwater flows is from Russia to Belarus.

These are just preliminary conclusions based on available publications, the major ones of which are listed below. The more specific conclusions, including directions of the groundwater flows, the hydro-chemical composition thereof, and the use-rate of the transboundary aquifers will be possible to drawing up, once special survey is complete in the framework of the future international (two- or three-party) projects.

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Chapter 9
Groundwater Monitoring and Transboundary Cooperation in Lithuania

Jurga Arustienė and Jurgita Kriukaitė

Abstract In Lithuania the transboundary groundwater flows have been identified in border area with Belarus, Latvia, Poland and Kaliningrad oblast (Russia). There is a different level of aquifer identification. Although the research do not indicate the influence of groundwater abstraction on the qualitative and quantitative parameters. The paper describe the major projects carried out in the areas of transboundary aquifers base on the cross-border activities conducted in accordance with the requirements of the EU Water Framework Directive. The need of obtaining representative information on the qualitative and quantitative status of drinking groundwater resources was identified. This information should become a background for scientific works for sustainable management of groundwater resources shared with neighboring countries.

Keywords Groundwater monitoring • Transboundary aquifers • Groundwater status assessment

9.1 Introduction

The Republic of Lithuania is a country situated along the south eastern shore of the Baltic Sea, and across the Baltic Sea to the west lie Sweden and Denmark. It shares borders with Latvia to the north, Belarus to the east and south, Poland to the south, and a Russian exclave (Kaliningrad Oblast) to the southwest. Lithuania has a population estimated at 3.2 million in 2011, and its capital and the largest city is Vilnius. Lithuania has four official river basin districts that are part of the Baltic

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Sea region. The largest part of the country is within the Nemunas rivers basin, which is shared with Belarus and Kaliningrad oblast, the Venta and Lielupe river basins in the north shared with Latvia and the Daugava basin.

9.2 Groundwater Bodies and Their Status in the Transboundary Context

In Lithuania, the drinking water supply relies only on groundwater. Therefore, sustainable management of groundwater resources and their protection are very important tasks included in River Basin Management Plans. Implementing the requirements of the Water Framework Directive, (2000/60/EB) 20 groundwater bodies were delineated in the territory of Lithuania. The groundwater bodies have been identified taking into account the lithological, hydrodynamic and hydrochemical differences of aquifers and groundwater use within the bodies. Actually, 15 of the groundwater bodies are transboundary. Though the boundaries of groundwater bodies do not match with those delineated in Latvia and Poland, adjacent groundwater bodies have the same hydrogeological background, so are comparable.

Mathematical modelling was used for the impact assessment of point and non-point pollution on the quality of groundwater bodies and surface-groundwater interaction [1] in Lithuania. It has been established that groundwater abstraction has no negative effect on surface water bodies or terrestrial ecosystems dependent on groundwater, or on the status of groundwater aquifer in the neighbourhood of preserved natural objects. The results of mathematical modelling and groundwater quality maps indicate that groundwater chemical status in Lithuania is good – anthropogenic activities do not affect groundwater status on a regional scale. Salt water intrusions under Lithuanian geological conditions are a potential source of risk, especially in the confined aquifers. Five groundwater bodies potentially at risk have been identified. The chemical composition of groundwater in these bodies fails to conform to the requirements of the established drinking water standards due to natural reasons. Since increasing trends of water deterioration as a result of human activities are not clear yet, it is suggested that additional monitoring is carried out during the next planning period (2010–2015) and that the impact of groundwater abstraction activities on the changes of water quality is analysed.

Assessment of transboundary impact on groundwater resources – quality and quantity revealed, that groundwater abstraction in neighbour countries does not significantly affect groundwater resources, neither diffused nor point source pollution affect groundwater quality on the Lithuanian side [2]. International impact on surface waters is much more significant. The River Nemunas is the natural boundary between Lithuania and Kaliningrad oblast; it serves as discharge area for shallow and Cretaceous confined aquifers, and prevents transboundary contamination of groundwater on both sides. Groundwater abstraction in Kaliningrad oblast near the border towns Sovietsk and Neman could have some impact on the Pagėgiai well field

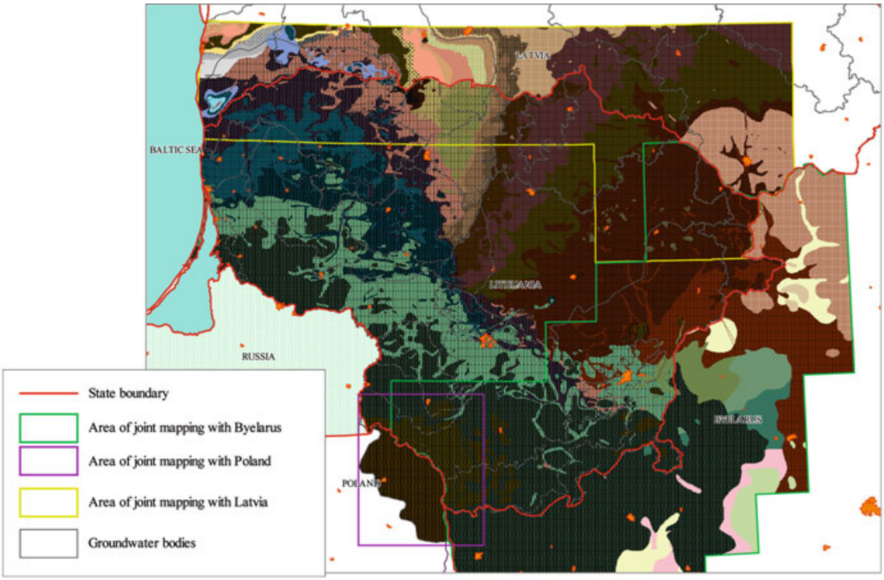

Fig. 9.1 Areas of cross-border cooperation (in the background hydrogeological map of pre-quaternary deposits)

located on the Lithuanian side. Modelling results show that maximal abstraction on the Kaliningrad side might result in the lowering of the groundwater level by 0.4–0.6 m on the Lithuanian side, but this should not affect the well field resource.

In the largest part of the south eastern border with Belarus, forests with wetlands are prevalent; the territory is sparsely populated, without industry, so groundwater pollution and abstraction do not affect the status of groundwater bodies. In the border area with Poland recreational land use continues, the major settlements of Suwalki and Augustów are located 35 km from the state border, so groundwater abstraction could not affect the status of groundwater bodies (Fig. 9.1).

The major groundwater flow direction in the Lithuania–Latvia cross border area is oriented towards the River Daugava on the Latvian side and prevents the possibility of contamination of aquifers from Latvia (Fig. 9.1).

9.3 Groundwater Monitoring in Lithuania

In Lithuania, three levels of groundwater monitoring – national (surveillance), municipal and economic entities – are legally defined. The Lithuanian Geological Survey is responsible for the execution of national groundwater monitoring and supervision of the monitoring methodology of economic entities, as well as data analysis and selection of environmental measures.

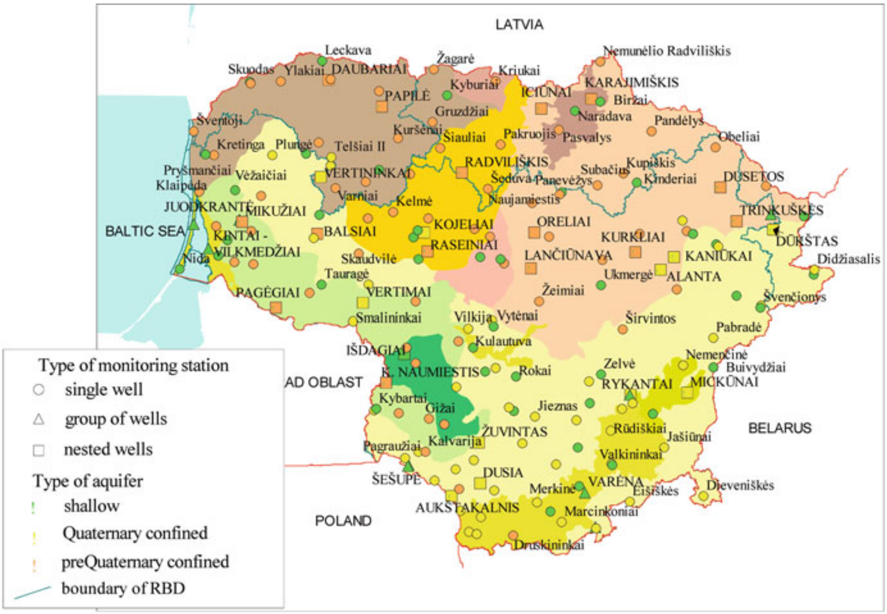

Fig. 9.2 National groundwater monitoring network

The National groundwater monitoring covers the entire country and reflects different hydrogeological and environmental conditions (Fig. 9.2). Groundwater monitoring is executed as part of the state Environment Monitoring Programme for 2011–2017, which succeeds the previous programme for 2005–2010. The main tasks are to assess renewal of groundwater resources, chemical status of groundwater bodies, changes of groundwater quality and main factors governing the observed processes. In the sense of the Water Framework Directive requirement for groundwater monitoring, national groundwater monitoring in Lithuania is in accordance with the definition of surveillance monitoring.

Groundwater level and temperature are measured daily by automatic data loggers in 75 observation wells since 2005 (previously it was done manually). Taking into consideration the necessity of high quality on-line data within the frame of the programme, an ad hoc project “Installation of telemetric stations and telemetric centre” was implemented. During this project, 18 wells located in meteorological and two in groundwater monitoring stations were equipped with telemetric stations, which sent the groundwater level and temperature measurement data daily to the information centre installed in the Lithuanian Geological Survey. Groundwater level measurements are focused on shallow groundwater in order to follow up impact of climate changes to groundwater resources recharge.

Groundwater sampling and analysis of different compounds are performed using the rotation principle. Shallow groundwater is sampled more often than confined aquifers, and analysis of such compounds as pesticides, heavy metals, organic compounds is envisaged once in a 5 years monitoring cycle. Groundwater is sampled annually for basic chemical composition (main ions and other parameters) and nutrients. Thought some monitoring stations have more than 30–40 years of observations history, such compounds as pesticides, organo-chlorides and some metals were rarely investigated. Currently 180 monitoring wells are under observation.

Municipal groundwater monitoring intended for observing the groundwater in the areas important for municipalities and is usually part of the environmental monitoring programme has recently been executed in seven municipalities (out of 60): Šiauliai since 2000, Alytus and Druskininkai 2001, Panevėžys and Kaunas 2005, Varėna 2006 and Vilnius 2007.

Environmental monitoring in the locations of economic entities is performed to assess the discharge of pollutants and their impact on the environment as well as to choose the appropriate environmental measures for mitigation of their negative impact. Groundwater monitoring is obligatory for groundwater users (well fields extracting more than 100 m^3/day) and economic entities, which are listed as potential polluters. Groundwater monitoring is executed based on individual monitoring programmes prepared for a period of 5 years, which are approved by representatives of the Lithuanian Geological Survey and Regional Environmental Departments. All groundwater monitoring data are provided to the Lithuanian Geological Survey and stored in the Geological Information System.

Groundwater monitoring in 2010 was conducted in 895 potential pollution sites. Petrol stations (564) and oil storage units (86) compose the largest element. During recent years, the waste management system has been transformed, old landfills were closed and ten new regional centres were installed. Groundwater monitoring networks were installed in the vicinity of 76 former landfills. During the last few years, the number of agricultural enterprises, performing groundwater monitoring, doubled from 41 in 2006 to 82 in 2010. Most of the waterworks also perform groundwater monitoring.

9.4 Multilateral Projects

The transboundary cooperation between geologists, hydrogeologists and environment specialists was and still is depended on political boundaries. Formerly, before 1991, Lithuania's neighbours, except Poland, were republics of the USSR. Hydrogeological investigations usually were carried out using similar methodology and special projects such as compilation of regional hydrogeological maps in scale 1:500,000 (published in 1980) resulted in the close cooperation of specialists. Currently Belarus and Russia are non-EU countries and cooperation in transboundary issues is based on good neighbour practice rather than on obligatory requirements. Despite differing political situations, the Lithuanian Geological Survey can present examples of multilateral projects with all neighbouring countries carried out during the last two decades. Mostly, cooperation starts as joint mapping in border areas, later environment projects proceed.

9.4.1 Lithuania–Latvia

The project “Pre-Quaternary geological map of Lithuanian–Latvian cross-border area at a scale of 1:200,000” was started in 2000 by the Geological Survey of Lithuania together with the Geological Survey of Latvia and completed in 2003 [3]. The aim of the project was to compile a set of digital geological and structural maps of the Lithuanian–Latvian cross-border area. As a result, the pre-Quaternary geological map at a scale 1:200,000, and a set of structural maps for the reference strata at a scale of 1:500,000 for the cross-border area have been compiled. The maps were compiled based on a complex integration of available well data stored in the archives of the Lithuanian and Latvian Geological Surveys as well as seismic, well log and published data. The substantial problems related to the differences of the local stratigraphical schemes were solved after the compilation of the common legend, which was suitable for the geological maps of both the Latvian and the Lithuanian territories. The fact that the newly compiled set of maps is prepared in digital form is especially important, which enables efficient updating of maps. In addition, the maps may be easily plotted in different sizes and efficiently used as a background for hydrogeological, ecogeological and other scientific and applied maps.

A digital Quaternary geological map at a scale 1:200,000 was prepared in 2008 for 20 km wide areas on both sides across the Lithuanian-Latvian [4]. Close long-lasting collaboration of Lithuanian, Latvian and Estonian geologists during the mapping of Quaternary deposits ensured the application of unified mapping methods and map legend, thus during the compilation of the Latvian-Lithuanian cross-border Quaternary geological map only the discrepancies of geological boundaries because of different scales had to be eliminated. The correlation of geological boundaries was based on remote sensing methods, i.e. on orthophotographs and aerial photos after their stereoscopic study. Cartographers of a map expect that despite small discrepancies the newly compiled map shall be useful for the solution of different environmental and land use problems in the cross-border area.

9.4.2 Lithuania–Belarus

The joint Lithuanian–Belarusian project of the integrated geological mapping for 51,000 km^2 of the cross-border area was completed in 2005 [5]. A set of maps at a scale of 1:200,000 was compiled using the integrated topographic basic map as a background. The set consists of pre-Quaternary geological map, map of the Quaternary deposits, Geomorphological map, Natural resources map and Hydrogeological map of the pre-Quaternary aquifers. The pre-Quaternary geological map and information of wells serve as a basis for the hydrogeological map of the pre-Quaternary aquifers in the Lithuanian–Belarusian cross-border area. The pre-Quaternary geological map and information concerning wells serve as a basis for the hydrogeological map of the pre-Quaternary aquifers in the Lithuanian–Belarusian cross-border area. Six aquifer complexes were mapped. The Paleogene–Neogene aquifer complex is only located at the south western edge of Lithuanian territory and occurs at a depth of 40–120 m from the surface. The Upper–Lower Cretaceous aquifer complex is exploited in both Lithuania and Belarus. This complex extends the furthest and almost completely covers the north western and southern part of the mapped area. The depth of the complex is from 30 to 220 m. The Permian aquifer is found locally on the pre-Quaternary surface of Lithuania. The Upper–Middle Devonian terrigenous aquifer complex covers the northern part of the Lithuanian–Belarusian cross-border area. It lies at a depth of 50–180 m from the surface. The Middle Devonian Narva terrigenous aquifer complex extends into Belarus and is exploited there. In Lithuania, it is not used for water supply while passing into the regional Narva drainage basin. The Silurian, Ordovician, Cambrian and Vendian aquifer complexes are spread on the pre-Quaternary surface of the mapped territory in Belarus only.

9.4.3 Lithuania–Poland

The most fruitful cooperation during the last two decades was between specialists from the Lithuanian Geological Survey and the Polish Geological Institute. The cooperation started, when the joint Polish-Lithuanian environmental geological research “Belt of Yotvings – part of Green Lungs of Europe” programme was initiated in 1992. This programme dealt with the collection of all information significant for assessment of geological environments, resources and possible hazards in order to ensure sustainable use of the subsurface resources and better living conditions for the population. As a result “The Atlas – Geology for Environmental Protection and Territorial Planning in the Polish-Lithuanian Cross-border Area” [6] was printed at a scale of 1:500,000. It presents synthetic geological, geomorphological, geochemical, radioecological, hydrogeological, mineral resources and other environmental geological data intended for environmental protection and territorial planning of the cross-border area. In 2005–2007, a number of new joint projects were completed. Ten years after the geochemical mapping of the Lithuanian–Polish cross-border zone, the geochemists accomplished geochemical monitoring [7]. Geochemical investigations were repeated at each tenth sampling site in the years 1995–1996, and this time the topsoil and the subsoil were analysed. Geochemical data concerning soil quality in cross-border area were recently used for adjustment of recreational tourism routes. Geopotential and Geohazards maps were compiled additionally in 2006 within a framework of bilateral project [8]. The recent information on mineral resources, tectonic conditions, territorial land use and relief, as well as potential contamination sources was used for the Geopotential map compilation. The Geohazard map includes information about main tectonic elements, magnetic anomalies, macro seismic data; distribution of steep (>15°) slopes, groundwater monitoring points of cross-border area network; occurrence of high heavy metal (Pb, As) concentrations in topsoil, greatest potential contamination sources.

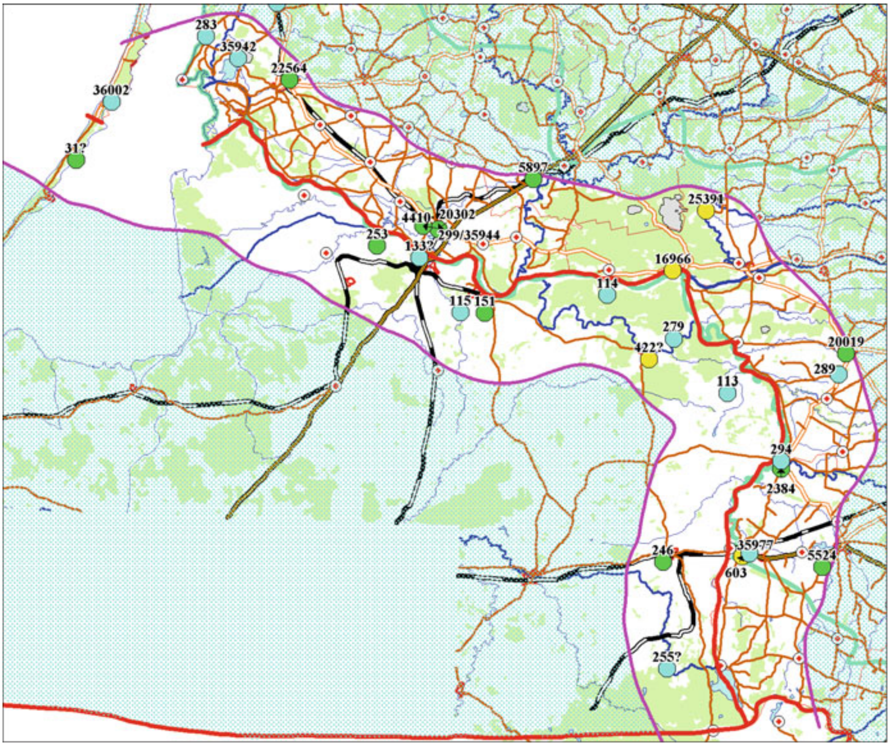

Fig. 9.3 Network of the groundwater monitoring in the Lithuanian–Polish cross-border area

The digital terrain model of the cross-border area is presented as the basis of this map. The model was prepared according to satellite images. Additionally geological information necessary for creation of "Geopark Yotvings" located in North Eastern Poland and South Western Lithuania was collected. Information about geotops was included in the database and specialists prepared the Geotourist map of the "Geopark Yotvings" at the scale 1:200,000 [9].

The joint groundwater monitoring in the Polish–Lithuanian cross-border area was launched in 1994. In Lithuania, it is executed as a part of the national monitoring programme. The main purpose of the current monitoring programme is to evaluate and monitor the fresh groundwater resource status and to establish the groundwater quality and its variation tendencies. In the Polish part, the monitoring network includes 15 stations and in the Lithuanian part it involves 15 stations composed of 20 national groundwater monitoring wells (Fig. 9.3), arranged in the shallow groundwater (5 wells), Quaternary confined aquifer (13 wells), and Palaeogen and Cretaceous aquifers (1 well in each).

From the beginning of joint monitoring special attention was paid to the quality and comparability of monitoring data – sampling and handling procedures, quality of laboratory analyses. Joint field investigations are carried out regularly (once per

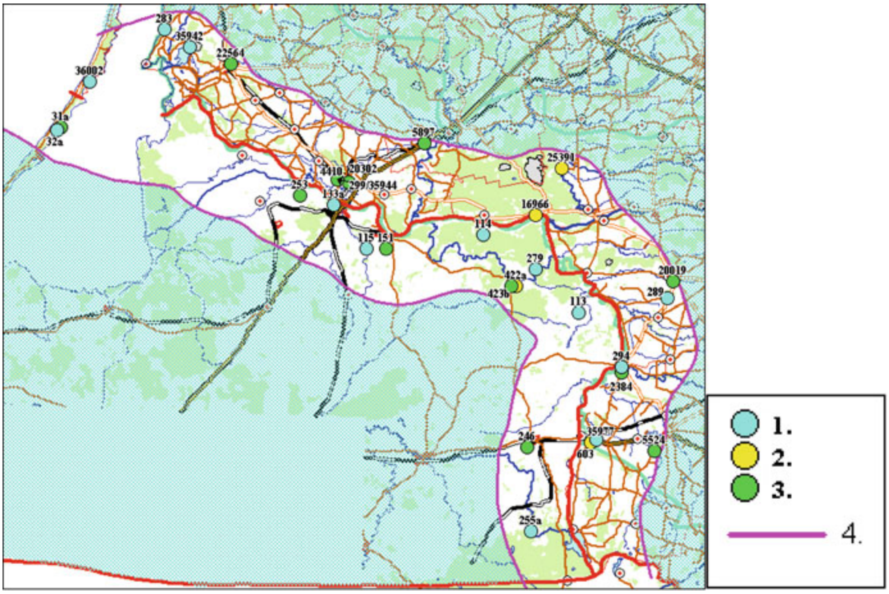

Fig. 9.4 The network of groundwater monitoring in the Lithuanian–Kaliningrad cross-border area. *1–3* groundwater aquifers: *1* shallow, *2* Quaternary confined, *3* pre-Quaternary confined, *4* boundary of monitoring in the cross-border area

year) together with the specialists from the Polish State Geological Institute in the selected frontier stations. The differences of chemical analysis performed in different laboratories, fall within an acceptable range of 10%.

9.4.4 Lithuania–Kaliningrad Oblast

The Lithuanian Geological Survey possesses unified geological data for the cross-border areas with Latvia, Belarus and Poland. Only the Kaliningrad area remains a "white spot". Despite this fact, groundwater monitoring in the Lithuanian–Kaliningrad cross-border area started in 2010 [10]. Groundwater monitoring is executed as a part of the State Environmental monitoring programme. The monitoring is conducted in a 10–15 km wide zone on either side of the state frontier (Fig. 9.4) and it embraces the monitoring of quality and quantity of the main aquifers. In the Lithuania part, it consist of 19 national groundwater monitoring wells, arranged in the shallow groundwater (9 wells), Quaternary confined aquifer (3 wells) and Cretaceous aquifers (7 wells). Groundwater levels are measured daily by automatic data loggers in six shallow groundwater wells. In the Kaliningrad part, the monitoring network consists of 13 observation wells, arranged in the shallow groundwater (7 wells), Quaternary confined aquifer (1 well) and Cretaceous aquifers (5 wells). The intercalibration of sampling methods and laboratory analysis is foreseen in the near future. Based on available information, aggregated maps of the cross boundary area have been drawn and the newsletter for 2010 has been developed. The website of the Lithuanian Geological Survey provides information on the investigation territory, monitoring network and results.

Such examples of co-operation show that we are prepared to go further in trans-boundary groundwater resources management and obtain representative information on the qualitative and quantitative status of drinking groundwater resources.

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Chapter 10
Groundwater Monitoring in Belarus: Implications and Future Prospects

Olga A. Berezko and Olga V. Vasneva

Abstract Peculiarities of groundwater monitoring in Belarus are discussed in the paper. Processes of their accumulation, analysis, systematization and data generalization concerning quantitative and qualitative parameters of groundwater are discussed. The structure and composition of the monitoring database is described. The positive directions of development of groundwater monitoring are discussed.

Keywords Groundwater monitoring • Groundwater quality • Groundwater level regime • Database

10.1 Introduction

Groundwater monitoring in Belarus is an integrated system of collection, accumulation, storage and processing of information about the underground hydrosphere conditions influenced by natural and anthropogenic factors and transmission of the results obtained to governmental and management authorities engaged in performing national tasks of environmental protection and efficient use of mineral resources.

Groundwater monitoring is performed in the framework of the National Environmental Monitoring System in order to assess and analyse the changes in groundwater quality and levels under natural conditions. The monitoring activities are executed by the State Enterprise "BelNIGRI" and Central Hydrogeological Unit of the Republican Unitary Enterprise (RUE) "Belgeologiya".

Observation stations are wells that are specially equipped in different aquifers and auriferous complexes.

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DOI 10.1007/978-94-007-3949-9_10,

Fig. 10.1 Sketch map of groundwater monitoring

Regulatory and legal framework governing the implementation of groundwater monitoring: The Code of Mineral Resources of the Republic of Belarus, the Water Code of the Republic of Belarus, the Instructions for the procedure of groundwater monitoring.

The main objectives of groundwater monitoring are as follows:

- Collection, processing, analysis and storage of groundwater quantitative and qualitative indices information, visualisation of cartographic material;
- Comprehensive assessment of major aquifers and complexes for qualitative and quantitative indices and forecast of their changes under the effect of natural and anthropogenic factors;
- Groundwater database maintenance;
- Preparation of reports, bulletins and other information concerning groundwater conditions;
- Presentation of information obtained as a result of groundwater monitoring to State authorities, local executive and administration bodies, scientific institutions, corporate entities and citizens [1].

Basic information for groundwater monitoring is the original (primary) information, i.e. data on the levels, chemical composition, hydrogeological sections and registrations of observation wells. The primary information is supplied by the Belarusian hydrogeological expedition of the Central Hydrogeological Unit of the RUE "Belgeologiya" to the information-analytical centre. A comprehensive assessment of the main aquifers and complexes from qualitative and quantitative indices and forecast of their changes under the influence of natural and anthropogenic factors are undertaken at observation sites found in natural and slightly disturbed hydrogeological conditions (Fig. 10.1). The optimisation of the network to create the necessary and sufficient number of observation sites was performed in 2010. The network of monitoring observations currently includes 94 operational hydrogeological stations (349 observation wells). Observations are made within five river basins: Western Dvina, Western Bug, Pripyat, Niemen, Dnieper.

Reasons for exclusion of wells from the register are: (1) failure, (2) abandonment of flowing wells, etc.

In accordance with the scale of monitoring processes the observation network is divided into three levels: national, background and transboundary ones. Each observation site describes the groundwater regime within a definite specific territory.

10.2 Groundwater Quality

Under natural and slightly disturbed conditions the groundwater quality is assessed in accordance with Sanitary Rules and Standards (SanPiN 10–124 RB 99 Drinking water. Hygienic requirements for water quality in centralised drinking water supply systems. Quality Control).

The chemical composition of groundwater is determined using 33 macro – and micro indices. Water is sampled for physical and chemical analyses once a year, and groundwater levels are measured three times a month. The chemical analysis of water is made at the Central Laboratory of the RUE "Belgeologiya".

Observations of groundwater quality in the country performed over the past 6 years show that changes in their chemical composition are due to both natural and anthropogenic factors. Increased concentrations of iron (1–10 MAC and above) and manganese (1–3 MAC), determined in groundwaters of Belarus are typical of humid areas of the East European platform, and the lower fluorine and iodine contents are due to natural hydrogeological conditions.

The anthropogenic effect is manifested in increased groundwater indices for ammonium nitrogen, nitrates, oxidation value, hardness, which indicate the presence of local sources of groundwater pollution mainly of agricultural and residential origin [2].

10.3 Groundwater Level Regime

The groundwater level regime is also studied within five river basins, that enables characterisation of the water level regime all over the territory and identification of the main factors responsible for its formation, such as:

1. Climatic factors involving precipitation and air temperature.
2. The territory of Belarus is situated in a seasonal spring and autumn feeding area. The annual groundwater and artesian water levels show respective seasonal rises alternating with summer and winter declines.
3. The observations of several years made in the territory of Belarus have identified some regions showing lowered average annual groundwater levels (areas of the Bialowieza Forest, Lake Naroch, lower reaches of the River Pripyat), which is due probably to the effects of land reclamation, or to a large number of resorts and holiday homes located in these areas (National water inventory… 2010).

At present, to improve the accuracy of information the monitoring network is being equipped with automatic instruments recording the water levels in wells. As of 2009 a total of 99 automated water level gauges, have been installed.

10.4 Database

The maintenance of the groundwater monitoring database is conducted using MS Access 2003 as a part of the MS Office standard package, which makes it open to users and external applications. Currently, the database of groundwater monitoring includes the following information:

1. General information of hydrogeological stations (rank, year of opening, the nearest settlement, administrative district, agency, river basin, water body, observing organisation, hydrogeological section and arrangement of wells).
2. Registrations of observation wells for hydrogeological stations, which provide the background information about the observation wells (drilling date, location coordinates, distance to a permanent stream, etc.). This information enables the more detailed study of geological and hydrological conditions of each particular well, lithological description of rocks, aquifer thickness, and well design.
3. Information from all the observation sites (observation wells), namely: mean monthly values of groundwater levels, physical and chemical composition of groundwater.

The database of groundwater monitoring allows a prompt graphics processing of the groundwater quality and level data, as well as to request information of the water quality composition at observation sites and of excess over the maximum allowable concentrations for all the monitored components, and to grant requests of authorities [3].

Annual monitoring observations are presented as annual reports, information and analytical reports, publications and information bulletins containing data of the groundwater conditions, are passed to the State authorities, to local executive and administration bodies, scientific institutions, legal persons and citizens.

10.5 Future Prospects

Groundwater monitoring is a complex system progressing with time. This requires continuous improvement of the observation network, design of observation sites, research methods as applied to new challenges of environmental management. Therefore, the positive directions of development of groundwater monitoring are as follow:

– Giving the State status to the observation regime network;
– Joint monitoring of border areas of neighbouring states by both states' specialists;
– Equipment of all the monitoring sites with automated instruments for measuring water levels and temperature to provide more accurate baseline data;
– Development and improvement of an automated database system for monitoring groundwater in accordance with modern information technologies;
– Creation of an integrated monitoring, i.e. linking groundwater monitoring to other types of monitoring within the National Environmental Monitoring System;
– Development of working mathematical models predicting changes in groundwater quality under natural conditions and in pollution areas;
– Improvement of the hydrogeochemical observation network at sites of anthropogenic impact, in particular, landfills, fields of filtration, landfilled hazardous substances, slurry tanks, etc.

The system of groundwater monitoring in the Republic of Belarus has progressed to a reasonably good level. However, further improvement of the observation system, the regime network structure, research methods applied to solving problems of groundwater protection, management and efficient use is required.

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Chapter 11
Groundwater Resources of Moldova and Transboundary Impact

Gheorghe Duca, Lidia Romanciuc, and Diana Porubin

Abstract In Moldova more than 95% of all drinking water for rural and urban settlements is drawn from groundwater sources and serves as the main source of drinking water for about 65% of the population. Moldovan citizens have witnessed significant deterioration of water supply services and a virtual cessation of wastewater treatment. The data show that 47% of the Moldovan population had no access to safe drinking water and 54.8% had no water piped to their households. The quality of surface and groundwater of the country in most cases does not reach the European and international standards. The transboundary impact is very important for the relations between Ukraine, Moldova and Romania and affects the socio-economic life of population. Problems such as the hydro-electric power station construction on the River Nistru, flow of waste-water, biodiversity of the River Nistru, use of water of the Nistru and Prut for irrigation affect Moldova and its neighbours and must be resolved by mutual consent. In this regard, the Moldovan Government has concluded bilateral agreements with Romania and Ukraine.

Keywords Drinking water • Groundwater • Wastewater treatment • Management of water resources • Transboundary impact

The water resources of the Republic of Moldova, which extend to **3,621 rivers** and rills with a total length approx. 16,000 km, **4,117 natural lakes** and artificial ponds, more than **7,000 springs** and approx. **166,500 groundwater wells**. Estimated theoretical potential of water resources in Moldova is **16 billion m³** (Fig. 11.1).

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Fig. 11.1 Water map of Republic of Moldova

Approximately 70% of the population lives in rural areas and 30% in urban areas. In Moldova more than 95% of all drinking water for rural and urban settlements is drawn from groundwater sources and serves as the main source of drinking water for about 65% of the population. Approximately 30% of the population is connected to piped supply of potable water supplies and sewerage systems, however in rural areas only 10% of the population are connected to potable water supplies and 2–3% to sewerage systems. Although most urban water supply systems provide treated water of acceptable quality, in the rural areas however, only 20% of deep and shallow wells are satisfactory. The average water consumption is 50 l per person per day. The total water consumption for rural areas is 50,000 m^3 per day, but many of the shallow wells do not meet health and epidemiological standards. Moldovan citizens have witnessed significant deterioration of water supply services and a virtual cessation of wastewater treatment. This has led to significant damage to people's health, caused by contaminated water and environmental degradation, caused by the inability to collect, treat and safely discharge wastewater.

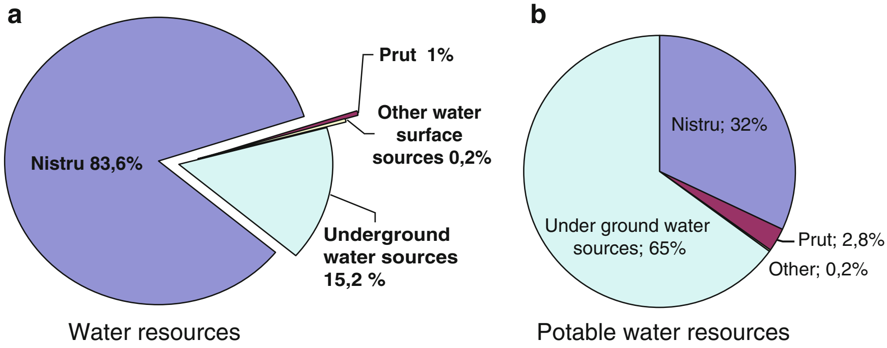

Fig. 11.2 Access to water sources. (**a**) Water resources; (**b**) potable water resources

The problems are closely related to the management of water resources, and namely the poor management that results in: limited access to water resources, poor water quality, effects of transboundary impact, inadequate water treatment and legislation.

The main sources of water provision are (Fig. 11.2):

– Rivers Nistru – 83.6%,
– River Prut – 1%,
– Ground waters – 15.2%,
– Other – 0.2%.

Groundwaters are considered the main source of drinking water in Moldova (Fig. 11.2), which supply approximately 100% of the rural population and 30% of urban population, or 65% of the total population. Of the surface sources the most important is the River Nistru, which accounts for 32%, the River Prut – 2.8%, other surface sources account for 0.2%.

The map (Fig. 11.3) demonstrates the expansion of centralised water and sewerage systems, which led to an improvement in public access to these services.

- Recent data show that, in 2008–2009, 47% of the Moldovan population, including the urban population from big cities, had no access to safe drinking water and 54.8% had no water piped to their households (*National Scientific- Practical Centre of Preventive Medicine*).
- There are significant local residential differences concerning access. The worst situation in this respect is in the central region of Moldova, where 72.3% of the population has no mains piped water supply in the house, compared to the South (68.9%) and the North (67.5%).

The quality of surface and groundwater of the country in most cases does not reach the European and international standards (UNESCO, the International Health Organisation, etc.). And the surface waters on the majority of the territory of Moldova are polluted by anthropogenic sources, in particular nitrates.

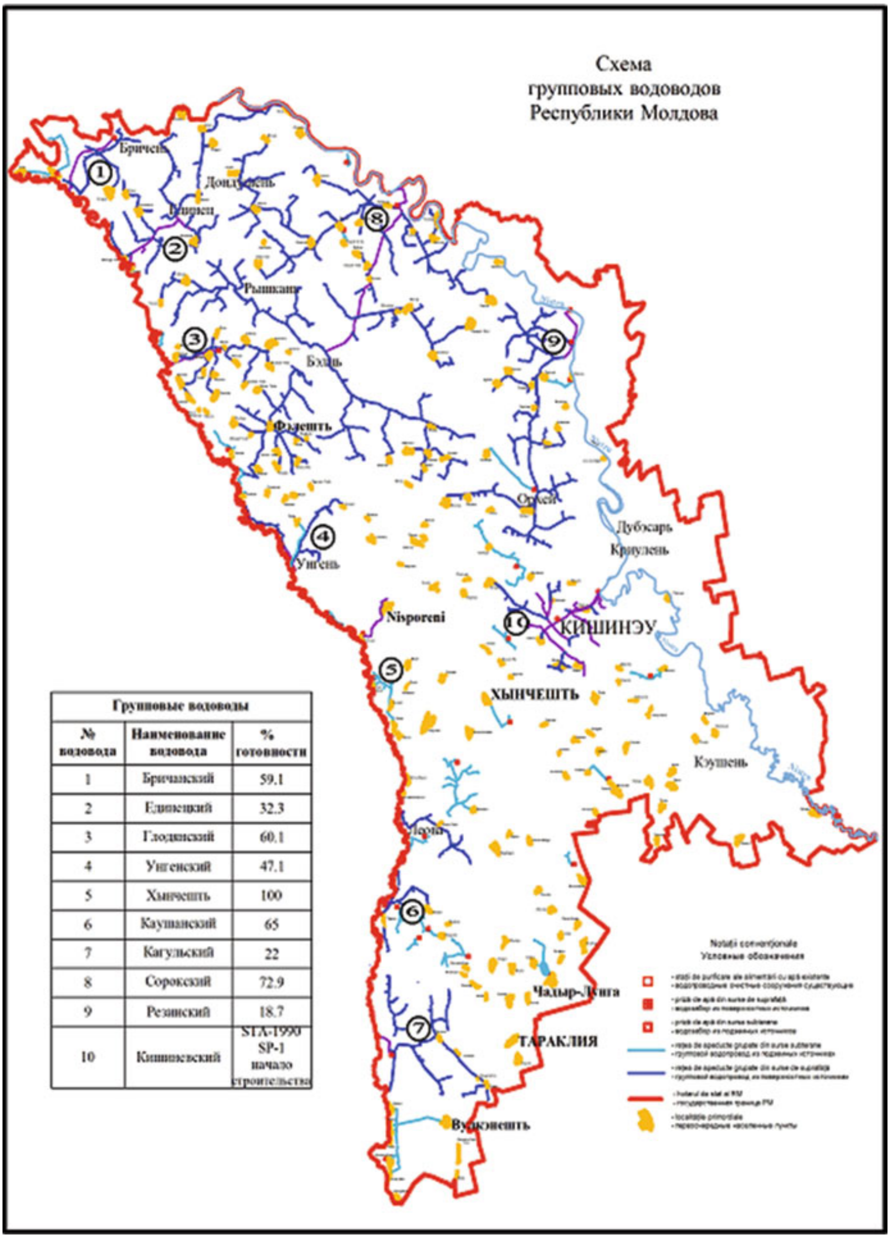

Fig. 11.3 Expansion of centralised water and sewerage systems has led to an improvement in access to these services

According to monitoring results, the pollution level of Prut, Danube and Nistru in recent years did not change significantly compared to previous years, with some exceptions.

In general, the waters of the above mentioned rivers are considered moderately polluted. Cases of high contamination were not detected. According to hydrochemical indicators, the water in these rivers corresponds to the II–III grade (clean and moderately polluted).

Therefore, based on their consumption and quality, these rivers are used as sources of drinking water. Small rivers remain highly polluted.

Throughout the country the quality of groundwaters does not meet the standard "potable water". In 87% of wells the water is polluted with nitrogen compounds (nitrates, nitrites), sodium, ammonia, strontium and hydrogen sulphide. According to research results, poor water quality is a determinant of various diseases such as: liver or gastrointestinal diseases, dental fluorosis etc. Using water polluted by nitrates leads to the generation of endogenous nitrous compounds that are considered super-mutagenic substances, which cause growth of tumour diseases. Epidemiological investigations indicated that the morbidity increased three times in areas where nitrate concentration exceeds 170 mg/l, compared with areas where nitrate concentration does not exceed the standard limit of 45 mg/l.

Sources of pollution of surface and groundwater are:

- Discharges of untreated water from municipal systems;
- Inadequate management of solid waste in all localities;
- Chaotic accumulation of livestock manure;
- Deposit of pesticides, etc.

11.1 Transboundary Impact

The main rivers of Moldova exposed to transboundary impact are the Nistru, Prut and the Danube. The transboundary impact is very important for the relations between Ukraine, Moldova and Romania and affects the socio-economic life of population. Problems such as the hydro-electric power station construction on the River Nistru, flow of waste-water, biodiversity of the River Nistru, use of water of the Nistru and Prut for irrigation affect Moldova and its neighbours and must be resolved by mutual consent. In this regard, the Moldovan Government has concluded bilateral agreements with Romania and Ukraine concerning information exchange on water quality of the Prut, the Danube and Nistru rivers.

The water contamination due to the social industrialisation remains one of the major ecological problems of this century.

In Moldova, rural areas and many enterprises lack wastewater treatment facilities or if available – they are in an unsatisfactory condition.

In the 1990s more than 600 treatment plants functioned in Moldova. At present, only 154 remain, which are currently working using obsolete facilities. In rural areas the situation is even worse because in most cases, the treatment facilities do not conform to modern requirements. There are cases when they are poorly connected to discharge collectors in a pond, and run-off infiltrates into the soil and groundwater.

The current legal framework (commencing at the Water Code 1993) does not fully take account of the water-related legislation of the EU, to which the Republic of Moldova seeks convergence.

- The fundamental objective of the National Development Plan 2008–2011 is the creation of the necessary conditions for improving the quality of life through sustainable and inclusive economic growth.
- The National Development Strategy (NDS) 2008–2011 targets the consolidation of measures for preventing pollution and promoting efficient use of natural resources in order to ensure continued health and quality of life.

11.1.1 What Is the Contribution of the Academy of Sciences of Moldova to the Improvement of the Situation Regarding Water Resources Management?

First of all, a State Programme is conducted on the subject of Scientific Research and Management of Water Quality. Development of both bilateral and multilateral international cooperation contributes to the exchange and transfer of knowledge and best practices on the inclusive issues of water resources management. Additionally, specialised events such as Ecological Chemistry or Water Quality Monitoring and Management are organised from time to time to raise public awareness on the issues related to water resources and their management.

The State programme combines activities within 13 research projects in five scientific fields:

- Investigation of Water Structure and Water Quality
- Surface Water
- Groundwater
- Water Treatment and Supply
- Irrigation Technologies.

The Academy of Sciences of Moldova (AMS) has undertaken a series of measures to establish the scientific approach in solving the problems related to management of water resources.

The State Programme "Scientific Research and Management of Water Quality" focuses on:

1. Increasing access to drinking water sources and improving the water supply and sewerage service quality;
2. Improving the environmental protection measures and reducing the influence of pollution on water supply depletion;
3. Preventing and reducing the degradation of water resources and increasing efficiency of their use; and
4. Creating a system of effective monitoring of natural disaster, prevention of compensation system damage.

ASM develops bilateral and multilateral cooperation with foreign Research and Development Institutions. Approx. 25% of the total numbers of supported projects are designated for water resources monitoring and management. Starting in 1985, a series of successful conferences on Ecological Chemistry were organised in Chisinau, each time gathering participants from NIS countries, European Union, USA and other countries. The next Ecological Chemistry Conference will be organised in March 2012. It will discuss such subjects as:

1. Ecological Chemistry of Water
2. Ecological Chemistry of Air
3. Ecological Chemistry of Soil
4. Ecological Chemistry and Healthy Style of Life
5. Ecological Chemistry and Sustainable Development

Three of these subjects will cover issues related to water management and water pollution impact on human health.

The measures taken to improve water supply have not brought significant results, due to the lack of connection between the common concept of national management of water resources and local solutions. In this context, the Academy of Sciences of Moldova proposes as quickly as possible:

To elaborate the concept of development of water supply and sewerage systems, including surface and transit water, by specialised agencies in cooperation with the scientific community, in order to reduce the consumption of groundwater:

- Towns from the northern region of Moldova will be connected to the Prut and Nistru rivers hydrographic network, including the Soroca-Balti-Costesti reservoir storage aqueduct;
- The centre of the country could be supplied from the River Nistru in the Vadul-lui-Voda region;
- The southern region of the Republic is recommended to be supplied from the River Danube.

Water supply must be arranged through a closed cycle system undergoing prior purification in the catchments facilities with further possible usage for irrigation.

Based on the new concept it is necessary to:

- Revise the National Strategy for water supply and sewerage of the localities;
- Create a single national database on water quality. The Academy of Sciences of Moldova has already launched the initiative to create such databases;
- Create an Interministerial Committee that shall monitor the efficient implementation of objectives for the water supply sector;
- Sign a transboundary agreement between Ukraine-Moldova-Romania on monitoring, forecasting, flood prevention and sustainable exploitation of aquatic ecosystems (including relaunching of international research programmes in the basins of the Nistru and Prut).

All these measures shall help Moldova within a period of 3–4 years to implement efficient management of water resources adapted to the requirements of the Framework Water Directive of the European Union.

Chapter 12
Hydrogeological and Geo-Ecological Studies Performed at the Ukrainian State Geological Research Institute (UkrSGRI)

Irina Sanina and Nataliya Lutaya

Abstract Department of Hydrogeology, Geological Engineering, and Geo-Ecological Research is a part of the Ukrainian State Geological Research Institute (UkrSGRI). It supports different geological enterprises as well as local authorities by providing scientific methodology. One of the priority works is delivering high standard maps based on computer databases. The natural and industrial factors of activation of dangerous external geological processes and events in Ukraine became the basis for creating the environmental forecasts. Department research touches many environmental issues and are aimed at the implementation of the national Ukrainian environmental policy, the use of natural resources, and the provision of environmental safety.

Keywords Aquifers • Trounsboundary groundwater • Hydrogeology • Geoecology

The hydrogeological, geo-ecological studies are carried out at Department of Hydrogeology, Geological Engineering, and Geo-Ecological Research of the Ukrainian State Geological Research Institute (UkrSGRI). Yet earlier, in 2001, Department of Geological Engineering and Ecology was established following integration in 2000 into the UkrSGRI of the "GEOINFORM" State Geological Enterprise's special Geo-Ecological Research Department and its Scientific and Methodology IT Centre, including their expert-staff. After that merger, the Institute's scientific and research profiles were considerably expanded, and also both the name and the organisational structure of this newly founded establishment were changed respectively into

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Department of Hydrogeology, Geological Engineering, and Geo-Ecological Research. The major activity profiles of this Department are following:

- provide scientific and methodological support to the hydrogeological, geo-ecological works carried out by geological enterprises;
- improve the current hydrogeological, geo-ecological surveying methods, and develop new ones;
- develop the basis for hydrogeological, geo-ecological cartography and mapping procedures;
- produce special hydrogeological, geo-ecological maps;
- structure and develop the problem-oriented databases to store hydrogeological and geo-ecological information;
- develop the concepts of and methodological guidelines for implementation and performance of the ecological monitoring system for geological environment and geochemical status of landscapes;
- provide the Ukrainian District-level authorities, the Ministry of the Environment and Natural Resources, and other stakeholders concerned with the relevant information on ecological state of geological environment in the national territory of Ukraine.

The Departmental personnel extensively use the state-of-the-art information an telecommunication technology including the geographic information systems (GIS) in their scientific studies.

A number of hydrological, geological engineering and geo-ecological research studies were performed in the period when the Department of Hydrogeology, Geological Engineering, and Geo-Ecological Research has been operated as an organisational entity of the Head Branch of the UkrSGRI.

The ***study on groundwater resources*** is its major research profile dedicated to this most important and dully protected source of water supplies. Other major research area includes development of scientific and methodological basis for hydrogeological survey.

Following the aforementioned basic activity profile, in 2005, the UkrSGRI completed its study on the "Development of the estimation methodology for available and forecasted drinking groundwater resources in Ukraine" in the framework of the "Comprehensive Target Programme for intensification of the use of the groundwater resources as a source of drinking water supplies to populations in Ukraine". Consequently, the first ever methodological basis was developed for estimation of the groundwater resource storage and volume by means of field observation of the groundwater supply intakes, drainage and irrigation systems, and pollution sources thereof. Moreover, the study results provided for development of database for groundwater resources available and forecasted, including assessment of the groundwater volume forecasts, as well as the guidelines for estimation of the groundwater condition.

Another study on the "Ecological and hydrogeological justification to select the subsurface spots of the natural resources eligible for drilling water prospection and exploration wells in the central and northern parts of the Ukrainian Shield" was begun

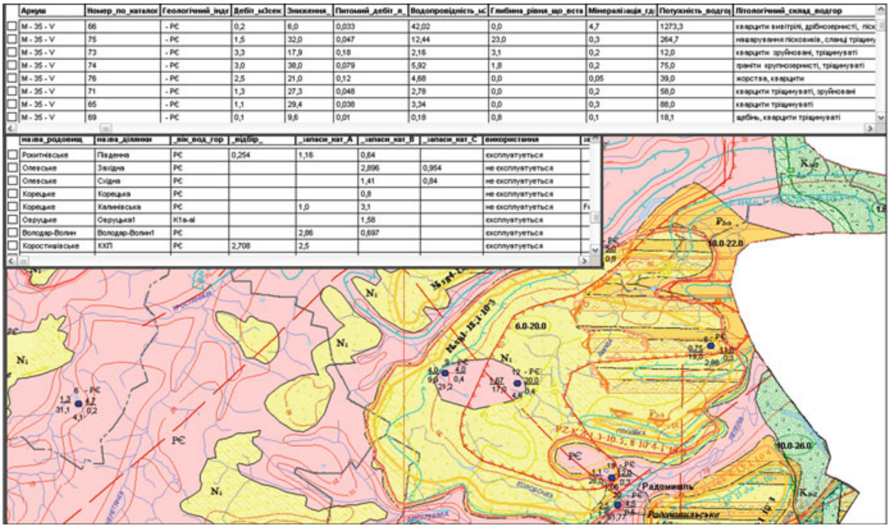

Fig. 12.1 Part of the special digital hydrogeological map in an active window

in 2003 and aimed at development of the methodological basis for hydrogeological works, the purpose of which was to solve water supply problems in the regions affected by problematic water balance. In result of that study the "Guidelines on the geo-ecological recommendations for the selection principles of the subsurface spots of the natural resources for drilling water prospection and exploration wells", and the "Special scale 1:200 000 digital hydrogeological map of natural parts eligible for drilling the wells prospective for water abstraction and exploitation" (Fig. 12.1).

The issues of the ***development and implementation of the geo-ecological and hydrogeological cartography and mapping methods*** were and have been amongst the major Departmental priorities.

In 2002, the "Development of the temporary requirements on the design of and the preparation for production of the hydrogeological map and the map of ecological state of geological environment, including scale 1:200 000 requirements and guidance for additional hydrogeological survey in the Ukrainian national territory, and drawing up scale 1:200 000 National Hydrogeological Map of Ukraine" were completed as a part of the GDP-200 Project (Fig. 12.2).

In result of the work completed in the framework of the GDP-200, the legal, regulatory and methodological basis for hydrogeological mapping as well as for mapping (scale 1:200 000) the ecological state of geological environment as a part of works on GDP-200, and also the hydrogeological additional survey of the Ukrainian national territory and preparation of (scale 1:200 000) hydrogeological map of Ukraine for the publication purposes were produced.

The aforementioned works were continued with preparation of methodological documents including the "Scale 1:200 000 methodological elaborate for the

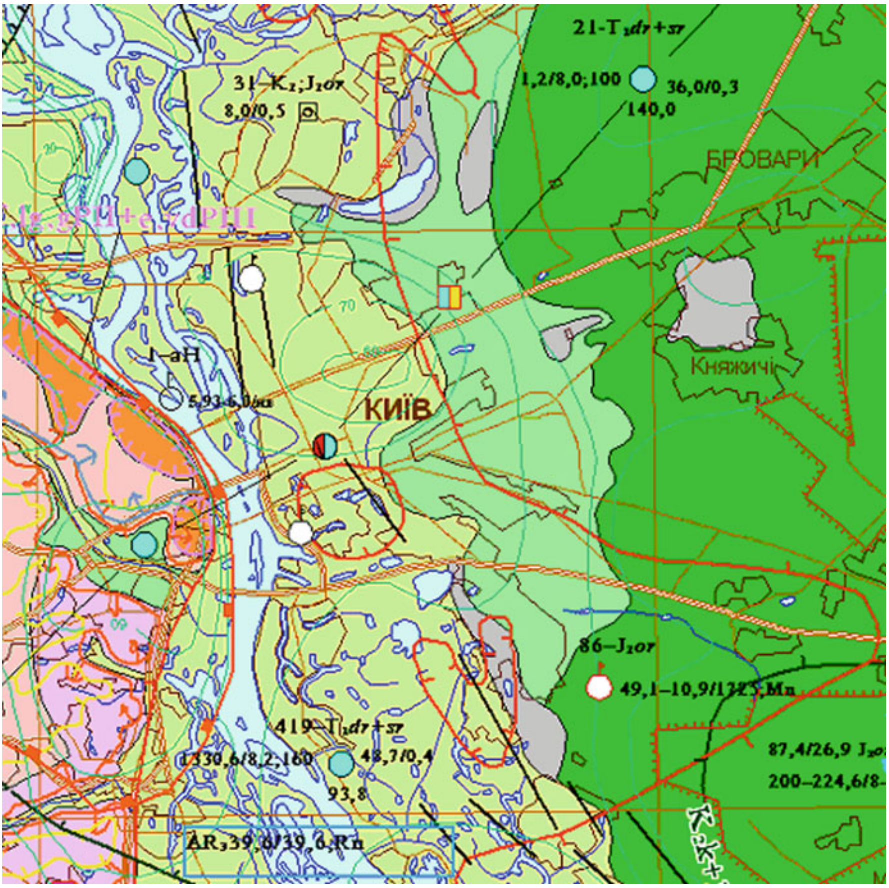

Fig. 12.2 A part of scale 1:200 000 model hydrogeological map

pre-project period of the hydrogeological additional survey" (in 2003), and the "Scale 1:200 000 provisional requirements on the hydrogeological additional survey of already mapped regions of Ukraine" (in 2005). A conceptually new hydrogeological regional division of the Ukrainian national territory was established. The current work is under way to cover preparation, drawing up and refinement of scale 1:1 000 000 digital hydrogeological map of Ukraine, and development of scale 1:200 000 regulatory and methodological basis for hydrogeological additional surveys of the national territory to be carried out in Ukraine by competent enterprises and organizations.

The Departmental experts provide assistance to contractors of hydrogeological and geo-ecological mapping and cartography works as regards the geological and hydrogeological supplementary surveys and development of the respective symbolisation system thereto.

According to the Regulation on the National Environmental Monitoring System, as approved on September 30th, 1998, by the Council of Ministers of

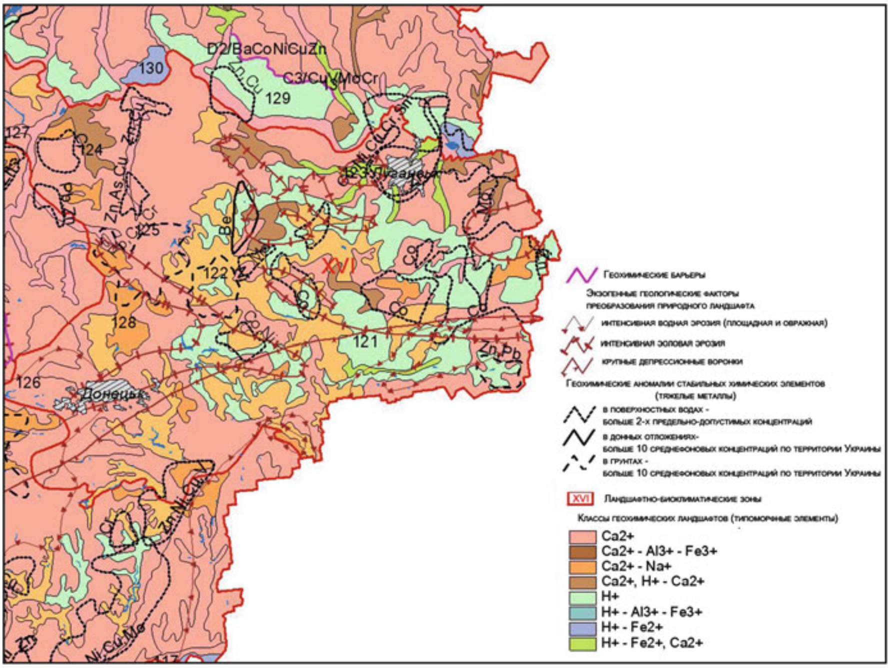

Fig. 12.3 Fragment of the digital landscape geo-chemical map in an active window

Ukraine, the State Geological Survey is responsible for monitoring groundwater condition, internal and external processes and geo-chemical landscape, as well as the geo-ecological mapping of the national Ukrainian territory. All these responsibilities upgrade the importance of geo-ecological works and place them at the supreme national level.

Development of the methodological basis for both monitoring the geochemical state of landscapes and the research techniques of the eco-geo-chemical surveys are important directions of the Departmental scientific activities. Pursuant to the said Regulation of the State Environmental Monitoring System, in 2003 the UkrSGRI completed the "Development of a system to monitor the geochemical state of the Ukrainian landscapes for its further assessment and preparation of the priority emergency response to potential environmental hazards". This work resulted also in development of the structure and implementation of databases under GIS for information storage and processing on natural and anthropogenic conditions and factors which determine geochemical state of landscapes (Fig. 12.3). In the framework of that work, a number of the status and analytical reports were prepared on the implementation results of the priority comprehensive measures aimed at identification and removal of the emergency situations in the Nikolayev Region of the Pervomaysky District those were submitted on the operational basis to competent Central and branch authorities for their managerial decisions.

This field of studies led to completion of survey on the "Development of the methodology and information support to the Ukrainian monitoring system of geochemical state of landscape". In this work, certain procedural documents were developed to regulate performance of the eco- and geo-chemical studies and monitoring the geochemical state of landscapes. The methodology approaches to selection of the observation sites to examine the geochemical state were proposed and the relevant assessment criteria of such state were improved.

In order to ***evaluate the impact from extraction of hydrocarbon deposits on the ecological state of geologic environment,*** a survey on the "Hydrogeological conditions of the oil and gas deposits in Dnieper-Donets River Basin (DDRB) and the regularities of hydrogeological inversion" was completed in 2006. As a result of this work, the permeability of deep level clay rock horizons was evaluated and the occasionality of the permeability of fluid-bearing horizons determined. These conditions caused the area-limited cones of the influence formation and a limited negative influence on rock mass due to reduction of the mass formation pressure during extraction of the hydrocarbon deposits.

Moreover, the effectiveness of the Jacob's method for analyzing the usage of experience of hydrocarbon deposits extraction and forecasting their further exploration was proven and a new vision of deep hydrogeological spatial development of the inversion processes in the DDRB proposed.

Currently, the most acute at the country scale the geo-ecological problems persist in the Donbas Basin. To determine the environmental state in this region, a survey titled the "Regional evaluation of changes in the Donbas geological environment caused by winding up operation of coal mines" has been completed.

This survey was supplemented with a study on the "Development of computer database of factual and cartographic data covering the impacts from mining operations on the geological environment and surveying the hydrogeological conditions of coal deposits extraction in the Donbas", as completed in 2005. The IT package titled "HydroDonbas" developed in the framework of this project includes cartographic and factual database jointly with special data processing software which provides for both the prompt updating the database and the effective information processing (Fig. 12.4). Development of this solution marks a significant step towards provision of ecological information to the environmental works in mining regions.

Crisis developments relating to the state of the environment appear in Ukraine mostly due to the ***external geological processes***. In 2002, a report was prepared on the "General material considerations and regional evaluation of the natural and industrial factors of activation of dangerous external geological processes and events in Ukraine". In this report, data covering long-term periodical observations of flooding, landslides and karst phenomena and of the daily settlement of soil in Ukraine was collected and analyzed with the aim of upgrading the reliability and operability of the forecasts accuracy and efficiency, and to determine the factors which influence the spatiotemporal model of activation of the external processes therein.

Disposal of the long-life radioactive waste (DLLRW) is a critical problem in Ukraine. In 2002, in the framework of the "Justification of the exploration works for evaluation of geological structures and strata exploitability for disposal of the long-life radioactive waste in Ukraine", the "Guidelines on the medium- and the large scale exploration works aimed at the evaluation of the geological structures and strata

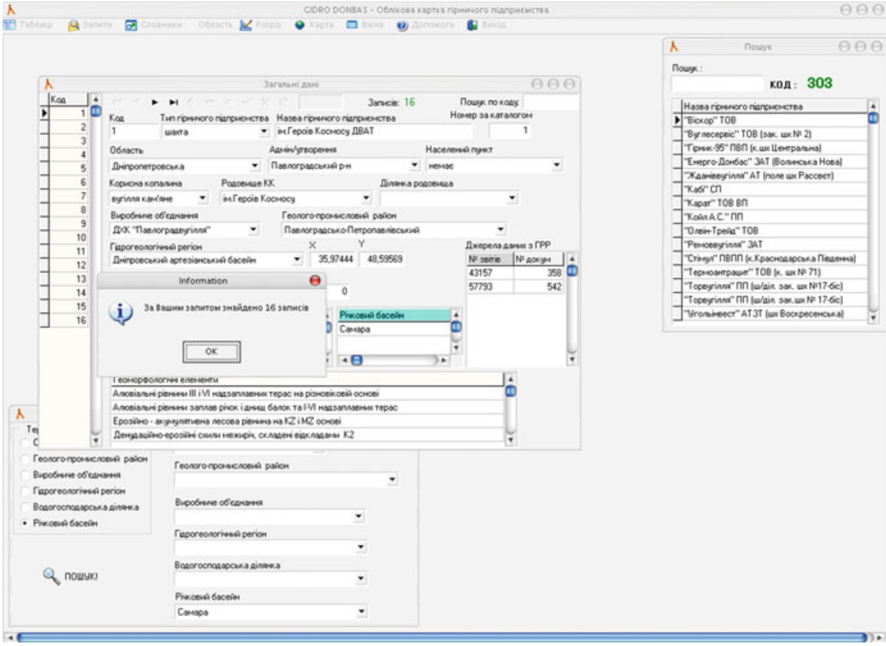

Fig. 12.4 Request processing examples ("HydroDonbas" software): the results for a number of mining enterprises in the Samara River basin surveyed

exploitability in the Ukrainian Shield for isolation of the DLLRW in Ukraine" were developed. These Guidelines were approved as a branch legal guidance document determining the methodological approach to justification of staging, composition, scope, and sequencing of exploration works and surveys focused on evaluation of geological structure exploitability for disposal of the DLLRW.

The works on the "Processing the input data for development of the GIS system for geo-ecological setting of the ***Dnieper River Basin***" were performed (in 2002) pursuant to the principal directions and provisions included in the "National programme for sanitation of and improvement in the quality of drinking water in the Dnieper River Basin" aimed at the implementation of the national Ukrainian environmental policy, the use of natural resources, and the provision of environmental safety to the Dnieper River Basin. The mapping database developed on the ecological state of geological environment in the Dnieper River Basin (Fig. 12.5) provides the basis for preparation of proposals for surveying further the aforementioned area and for taking the environmental protection measures, as required. These works were continued according to the "National Programme for environmental improvement in the Dnieper River Basin", with research works aimed at the "Update of the geo-ecological database for the Dnieper River Basin, and the scale 1:1 000 000 hydrogeological mapping of Ukraine with application of the GIS technology". The purpose of these works is to update the GIS database for prompt evaluation of the groundwater conditions and drinking water quality.

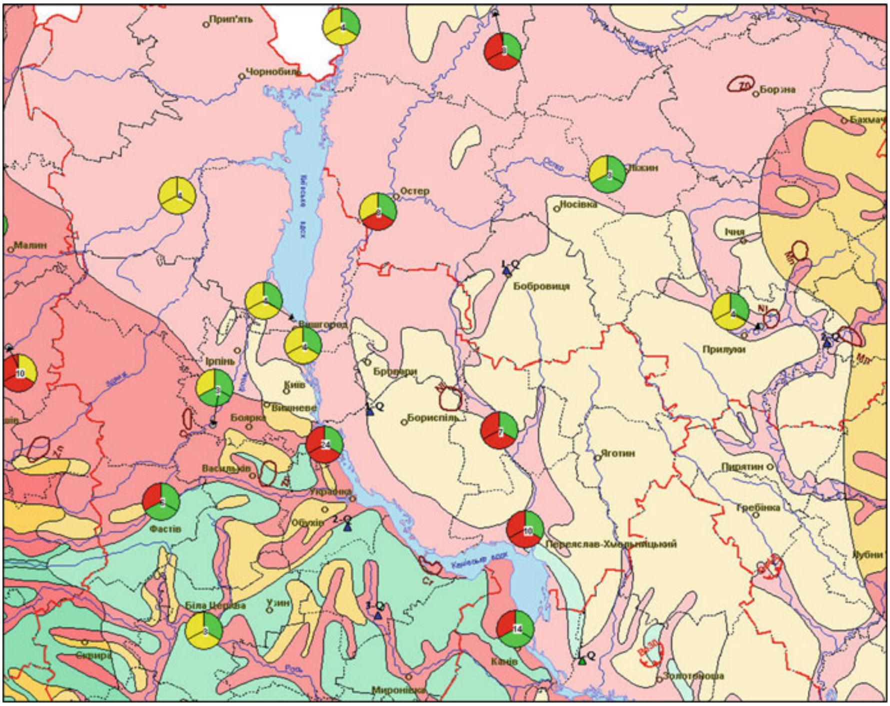

Fig. 12.5 Fragment of the contour map titled “The risk to groundwater pollution in the Dnieper River Basin”

A survey on the “Comprehensive evaluation of the ecological state of the ***Ukrainian boundary areas***” was completed in 2005. It was performed pursuant to decisions included in protocols of Sessions IV and V of the Intergovernmental Council of the Commonwealth of Independent States, as regards exploration, use and protection of natural resources. This work continued with geo-ecological surveys and mapping performed in the Ukraine mainland and its adjacent offshore zones. As a result, the individual geological environmental components were evaluated (Fig. 12.6), and an overall assessment of ecological state of the geological environment in Ukraine was done, as well as the system of its monitoring for determination of natural processes and the effects from economic operations on geological environment were evaluated.

During survey concerning the “Development and justification of the regional geo-ecological examinations methods”, according to the “Regulation on scale 1: 200 000 national geo-ecological map of Ukraine”, the cartographic and factual database containing geo-ecological information (Fig. 12.7) was developed, and the geo-ecological environmental evaluation criteria improved, while taking into account the experience gained from the geo-ecological surveys. In Fig. 12.8, the isotropic hydro-chemical fields are shown. These fields may be used as the regional hydro-geochemical background for the minor geo-ecological studies.

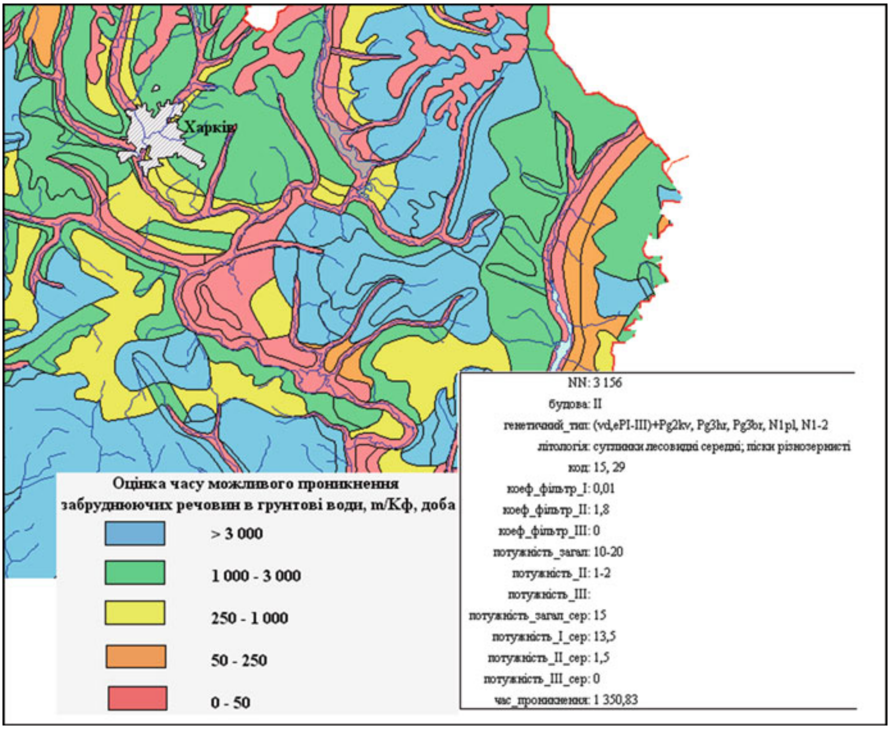

Fig. 12.6 The evaluation results for the periods of pollutant penetration through the solid vadose zones in the Kharkov Region

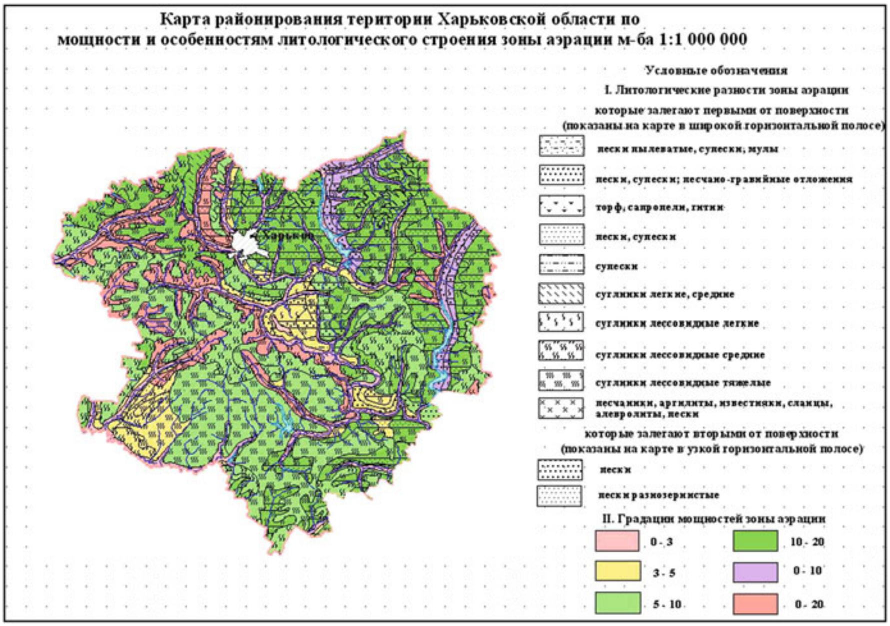

Fig. 12.7 Lithologic structure and thickness of the Kharkov Region vadose zone

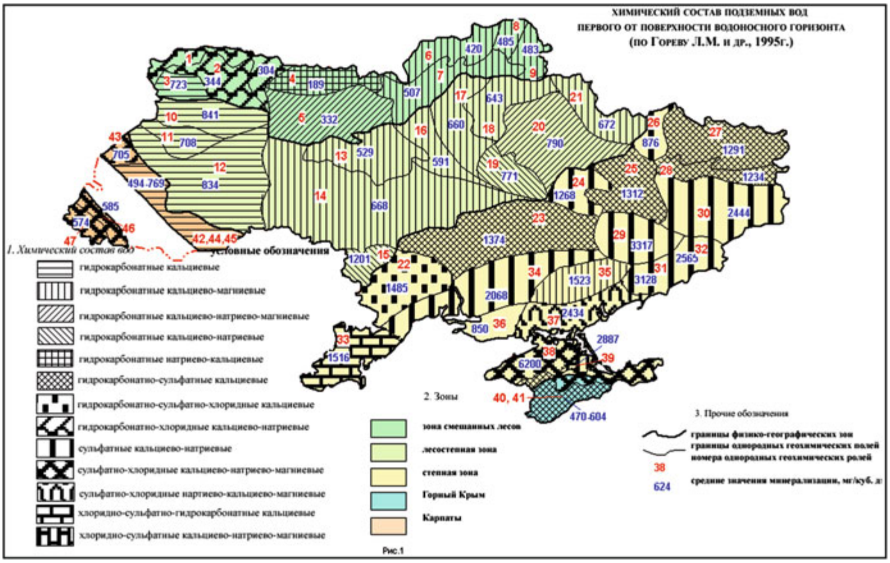

Fig. 12.8 Evaluation of natural hydro-geo-chemical background during regional geo-ecological surveys

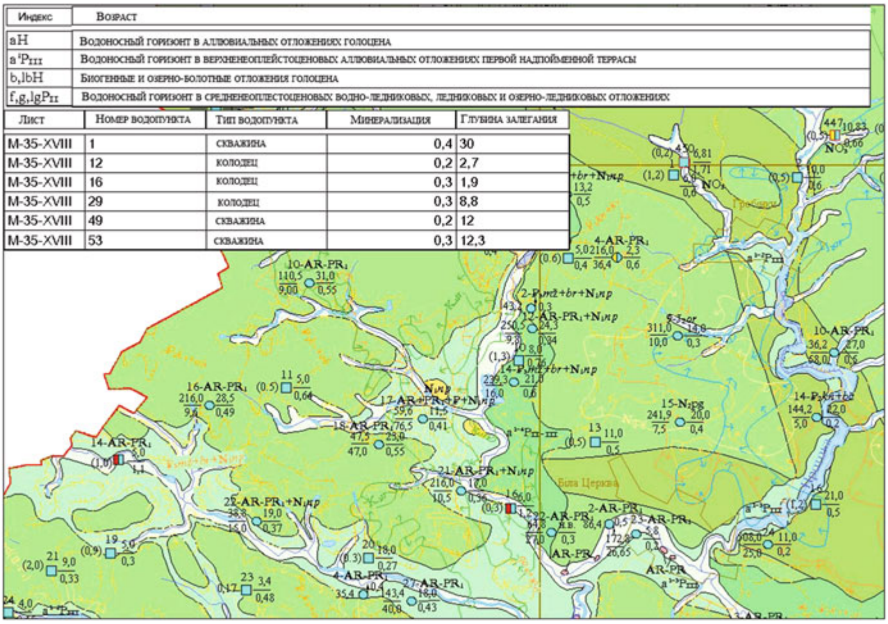

Fig. 12.9 Fragment of hydro-geological digital map of the Kiev Region

A survey aimed at the "Development of the methods and the geo-ecological reviewing of the Ukrainian regions in GIS" were begun in 2005. Those include provision of the relevant information to the regional executive authorities and the local governmental bodies competent to develop and implement the local drinking and domestic water supply programmes, approval (taking into account the legal requirements) of the urban planning programme projects, master physical management plans, and other urban planning documents, as well as implementation of the regional socio-economic development and environmental protection programmes (Fig. 12.9).

Chapter 13
Hydrogeological Study of a Hungarian–Ukrainian Transboundary Aquifer

Peter Szucs, Margit Virag, and Ivan Szascsenko

Abstract In the framework of an EEA Norway grants project involving industrial and scientific partners, complex hydrogeological investigation and groundwater modelling of a regional transboundary aquifer between Hungary and Ukraine were implemented in 2009. This challenging cooperation work was completed by an EU country (Hungary) and a non-EU country (Ukraine). This pilot project demonstrated how the EU Water Framework Directive might be applied for a regional scale transboundary aquifer between Hungary and Ukraine. The transboundary aquifers play a significant role in Hungary because the land of the country is mainly located in a deep and closed basin called the Carpathian Basin. 40 of the total 185 groundwater bodies are classified as transboundary in Hungary. The authors of this work were involved in participation in an earlier NATO Science for Peace Project [1] which investigated a transboundary aquifer between Hungary and Romania some years ago. The experience gained in that project [2] was utilised by the researchers in the current work to conduct the present complex hydrogeological study in a well-organised and efficient way.

In order to achieve sustainable water management (Lenart et al. Complex hydrogeological study of the alluvial transboundary aquifer of Somes/Szamos (Romania – Hungary), 2003) of the investigated internationally shared aquifer, the main tasks of the present international project were: (a) development of a common

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hydrogeological data-base; (b) additional field measurements; (c) interpretation of the geology for a common conceptual hydrogeological approach; (d) creating the conceptual flow model of the investigated transboundary aquifer; (e) regional scale groundwater flow modelling; (f) model simulations of different scenarios for groundwater management purposes; (g) review of the main results obtained from the transboundary approach as perceived in the European Water Framework Directive. As one of the main products, a common regional groundwater flow numerical model has been built and calibrated on historical measured field data. It is already and shall be in the future very useful for a possible joint management of groundwater resources between Hungary and Ukraine. The derived results enable a better evaluation of groundwater resources and a sustainable management of these resources.

Keywords Modelling • Transboundary aquifer • Water management • Hydrogeology

13.1 Regional Scale Groundwater Modelling

The targeted aquifer, which extends on both sides of the Ukrainian-Hungarian border over a 550 km^2 area (see Fig. 13.1), supplies drinking water to a population of about 100,000 inhabitants in Ukraine and in Hungary. The project focused on improving the previous understanding of the groundwater conditions including flow and pollutant transport across many scales, using data acquisition techniques and computer simulation models. On the basis of analysis of the available data [3], new campaigns of field measurements were undertaken focusing on the following aspects: piezometric levels or hydraulic heads; pumping tests for hydrodynamic parameters. The priority was given to measurements in areas with low density of observation wells, in order to prepare ideally all the needed data enabling reliable groundwater modelling.

One of the most important steps in the mathematical modelling was the choice of the conceptual model of the aquifer. By keeping the essential features of the system, a reasonable compromise between the complexity of the multi-layered aquifer and the available reliable data concerning the actual structure and hydrogeological parameters was proposed. The Hungarian and Ukrainian experts agreed on a conceptual model consisting of three Pleistocene aquifer layers. The groundwater flow simulations were carried out with the Processing MOFFLOW Pro program package. As a first step, a steady-state flow model reflecting average conditions was created and calibrated. The calibration results and the simulated heads (see Fig. 13.2) confirmed the reliability of the conceptual model and the accuracy of the applied regional scale flow model [4].

The thickness of the Pleistocene transboundary aquifer increases from the Ukraine to Hungary (see Fig. 13.3). The total thickness of the targeted aquifer can exceed 130 m. A MODFLOW grid system was generated to simulate the hydrodynamic behaviour of the groundwater flow systems. Then the boundary conditions

Fig. 13.1 The area of the investigated transboundary aquifer between Hungary and Ukraine

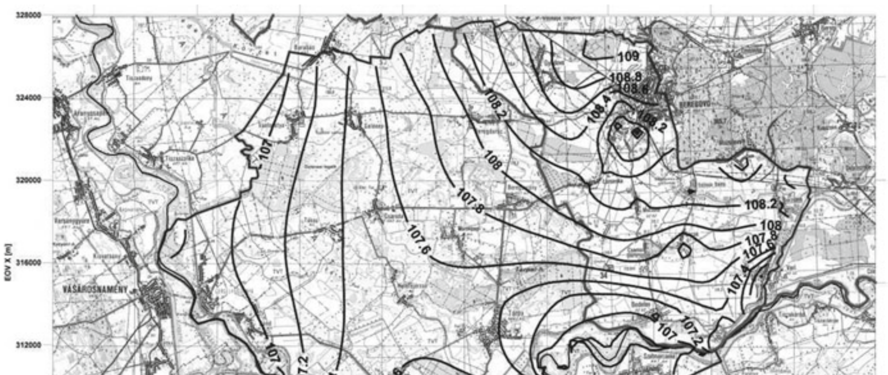

Fig. 13.2 The calibrated hydraulic head map for the transboundary aquifer in case of the steady-state regional groundwater model

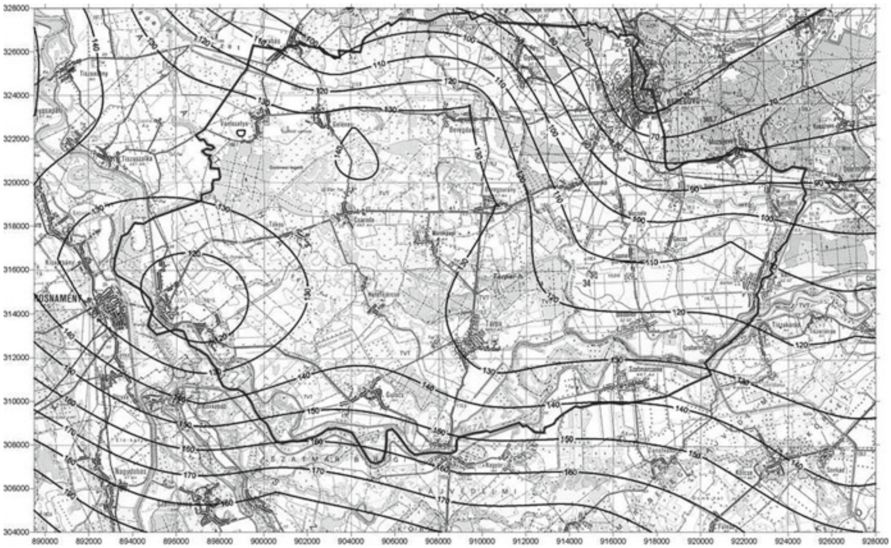

Fig. 13.3 The thickness of the investigated Pleistocene aquifer between Hungary and Ukraine

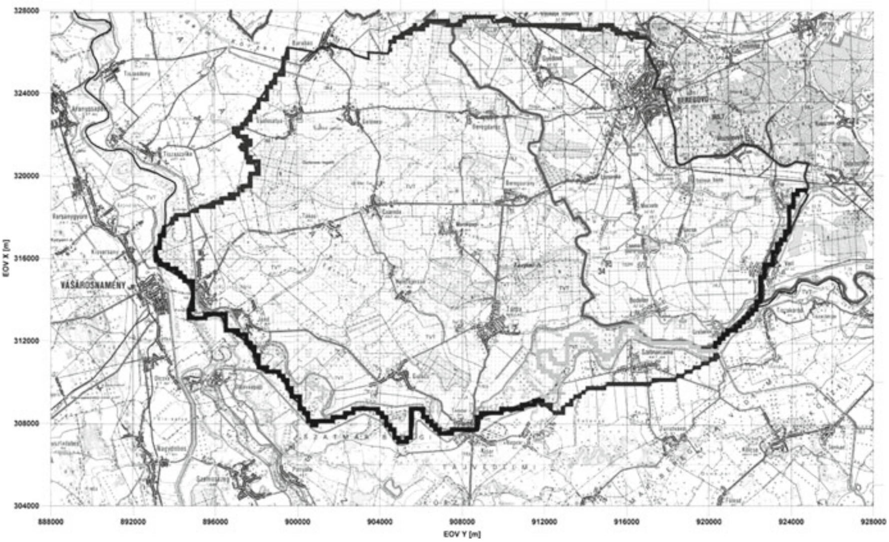

Fig. 13.4 The grid system and the boundary conditions in the MODFLOW based flow model

were determined for the modelling activity using mainly natural geological and river conditions (see Fig. 13.4). The calibration results of the regional scale flow model were satisfactory. The RMSE value was 0.32 m. As a next step, different future production scenarios were investigated. The expected future Ukrainian

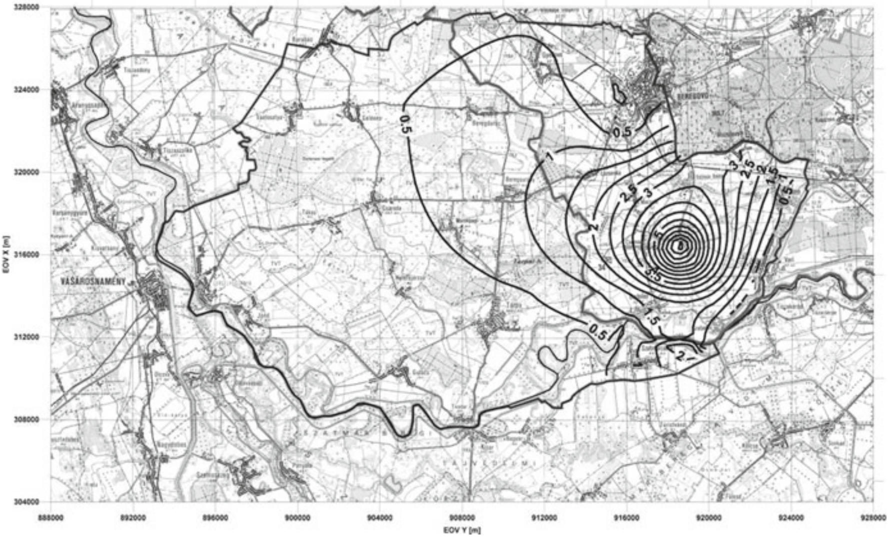

Fig. 13.5 The expected shallow groundwater level decrease in case of a future production scenario

groundwater production increase is much more significant than the Hungarian one. As a result, groundwater level depressions are expected more on the Ukrainian side. Figure 13.5. demonstrates that in some places the simulated shallow groundwater level decrease can exceed significantly the 0.5 m level. That means that harmful effects concerning the ecosystems may occur in those areas if the given production scenario occurs . In order to avoid the harmful consequences, some future common measures between Hungary and Ukraine should be introduced.

The collaboration between the Hungarian and Ukrainian experts was outstanding. Some of the obtained results have already been involved in the water management policy of this transboundary region. The monitoring activity (see Fig. 13.6), the data exchange, and modelling activity shall be continued in the future to obtain more detailed knowledge of the targeted internationally shared aquifer. The key numbers of the water balance for this internationally shared aquifer have also been determined for water management activity.

As an assessment of the quantitative status, water balance tests were performed for the investigated, internationally shared aquifer. We tried to assess the annual average abstraction against the available groundwater resource. Based on the field measurement, it is reasonable to assume that the groundwater body is of good status. The tests for groundwater dependent terrestrial ecosystems showed that a 0.5 m depression in the shallow groundwater could be tolerable. It was also a great asset that the mineral water and thermal water resources [5] were also reviewed and estimated in the region between Hungary and Ukraine (see Fig. 13.7).

Fig. 13.6 Field measurement shall be continued in the future in the framework of the common monitoring activity

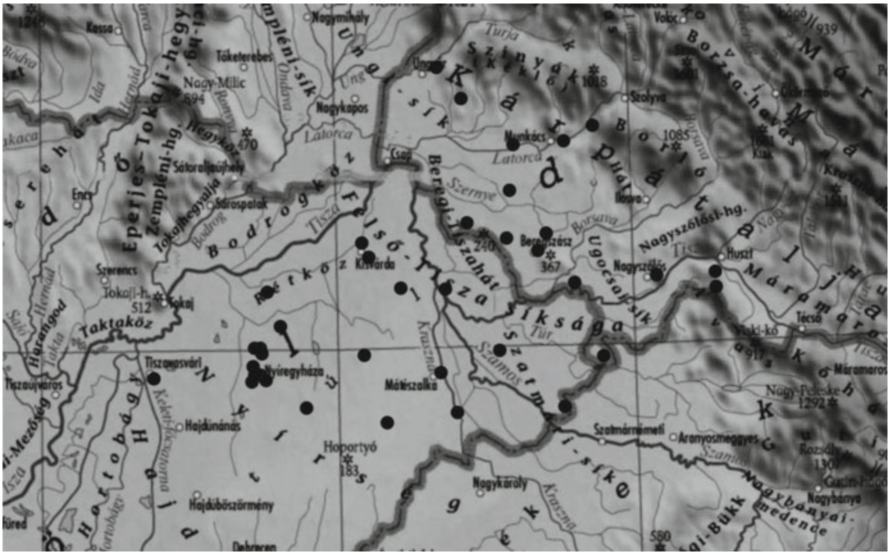

Fig. 13.7 The main mineral and thermal water wells in the transboundary region between Hungary and Ukraine

Acknowledgments The collaborating Hungarian and Ukrainian partners gratefully acknowledge the EEA Norway grants for the support of this research. Special thanks to the end-users and field experts, who provided a lot of help in order to finalise the project.

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Chapter 14
Evaluation of the Environmental State of Hungarian-Slovakian Transboundary Groundwater Bodies Within the "ENWAT" EU Project

Peter Malík, Károly Brezsnyánszky, Gábor Gaál, Teodóra Szőcs, György Tóth, András Bartha, Gergely Havas, Jozef Kordík, Juraj Michalko, Dušan Bodiš, Jaromír Švasta, Igor Slaninka, Jussi Leveinen, Juha Kaija, Katalin Gondár-Sőregi, Károly Gondár, Éva Kun, Sándor Pethő, and Viktor Ács

Abstract Groundwater bodies along the Hungarian-Slovakian border form interconnected systems, which supply both countries with drinking water. Also surface waters, rivers and wetland ecosystems are dependent on the underlying groundwater. The EU Water Framework Directive deals with the quantitative and qualitative status of groundwater and protection of the ecosystems, which depend on groundwater as first priority objects. Three transboundary groundwater bodies were investigated in the Hungarian-Slovakian border region: Ipoly/Ipeľ Valley,

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Aggtelek-Slovak Karst region and Bodrog region within the European Union INTERREG IIIA type of project, named "Environmental state and sustainable management of Hungarian-Slovak transboundary groundwater bodies (ENWAT)". Results of the project, based on hydrogeo-chemical evaluations and hydrogeological models, local needs, cost aspects and best practices, are a step forward in the creation of a joint Hungarian-Slovakian water management plan by supplying basic data and fresh information on transboundary groundwater bodies. The study also indicated the need to continue the process of pollution spread characterisation and the risks assessment in the case of groundwater resources by more detailed sampling and modelling on both sides of the border. Co-ordination and implementation of such activities jointly could provide logistical advantages, reduce overlapping activities and lead to savings of time and money.

Keywords Groundwater • Transboundary aquifer • Groundwater bodies • Hungary • Slovakia • Hydrogeology

14.1 Introduction

In the period of 2006–2008, two national Geological Surveys, the Geological Institute of Hungary – MÁFI and the State Geological Institute of Dionýz Štúr – ŠGÚDŠ have cooperated in data and information collection and exchange to contribute to a water management plan for three transboundary groundwater bodies of Northern Hungary and Southern Slovakia. Both countries, as EU member states, are obliged to implement the EU [1] that deals with the quantitative and qualitative status of groundwater and protection of the ecosystems, which depend on groundwater as first priority objects. The role of transboundary aquifers in groundwater management must be considered by all implementing states, and transboundary groundwater bodies should be delineated. With the help of the European Union INTERREG IIIA project programme, a project proposal named "Environmental state and sustainable management of Hungarian-Slovak transboundary groundwater bodies (ENWAT)" was accepted and successfully managed by Geological Surveys of both participating countries [2]. The three transboundary aquifer regions were selected: the River Ipoly/Ipel' region, the Aggtelek – Slovak Karst region and the River Bodrog region (Figs. 14.1 and 14.2). These groundwater bodies along the Hungarian-Slovakian border form interconnected systems, which supply both countries with drinking water. Also surface waters, rivers and wetland ecosystems are dependant on the underlying groundwater.

The ENWAT project was based on hydrogeo-chemical evaluations, hydrogeological models, local needs, cost aspects and best practices. In a certain phase of the project, the Geological Survey of Finland – GTK, joined the ongoing operation, providing its expertise in water management practice [3, 4]. Common water management plans containing also Programmes of Measures were prepared for every transboundary groundwater body (Fig. 14.3), in order to cover the elements defined

Fig. 14.1 Position of the studied Slovak/Hungarian transboundary aquifers on the political map of Europe

in Annex VIII of the [1] and to optimally sustain water management. Also other relevant EU directives, especially the [5] and the [6], EU guidelines and national legislation and guidelines related to water management, were taken into account in

Fig. 14.2 Position of the studied Slovak/Hungarian transboundary groundwater bodies

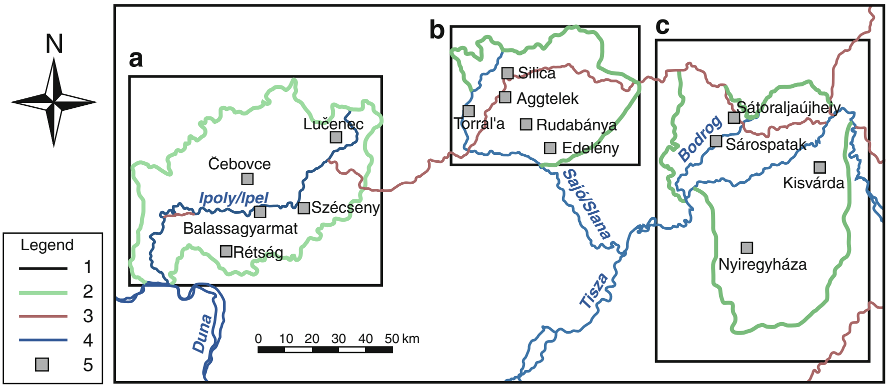

Fig. 14.3 Locations of the studied areas: *1* state border, *2* model frame, *3* model boundary, *4* stream, *5* settlement, *A* River Ipoly/Ipeľ region, *B* Aggtelek-Slovak Karst area, *C* River Bodrog and its catchments region

preparing the groundwater management plans. Water management plans were based on regional hydrogeo-chemical and socio-economic data, results of the hydrogeological modelling, identification of threats, local needs and best practices. The most significant and major target group was the rural population living in these regions, using groundwater bodies not only as a major drinking water supply, but also for irrigation, industrial and recreational purposes. Two different scenarios were evaluated: (i) present or increased water usage under current climatic conditions; (ii) sustainable water usage considering the effects of global climate change, till 2050. The effects influencing the current water usage and the future of water production, as well as the effects influencing the chemical status of groundwater were evaluated. Specific water management measures were presented so that the present unfavourable anthropogenic influences would be prevented and that the possible upward adverse trends would be reversed [3, 4].

14.2 Objectives, Goals and Target Groups of the Enwat Project

The main objectives of the ENWAT project were: (a) to supply a water management plan for three transboundary groundwater bodies to support the safe and healthy water supply of the studied regions; (b) to serve as environmental basis for a decision-making process involving major cross-border investments; (c) to supply information on the quantitative and qualitative status of groundwater concerning potential negative health impact of the use of groundwater; and (d) to provide rational water use information to the population of the region.

Quantifiable aims of the project were: (a) development of common methods regarding standardisation and co-ordination of practical procedures defining quantitative and qualitative parameters in transboundary groundwater bodies; (b) creation of uniform data structure and uniform geographical referencing (coordinate system) intended for data exchange and common assessment; (c) establishing and harmonisation of threshold values of selected indicators showing chemical status of groundwater; (d) generation and supplying the database with data representing groundwater quantitative and qualitative indicators and their inter-connection with GIS; (e) implementation of joint hydrogeological and hydrogeo-chemical mapping in the area lacking relevant data; (f) organisation of an international conference and dissemination of project results among the wider public via scientific leaflets, publications and promotion materials; and (g) creation of a web pages with project results, publicly accessible, showing the relevant information on groundwater quantity and quality in the regions as a support for decision making in the area.

The main project goals were to enhance water protection policy and rational water use established in the [1] by: standardisation, co-ordination and harmonisation of practical procedures of assessment, monitoring and environmental management of transboundary groundwater bodies, to support cross-border co-ordination related to water management and international catchment plan design, to perform hydrogeological and hydrogeo-chemical investigation (analysis and completion of needed information (primary data) in transboundary groundwater bodies), to achieve creation of uniform procedures for assessment of qualitative and quantitative parameters in transboundary groundwater bodies.

The main project principles may be formulated [7] as follows:

(a) Clean drinking water is crucial for the region and the most important stakeholders are in this respect the local municipalities;
(b) The protection and restoration of ecosystems, which depend on the underlying groundwater is the concern of nature protection organisations and the municipalities;

(c) Tourism is an important activity, which depends on clean groundwater. This interest circle includes municipalities, nature protection organisations and tourist enterprises;
(d) Sustainable agricultural activity depends on groundwater and interested users in this field are agricultural enterprises, farmers, municipalities and waterworks;
(e) Water suppliers and local water works of the border regions in Hungary and Slovakia are benefactors as suppliers of clean water for the local population;
(f) The ultimate beneficiary of an adequate water management plan is the local population, which draws its water supply from the groundwater for drinking, domestic use, recreational activities etc.

14.2.1 Practical Project Results in Individual Regions – Ipoly/Ipel' Region

The Ipoly/Ipel' valley area and its broader vicinity suffer from a lack of drinkable water sources. The alleviation of the quality problems and increased utilisation of the water from Ipoly/Ipel' alluvium for water supply on both sides of the border is the reason for the choice of this area as "important". The area of interest is delimitated by the extent of the youngest alluvium of the River Ipoly/Ipel' and partially also by some of its tributaries. The alluvium lies on the impermeable clayey sediments of the Neogene filling of Juhoslovenská and Podunajská panva Basins on the Slovakian side, and on the Nógrád Paleogene and Neogene (sands, aleurites, clays and rarely limestones) sediments, and partly volcanic rocks on the Hungarian side. The main aquifer is the alluvial sediments of the River Ipoly/Ipel' and the connecting terraces. Their thickness is about 4–20 m, sometimes more. The gravels and sands are covered with 2.5–4 m thick clayey flood sediments. The changing thickness sometimes causes the occurrence of confined groundwater. The gravels and sands have increased transmissivity values. The width of the river flood plain is about 2–4 km, sometimes only tens of metres. Groundwater recharge occurs by infiltration of precipitations and infiltration of surface water at high water levels. The changing (decreasing) surface water level of the river has a negative impact on the water supply possibilities.

Numerical groundwater flow model, created for the Ipoly/Ipel' valley and its catchments [8] showed the existence of the sensitive hydraulic state of equilibrium between the alluvium of Ipoly, the older porous medium filling the basin, and the mountains in the surroundings created by volcanic activities; the very close relationship between the River Duna/Dunaj (Danube) and the lower section of the River Ipoly/Ipel' valley, and the sustainable status of water production under the circumstances.

Results of the mutual hydrogeo-chemical research have revealed a strong variability of groundwater chemical composition and quality is characteristic for the Ipoly/Ipel' region. Ca-Mg-HCO_3 chemical type dominates in the groundwater as the result of dissolution of carbonates and hydrolytical decomposition of silicate minerals. Groundwater qualitative properties in the region reflect either the natural character of the area or addition of compounds due to anthropogenic activities. Anthropogenic contamination of groundwater is mostly caused by agricultural activities and

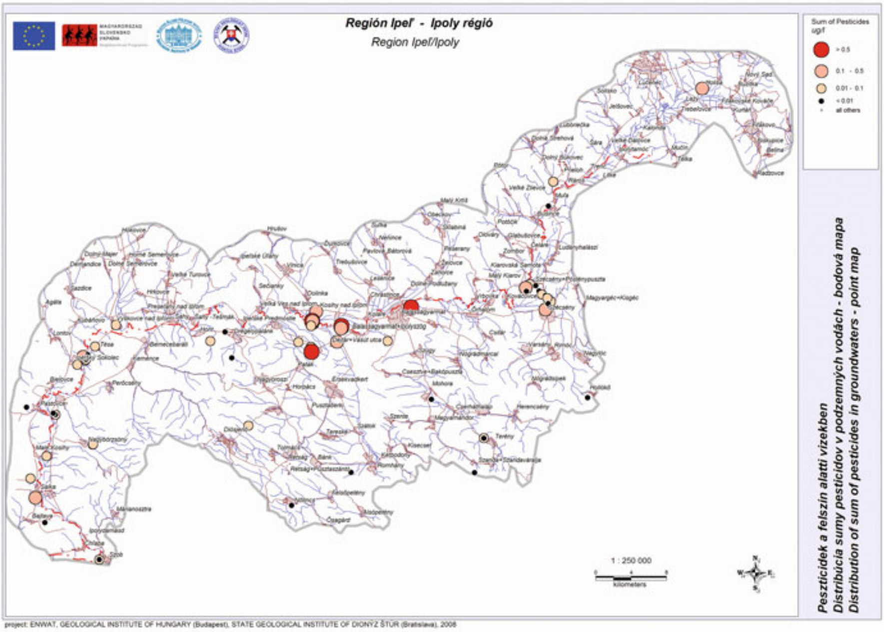

Fig. 14.4 Ipoly/Ipeľ region: distribution of pesticides in groundwater

production of waste waters. Mostly it is contamination of the uppermost groundwater horizons that occurs in the area. Diminished groundwater quality is mostly characterised by high contents of nitrates, chlorides, ammonia ions, phosphates or specific organic parameters (PAH, COD) and occasionally pesticides (Fig. 14.4). One of the project goals was to fill the gap in our knowledge regarding organic contaminants by additional sampling and analyses. One may find the most contaminated groundwater around settlements; every site needs detailed survey in the future.

As for water management aspects, the water production in the Ipoly/Ipeľ valley is sustainable; however, some parts of the groundwater bodies have poor chemical status. Locally high pesticide concentrations ($>0.5\ mg \cdot l^{-1}$) are found in both surface water and in groundwater along the Ipoly/Ipeľ valley. Pesticides in unsaturated soils can be released by erosion and climate change may increase this risk. Nitrates have also a substantial impact on the shallow parts (0–20 m) of the groundwater systems. In general, the pesticide concentrations detected suggest that water quality may be considered to be at risk until further investigations have been made and the additional measures as defined by WFD, have been taken. More information on the pesticide concentrations in groundwater, unsaturated zone and surface water must be collected urgently.

The investigations indicated that there are local pollution problems and direct and indirect sources of hazardous pollutants that may cause groundwater pollution also in the future. Evidently, there is a need to continue the characterisation of pollution spread and the risks for groundwater resources by more detailed sampling and modelling on both sides of the border. Co-ordination and implementation of such activities jointly could provide logistical advantages, reduce overlapping activities and lead to savings of time and money. If not a prerequisite then at least a great benefit for integrated water resources management and successful implementation of the WFD, are the direct links and co-operation between regional and even municipal authorities and expert organisations. One of the underlying objectives of WFD is to create a common understanding of activities dealing with the transboundary water resources. This is particularly so in management of pollution cases and in crisis situations requiring fast response and action, it is important that the cross-border authorities are familiar with exchanging information and communicating directly with their transboundary counterparts rather than using high-level representatives as middle-men without a good knowledge of the conditions in the field.

14.3 Practical Project Results in Individual Regions – AGGTELEK/SLOVAK KARST Region

The Aggtelek Mts. and the Slovenský kras Mts. (Slovak Karst) form a large common karstic aquifer system in the Eastern part of the countries. It is selected for presentation in the Danube-basin report as a highly important transboundary water body: The National Park covers the majority of its surface, where the groundwater role is supplemented by springs and stalactite caves. Significant drinking water resources in Slovakia and regionally important resources in Hungary are located in this vulnerable area and require protection.

The groundwater body is in a Mesozoic complex with morphologically visible karstic plateau and canyon-like valleys of watercourses, separating different units. Hydrogeological units are very different according to the character of permeability, character of groundwater circulation, type of groundwater regime, and also in the resulting yield of groundwater springs. From the hydrogeological point of view, the most important tectonic unit in the area is the Silicikum unit, mainly its Middle Triassic and Upper Triassic part. The most important aquifer here is the Middle and Upper Triassic limestone and dolomites with karst-fissure type of permeability. Similarly there are important hydrogeological units on the Hungarian side are Alsóhegy, Nagyoldal, Haragistya and Galyaság, which contain the Aggtelek-Domica cave system. Tertiary basins act as a regional impermeable barrier for the groundwater accumulated in Triassic limestone.

The transboundary karstic aquifer is divided into two water bodies by the state-border. The horizontal extensions are 598 km^2 and 472 km^2 respectively in Slovakia and in Hungary, thus the total area is 2069 km^2.

Based on the groundwater modelling procedure of the Aggtelek/Slovak Karst region, the following statements were proved: (a) the budget of karst-water system is determined by natural factors, mainly effective precipitation. Thus the system very sensitive to changes of climate; (b) the main discharge of springs controls the natural balance; and (c) significant increase of water withdrawal combined with

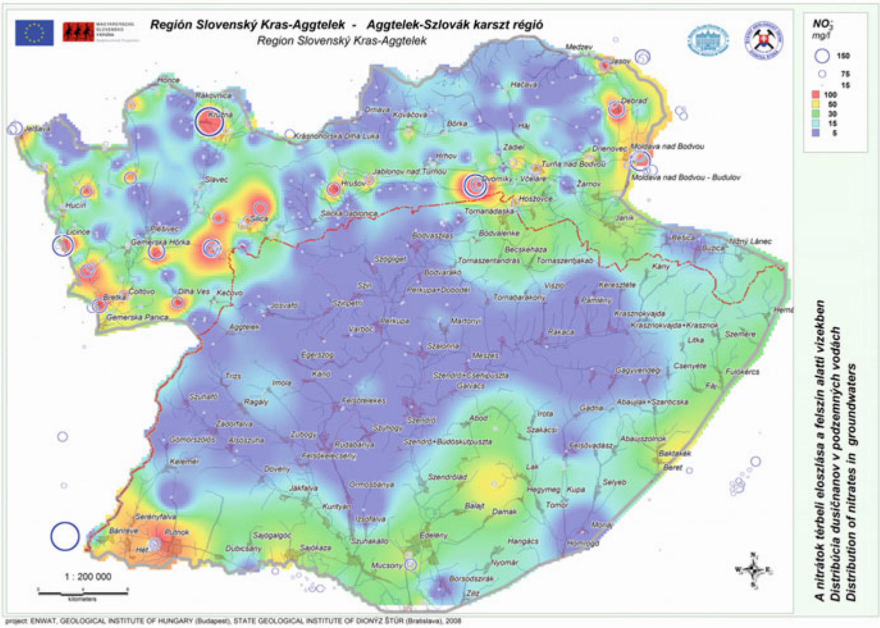

Fig. 14.5 Aggtelek-Slovak Karst region: distribution of nitrates in groundwater (not valid inside the settlements' area)

climate change effects would dry out some of the springs causing problems for water supply [8].

Groundwater chemical composition and quality originates mainly from the processes of the water-rock interactions. Groundwater circulates predominantly in limestones and dolomites of the Mesozoic rock formation (Middle and Late Triassic). The Ca-HCO_3 and Ca-Mg-HCO_3 types of chemical content dominate in groundwater that is not affected by anthropogenic activities. The natural character of the groundwater circulation system conditions good qualitative properties of the groundwater – most of the area consists of best quality groundwater. This groundwater fully meets criteria determined for their use for drinking purposes. In most cases, concentrations of trace elements are very low and mostly below the limits of quantification. Anthropogenic contamination was documented only rarely, usually close to settlements. It was mostly indicated by higher contents of nitrates (Fig. 14.5), chlorides, sulphates, chemical oxygen demand and potassium. High iron and manganese may be found at the adjoining Tertiary artesian aquifers with reductive conditions.

In the Aggtelek/Slovak Karst area the chemical status of groundwater may be considered to be good, but future climate change may increase extreme hydrological events. In the worst scenario from the water management point of view, higher and more rapid flood peaks will apply pressures to water channels by erosion while drought periods damage the ecology of the fragile karst area and thus chances for ecotourism. A significant threat in this poor part of Slovakia and Hungary is the uncontrolled land use and building on flood-prone areas. Rehabilitation and creation of wetlands provides water storage and prevention of basal erosion in flow channels as well as cost-efficient measures to reduce local nitrate problems and eutrophication of surface water (e.g. by development on wetlands).

14.4 Practical Project Results in Individual Regions – Bodrog Region

At the common eastern border of Slovakia and Hungary, the alluvial aquifer system corresponding to the River Bodrog catchment area in Slovakia and the Tisza-valley between Záhony and Tokaj (confluence with the River Bodrog) has been selected as being important due to (i) its significance in meeting the water demand of the region, (ii) contamination threat of the groundwater in the vicinity of state border between Slovakia and Hungary. A part of the aquifer system is in Ukraine. The aquifer is the alluvial deposit of the River Bodrog and its tributaries. The Tisza divides the lowland area in Hungary into Bodrogköz (northern part) and Rétköz (Southern part). Holocene silty-clay layers cover the surface with peaty areas. The Quaternary aquifer is around 60 m thick on the Slovakian side and its thickness gradually increases in Hungary towards the south (50–200 m). The fluvial sediments (from sandy gravels in the North to sands is the South with intercalated silt and clay lenses) can be characterized by 5–30 m/d hydraulic conductivity.

In the Slovakian part only the Quaternary aquifer system is part of the transboundary water body-complex while in Hungary the Upper part of the Pannonian formation is also attached (depth is approx. 500 m, corresponding to water temperature less than 30°C). The horizontal extension of the water body on the Slovak side is 2,466 km^2, while in Hungary the two water bodies cover an area of 2,300 km^2. The main recharge area is in Slovakian territory, and partly in the Tokaj Mountains. The rainwaters infiltrate at the marginal mountains and penetrate into permeable deep aquifers. In the upstream part of the catchment area surface waters also contribute to the recharge.

Groundwater modelling results of model created for the area of the Bodrog basin and its catchments are as follows [8]: (a) the main recharge areas are situated to the south of Bodrog region, from where the effectively infiltrating water forming the regional flow system migrates toward the central region of the basin; (b) the Tokaj Mountains to the west are significant recharge area as well, where water flows through the weathered, fissured volcanic rocks or in the alluvial sediments of the streams and reaches the basin deposits, then it is shortly discharged into the Bodrog-valley and the west side of Bodrogköz; (c) the regional discharge-factor is the groundwater evapo-transpiration at Bodrogköz and Rétköz regions, while along the River Tisza a line-discharge is subsidiary; and (d) at present there are no adverse effects of groundwater abstraction on the dependent ecosystems, or on the safe yield of groundwater in both countries.

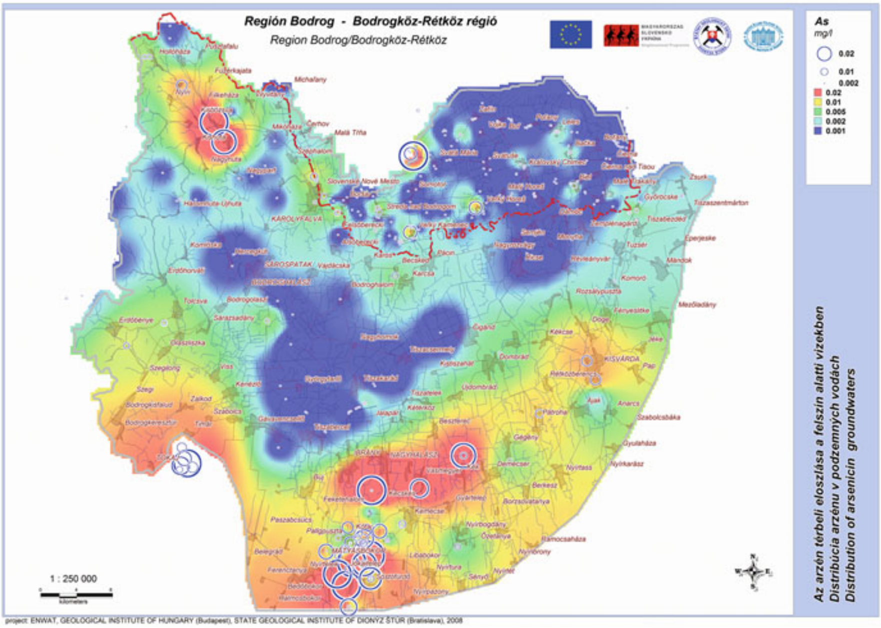

Fig. 14.6 Distribution of arsenic in groundwater of the Bodrog region

Pronounced variability of groundwater chemical composition is characteristic for the Bodrog region. In respect of prevailing processes of chemical content formation, Ca-HCO_3 and Ca-Mg-HCO_3 types of chemical content dominate in groundwater as the result of dissolution of carbonates and hydrolytical decomposition of silicate minerals. Groundwater qualitative properties reflect either the natural character of the area or significant addition of compounds due to anthropogenic activities. Anthropogenic contamination of groundwater is mostly produced by agricultural activities and production of waste waters. Mostly it is contamination of the uppermost groundwater horizons that occurs in the area. High nitrate concentrations (>50 $mg \cdot l^{-1}$) and very low contents of dissolved oxygen (less, than 5 $mg \cdot l^{-1}$) were documented in most groundwater samples (first aquifer of the Slovak area). Moreover, high concentrations of chlorides, sulphates and phosphates or specific organic parameters (PAH, COD) and occasionally pesticides are also documented. The character of groundwater quality on the Hungarian side is different. Generally lower concentrations of nitrates, sulphates and chlorides and higher contents of iron, manganese, ammonium ions and in some cases arsenic (Fig. 14.6) were recorded. This is caused by the fact that groundwater analyses on the Hungarian side represent relatively deeper aquifer horizons, in which anoxic conditions may be expected. Lack of dissolved oxygen usually in combination with high concentrations of iron, manganese and ammonia were observed quite frequently in groundwater. In most cases, the concentrations of trace elements correspond with natural conditions of the groundwater circulation, i.e. their concentrations are very low. Locally higher concentrations of trace elements were reported only for aluminium, zinc and selenium.

The water management perspective of the Bodrog region transboundary aquifer leaves little cause for complacency. The drainage basin is in a state of equilibrium, but the chemical status of groundwater is strongly affected by human activities. In spite of lower average nitrate concentrations in Hungary, data includes high measured nitrate concentrations particularly in association with potential pollution sources such as rural settlements. Increasing evaporation due to warming climate or changes in river dynamics can critically increase concentrations of dissolved components in shallow groundwater. Due to the relatively high TDS and Cl^- concentrations in shallow groundwater the future management of water resources should give attention to the potential impacts of increasing evaporation in a warming climate.

14.5 Conclusions

The investigations indicated that there are local pollution problems and direct and indirect sources of hazardous pollutants that may also cause groundwater pollution in the future. Evidently, there is a need to continue the characterisation of pollution spread and the risks for groundwater resources by more detailed sampling and modelling on both sides of the border. Co-ordination and implementation of such activities jointly might provide logistical advantages, reduce overlapping activities and lead to savings of time and money. If not a prerequisite then at least a great benefit for integrated water resources management and successful implementation of the WFD, are direct links and co-operation between regional and even municipal authorities and expert organisations. One of the underlying objectives of WFD is to create a common understanding of activities dealing with transboundary water resources. Particularly e.g. in management of pollution cases and in crisis situations requiring fast response and actions, it is important that the cross-border authorities are familiar with exchanging information and communicating directly with their transboundary counterparts rather than using high-level representatives as middle-men without a good knowledge of the conditions in the field.

The study indicated the need to continue the characterisation of pollution spread and the risks for groundwater resources by more detailed sampling and modelling on both sides of the border. Co-ordination and implementation of such activities jointly could provide logistical advantages, reduce overlapping activities and lead to savings of time and money. If not a prerequisite then at least a great benefit for integrated water resources management and successful implementation of the WFD, are the direct links and co-operation between regional and even municipal authorities and expert organisations [4]. Particularly e.g. in management of pollution cases and in crisis situations requiring fast response and actions, it is important that the cross-border authorities are familiar with exchanging information and communicating directly with their transboundary counterparts rather than using high-level representatives as middle-men without a good knowledge of the conditions in the field.

A selected list of groundwater management activities especially for the development of water services in rural areas is presented: (1) Support modernisation and updating of municipal water works, wastewater treatment and solid waste management in areas left without regional water services; (2) Training of local experts for different aspects of water services; (3) Support municipal administration outlining model contracts, guidelines for procuring services or setting Private-Public-Partnership arrangements in compliance with national legislation;(4) Support establishment of water co-operatives for improving water supply of small settlements, or groups of households, farms and small companies in conjunction with the regional and local social and economical development measures, supporting improvement of the living conditions of the poor and socially excluded part of the population, particularly the Roma-minority both in Slovakia and Hungary; (5) Support installation of small and cost efficient wastewater and sewage treatment systems; 6) Development programmes supporting the needed social integration should be initiated; (7) Assure by the further co-operation of decision makers and stakeholders in cross-border, regional and municipal level, that afore mentioned actions shall be in compliance and integrated with the ongoing RBMP-process as laid out in WFD [4].

Details of ENWAT projects and complete results are now available at: http://www.all-in.sk/enwat/dvd/index.html.

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Chapter 15
The Narew River Basin Management Problems – Integrated Approach

Tomasz Okruszko, Marek Gielczewski, Mateusz Stelmaszczyk, Mikołaj Piniewski, and Marta Utratna

Abstract An integrated approach to river basin management seems to be the most appropriate and promising way to achieve sustainable development of the large river catchment. Such approach is especially essential in the areas where economical activities are occurring together with great needs for nature protection due to its unique values and, local and global importance for ecological completeness. The Narew River Basin is a perfect example of such area. The main water management problems (key pressures and impacts) of the basin were identified. The present state of components of the integrated water management was recognized. Finally, the main directions for achieving integrated management, with their strengths, weaknesses, threats and opportunities, were elaborated.

Keywords Water management • River basin • Integration • Nature protection • Sustainability

15.1 Introduction to the Narew River Basin

15.1.1 Geomorphology, Climate and Hydrology

The Narew River Basin is situated in the north-eastern part of Poland (Fig. 15.1). The Narew River is the fifth largest in the country with regard to river length (484 km) and the size of the basin (ca. 28,000 km^2 before joining the Bug river). The entire basin, except for the most upper part (ca. 1,200 km^2), is located in Poland, but the head catchment is located in Belarus.

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DOI 10.1007/978-94-007-3949-9_15,

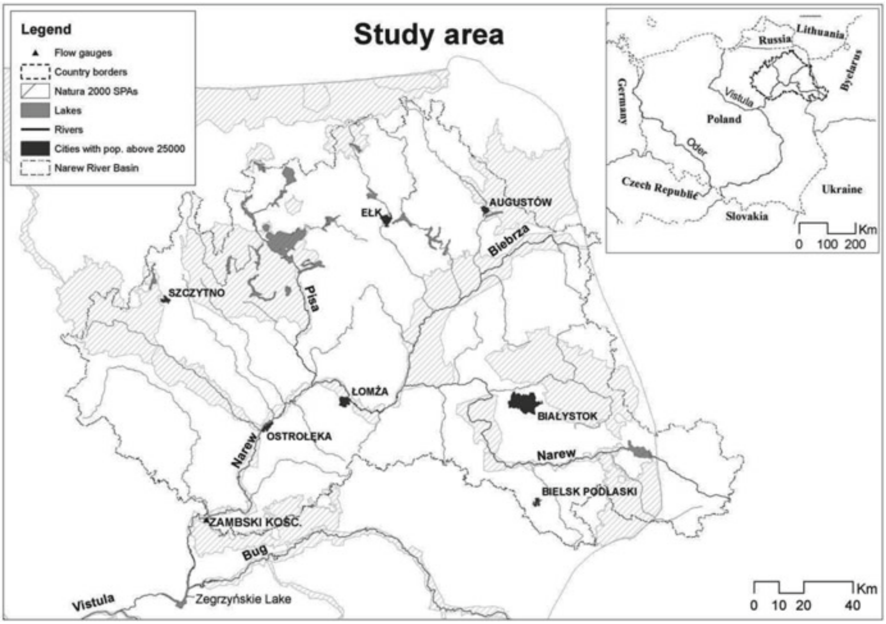

Fig. 15.1 Location of the Narew River Basin (After Gielczewski et al. [1])

The basin is developed in the reach of two last glaciations periods: Riss and Wuerm. From north to south the basin includes the following sequence of glacial landscapes types: moraine lake district, outwash plains, ice-marginal river valleys and moraine hills. Sandy soils of various types predominates. During the Holocene the main valleys have been filled up with mesotrophical-eutrophic peat layers which still are partly undrained at present.

Poland is located in a temperate climatic zone in which marine and continental air masses collide. This climate type features characterize also the Narew River Basin. However, due to its location in northeastern Poland the impact of continental air is more visible in the basin compared to the rest of the country. The yearly average temperature is 7.2°C and precipitation equals 617 mm.

The river network of the basin is fully developed and reach in tributaries, which mostly originate in the postglacial lakes located in the northern part of the basin. In the lake district region there are more than 500 lakes greater than 1 ha. A few irrigation and navigation channels creates interconnections between lakes and the river network. The flow regime is typical for the lowland rivers in this part of Europe with peak flows after snow melting and regularly appearing low flow periods in the fall of the summer. The yearly average flow recorded in the most downstream gauging station – Zambski Koscielne (before confluence of the Bug and Narew rivers in the artificial lake) equals to 147 $m^3 \cdot s^{-1}$, when the average yearly minimum is 55 $m^3 \cdot s^{-1}$.

15.1.2 Population and Economy

The area of Narew River Basin belongs to poorly populated in the scale of the country. The estimated number of inhabitants of the region is about 1.6 million. On average 55 inhabitants occur for square kilometre of the basin area, while in the rest of the country average population density is more than twice as large, being up to 119 inhabitants per square kilometre. More than half of the population (60%) lives in the cities and towns. The biggest city on the analyzed area is Białystok, the capital city of Podlaskie voivodeship, with 295,000 inhabitants [2]. The other cities are decidedly smaller and none of them exceeds 70,000 inhabitants. All cities have sanitary sewerage systems, transporting effluents to wastewater treatment plants, and storm drainage systems that drain off precipitation water to the nearest receiving water. In most of the cities sewerage network is distributive.

Narew River basin is an agricultural region, with a small degree of industrialization and no heavy industry. Existing production is connected with agriculture and forestry, and is based local raw materials, which are mainly: milk, meat, cereals, vegetables, fruits and wood. Industries that are developing are mainly agricultural, food and timber processing, and recently tourism. Wastewater from enterprises located in the cities in most cases discharge through the municipal main sewerage system and thence to wastewater treatment plants. Enterprises that are disperse through the basin area have their own effluent treatment.

15.1.3 Land Use and Nature Characteristics

Agricultural land dominates the basin, covering just above 60% of its area (Fig. 15.2). The upland of basin area is mainly used for arable land, when the valleys are used as pastures and grasslands.

The forestation ratio of the Narew River Basin is slightly over 34%, which somewhat exceeds the entire country average (Table 15.1). The largest and compact forest complexes are located in the north, west and east parts of the basin.

The basin is rich in nature areas and resources. It is the core of the region known as "the Green Lungs of Poland". The Narew and the Biebrza river valleys are among Europe's last active, regularly flooded riverine valleys. Until now, a considerable part of this area had been utilized for the purposes of extensive (environmentally sound) agricultural practices, thanks to which it still boasts wet meadows of a significant biodiversity value. Additionally in the south-eastern part of the basin, there are number of alder carrs which are groundwater fed. All those habitats are protected in the form of national parks.

The vegetation cover of the Narew river valley comprises of several dominating communities such as: reed beds, sedge communities, fens, humid meadows, single mown meadows and herbaceous communities. Many of water dependent plant habitats

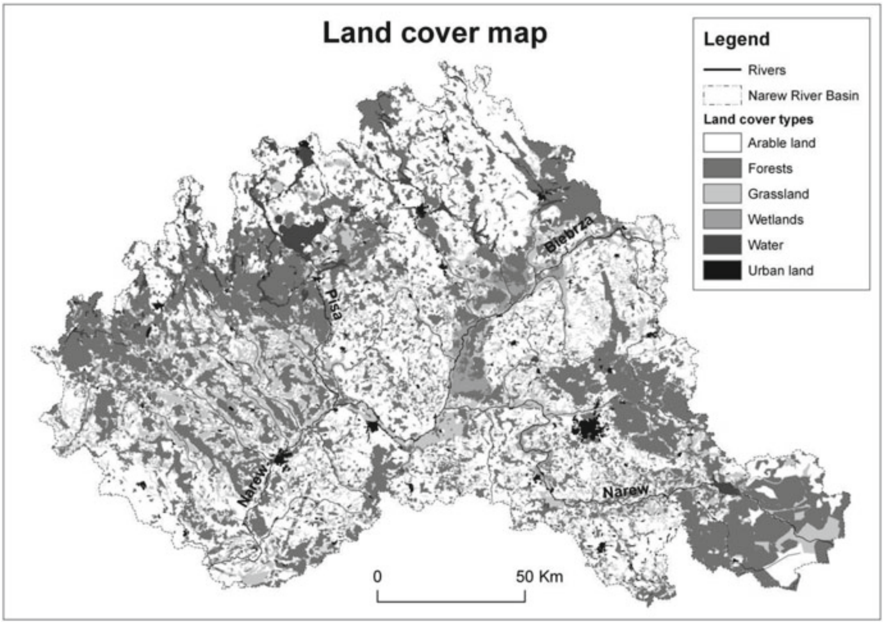

Fig. 15.2 Land cover in the Narew River Basin (After Gielczewski et al. [1])

Table 15.1 Comparison of land cover structure in Poland and in the Narew River Basin based on Corine land cover 2000 and 2006 [3]

Land cover types	Arable land	Forests	Grassland	Wetlands	Water	Urban land
Poland (%)	54	31.2	8.9	0.3	1.4	4
Narew River Basin (%)	44	34.2	16.9	2.1	1.5	1.3

which have been recorded in the valley are listed in the Council Directive 92/43/EEC of 21st May 1992 [4] (Habitat Directive). Among these are the following:

- Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation (3,150),
- Natural dystrophic lakes and ponds (3,160),
- Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation (3,270),
- Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Eu-Molinion) (6,410),
- Hydrophilous tall herb fringe communities of plains (6,430),
- Active raised bogs (7,110),
- Transition mires and quaking bogs (7,140),
- Galio-Carpinetum oak-hornbeam forests (9,170),
- Bog Woodland (91D0),

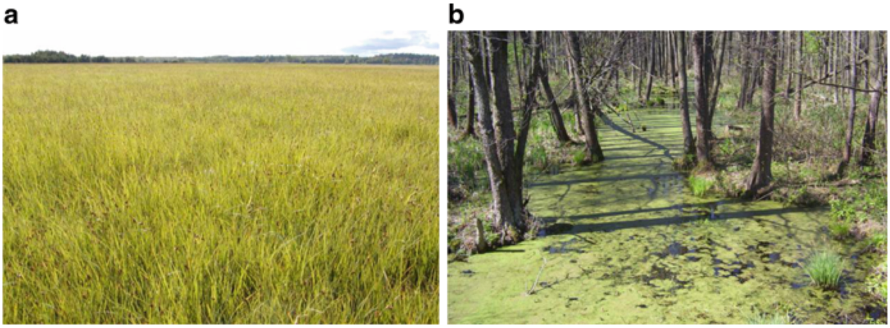

Fig. 15.3 Examples of habitat directive habitats (**a**) molinia meadows; (**b**) alluvial forest

Table 15.2 Special protection areas and special areas of conservation in Narew River Basin

SPAs		SACs	
Name	Code	Name	Code
Biebrza Protection Area	PLB200006	Biebrza Valley	PLH200008
Augustowska Forest	PLB200002	Agustowska Protection Area	PLH200005
Piska Forest	PLB280008	Narew Bog Valley	PLH200002
Knyszynska Forest	PLB200003	Knyszynska Protection Area	PLH200006
Lower Narew Valley	PLB200007	Upper Narew Valley	PLH200010

- Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Pandion, Alnion incanae, Salicion albae) (91E0),
- Riparian mixed forests of Quercus robur, Ulmus laevis and Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia, along the great rivers (Ulmenion minoris) (91 F0).

Three of the selected habitats – 7,110, 91D0 and 91E0 are priority habitats, i.e. ones under Community's special protection due to its natural range (Fig. 15.3).

The Narew river valley is also a very important area from wild life existence and protection point of view, especially with regard to bird communities. Many of those birds are protected under Council Directive [5] 2009/147/EC on the conservation of wild birds (commonly referred to as "Birds Directive"), the aim of which is to protect all European wild birds and their life habitats in particular through designation of Special Protection Areas.

Special Protection Areas (SPAs) and Special Areas of Conservation (SACs) together form the Natura 2000 network of protected areas. Some of those are listed in Table 15.2.

The Narew river valley also meets all criteria of Bird Life International. The area is a nesting ground for 90 endangered species out of which 52 are wetland birds. Three of those species are threatened with worldwide extinction. It is also a breeding area for 1% (or more) of European population of at least ten species of wetland birds. The most interesting species are: Eurasian Bittern (*Botaurus stellaris*), Little

Bittern (*Ixobrychus minutus*), Whooper Swan (*Cygnus cygnus*), Black Stork (*Ciconia nigra*), Black and Red Kite (*Milvus migrans*, *Milvus milvus*).

The basin's natural value and importance is emphasised by the existence of three large national parks: Narew National Park, Bialowieski National Park (the oldest in Poland – founded in 1932) and Biebrza National Park, which is the largest in Poland.

15.2 Water Quality and Water Use

In the previous two decades there were a few basin-wide studies conducted to investigated and describe water quality in the Narew River Basin (e.g. [6–8]). These studies differ from each other by discrepanding temporal variation and by the different spatial resolution. Even though, all these studies revealed similar results and concluded the same water quality patterns and status in the Narew River Basin. According to their findings the general statement was allowed that surface water quality in the Narew river was fairly good and the main conclusion was drawn that nitrogen and phosphorus are key components limiting quality of the surface water of the study area.

Despite the fact that, in general, water in the Narew River Basin was of relatively good quality there are some problems related to this issue. The latter of these studies [8], the most spatially detailed, identified the main existing problems. The study revealed that Narew water was not of the highest quality mainly because it contains a high concentration of nutrients. On the other hand, the concentrations of heavy metals and sulphur compounds in the Narew River Basin did not exceed the limits for the first-class water quality.

Wide analysis of the spatial distributions of nutrient concentrations associated with land use types provided a general insight into the concentration ranges and patterns within the basin. Generally, spatial distributions of nutrients showed increased concentrations in the downstream direction and in sub-catchments influenced by an effluent from point sources. The concentrations were slightly higher in the lower and middle parts than in the upper parts of the basin although the concentrations of the mainstream in the middle basin decreased due to a dilution by tributaries with lower concentrations (the Biebrza and Pisa rivers). Remarkably, agriculture is currently not a significant pollution source. The differences in concentration of nutrients between agricultural and forested areas were very small, which may result from the typical land use pattern in the Narew River Basin. As most arable lands are relative remote from the rivers and tributaries, their effect on water quality is less noticeable. The very extensively used grasslands (mostly for hay-making) do not bring nutrient input to the rivers either. A significant impact of point sources was observed in the basin, although downstream a remarkable decrease in nutrient concentrations occurs probably because of a combination of dilution, uptake by aquatic vegetation, aquatic soil adsorption and bio-chemical degradation processes [9].

At the basin scale the surface waters in the Narew River Basin were found to be of high quality when referred to water quality standards and ecological characteristics of the aquatic vegetation [10], despite, an increase of nutrient concentrations in the downstream direction and downstream from point sources.

The main potential water use in the basin is a sub-surface irrigation of grasslands in almost all tributaries to the Narew River. However, despite the existence of necessary infrastructure these areas are only sparsely irrigated. The use of surface water for domestic use is restricted to water works of Białystok, which uses bank infiltration water from the Suprasl River. There is a limited use for industrial aims as cooling water for power plant of Ostrołeka or technical water for the sugar beet processing in Łapy, hard-board production in Grajewo or timber mill in Hajnówka. The most important industry for the region – food processing is based on groundwater resources. The same counts for the domestic use in the towns and villages. The groundwater resources are rich and so far clean. Surface waters are used as recipients of treated sewage waters.

15.3 Key Pressures and Impacts – Main Water Management Problems

15.3.1 Activities Prior WFD Implementation

In July 1999, the Narew River has been chosen as a pilot basin for implementation of the WFD in Poland. There are four other basins in Poland were different type of implementation strategies are tested; with the Narew being the biggest. The project has been conducted in the frame of so called “twining agreement” between Polish Ministry of Environment and French Ministry of Spatial Planning and Environmental Protection.

As a result of a work of Polish and French specialists as well as the river basin committee members, the following main problems of water management has been identified:

– improving quality and protection of groundwater in aquifers without upper impermeable layer;
– decreasing of point source pollution in particular in the Lake Districts of Mazury and Augustów;
– protection of quality of water resources of the biggest water reservoir named Siemianówka;
– mires and peatland protection in all river valleys with the special attention paid to the national parks areas;
– sustainable water management for agriculture (in particular in upper reaches of the rivers).

15.3.2 Implementation of EU Water Framework Directive

The newly drawn and approved river basin plan has to provide the measures to solve main problems indicated in the previous studies as well as during process of drawing of River Basin Management Plan. Warsaw Regional Water Board is responsible for establishing such a plan under the requirements of WFD. Narew river is spatial diverse. Some parts are not available for shipping, unregulated. Others are navigable and river improvements allow tourism and recreation there.

According to Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive) water management plans are fundamental for making decisions which have impact on the conservation status of water resources [11].

The water management plan for the basin of the Vistula River (in which lies the Narew valley), approved on 22 February 2011, lists a series of plans for Narew basin. One of them is to create a tourist complex in Nowogrod (for Narew river), and in Serwatki, Morgowniki, Baliki and Ptaki (for Pisa river), with the intention to aid local economic development.

Actions dedicated for the protection against flooding, listed in the document, are:

- increasing the number of undertakings in the field of construction and modernization of flood embankments along the Narew river,
- construction of the Strzegowo-Unierzyz reservoir on Wkra river (right-bank tributary to Narew),
- reconstruction of weirs on the Suprasl river (right-bank tributary to Narew),
- erosion control of Pisa river (right-bank tributary to Narew) banks.

Many scheduled activities are also aimed at allowing for fish migration. Among these are improving fish ladders and hydraulic engineering equipment serving this purpose.

15.3.3 Beyond 2015

The Narew River Basin had been selected as one of ten Pilot Areas in Europe of the SCENES project. SCENES (Water Scenarios for Europe and Neighbouring States), the EU FP6 research project, was focused on development and analysis of comprehensive scenarios of Europe’s freshwaters up to 2050 [12, 13].

The scenario development process applied in the Narew River Basin used a coherent methodology developed for all SCENES Pilot Areas. Lake Peipsi basin in Estonia [14] and Candelaro basin in Italy [15] are among the examples. Complex methodology for scenario development in the stakeholders’ participatory process on the Pan-European and Pilot Area scales was initially elaborated by Kämäri et al.

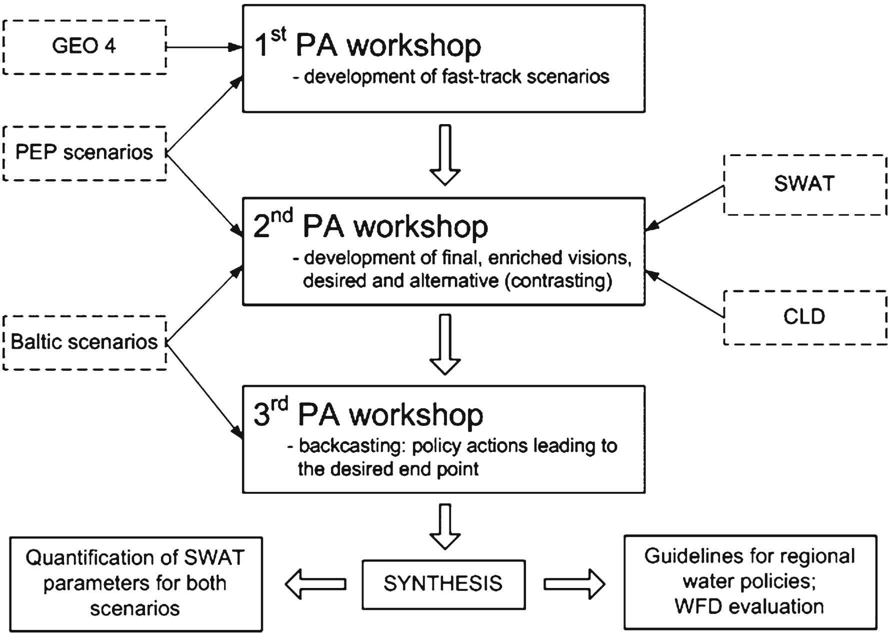

Fig. 15.4 Schematic representation of scenario development process in the Narew River Basin (After Gielczewski et al. [1])

[12] and further developed by Kok and van Vliet [16]. In general, the scenario development process consists of four steps [13]:

Step 1. Characterising present and near future;
Step 2. Looking at the future (long-term visions);
Step 3. Critical review of developed visions;
Step 4. Playing it back (short-term options).

In the Narew River Basin case three scenario development workshops were organized in 2008 and 2009 (Fig. 15.4) to carry out the scenario development process according to proposed methodology. During the first workshop two first steps were performed, and next, at the second and third workshops, third and fourth steps were applied respectively. In the whole process in the Narew River Basin three qualitative methods (card-technique, discussion groups and collages) and three semi-quantitative methods (Fuzzy Cognitive Maps, spidergrams and time trends) were used. The selected methods for scenario development process aimed at transition from basic qualitative to more quantitative information which can be more applied e.g. in modelling exercise. Four steps of scenario development process are ordered in a way that makes a logical sequence, starting from a simple description of the present situation and ending with collection of semi-quantitative data about the water issues. Such an approach reduces the data gap between qualitative storylines and quantitative models.

Since throughout the activities of the SCENES project, workshops were held in parallel at regional (e.g. Baltic scenarios) and pan-European (i.e. PEP, Pan-European Panel scenarios) scale, the scenario development process involved also exchange of data and information between workshops at different levels. This kind of exchange was called cross-scale enrichment of scenarios [16]. At the Pan-European meetings experts used their knowledge to determine pathways that could be followed on Pilot Area levels. At the regional Baltic scenario development workshops the representatives of the Narew River Basin took part in discussion, development and reviewing of the regional scenarios, which were built on a basis of the Pan-European scenarios and a data obtained during Pilot Area workshops [17].

15.3.4 GEO4

In SCENES Global Environmental Outlook (GEO-4) scenarios were used as a starting point for discussing and developing future visions for the Narew River Basin. The GEO-4 scenarios prepared by United Nations Environment Programme [18] describe possible ways of how the world and Europe will look like in 2050. They present four alternatives named as: *Markets First*, *Policy First*, *Sustainability First*, and *Security First*. As described in GEO-4 report [18] the main elements of the four scenarios are as follow:

- *Markets First*: the private sector, with active government support, pursues maximum economic growth as the best path to improve the environment and human well-being for all.
- *Policy First*: the government sector, with active private- and civic-sector support, implements strong policies intended to improve the environment and human wellbeing, while still emphasizing economic development.
- *Security First*: the government sector and the private sector vie for control in efforts to improve, or at least maintain, human well-being for mainly the rich and powerful in society.
- *Sustainability First*: the civic, government and private sectors work collaboratively to improve the environment and human well-being for all, with a strong emphasis on equity.

In SCENES project two alternative visions for the Narew River Basin were elaborated by the stakeholders' panels. One vision, which was more plausible for stakeholders, along the line of the *Sustainability First* scenario and an alternative vision based on principles of the *Markets First* scenario.

The water scenarios development process for the area included also the backcasting analysis of the elaborated storylines. All the stakeholders groups had independently selected a good water status according to EU Water Framework and Bathing Directives [11, 19] as one of the ultimate goals to be analyzed for both scenarios in the time horizon of 2050. The scenarios differed by the achieved "level" of this good status. A good water status according to above mentioned EU Directives was assumed for the *Market First* scenario, when for the *Sustainability First* one it is expected to reach even better water status, so-called good water status "plus". This status assumes that waters will be of higher standard than this set nowadays by WFD. For both scenarios the milestones and interim objectives, together with possible barriers have been discussed and defined. In case of the *Sustainable First* scenario (Fig. 15.5a) the most important short term objectives are the establishment of a coherent legal system by improvement of law regulations and change in ecological awareness of the society by amendment of the educational system. They are vital in achievement of mid- term objectives, such as achievement of spatial order, agriculture practicing according to Good Practices Codex, wide use of innovative environmental, especially water efficient, technologies leading to reduction of pollution from agricultural, municipal, industrial and infrastructural sectors, acceptation and observation of law regulations, that have to be reached in order to fulfil the ultimate goal. Successful implementation of this scenario would need achievement of several milestones among which the following seem to be the most important: appearing of charismatic leader either the individual or a body (establishment of the Narew River Basin Council may be an example) that will show the way and drive the changes; establishment of efficient and environmental monitoring that will provide sufficient information about system functioning and allow for quick preparation and application of improvement plans, if necessary; securing the sufficient financial support, mainly from EU, for stimulating necessary activities, especially in water management and agriculture but by quitting the direct subsidies. The major barriers for realization of this scenario are related to short term objective since they may stop the entire process before it will get really running. Once the process starts, it will be difficult to stop and might only slow down temporarily. A charismatic leader not coming into view may hamper the development in this direction, especially that it might be due to a lack of trust within society towards this economically less profitable way of development, which is the next barrier. As a consequence, a lack of law observation and inertia to changes in the educational system may produce difficulties in the implementation of this scenario.

In the *Market First* scenario (Fig. 15.5b) a significant milestone or rather turning point related to self-reflection of society is expected in the second half of the period (circa 2035). For the first part of the period the interim objectives are related to development of economy sectors such as larger scale farms, intensive light industry, road transport and tourism. They are supported by development of innovative but profit-oriented, neglecting environment technologies, liberalization of legal system, especially loosing of environmental protection law. A development towards these objectives will induce much higher energy demands. Solving energy supply problems, by a nuclear power plant for instance, will be one of the main milestones for that period. An expected self-reflection will be a result of decreasing regional attractiveness and overexploitation of the environment, possibly leading to ecological disasters. In turn, this will lead to a process similar to the *Sustainability First* scenario based on changes in education, tightening up legal regulation including efficient environmental monitoring and introduction of environmental high fines and fees/taxes (polluter pays principle) as a milestone. A lack of self-reflection is the main barrier for achieving the good water status in this scenario.

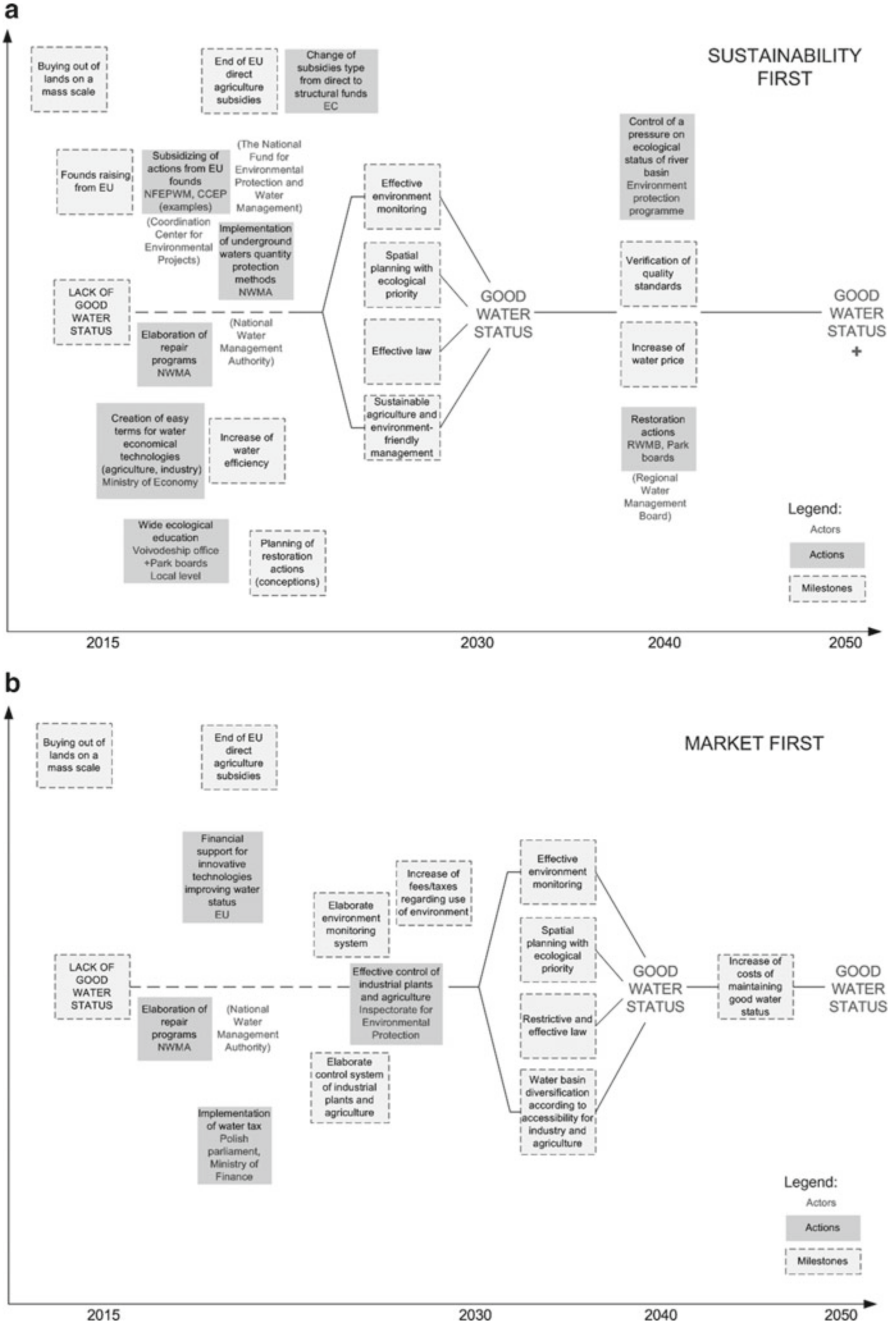

Fig. 15.5 Backcasting graphs for: (**a**) the *Sustainability First* scenario; (**b**) the *Markets First* scenario (with indicated actors playing most important role, main possible milestones, and actions necessary to undertaken to achieve the ultimate goal)

15.4 Response to Key Pressures and Impacts

Tackling the issue of solving the main water management problems of the Narew River Basin and successful response to existing in the area key pressures and impacts, presented in the previous section for the different time scales, requires performing adequate actions in the several fields. These fields, their present status, already taken steps and necessary actions are as follows.

15.4.1 Integration

Regional Board for Water Management in Warsaw is responsible for the most of water-related issues in the Narew River Basin. However, some duties are shared (divided) between the Board and voivodeship (local administration) authorities e.g. water licensing. Similarily, on the state level there are some tasks in small rivers, like drainage irrigation schemes and flood protection performed by institutions appointed by the Ministry of Agriculture. On international level there is no agreement on co-operation with Belarus (where the Narew river originated from).

15.4.2 Role of Wetlands

The basin is rich in wetlands of international significance [20, 21] and two of three national parks located in the basin are devoted for wetland protection. Floodplain wetland vegetation is clearly dependant on frequent inundation of river water and many of its indicator species belong to the most ecologically valuable ones. However, there is no policy for recognition of wetlands as an ecosystem service provider for water management, despite the fact that the river basin management plan should be oriented on wetland protection. Several recent studies carried out in the wetlands of the Narew National Park [22, 23] and in a larger scale, for 16 floodplain wetland sites in the Narew River basin [24] showed that negative signs in hydrological conditions of wetland communities had been observed in recent years, which should draw attention of water managers to the problem of establishing a proper policy of wetland protection.

15.4.3 Role of Protected Areas

In the common legislation practice the role of protected areas as water users is growing. E.g. managing good ecological status for water bodies within the Natura 2,000 sites becomes one of the biggest challenges for water managers. The higher water demands in terms of quality but also sometimes in quantity (flood pulse for riparian wetlands) leaves less space for the different water use in other sectors (especially agriculture).

15.4.4 Water Quantity Problems

There are no water quantity problems in the basin. In the few smaller rivers, the drainage irrigation systems cause the problems during the low flow periods.

15.4.5 Water Quality Problems

The water in the Narew River and its tributaries is of medium quality. The main pollutants are nitrates, phosphates, *E. coli* (as in the most of the country) and additionally chlorophyll in the upper course due to the blue-algae bloom in the Siemianowka reservoir. A number of lakes in the Lake District are fairly eutrophic. Restoration measures are not conducted. Currently municipal sewage treatment plants mainly control sources of pollution.

15.4.6 Impact of Infrastructures

There are five weirs on the course of the Narew River, none of them equipped with the fish ladder. The Narew river was slightly trained in mid-1970s for the flood control and drainage reason. The Siemianówka Reservoir requires special attention, while an impact of existing infrastructure is taken into account. The reservoir brings to water management issues many long time abandoned problems from the past. It started its operation in 1990 after 20 years of construction works. The total capacity of the reservoir equals to 79 million cubic metres. It was planned at early 1960s, as a water reservoir supporting the huge investments in drainage of the Narew river valley wetlands. The assumptions at the planning phase were that the reservoir would enable to reach several goals:

- to meliorate wetlands of the Upper Narew and Supraśl rivers,
- to cover water management requirements for the Bialystok agglomeration,
- to increase water outflows of the Narew and Supraśl rivers in order to better their sanitary state,
- to attract tourist to the region
- to be suitable for fishing.

In the meantime the socio-economical situation of Poland has changed dramatically. Moreover, the ecological value of wetlands became widely recognised and so important that instead of drainage, the Narew National Park was created. Białystok municipal drinking water production company after introducing the financial instruments for water saving uses only half of water previously pumped from the surface waters. Therefore, only the recreational goals of reservoir remained. Unfortunately, the bloom of the blue-algae, which started from mid-1990s does not allow for rational use of water for this purposes, either. The extensive dispute how rationally use the reservoir and not to spoil the natural values of the Narew National Park (a flood pulse concept) started a few years ago between the reservoir administration, local administration, researchers, NGO's and has not arrived to the conclusions yet.

15.5 Conclusions – SWOT Analysis

The analysis performed with the different time horizon show lot in common for the main pressures and problems to be solved. As a conclusion in finding the main challenges in approaching water management problems in the Narew River basin in an integrated way, it is useful to employ the simple **S**trength, **W**eakness, **O**pportunities and **T**hreats analysis. As this type of approach links the specific water management problems with the overall socio-economical perspectives on the country scale.

15.5.1 Strengths

- High natural values of number of medium sized rivers, especially lack of their fragmentation due to low number of hydraulic structures;
- Very high natural values of number of floodplains of medium and big size rivers, including wetlands in different protection status;
- Positive trend in water quality due to investments in sewage treatment plants both in cities as well as in industrial facilities, collapsing of the water demanding industry;
- Working practice of management on river basin scale via Regional Water Management Boards;
- Good working Water Permits system;
- Introduction in number of cities water metering leading to significant savings of water;
- Lack of industrialised, intensively irrigated agriculture;

15.5.2 Weaknesses

- Weak co-operation between key departments of Polish Ministry of Environment (the Water Management and the Nature Conservation Departments) and between different ministries dealing with water issues (e.g. between Ministry of Environment and Ministry of Agriculture), the same counts for the regional (voievodship) level;

- Very low budget investments in modern water management facilities (monitoring, floodplain restoration projects, river basin management plans, etc.) or modernisation of the old hydraulic structures;
- Transformation of small rivers into drainage channels being nowadays in very poor hydraulic and ecological conditions due to lack of maintenance in last 30 years;
- Limited numbers and weakness of Polish NGOs which could play a key role in implementing of WFD;
- Lack of transboundary agreement with Belarus resulting in very limited effective collaboration between both countries;
- Large and difficult to fill gap in understanding in practical terms "integrated management" between Polish engineers and environmentalists even in the currently run governmental programs.

15.5.3 Opportunities

- Necessity for Poland to restructure approach to water management in order to meet requirements of WFD;
- Necessity for Poland to meet requirements of other EU Directives;
- National Water Management Plan, which is currently developed may include the newest approach to water management;
- Potential in using of EU agro-environmental schemes for achieving good ecological status of water;
- Possibility to create a strong pro-environment lobby in river basin committees to be established by supporting capacity building among Polish NGOs;
- Increasing interest of society in public participation in discussion over vital socio-economical and ecological issues such as water management.

15.5.4 Threats

- Generally very challenging deadlines for implementing WFD in EU countries;
- Significant number of old hydraulic infrastructure in small tributaries;
- Lack of stable, economical solutions for maintenance of the infrastructure;
- Increasing flood and drought hazard due to the climate changes;
- Very limited amount of time left for present Polish water managers for revolutionary change of their "state of minds", especially the way in which water is perceived through the perspective of WFD and the need of introducing participatory process in decision making;
- Assuming that "information" is equal to "participation" also by river basin stakeholders;
- Development of intensive, farm type of agriculture subsidised by CAP of EU;

All factors indicated in the SWOT analysis impacts the way, in which water management problems of the Narew River basin will be solved. The specific feature of this catchment is domination of agriculture related problems and high ecological value of the river valleys. It means that water management plays a special role in compromising the social needs of the inhabitants (either farmers or employees of the food processing industry), economical pressure for the more intensive land use and ecological necessity of preserving the natural values of the region.

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