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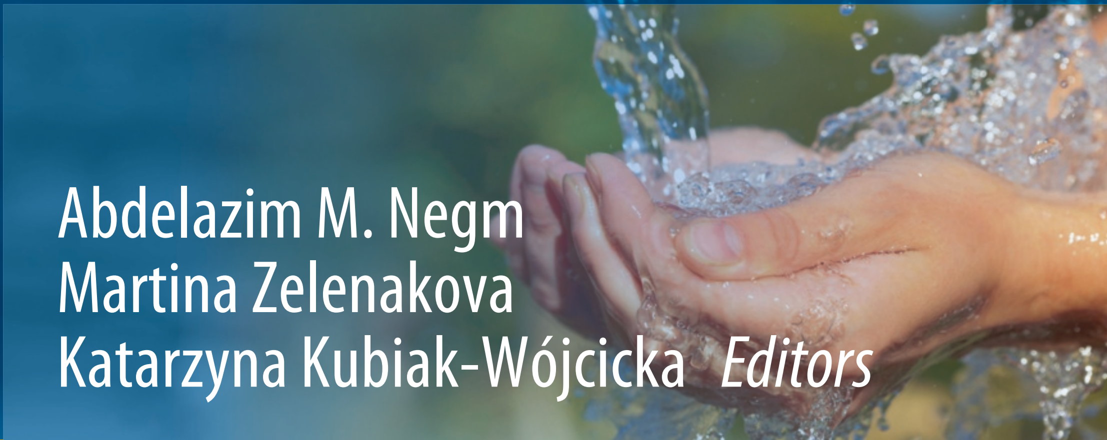

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Water Resources Quality and Management in Baltic Sea Countries

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Water Resources Quality and Management in Baltic Sea Countries

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Preface

This volume is titled *Water Resources Quality and Management in Baltic Sea Countries*. It was created to emphasize the importance of sustainable water management in countries within the Baltic Sea basin and their impact on the state of its environment.

The Baltic Sea is a unique body of water. This sea is relatively shallow, semi-closed, which is characterized by a slow water exchange cycle. The Baltic Sea is particularly sensitive to pollution. The basin area of the Baltic Sea is about four times larger than the surface of the sea.

The Baltic Sea Region is a highly diversified area in economic, environmental, and cultural terms. There are nine countries in the basin area of the sea that have many common resources and show significant interdependence.

Potential benefits associated with the clean Baltic Sea prompted representatives of states to undertake joint actions for the protection of the Baltic marine environment. In such circumstances, the Baltic Sea Region can be a model of regional cooperation that allows testing and development of new concepts and strategies as examples of best practice.

The main problem in the Baltic Sea is eutrophication. It is caused by an excessive influx of nutrients (nitrogen and phosphorus compounds) from the catchment area. All amounts of nutrients introduced into the sea have a long-lasting effect on the state of the whole sea. Therefore, the problem applies to all countries in the catchment area and no country or region can solve this problem alone.

Despite the visible effects of improving the state of the Baltic Sea environment, the countries of the region still have a lot to do. Many activities for the environment of the Baltic Sea are financed thanks to co-financing from European Union funds and other financial programs.

Therefore, environmental protection of the Baltic Sea is permanent and, at the same time, an essential element of cooperation between the countries of the Baltic Sea region.

This book consists of 14 chapters, which are presented in eight parts. This is the result of the teamwork of scientists from various countries who deal with the issues of sustainable water management. Detailed water quality issues were discussed for Latvia, Estonia, Germany, and Russia.

It worth mentioning that due to a large number of qualified chapters sent from Polish scientists, it was not possible to include them in this book, and instead, two volumes are being written about water resources in Poland, covering all details of Polish water resources by the same editor and will be published by Springer too.

We hope that researchers, designers, and employees in the field of sustainable development and the environments described in the book will find here a useful source of information. The book certainly does not exhaust the entirety of the issues contained in the title, which is why each chapter contains a bibliography extending the problems discussed.

The first part consists of *Introduction*, which was written by the volume's editors and reviewed by Prof. Omran. The goal is to familiarize the reader with the research issues that have been discussed in this volume.

The second part discusses *Overview of Water Bodies and Water Resources in Baltic Sea Countries*. This part consists of two chapters. The first chapter in this part was presented by El-Sayed E. Omran and Abdelazim M. Negm. The chapter is entitled "Overview of the Water Bodies in the Baltic Sea Countries." This chapter discusses various aspects of the Baltic Sea to develop a synthesis of existing knowledge and to add a new perspective on the body of water in the Baltic Sea.

The second chapter titled "Overview of Water Resources, Quality, and Management in Baltic Sea Countries" was presented by Mahmoud Nasr and Abdelazim M. Negm. This chapter discusses the issue of protecting the Baltic Sea's water resources through legal regulations that have been taken in countries belonging to the Baltic Sea catchment area. The authors indicated the state and sources of financing that contributed to the reduction of sources of pollution of the Baltic Sea waters.

The third part titled *Quality of Groundwater in Baltic Sea* presents the chapter "Environmental Quality of Groundwater in Contaminated Areas—Challenges in Eastern Baltic Region." This chapter was written by a team of scientists under the direction of Juris Burlakovs. The purpose of this chapter is to give an oversight view on problems and challenges linked to groundwater quality in the Eastern Baltic region. On the basis of specific case studies, the authors explained problems with groundwater monitoring, remediation, and general analysis of the quality of the environment.

The fourth part of the book is entitled *Water Quality and Wetlands in Latvia* and consists of a chapter entitled "Water Quality Assurance with Constructed Wetlands in Latvia." This chapter was written by Linda Grinberga. This chapter outlines the experience of Latvia in wastewater treatment and nutrient retention in constructed wetlands. In Latvia, constructed wetlands as a domestic wastewater treatment systems were initially implemented in the year 2003. Basing on the initial results presented in this chapter, constructed wetlands could gain more trust to be implemented for water quality assurance as treatment systems for the wastewater from household and agricultural sectors in Latvia.

The fifth part of the book is entitled *Potential Management of Water Contaminates in Germany* and consists of three chapters.

The first chapter in this part entitled "Phosphorus Fluxes in the Baltic Sea Region" was written by Judith Schick, Sylvia Kratz, Elke Bloem, and Ewald Schnug. In the chapter, different options were compiled and discussed, which have the potential to reduce the phosphorus of the Baltic Sea. Within the frame of the EU research project "PROMISE—Phosphorus Recycling of Mixed Substances," data available on phosphorus fluxes of the riparian countries of the Baltic Sea Region was collected and analyzed. The results of this data analysis have been presented in this chapter.

The next chapter entitled "Regulatory Scenarios to Counteract High Phosphorus Inputs into the Baltic Sea" was written by Elke Bloem, Silvia Haneklaus, and Ewald Schnug. In the chapter, different options were compiled and discussed, which have the potential to reduce the pollution of the Baltic Sea significantly in the future. These different options are intertwined so that each action alone will never achieve the same efficacy in reducing phosphorus losses to water bodies as the implementation of the full range of options. These strategies will help reduce phosphorus supply and protect sensitive waters such as the Baltic Sea from further eutrophication.

The chapter "Challenges of Flood Risk Management at the German Coast" was written by Helge Bormann, Jenny Kebschull, and Frank Ahlhorn. This chapter presents the challenges associated with water management in coastal regions, as well as challenges arising from the impact of climate change (imperfect), flood protection systems, and a lack of risk awareness. Based on the results of two case studies, the need to develop integrated risk management methods was emphasized, which is based on multiple scenario analyses and which involves as many stakeholders as possible to share responsibility and come to a joint strategy.

The sixth part is titled *Potential Stresses on Water Resources in Russia*. It consists of two chapters. The chapter entitled "Water Resources of the Russian Part of the Baltic Sea Basin and Their Possible Changes Under Global Warming" was written by Mikhail V. Georgievsky and Maria A. Mamaeva. The chapter presents the results of studies on the assessment of streamflow in the rivers of the Russian part of the Baltic Sea basin. Those studies were carried out by specialists from the State Hydrological Institute in different years., including assessments for the territory of the former Soviet Union. An overview of monographs and other reference publications on the country's water resources assessment, with an emphasis on water resources estimates were defined for the Baltic Sea basin, and predictive estimates of possible changes in river streamflow that was made at the State Hydrological Institute are presented.

The chapter,"Schemes of Integrated Use and Protection of Water Bodies in the Russian Part of the Baltic Sea Basin as a Basis for Water Resources Management," was written by Mikhail V. Georgievsky, Vladimir V. Kostko, and Maria A. Mamaeva. The chapter deals with the legal and methodological support for the use of water resources of the Russian Federation in the frame of development and implementation of the schemes of integrated use and protection of water bodies, including development standards for the permissible impact on water bodies, in accordance with the Water Code of Russia. The chapter describes the regulatory and legal provision of schemes (Water Code and Water Strategy of the Russian Federation); basin management principle, applied in Russia in the field of use and protection of water bodies; content and structure of schemes. The schemes that have been developed and approved for river basins flowing into the Baltic Sea from Russia are listed.

The seventh part, *Implementation of Water Policy for Estonian Water Resources*, consists of two chapters.

The chapter "Estonian Fluvial Water Bodies and Inundation Directive" was written by a team of authors under the direction of Elve Lode.

This chapter discusses the result of work on the implementation of flood risk maps for water bodies in Estonia in 2016. In accordance with the EU Floods Directive (2007/60/EC) with insurance purposes, these maps were prepared with return periods of 2, 5, 10, 25, 50, 100, 200, 500, and 1000 years. The authors note that the result obtained largely depends on the availability of hydrological data and the quality of digital altitude models.

The chapter "Joint Methodology for the Identification and Assessment of Groundwater Dependent Terrestrial Ecosystems in Estonia and Latvia" was written by a team of scientists under the direction of Jaanus Terasmaa. This chapter discusses the interactions between ground and surface waters as well as the role of groundwater in terrestrial and aquatic ecosystems. The authors developed a theoretical approach to identifying, assessing, and monitoring terrestrial groundwater ecosystems. The methodology used can be used in other countries.

The last part of the book entitled *Conclusions* is consisted of two chapters. The first chapter is titled "Update, Conclusions, and Recommendations for "Water Resources Quality and Management in Baltic Sea Countries"" and was written by the editors and reviewed by Prof. Omran while the second chapter is titled "Estonian Wetlands and the Water Framework Directive" and was added to the conclusions part due to its uniqueness nature. Both chapters must read to integrate and complete the whole image of the book in the mind of the reader.

Thanks to all who contributed to this high-quality volume, which is a real source of knowledge and the latest research findings in the field of water resources in Baltic Sea countries. We would love to thank all the authors for their invaluable contributions. Much appreciation and great thanks are also owed to the editors of the Earth and Environmental Sciences series at Springer for constructive comments, advice, and critical reviews. Acknowledgements are extended to include all members of the Springer team who have worked long and hard to produce this volume. Editors welcome any constructive comments to enhance and might be extend the next editions with new contents.

Toruń, Poland — Katarzyna Kubiak-Wójcicka
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Contents

Introduction

Introduction to “Water Resources Quality and Management in Baltic Sea Countries”

Abdelazim M. Negm, El-Sayed E. Omran, Katarzyna Kubiak-Wójcicka and Martina Zelenakova

Abstract This chapter introduces the book titled “**Water Resources Quality and Management in Baltic Sea Countries**” by presenting a summary of each chapter. The chapters are grouped into five themes to cover a variety of topics on water resources quality and management in Baltic countries including (Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland and Germany). Thirteen chapters are presented in this book. The subjects include characteristics of water bodies in Baltic countries, water resources and their Baltic Sea reliability and overview of publications. The volume also discusses groundwater quality, wetlands, and water contamination management.

Keywords Water resources · Management · Contaminant · Groundwater · Constructed wetlands · Water bodies · Baltic Sea countries · Latvia · Germany · Russia · Estonia · Water quality

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1 Background

The Baltic Sea is an extremely specific and unique body of water along which nine countries lie: Denmark, Sweden, Finland, Estonia, Lithuania, Latvia, Russia, Poland, and Germany. The location of these countries is shown in Fig. 1. All of these countries, except Russia, belong to the European Union. The unique nature of the Baltic Sea makes it particularly vulnerable to current changes. This volume discusses issues related to water resource management in the Baltic countries, which significantly affect the state and quality of water in the Baltic Sea.

Fig. 1 The Baltic Sea region with political borders

The area of the Baltic Sea catchment is about four times larger than the surface of the sea. A comprehensive review of the state of water resources, quality and management in the countries of the Baltic Sea is made in Chaps. 2, 3 and 4. The remaining chapters discuss the management of water resources, their size and water quality, and management in individual countries (Russia, Niemcy, Estonia, Latvia, Lithuania).

In Chap. 2, the water bodies of the Baltic Sea countries are introduced while in Chap. 3, the basic information on water resources and their qualities and their related publication from Scopus and Web of Science are presented. These two chapters are introduced in Sect. 3.1.

Due to the importance of groundwater as freshwater for Baltic Sea countries, Chap. 4 (Sect. 3.2) discusses the quality of groundwater in Baltic countries.

Due to a large number of submitted qualified chapters from Poland scientists, authors and researchers, it was not possible to include them in this book and instead, two volumes on Water Resources in Poland covering all details of Polish water resources are being under production, Zeleňáková et al. [1, 2].

2 Themes of the Book

The book intends to address the following main themes in more detail:

- Overview of Water Bodies and Water Resources in Baltic Sea Countries
- Quality of Groundwater in Baltic Sea
- Water Quality and Wetlands in Latvia
- Potential Management of Water Contaminates in Germany
- Potential Stresses on Water Resources in Russia
- Estonian Water Resources.

3 Chapters' Summary

The next subsections present the main technical elements of each chapter under its related theme.

3.1 Overview of Water Bodies and Water Resources in Baltic Sea Countries

Two chapters are presented under this theme. The first one is titled "**Overview of the Water Bodies in the Baltic Sea Countries**". It used remote sensing to provide the audiences with information on the various aspects of the Baltic Sea to develop a synthesis of the existing knowledge and add a new perspective on the water bodies in the Baltic Sea Countries. The authors focus on the following Baltic Sea issues: geography, development and history of the Baltic Sea, Eastern Baltic Sea dynamic coastline, Baltic Sea drainage basin, fragile ecosystem, Baltic Sea surface topography and its North Sea transition zone, general water types considered in Europe's Coastal Seas. Also, they discuss where the land is going up or the water is going down to understand the future Baltic Sea level rise and to enable different adaptation approach to climate change. Some of the problems facing the Baltic Sea are provided to highlight that they need solutions.

The second chapter is titled "**Overview of Water Resources, Quality, and Management in Baltic Sea Countries**". It provides an overview of the water status and features for the Baltic Sea countries. This objective is attained based on a systematic literature review method and an analysis of relevant documents and reports about the Baltic Sea Basin. Most information is collected from peer-reviewed journals available in the Web of Science, Scopus, and Google Scholar databases. Some recommendations that could be used to improve the Baltic Sea quality are considered. Lastly, a summary of the essential conclusions and perspectives for further researches is demonstrated.

The Baltic Sea region consists of 8 EU member states (Denmark, Poland, Germany, Finland, Sweden, Estonia, Latvia and Lithuania) and one non-EU member state (Russia). The economic condition of these countries is varied. The countries forming the European Union before the accession of new members in 2004 are Germany, Finland, Denmark, Sweden. Other countries: Poland, Lithuania, Latvia and Estonia joined the EU in 2004.

Surface water and groundwater resources differ widely among these countries due to the existence of various rivers, lakes, streams, dams, drains, reservoirs, and aquifers. Due to the importance of the resources of the Baltic Sea, numerous studies have recently been carried out to cover the Baltic countries' water status. According to the Scopus database, the total number of published documents using the research keywords "Water", "Baltic", and "Countries" was 140 during 2001–2010, which increased to 186 documents from 2011 to 2019. The documents were funded by the European Commission, Academy of Finland, California Environmental Protection Agency, Norges Forskningsråd, and other sponsors. The peer-reviewed and highly ranked international journals that handled these publications include Marine Pollution Bulletin, Agriculture Ecosystems Environment, Ambio, Hydrobiologia, Ecological Economics, and Water Science and Technology.

The Baltic countries have agreed on a number of international cooperation and European agreements to ensure long-term protection of the quality of the Baltic Sea environment. An example of such cooperation is the Convention on the Protection of the Baltic Sea Environment (Helsinki Convention), which referred to the comprehensive protection of the Baltic marine environment (http://stateofthebalticsea.helcom.fi/in-brief/). The Baltic countries have pledged to take appropriate steps to reduce pollution of the Baltic Sea. The Helsinki Convention did not enter into force until May 3, 1980. The Helsinki Commission—HELCOM, which is the executive body of the convention, has become a permanent organizational structure of the convention.

National efforts have also been made to obtain healthy ecosystems throughout the Baltic Sea region and to solve major problems affecting marine eutrophication.

In recent years, there has been a systematic decrease in pollution introduced into the Baltic Sea. The good quality of river waters flowing into the sea is of key importance for achieving good environmental status of marine waters. Further reduction of pollution coming from individual catchments depends on the progress of introducing solutions in individual countries. Lithuania, Latvia, Estonia and Poland are still facing these challenges.

The Baltic countries have signed a number of international European agreements to ensure long-term protection of the quality of the Baltic Sea environment. An example of such cooperation is the Convention on the Protection of the Baltic Sea Environment (Helsinki Convention), which referred to the comprehensive protection of the Baltic marine environment (http://stateofthebalticsea.helcom.fi/in-brief/). The Baltic countries have pledged to take appropriate steps to reduce pollution of the Baltic Sea. The Helsinki Convention entered into force on May 3, 1980. The Helsinki Commission—HELCOM, which is the executive body of the convention, has become a permanent organizational structure of the convention. National efforts have also been made to obtain healthy ecosystems throughout the Baltic Sea region and to solve major problems affecting marine eutrophication.

In recent years, there has been a systematic decrease in pollution introduced into the Baltic Sea. The good quality of river waters flowing into the sea is of key importance for achieving good environmental status of marine waters. Further reduction of pollution coming from individual catchments depends on the progress of introducing solutions in individual countries. Lithuania, Latvia, Estonia and Poland are still facing these challenges.

3.2 Quality of Groundwater in the Baltic Sea

Only one chapter was selected to discuss issues related to the groundwater quality in Baltic Sea countries. This chapter is titled "Environmental Quality of Groundwater in Contaminated Areas—Challenges in Eastern Baltic Region". The chapter provides an insight into the Eastern Baltic region's problems with contaminated sites and groundwater quality. Case studies provide a comprehensive perspective on groundwater quality, monitoring, treatment options, and future challenges for practical solutions for contaminated areas. Globally, the growing coastal population, including the Baltic Sea region, is facing new challenges. Agricultural, housing, industrial, and transport activities affect the environmental quality of water resources.

In addition to research conducted in the field of pollution of the Baltic waters with petroleum products and heavy metals there appear, new dangerous pollutants such as pharmaceuticals and plastics.

In chapter also nutrient problems creating excessive eutrophication and saltwater intrusions in groundwater by excessive pumping are described. Environmental contamination of Eastern Baltic is mainly of historical origin however we may scale it further as it is a worldwide issue. Remediation is compulsory where prescribed risk is based on numerical criteria or standards and we must learn how to assess, monitor and choose prevention and treatment options through the case studies that are already performed in industrial scales.

3.3 Water Quality and Wetlands in Latvia

The chapter with the title "Water Quality Assurance With Constructed Wetlands in Latvia" is presented under this theme. It outlines the experience of Latvia in wastewater treatment and nutrient retention in constructed wetlands. Constructed wetlands for water quality assurance were implemented since 2003 in Latvia. Several constructed wetlands with different technical constructions were adapted to retain nutrients and to reduce organics from the water. Vertical subsurface flow constructed wetland was designed and built to receive wastewater from the Tervete Rehabilitation centre located in the Zemgale region, Tervete Municipality as a pilot-scale demonstration object. The domestic wastewater from a small village Birze after a partial treatment was discharged in a surface flow constructed wetland. Horizontal subsurface flow constructed wetland was installed at the farm Mezaciruli, Zalenieki county to purify stormwater from the hard surfaces from the farmyard. Two wetlands built by surface flow were implemented to retain nutrients from the waters when runoff was formed in a tile-drained agricultural catchment basin.

3.4 Potential Management of Water Contaminates in Germany

Three Chaps. (6, 7 and 8) are presented in the book under this theme. The chapter entitled "Phosphors Fluxes in the Baltic Sea Region - a Meta Data Analysis" focuses on the analysis of phosphorus analyzes to help understand the P use efficiency of countries or regions and guide stakeholders and decision-makers in the right direction as to what action needs to be taken to boost P use performance. Phosphors budgets and fluxes in 8 countries of the Baltic Sea Region who share a direct coastline to the Baltic Sea (Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, Poland and Germany) are assessed and suitable strategies are discussed to identify and improve the P use efficiency in these countries. Eurostat provides data on gross P budgets, but such budgets are limited to quantifying an agricultural system's inputs and outputs. To provide more insight into how nutrients flow through the system, the literature compares and explores these data in relation to P flow analyzes of these countries. Flow analyses allow to take a look at internal P flows and to identify P losses from the system into the environment. The authors claimed that substantial efforts were needed to protect the Baltic Sea from further agricultural eutrophication. Consequently, the chapter titled “Regulatory Scenarios to Counteract High Phosphorus Inputs into the Baltic Sea” discusses the regulatory scenarios that could help to counteract the high phosphorus inputs into the Baltic Sea by harmonizing European regulation. To this end, regulatory measures need to be taken to control the application of manure and sewage sludge to reduce the nutrient surplus in agriculture and to mitigate the eutrophication of water bodies such as the Baltic Sea.

Nutrient surpluses in agriculture with the consequence of eutrophication of water bodies like the Baltic Sea are a problem, which needs to be addressed by legal restrictions in all European partner countries. In the current chapter different possibilities are discussed that can be implemented alone or as a package of measures to face this problem.

It is mandatory to harmonize European regulations on analytical methods for determining soil nutrient status and guidelines for fertilizer derivation algorithms. Sewage sludge application should be harmonized as well and recycling procedures instead of field application should be favoured for contaminated material. Moreover manure application rates should be directed by its nitrogen (N) and phosphorus (P) content as the ratio of N to P differs in relation to the source (cattle, pig, poultry) and kind of manure (slurry, liquid, solid). Therefore it is necessary to take both nutrients into account.

Such measures will result in manure and sewage sludge surpluses that can be addressed through useful recycling procedures. Their regional emergency is one problem with manures, as livestock businesses are concentrated regionally. Transportation is no economic option, because of the high transportation costs. This problem can be addressed by recycling procedures and by changing the legal status of big livestock enterprises from farm to industry. This change would make these enterprises accountable for acts and decrees for industrial companies and responsible for handling their wastes in an environmentally friendly way.

The third chapter from Germany is titled “Challenges of Flood Risk Management at The German Coast”. It highlights key challenges of flood risk management at the German coast. The chapter highlights the hydrological boundary conditions of coastal systems, describes the shift from a safety-based approach to a risk-based approach while dealing with floods, highlights the role of impacts of climate change and analyzes the perception of flood risks in North West Germany. A modern understanding of dealing with floods and coastal development requires an integrative risk-based approach. While good practice examples exist and the EU floods directive explicitly demands such approaches, they are not yet implemented along the German North Sea coast. According to the definition of risk, the implementation of a risk management approach requires the consideration of economic values and potential damages. For a heterogeneous area, the idea of equal safety is no longer appropriate. Since dimensioning of dikes due to climate change assumptions directly affects the coastal drainage system, integrative planning and dimensioning of coastal protection and drainage system is essential but not yet common practice in Germany. This includes funding schemes which are not yet available. Taking decisions for an uncertain future requires explicit consideration of uncertainties, e.g., by applying scenario-based impact assessments to adapt coastal protection and drainage. Moving from a safety-based approach to a risk management approach also demands for activities in multiple fields of action such as prevention, spatial measures and emergency management. Since different actors are responsible for these topics, multiple actors also need to be mobilized and involved, including public organizations, aid organizations and citizens. Available investigations for North–West Germany show that not all actors are sufficiently aware of their responsibilities. Collective action is recommended to implement a risk-based management approach in coastal regions based on these challenges. This action is explicitly required in North–West Germany, but will also generally assist in other coastal regions.

3.5 Potential Stresses on Water Resources in Russia

Two Chaps. (9 and 10) from Russia are presented in the book. Chap. 9 is titled "Water Resources of the Russian Part of the Baltic Sea Basin and Their Possible Changes Under Global Warming". It summarizes the results of studies on water resources issues carried out in Russia (and in the State Hydrological Institute (SHI) in the first place). Starting with the publication of the monograph "Water Resources and Water Balance of the Soviet Union" (1967), which for the first time conducted a comprehensive assessment of the Baltic Sea Basin's water resources and water balance, and ending with generalized and systematized materials presented in the Integrated Use and Protection of Water Bodies Schemes. The changes in water resources and hydrological regime of the rivers occurring since the end of the 70s—the beginning of the 80s of the last century on the territory of Russia under the influence of climate change are described. Predictive estimates of possible changes in river streamflow of the Russian Part of the Baltic Sea Basin based on an ensemble of 24 Atmosphere-Ocean General Circulation Models are presented. Finally, conclusions are given regarding the prospects for solving problems in the study of water resources presented at the last VII All-Russian Hydrological Congress.

The second chapter is titled "Schemes of Integrated Use and Protection of Water Bodies in the Russian part of the Baltic Sea Basin as a Basis for Water Resources Management". It describes the regulatory and legal provision of integrated use and protection schemes for water bodies, including development standards for the permissible impact on water bodies developed and approved for river basins flowing from Russia's territory into the Baltic Sea. Schemes for integrated use and protection of water bodies: are the basis for the implementation of water management actions and measures to protect water bodies in river basins; include the latest systematized materials on the status of water bodies and their use; are instruments (information and intellectual supporting tools) for making management decisions on river basins (achieving water quality targets for water bodies and reducing the negative consequences of floods and other negative water impacts); within the next 15–20 years will remain the only approved documents recommended by the Government of the Russian Federation. Basin management principle applied in Russia in the field of use and protection of water bodies as well as the content and structure of Schemes are described. Schemes and PIW, which were developed and approved for the Russian part of the Baltic Sea basin are also listed.

3.6 Estonian Water Resources

Under this section, two Chaps. (11 and 12) from Estonia are presented in the book. Chap. 11 is titled “Joint Methodology for the Identification and Assessment of Groundwater Dependent Terrestrial Ecosystems in Estonia and Latvia”. It presents a methodology to identify and assess the groundwater-dependent terrestrial in Estonia and Latvia. It will help to define quantitative and qualitative effects on terrestrial ecosystems based on groundwater in the groundwater body. Groundwater Dependent Terrestrial Ecosystems (GTDEs) are valuable ecosystems, and its existence and good health rely on groundwater supply. As the Water Framework Directive aims to protect all water resources, including groundwater bodies, the assessment of GDTE should be a part of groundwater management. Groundwater body could have a two type of negative effect on the GDTE: (a) quantitative effect—human influence (such as groundwater abstraction) has lowered groundwater level, so that does not provide enough water to sustain the GDTE in its natural state; (b) qualitative effect—human influence (such as fertilizer application) has affected the groundwater body in a way that it is chemical composition causes the deterioration of the ecosystem. Estonia and Latvia are two northernmost Baltic states, sharing the common border, long history and shared water resources. In Estonia, a methodology for identification, assessment, and monitoring of the groundwater-dependent terrestrial ecosystems has been developed. Similar conditions enabled Latvia to adapt and jointly develop this methodology. A two-step approach is used to define GDTEs in Estonia and Latvia. First, habitat types listed in the EU Habitats Directive were selected. Second, additional criteria were applied to select GDTEs for assessment. Identification of GDTEs in the landscape is a difficult task considering the need for research in multidisciplinary teams, time, and funding resources. Since groundwater threshold values for GDTEs are missing in many countries, the authors suggest using indirect data (such as quantities of fertilization, location of polluted sites and data on land cover). Such analysis will indicate if there are any significant human-induced chemical pressures, their type and will point out the relevant parameters to be monitored and analyzed in the future.

Chapter 12 is titled “Estonian Fluvial Water Bodies and Inundation Directive”. The chapter is based on project results of “Assessment of wetland status and setting of environmental objectives”, initiated and financed by the Estonian Ministry of Environment during 2011–2012. Nonetheless, the performance of this work only partly fulfills the overall objective of the EU Water Framework Directive (WFD) concerning the use of wetland safety and restoration in order to achieve the WFD objectives in a cost-effective and sustainable manner. The Introduction part of the chapter offers a brief overview of the WFD’s goals of protecting various surface water bodies

(WBs), WB management concepts, and methods for assessing the importance of WFD's significant wetlands with associated WBs hydro-ecological interface status. The Material part includes a short overview of Estonian water bodies, and wetlands, divided into the four main types: (1) inland wetlands or mires, (i.e, bogs, poor fens and fens); (2) floodplain wetlands; (3) spring mires; and (4) coastal wetlands.

The Methods part presents the soil-based methods for the determination of WFD important wetlands associated with different types of water bodies, i.e., identification of the areal extent of the wetlands or their parts on the landscape, and identification of the areal extent of the wetland within the catchment of defined WBs.

The book ends the conclusions part which contains two chapters. The "Update, Conclusions, and Recommendations for "Water Resources Quality and Management in Baltic Sea Countries"" and the special chapter on "Estonian Wetlands and the Water Framework Directive". In the concluding chapter, an update of the literature is made to cover some of the interesting topics which are relevant to the themes of the book. Some of these sources include Ahlhorn et al. [3], Bormann [4], Burlakovs et al. [5], Eurostat [6], Hogland [7], Serinaldi [8], Ahlhorn and Meyerdirks [9], Berbel [10], EU Water Framework Directive [11], Kiisler [12] and Terasmaa [13] among others. While Chap. 14, for the first time, Estonian wetlands were identified, their extents were calculated and ecological status were assessed; pressure factors and key management measures were described. However, in order to implement integrated water management, classification of functional relationships between wetlands and WBs should be conducted.

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Overview of Water Bodies and Water Resources in Baltic Sea Countries

Overview of the Water Bodies in the Baltic Sea Countries

El-Sayed E. Omran and Abdelazim M. Negm

Abstract The chapter takes a look at the Baltic Sea from various aspects to develop a synthesis of the existing knowledge and add a new perspective on the water bodies in the Baltic Countries Sea using RS. The Baltic Sea, with a composition that is neither sea nor fresh water, is one of the largest brackish water bodies in the world. The Baltic Sea Drainage Basin (BSDB) is a large heterogeneous region. The drainage basin is occupied by 14 countries and covers an area of 1,739,000 km^2 and home to about 84 million. There are 14 larger international river basins within the BSDB, with an approximate area of 1,050,000 km^2. Such river basins vary in size, many basin sharing countries, witnessed environmental issues, and how they are handled. Over 200 rivers discharge into the Baltic Sea, creating an area of about 1,700,000 km^2 of catchment and drainage that is about four times larger than the sea itself. This catchment area is considered to be part of the Large Marine Ecosystem of the Baltic Sea (BSLME). As a result of global warming, the future rise in sea level will affect the coastal regions of the world. Although the speed of sea-level rise is not clear, it will have serious and global implications. So how could one judge whether the land went up or the water went down? Well, a solution might be to calculate the occurrence frequency for a long time over a larger area, in this case, across the entire Baltic Sea. One of the solutions to cope with the rapidly changing environment is renewable energy. Wind and wave turbines are becoming increasingly common, although ensuring that they do as little harm as possible to the environment is crucial.

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1 Introduction

A separate Sustainable Development Goal (SDG) has been allocated to marine ecosystems among the 17 global goals established by the United Nations (UN), which is SDG No. 14 [1]. It was argued that we need to consider the ecosystems of the past in order to understand current environmental disturbances [2]. Today's highly disturbed seas may act as time machines for certain marine areas on a slower anthropogenic disruption trajectory [3]. The Baltic Sea is one of the largest semi-enclosed brackish water bodies in the world, enclosed by nine developed and industrialized nations and five more belonging to the catchment area, almost entirely land-locked and distinguished by very restricted movement of water. Because of its unique geographical, oceanographic, and climatic characteristics, the Baltic Sea habitats are highly susceptible to the environmental impacts of human activities at sea and in their catchment area [4].

The Baltic Sea is severe for shelf seas, let alone the open ocean, due to its young age, average water depth of only 58 m, and a low exchange rate with North Atlantic water. Our chapter's main idea is that these unique aspects are also specifically the requirements that led to the current multi-stressor situation (eutrophication, warming, oxygen, and acidification status), make the Baltic Sea a large-scale, real-world counterpart only in the future for other coastal regions.

As other landlocked marine areas, the Baltic Sea has a favorable water balance in temperate latitudes in tropical regions. The average annual freshwater deficit of 481 km^3 is almost the same as the annual North Sea saltwater inflow [5]. Freshwater balance [river runoff (428 km^3) + precipitation (237 km^3)—evaporation (184 km^3)] is dominated by runoff because precipitation and evaporation are relatively well balanced.

The Baltic Sea Drainage Basin (BSDB) is a vast heterogeneous region. The drainage basin is occupied by 14 countries and covers an area of 1,739,000 km^2 (Belarus, Czech Republic, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, Russia, Slovakia, Sweden, and Ukraine) and home to about 84 million. There are 14 larger international river basins within the BSDB, with an approximate area of 1,050,000 km^2. These river basins have different sizes. Some of these basins sharing among several countries. Also, these river basins share witnessed environmental issues and how they are handled. But there is something they have in common. All of them are international and are based in the same geographical area, the Baltic Sea Area.

However, increased industrialization and natural resource exploitation have resulted in the Baltic Sea Large Marine Ecosystem (BSLME) declining and decaying since the 1940s. Today, the Baltic Sea drainage basin is populated by more than 85 million people and their actions can affect and change the Baltic Sea climate for good or worse.

Over 200 rivers discharge into the Baltic Sea, creating an area of about 1,700,000 km^2 of catchment and drainage that is about four times larger than the sea itself. This catchment area is considered to be part of the Large Marine Ecosystem of the Baltic Sea (BSLME). Management measures to protect and repair the BSLME must, therefore, be carried out on land as well as at sea. This situation becomes even more critical as the Baltic Sea is a semi-enclosed brackish water region, after the Black Sea, the second largest in the world. It is marked by an ongoing vertical stratification of its water layers and resident (turnover) period estimated at 25–30 years for a full exchange of its water volume. Such factors significantly increase the Baltic Sea's vulnerability to pollutant accumulation.

The goal of the chapter is to develop a synthesis of the existing knowledge and add a new perspective on the water bodies in the Baltic Countries Sea using remote sensing (RS).

2 Geography, Formation, and History of the Baltic Sea

The Baltic Sea, with a total area of about 415,000 km^2, is the second-largest brackish (low-salinity) water body in the world. The Baltic Sea's northern part comprises the Bothnian Sea, the Bothnian Bay with the Quark in between, and the Gulf of Finland. The main part is the Baltic Proper, separated by the Archipelago Sea and the Aland Sea from the northern part. The Baltic Proper can be split "into the Northern Baltic Proper, the Southern Baltic Proper, and the Eastern and Western Gotland Basins. In the East from the Baltic Proper, there is the Gulf of Riga and the Gulf of Gdansk in the South" (http://lifempa.balticseaportal.net/media/upload/File/Deliverables/Book/SEE%20THE%20SEA%20EN%20veb.pdf). The relatively narrow Danish belts (the Wave, the Great Belt, and the Little Belt) and the Kattegat form the link to the North Sea. It thus knows as a semi-closed sea (see Fig. 1).

The Baltic region is known for many people around the world because of its amber wealth. Amber is a resin material derived from the extensive subtropical pine forests that occupied the region from 35 to 50 million years ago. The resin, before being deposited in the soil, often encapsulated and embalmed pieces of plants and small animals. It is often seen, often picked up and transported by sea, washed up on the beaches today. From archeological discoveries of amber products in Mediterranean cultures such as ancient Greece, Egypt, and Rome, we know that a substantial part of this amber came through the amber trade route linking the Mediterranean sea with the Baltic Sea.

Geologically, biologically and as far as humans are concerned, the Baltic Sea is a young (about 10,000 years old), relatively shallow with an area of about 413,000 km^2. Nevertheless, about 100,000 years ago, a thick ice belt covered the whole of Scandinavia and what is today the Baltic Sea. In the last glacial phase, the Baltic region

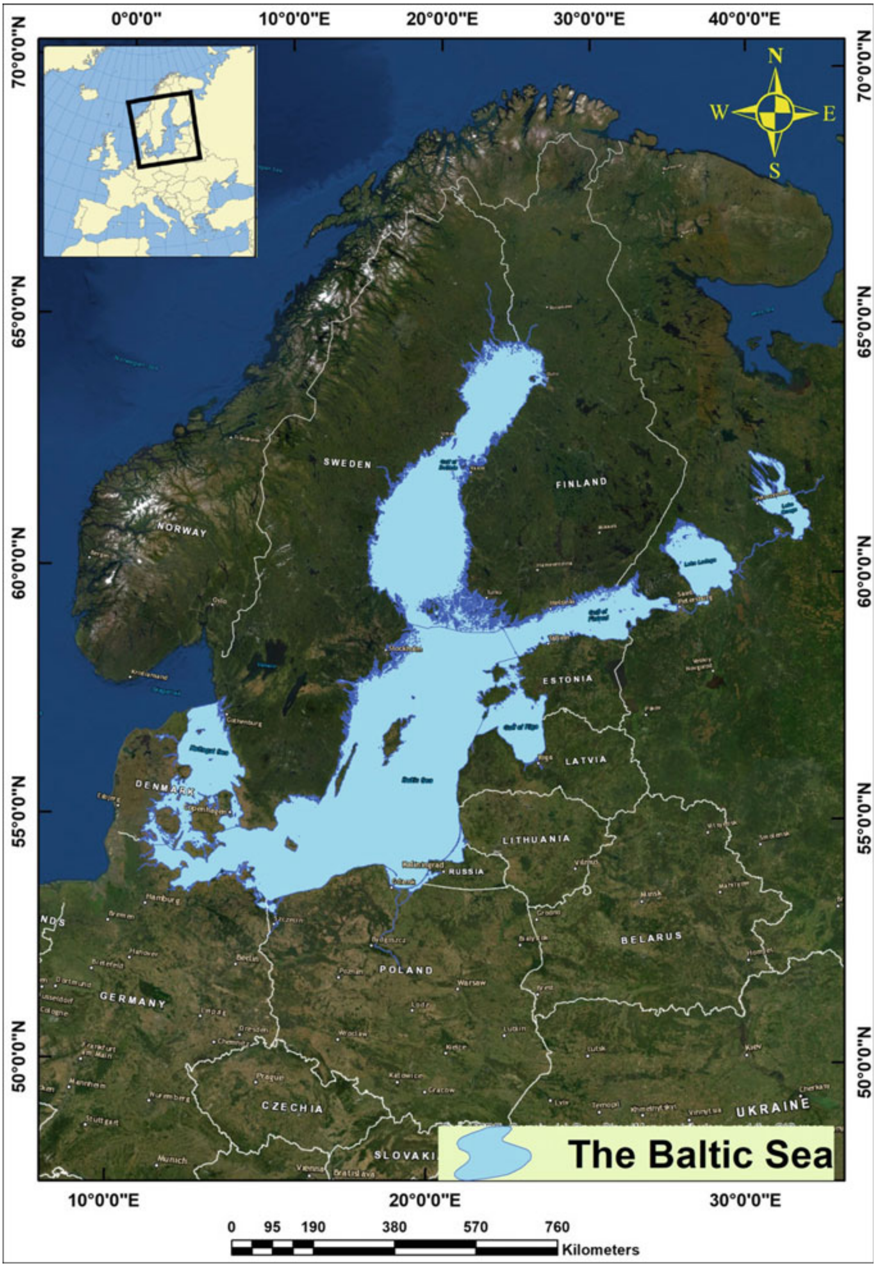

Fig. 1 The Baltic region map

was subject to glaciation over several ice ages. The last ice began to melt about 15,000–7000 years ago, and about 10,000 years ago, the ice was gone.

The ice began to melt between about 13,000 and 10,300 years before the present day (or BP) and a freshwater Baltic ice lake was formed. In the next phase, a largely marine area called the Yoldia Sea formed from 10,300 to 9500 years BP. Then a freshwater enclosed Ancyclus lake formed again from around 9500 to 8000 years BP before the establishment of the Littorina Sea between 8000 and 4000 years BP [6]. The marine life of the Baltic Sea is estimated to have less than about 4000 years old in its current state of development. but it was developed over a much more extended period [7].

In Öresund and the Great Belt, the Littorina Sea is distinguished by nearly marine environments, with saline water entering through broad straights. This, coupled with the warmer climate and increased availability of nutrients, resulted in significant ecological changes in the Baltic Sea environment, including higher primary production and a new species-rich fish population dominated by cod, flounder, plaice, mackerel, and herring. Since the "peak" Littorina time, salinity in the Baltic Sea has decreased by approximately 4 psu [8]. The Baltic Sea is a relatively young and complex formation in geological terms.

Many changes in the water body known today as the Baltic Sea have occurred since the end of the last Ice Age. Relieved from the heavy ice cover, the Earth's crust started to rise, resulting in its relation and disconnection to the North Sea and the Atlantic Ocean via the Danish Belts or what are today Sweden's large lakes, and the White Sea and the Arctic Ocean. It has also increased over the years and reduced in length. The following stages of the Baltic Sea can be distinguished [9] in the post–glacial period (see Fig. 2).

The area became a Barbarian Sea ruled by heathen Vikings, moving forward to around 1000 AD. The Vikings from the west of Denmark and Norway mainly migrated to the west while the Swedish Vikings traveled to the east, even to the Black Sea and the Mediterranean. According to some Scandinavian sagas, the Curonian tribes in the eastern Baltic stubbornly battled the Vikings and sometimes defeated them. Around 1400 AD, major unions formed around the Baltic, especially the Hanseatic League, which promoted trade between communities such as Lubeck, Rostock, Danzig, and Riga, as well as Novgorod in Russia and Bergen in Norway. The Hanseatic League was competing with Scandinavian traders and military forces, particularly the Gotland region.

An Iron Curtain isolated the socio-economically disadvantaged populations of the eastern Baltic, controlled by the Soviet Union to the east, from the richer countries to the west, until the early 1990s. A significant change began in the region in 1991, leading to the recognition of the following nine coastal Baltic countries: Russia, Poland, Estonia, Latvia, Lithuania, Germany, Denmark, Finland, and Sweden. The accession to the European Union (EU) in 2004 of Estonia, Latvia, Lithuania, and Poland leaves Russia as the sole coastal Baltic Sea country outside the European Union. The EU's enlargement will have significant impacts on the Baltic Sea States' land, coastal, and marine policies, particularly in the areas of agriculture, transport, environment, fisheries, water resources, and scientific research.

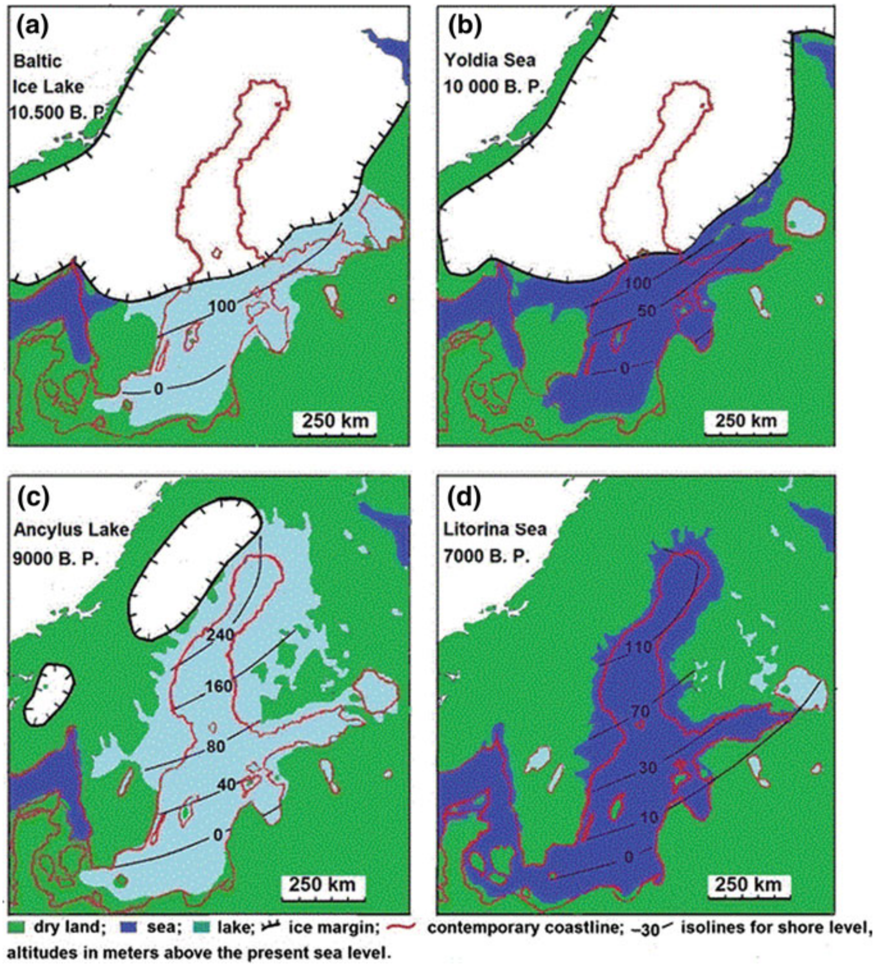

Fig. 2 Stages of early development of the Baltic Sea [10]

The Baltic is made up of three deep basins: the Arkona Deep inside the Baltic Sea entry, the Bornholm Deep, and the farthest inland Gotland Deep. Through the shallow, narrow entry, saltier, denser, and oxygen-rich water from the North Sea joins the Baltic Sea and propagates along the deeper areas, while a counter stream of freshwater flows outward to the surface. It results in two largely stratified sections of the water column, which seldom overlaps, throughout most of the ocean. Such stratification significantly prevents the flow of oxygen from the surface to the deeper water. North Sea oxygen-rich water inflow allows the deeper voluminous water masses to flush with their oxygen levels increasing. Such flushing activities often minimize the concentration of toxins in the water masses as a whole, including reducing the concentration of excessively high contaminants from land-based run-off. Therefore, oxygen-rich water inflow is vital to the biota's well-being and productivity as well as to the environmental quality of the Baltic Sea's aquatic ecosystems. However, these inflow causing Baltic Sea flushing are erratic and rare, with stagnant periods between flushing events lasting as long as several decades, such that oxygen levels decrease over time between each inflow due to the biological oxygen requirements of living organisms and the degradation of organic material. Although the influxes are essentially natural and related to weather change that is not due to human factors, these influxes tend to be diminishing in both frequency and intensity during the second half of the 20th century.

Throughout Europe, the abundance of brackish water fauna and flora has been diminished by several Pleistocene glaciations. About 15,000 years ago, as the ice covering the Baltic basin started its retreat, a large freshwater lake formed on its outskirts. The lake became a sea arm and subsequently underwent another period of freshwater before re-establishing a connection with the sea. The climate has become less saline, and brackish water levels have characterized the Baltic Sea for about the last 4000 years after a long and more saline time. The Baltic is distinguished by a lower number of plant and animal species (biodiversity) than in more saline water due to this background and its brackish nature. For most aquatic species, the brackish water is too salty, and for most marine species, it is too fresh.

3 The Dynamic Coastline of the Eastern Baltic Sea

Baltic Sea's full coastline is about 8000 km wide, 1847 km of which stretches across Lithuania, Latvia, and Estonia. Due to the diverse processes shaping the coastline, it varies within the Baltic countries and consists of a remarkable diversity of shore forms—shifting dunes, sandy beaches, rocky shores, calcareous cliff shores. The coastline (coastal zone) is a region where two different environments intersect—coast and sea. It is a rapidly changing environment in a constant process of destruction and regeneration of existing formations simultaneously [11].

Wind waves and the flow of sediment washed into the sea by rivers and borne along the shore by waves and underwater currents are the main driving forces in this relationship. Other significant factors are the shoreline and sea bottom structure and orientation as well as the sediment type: the direction of the underwater currents and sediment flow depends on how the shoreline is exposed to the dominant wind direction. The combination of all these factors will decide which system will prevail at a particular stretch of the coastline.

The cycles of erosion and deposition are more or less in equilibrium on most of the coastline and the beach shape is reasonably stable. Observations, however, show that coastal erosion has increased dramatically over the past decades, due to factors such as the following:

– Increasing occasions of strong storms (when wind speed exceeds 30 m/s and the water level increases more than 1 m above average);

– Artificial structures such as piers at harbors obstructing the movement of sediments and causing sand accumulation in front of the pier and intensifying erosion behind it;
– Sediment deficit in the movement of sediments caused by river damage;
– Ice scarcity along the coast shielding the coast against erosion;
– The increase of the World Ocean's mean water level.

Another phenomenon that influences the character of the coastline is the slow fluctuation of the Earth's crust such as the ongoing land-lifting post-glacial process. The vast, thick ice sheet exerted varying pressure on the surface in different areas during the Ice Age and created depressions. The land gradually began to rise again after the ice melted. This cycle can still be found as far as the Estonian coastline in the areas around the Gulf of Bothnia. The land elevation is achieving ca in these regions. Annually 4–10 mm; it is estimated that it will continue for another 10,000 years. It is estimated that rising land will create a bridge between Finland and Sweden about 2000 years from now, turning the Gulf of Bothnia into a lake. Archipelagos consisting of thousands of islands and small islets slowly emerging from the ocean are typical ecosystems of land level areas [7].

As a result of the procedures described above, the Baltic coastline has acquired its diverse character and regional specifics. Lithuania has the shortest stretch of coastline—only about 90 km away—mainly marked by a system of erosion forming sandy beaches and dunes. The extraordinary aspect of the Lithuanian coast is the Curonian Spit—97 km long (51 km from Lithuania) and a rounded peninsula up to 3.8 km wide, where the highest drifting dunes in Europe can be found: the highest reaches 60 m, although most of the spit is covered by forest. The spit separates the sea from the Curonian Lagoon—the largest of the lagoons in the southeastern coast of the Baltics, shallow and an almost freshwater body connected to the Baltic Sea through a very narrow strait at Klaipeda. It is one of the most productive waters in the Northern and Eastern parts of Europe, hosting 50 fish species [9]. In 1991, and later, the Natura 2000 site was developed to preserve the unique ecosystem of the Curonian Spit and the Curonian Lagoon.

The remaining Lithuanian coastline is made up of sandy beaches up to 300 m wide, formed by accumulation processes. Accumulation has largely been replaced by erosion processes over the last decades, however, and the Lithuanian coastline is being continually washed away by the ocean. Oland cap is a distinctive feature of this coastal stretch—a moraine cliff of 25 m high, formed in a region of evident erosion. Coastal areas from Klaipeda to Palanga are included in Pajuris Regional Park.

The Latvian coastline is ca. 497 km long and rather smooth as the result of alternating erosion and accumulation processes. Most of the Latvian coastline, however, are suffering from erosion, mostly on the western coasts, which are more vulnerable to strong winds and waves. The highest erosion points are near Bernati, where up to 64 m of land has been washed away during the last 15 years, and the Cape of Kolka that has lost 50 m [12]. Behind the reservoirs lie intense erosion areas, for example, around Liepāja, Pāvilsosta, and Ventspils. Already suffering from erosion are several coastal areas in the Gulf of Riga. It not only destroys the land but also threatens the coastal settlements and houses that were situated some distance from the sea at the beginning of the last century. Erosion processes have succeeded in spectacular moraine and sandstone cliffs being formed at the same locations. Latvia's longest and tallest moraine cliff (up to 20 m) stretches along the coast near Jūrkalne, while the most impressive sandstone cliffs can be found in the "Stony Beach of Vidzeme" Nature Reserve.

However, the Latvian coastline also includes vast sandy beaches with different stages of dunes, including moving dunes. The longest and most extensive beaches (70–100 m) can be found on the southern coastline of the Baltic Sea near Liepāja, along the Irbe Strait and in the southern part of the Riga Gulf. The accumulative coastline has been overgrowing in a few areas of the Gulf of Riga with meadows or reed stands, e.g., near the Estonian border where the Nature Reserve "Randu Meadows" was established to protect the largest complex of coastal meadows and lagoons in Latvia. Estonia has the three Baltic States' longest coastline—1240 km along the mainland and 2540 km on the islands. It is also the most embayed and pointed with varying sizes and shapes of islands. There's a minimum of ca. 1500 Islands, about 80% of which are small islands. In the natural conditions and character of the coastal systems, the Estonian coastline is also the most extensive. The land-up-lift system plays a significant role, most specifically in North-West Estonia, and is responsible for the number of islands and islets. The rather flat and low-lying coastal area of Estonia, particularly in the south, could be severely affected by the effects of climate change such as rising sea level and increasing frequency of storms, which exacerbate erosion processes. The rising sea level, however, is somewhat balanced by the up-lift property. The Estonian coastline offers a wide variety of shore forms and marine ecosystems. There are vast sandy beaches near Pärnu Bay on the southern coast. Often characteristic of the northern coastline along the Finnish Gulf and in areas of Saaremaa and Hiiumaa islands are sandy beaches and dunes, although some island shores are lined with gravel or pebbles. Silty shores filled with reed beds are very popular in Western Estonia—on the islands as well as the coastline along the Väinameri Straits. The main marine wetlands in Estonia are the Kasari delta, Matsalu Bay and adjacent tidal lagoons, shallow inlets and bays, coastal meadows and reed beds. Stony till shores are scattered throughout Northern and Western Estonia with erratic boulders. The most impressive characteristic of the Estonian coastline is the cliffs located along the northern coastline and in Saaremaa (Fig. 3) [9].

The North-Estonian Klint is the cliff bordering the coastal plain created by the slope of the calcareous plateau. The most remarkable cliffs are in the Western part of the Harju plateau on Väike–Pakri Island (13 m high), on Pakri Cape (24 m), at Türisalu (30 m) and at Rannamõisa (35 m). Under the shore, the cliff continues with steep slopes or several terraces, reaching 100 m high. The overall cliff height is thus measured at approximately 150 m.

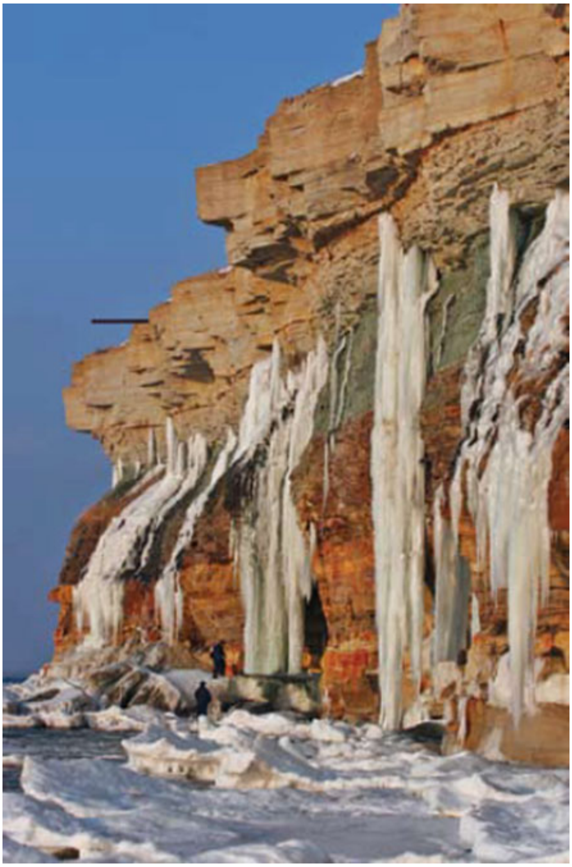

Fig. 3 The North–Estonian Klint is the cliff formed by the slope of the limestone plateau bordering the coastal plain [9]

4 Drainage Basin of the Baltic Sea

This section deals with large transboundary rivers and some of their transboundary tributaries discharging into the Baltic Sea. It also contains reservoirs in the Baltic Sea system.

The Baltic Sea, with a composition that is neither sea nor fresh water, is one of the most massive brackish water bodies in the world. Approximately 200 rivers in the basin flow into the sea, leading to the generally low salinity of the ocean [13]. Nearly half of the flow comes from the seven main rivers in the catchment area [14]. Salinity varies widely across the sea, but it is about one-fifth that of the world's oceans, which are too low to support most marine species and too salty for most aquatic animals [15]. The result is a unique, highly sensitive marine ecosystem.

Nine countries directly border the Baltic Sea ("littoral states"): Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden, and Russia. The catchment area covers 1.7 million km^2 and includes five more riparian countries: Belarus, Czech

Republic, Norway, Slovakia, and Ukraine. In the Baltic Sea zone, about 85 million people live. Around 20 million of those live within 10 kilometer (km) of the coastline of the ocean and about 50 million live within 150 km of the sea. Land cover and population density vary widely within the region. The region's southern part contains highly populated urban areas and extensive agricultural land. Vast expanses of trees, rivers, and wetlands cover the landscape in the north and include some very sparsely populated areas. The population density in Poland, Germany, and Denmark ranges from over 500 inhabitants/km^2 to less than 10 inhabitants/km^2 in the northern parts of Finland and Sweden [16].

Traditionally, the sea zone has been divided into the following sub-catchment areas: Bothnian Bay, Bothnian Sea, Archipelago Sea, Finnish Gulf, Riga Gulf, Baltic Proper, Belt Sea, and Kattegat [7]. Geography of the Baltic makes it particularly vulnerable to damage to the environment. The sea is relatively shallow, with an average depth of about 55 m and a one-fourth surface area of its catchment area. Therefore, relatively large sources of land-based pollutants are provided by a limited volume of water. In contrast, the Baltic Sea is semi-enclosed, with only a small outlet south of the Danish Strait allowing for limited water exchange with the North Sea and finally with the Atlantic Ocean [17]. Just 3% of the water is shared every year. The replenishment of the sea takes approximately 25–30 years, which ensures that any harm to the ecosystem can be maintained for a long time [18]. Table 1 shows the transboundary waters in the basin of the Baltic Sea.

5 Fragile Ecosystem

The Baltic Sea's unique ecological character is caused primarily by slow water exchange with the rest of the World Ocean. Through the Danish Belts, which are quite narrow and deep, the Baltic Sea is related to the North Sea—the depth at the shallowest areas of the Belt Sea is only 18 m, while in the Sound is only 8 m. Consequently, saline water inflows are typically minimal—ca. 475 km^3 per year relative to the brackish water outflow—approx. 940 km^3 into the North Sea. At the same time, the Baltic Sea is continuously provided with freshwater (approx. 660 km^3 per year) from over 250 rivers, including the Oder, the Vistula, the Nemunas, the Daugava and the Neva rivers, as well as precipitation.

This produces brackish water conditions with an average salinity of about 6–8‰, which is very low compared to the salinity in the ocean (ca. 35‰). The salinity in the semi-enclosed bays with large freshwater inflow is even lower, such as the mouth of the Finnish Gulf with the Neva River and the mouth of the Daugava River in the Gulf of Riga.

Saltwater intake and brackish water outflow are natural processes that take place simultaneously. Discharge of the brackish water occurs at the surface layer, while at the sub-surface layer more saltwater flows in the opposite direction. The effect is water column stratification and a boundary forming between the more saline bottom water and less saline surface water called halocline. Stratification can be noticed

Table 1 Transboundary waters in the basin of the Baltic Sea (recipient)

Basin/sub-basin(s)	Total area (km^2)	Riparian countries	Hydrology of the basin
Torne	40,157	FI, NO, SE	The river starts at Torneträsk Lake (Norway), which is the river basin's largest lake. The river's length is around 470 km. On the Torne tributaries, there are two dams: one on the Tengeliönjoki River (Finland) and the other on the Puostijoki River (Sweden). At the Karunki site, the discharge in the period 1961–1990 was 387 m^3/s, with the following minimum and maximum values: MNQ = 81 m^3/s and MHQ = 2197 m^3/s. Spring floods may occasionally cause damage in the downstream part of the river basin
Kemijoki	51,127	FI, NO, RU	The river originates near the border with Russia and usually flows southwest to the Gulf of Bothnia at Kemi for about 483 km. The river system is used for the development of hydroelectric power and is vital for salmon fishing and log transport. For 1971–2000, the mean annual discharge at the Isohaara site was 566 m^3/s with a minimum discharge of 67 m^3/s and a maximum discharge of 4824 m^3/s. Spring floods cause erosion damage on the bank of the Kemijoki
Oulujoki	22,841	FI, RU	The basin of Oulujoki is complex, with heavily modified bodies of water and natural waters. The Oulujoki basin's coastal area contains special brackish waters. At the Merikoski monitoring site (Finland), the mean annual discharge for the period 1970–2006 was 259 m^3/s (8.2 km^3/a)
Juustilanjoki	296	FI, RU	The Juustilanjoki basin on the Finnish side comprises the Mustajoki River, the Kärkjärvi River catchment and part of the Saimaa Canal, including the Soskuanjoki River. Average discharge was shown by random current meter measurements at the Mustajoki site to be 0.8 m^3/s, and at the Kärkisillanoja site of 0.2 m^3/s. Lake Nuijamaanjärvi (total lake surface 7.65 km^2) is part of the Juustilanjoki river basin. The lake is situated south of the Salpausselk ridge at the border of Finland and the Russian Federation. From the total lake area, 4.92 km^2 are in Finland and 2.73 km^2 in the Russian Federation

(continued)

Table 1 (continued)

Basin/sub-basin(s)	Total area (km^2)	Riparian countries	Hydrology of the basin
Rakkonlanjoki	215	FI, RU	The Rakkolanjoki River, a Finnish and Russian Federation transboundary river, is a Hounijoki tributary. The Hounijoki's final recipient is the Finnish Gulf (Baltic Sea). The mean annual discharge at the border with the Russian Federation is very small (1.3 m^3/s) and varies between 0.2 and 7.4 m^3/s (1989–2001)
Urpanlanjoki	557	FI, RU	The Urpalanjoki River flows to the Russian Federation from Lake Suuri-Urpalo (Finland) and ends up in the Finnish Sea. Its mean annual discharge at the gauging station in Muurikkala is 3.6 m^3/s (0.11 km^3/a). In the river basin, the Joutsenkoski and the Urpalonjärvi dams regulate the water flow. Altogether there are also 11 drowned weirs
Narva	53,200	EE, LV, RU	The Narva River is only 77 km long, but its flow is very high, ranging between 100 and 700 m^3/s. Its source is Lake Peipsi. The Narva reservoir was constructed in 1955–1956. Its surface area at normal headwater level (25.0 m) is 191 km^2 and the catchment area is 55,848 km^2. Only 40 km^2 (21%) of the reservoir fall within the territory of Estonia
Gauja/Koiva	8,900	EE, LV	The Koiva River's length is 452 km, 26 km of which is in Estonia. Run-off data is not available in Estonia. The Koiva basin's largest rivers are the Koiva itself and the rivers Mustjõgi, Vaidava, Peetri and Pedetsi
Daugava	58,700	BY, LT, LV, RU	The Daugava rises in the Valdai Hills and flows into the Riga Gulf through the Russian Federation, Belarus, and Latvia. The total length of the river is 1020 km
Lielupe	17,600	LT, LV	At the confluence of two transboundary rivers, the Lielupe River originates in Latvia: the Musa River and the Nemunelis River, also known as the Memele. The Musa has its source in the Tyrelis bog (Lithuania) and the Memele River in the Aukstaitija heights west of the city of Daugavpils (Latvia). The Lielupe River ends in the Baltic Sea. It has a pronounced lowland character. Besides the Musa and Nemunelis, there are numerous small tributaries of the Lielupe River, whose sources are also in Lithuania

(continued)

Table 1 (continued)

Basin/sub-basin(s)	Total area (km^2)	Riparian countries	Hydrology of the basin
Venta	14,2922	LT, LV	The source of the Venta River is Lake Parsezeris in Lithuania's Zemaiciu Highland; the Baltic Sea is its final receiver. The Barta /Bartuva River has its source in Lithuania's Zemaitija highlands and discharges into the Liepoja Lake (Latvia), which has a Baltic Sea connection. The Sventoji River's source is in the West Zemaitija plain in Lithuania; its final recipient is the Baltic Sea. All three rivers—the Venta, Barta/Bartuva and Sventoji—are typical lowland rivers
Barta	…	LT, LV	The Barta /Bartuva River has its source in Lithuania's Zemaitija highlands and discharges into the Liepoja Lake (Latvia), which has a Baltic Sea connection. The source of the Sventoji River is in the plain of West Zemaitija in Lithuania; the Baltic Sea is its final receiver. All three rivers—the Venta, Barta/Bartuva and Sventoji—are typical lowland rivers
Sventoji	…	LT, LV	The source of the Venta River is Lake Parsezeris in Lithuania's Zemaiciu Highland; the Baltic Sea is its final receiver
Neman	97,864	BY, LT, LV, PL, RU	The river Neman has its source in Belarus (Verkhnij Nemanec settlement) and ends up in the Baltic Sea. The basin's character is pronounced lowland. Large transboundary tributaries (shared by Lithuania) to the Neman River include the Merkys, Neris/Vilija and Sesupe rivers. In Lithuania, there are 48 reservoirs (>1.5 km length and >0.5 km^2 area) and 224 lakes (>0.5 km^2 area) in the RBD
Pregel	15,500	LT, RU, PL	There are two transboundary tributaries on the Pregel River: the Lava River (also known as the Lyna River) and the Wegorapa River (or Angerapp). The confluence of the Wegorapa and Pisa rivers in the Kaliningrad Oblast (Russian Federation) is generally regarded as the origin of the Pregel River. The major tributaries of the Pregel have their sources in Poland (the Wegorapa and Lava). Poland also shares the Russian Federation with a very small part of the Pisa. On Polish territory, there are 133 lakes in the Pregel basin with a total area of 301.2 km^2. There are also six NATURA 2000 sites, including the Lake of Seven Islands, a combined NATURA 2000 and Ramsar site of 10 km^2 situated very close to the Polish-Russian border

(continued)

Table 1 (continued)

Basin/sub-basin(s)	Total area (km^2)	Riparian countries	Hydrology of the basin
Vistula	194,424	BY, PL, SK, UA	The Bug River has its source in the northern edge of the Podolia uplands in the L'viv region (Ukraine) at an altitude of 310 m, also called the Western Bug to differentiate it from the Southern Bug in Ukraine. The river forms part of the Ukrainian-Polish frontier, crosses the Polish-Belarusian border, flows through Poland and empties into the Narew River near Serock (actually the man-made Zegrzynskie Lake, a dam built as the main source of drinking water in Warsaw). The most important transboundary river in the Vistula basin is the Bug River, shared by Belarus, Poland, and Ukraine
Oder	118,861	CZ, DE, PL	The 855 km long Oder River has its source at an altitude of 632 m in Góry Odrzańskie (Czech Republic), the southeastern portion of the Central Sudety mountain range. In the recorded period 1921–2003 (without 1945), the annual mean discharge at the Hohensaaten-Finow station (Germany, upstream basin area 109,564 km^2) has varied between 234 and 1,395 m^3/s. The mean average discharge was 527 m^3/s with an absolute maximum of 2580 m^3/s (in 1930) and an absolute minimum of 111 m^3/s (in 1921)

FI Finland, *NO* Norway, *SE* Sweden, *RU* Russia, *EE* Estonia, *LV* Latvia, *BY* Belarus, *LT* Lithuania, *PL* Poland, *SK* Slovakia, *UA* Ukraine, and *SE* Sweden between colder bottom water and warmer surface water forming a barrier called a thermocline, particularly noticeable during summer and early autumn, but disappearing during winter when the surface water cools. Such barriers separate the deep water from interacting with oxygen-rich surface water and create deeper layers of anoxic conditions. Also, at the same time, toxins and nutrients are accumulated in the lower layers leading to the formation of “dead zones,” covering up to 100,000 km^2 of the bottom of the Baltic Sea.

Living under such severe conditions is highly stressful for most marine organisms. Only a small number of species have advanced in colonizing this particular area, as salinity is too low for most species of the Atlantic and the North Sea, but still too high for the species of freshwater. Nonetheless, a mixture of species of marine and freshwater has adapted to these brackish waters. That species plays a specific role in preserving the stability and dynamics of the entire system in such a young and fragile ecosystem as the Baltic Sea, with minimal biodiversity. When one species falls out, it can cause irreversible network harm, as no other species can replace it [7]. Such factors clarify the Baltic Sea’s unique character and fragility as an ecosystem. It is highly vulnerable to change and contamination and is one of the most polluted oceans.

6 Surface Topography in the Baltic Sea and Its Transition Area to the North Sea

A map of the Baltic Sea’s mean topography of the sea surface and its transition area to the North Sea is drawn (Fig. 4). Two primary features of the topography of the sea surface are found here. First, there is a steady increase in sea surface height from the North Sea to the Baltic Sea, with a height difference of 35–40 cm between the inner part of the Gulf of Bothnia and the Skagerrak. The main reason behind this is the significant salinity disparity, close to the maximum possible. Second, in the border zone between the Kattegat and the Skagerrak, a steep gradient of sea-level exceeds 2 cm per 10 km. It represents the salinity front that divides the brackish Baltic Seawater from the saline water of the North Sea and the associated Baltic Sea. In the Oslo Fiord, a regional peak can be seen on the sea surface, indicating an accumulation of low-salinity water.

7 General Types of Waters Considered in the Coastal Seas Around Europe

For coastal seas across Europe, there are two general types of water considered: marine and transitional waters. Coastal waters are bodies of surface ocean water up to one nautical mile from the baseline on the seaward side from which the width of

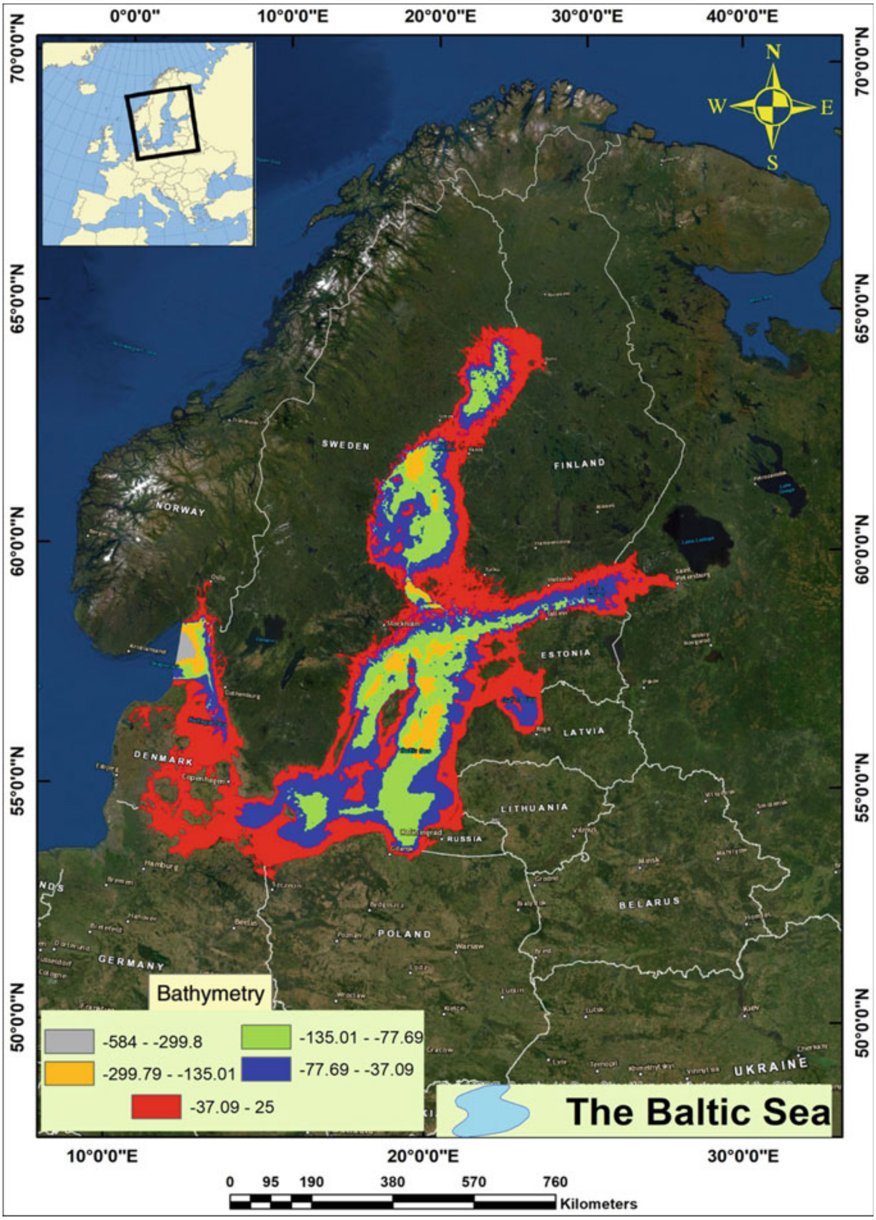

Fig. 4 The Baltic Sea's mean topography of the sea surface and its transition area to the North Sea

territorial waters is determined (Fig. 5). Transitional waters are surface water bodies in the vicinity of river mouths that are significantly influenced by freshwater flows.

Salinity is always the first variable in every water body to determine the environmental composition and classifies water bodies into salinity categories. Figure 6 displays the resultant surface salinity for the whole Baltic Sea. Salinity thresholds used to differentiate between types were chosen: Freshwater <0.5 PSU, Oligohaline waters 0.5–6 PSU, Mezohaline waters >6–18 PSU, Polyhaline waters >18–30 PSU [19].

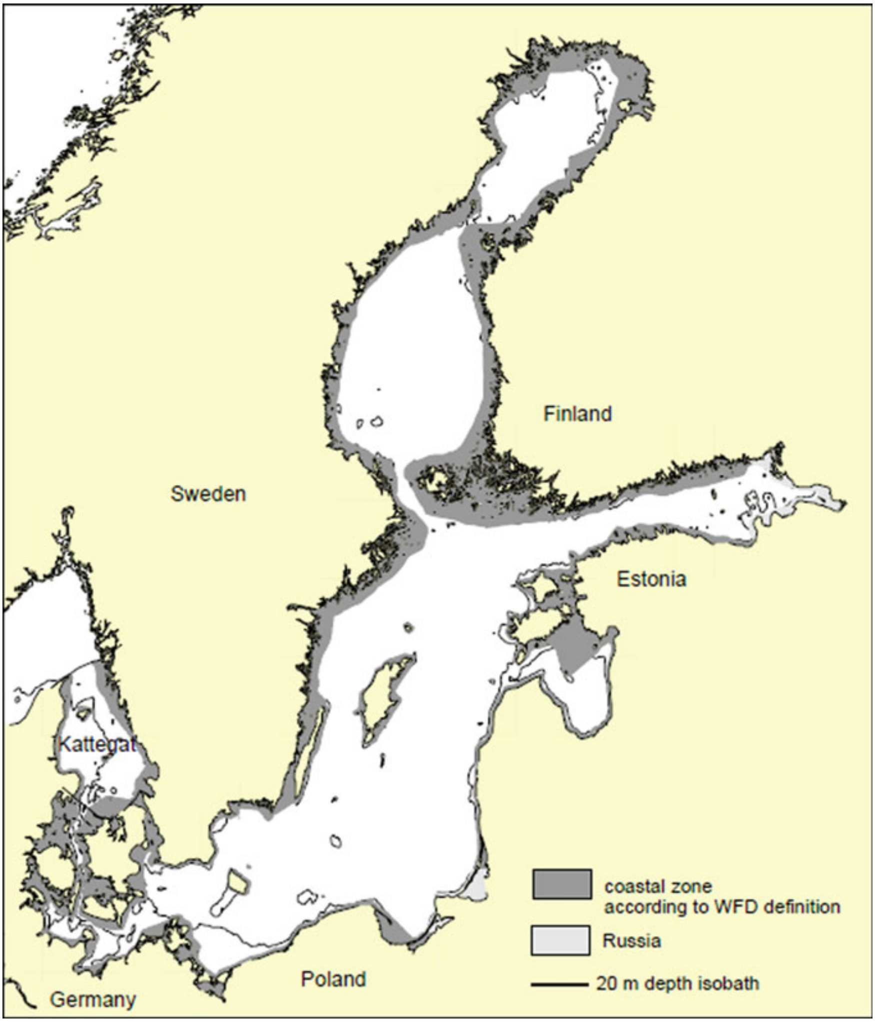

Fig. 5 The coastal waters of the Baltic Sea Ecoregion [19]

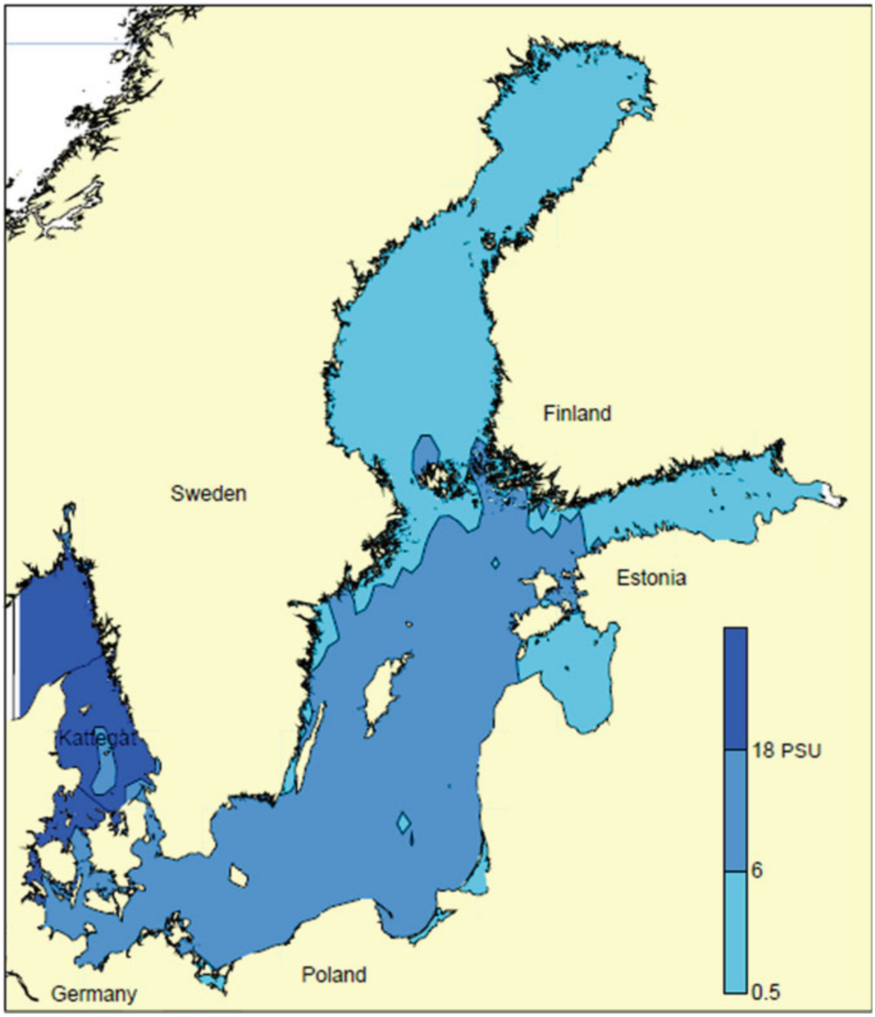

Fig. 6 Distribution of salinity in surface Baltic Sea waters up to 5 m depth [19]

Therefore, the typology of the Baltic Sea comprises three salinity classes, from oligohaline to polyhalite waters.

Water exchange in the coastal sea zone is considered to be an essential factor. The water exchange has a significant impact on the water column's concentration of substances and the system's sediment/water movement. It is understood that enclosed systems vary from open coastal waters, as many chemical and biological parameters depend on the time of absorption of water in both freshwater and marine systems [19]. Water exchange was also one of the main factors used in the typology of Sweden for which three water classes according to the water exchange time were used [19]: 0–10 days, 10–40 days and >40 days. This approach in differentiating open

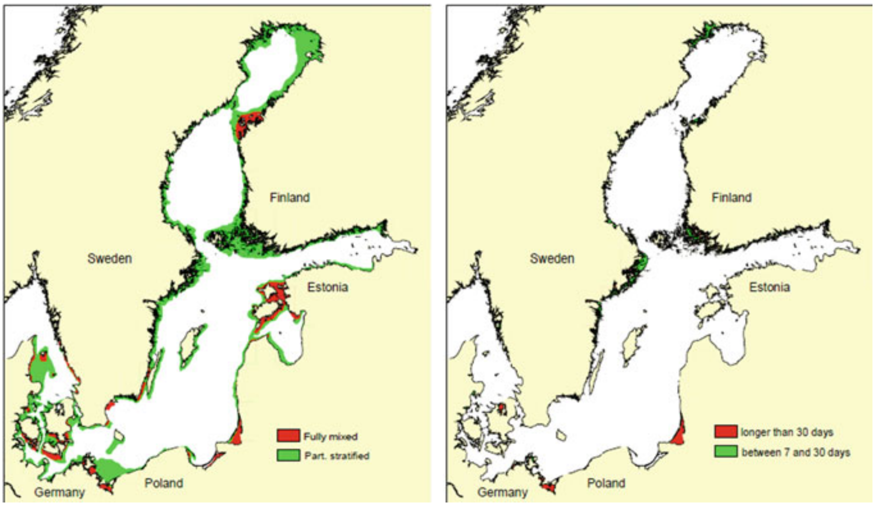

Fig. 7 Stratification (left) and water residence time (right) in selected inshore areas of the Baltic Sea [19]

coastal waters from enclosed areas and inner archipelagos was used. Using mathematical models, water residence time and stratification measurement are performed. Residence time is not an acceptable criterion for open waters because it depends on the size of the area considered. A very general first partition of the coastal zone was made based on residence time estimates based on the open sea exchange (>30 days, 10–30 days) and salinity stratification (Fig. 7).

Depth affects many other aspects of ecosystem features such as water column mixing and stratification, light penetration and distinctive sediment influences. Accordingly, in the Baltic Sea Ecoregion typology, it was presumed that the 20 m is a depth limit for most of the coastal WFD area. Only within a few baselines, delimited coastal waters are deeper than 20 m and in such locations, this typology leaves areas that, if possible, should be further categorized as different forms based on additional depth categories (e.g. under national typologies).

The typology method of the Baltic Sea makes the expansion to the whole Baltic Sea. It allows for a more comprehensive view of reference conditions, schemes for classification of water quality and monitoring (Fig. 8).

8 Is the Land Going up or the Water Going Down? Future Baltic Sea Level Rise

The first written document on raising the Baltic Sea level dates back to 1491. That year four townspeople from Östhammar, a town on the Baltic Sea coast somewhat north of Sweden, went to Uppsala to protest this their harbor could no longer be

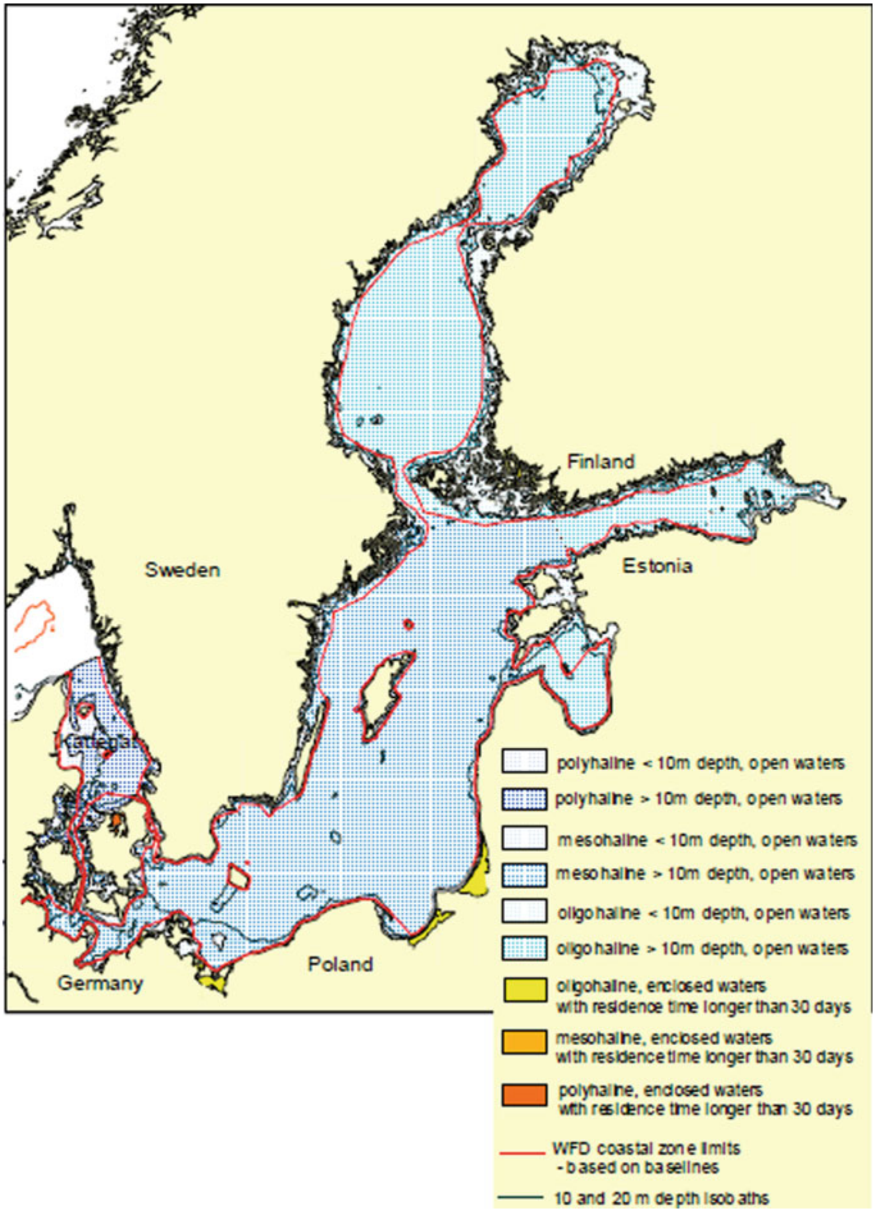

Fig. 8 Distribution of types for the entire Baltic Sea typology [19]

reached by ship [20]. During recent years, the land has grown outside the town at sea, so that where some years ago a cargo boat of five or six Swedish läster [about 15 tons] could come from the sea into the town of Östhammar not even a fishing-boat can go nowadays. And the land continues to grow and grow every year. Sweden was in union with Denmark and Norway at this time, their common king residing in Denmark.

The above-mentioned text is the earliest explanation of the phenomenon we know today as the postglacial rebound or postglacial land elevation. The location of the Östhammar harbour probably stemmed from the 1100s. By the end of the 1400s, the people then must have been subject to a land uplift of nearly 2 m, entirely sufficient to destroy their shallow harbour. Where their harbor is today is dry land. One of the original buildings from 1491, thus erected due to the land elevation, is still to be seen in the new town of Öregrund, namely the church. The same problem appeared one and a half centuries later, but now farther north, in the northern part of the Bothnian Gulf. It was appropriate to move the harbor town of Luleå here. The townspeople and their mayor have also requested permission to evacuate the town [20]. The Luleå harbor site dates back to the 1300s. By the middle of the 1600s, this shallow area had to be exposed to nearly 3 m of land elevation, making it distinctly necessary to move the town and its harbor. The new city kept the old name, while the old city still remains as an old market place called Gammelstaden, "the old town."

Many rivers flowing into Bothnia and Finland's Gulfs, as well as the Baltic itself, caused the seawater to be much lower earlier than it is now. Such water must have continued to flow to the North Sea, eroding and widening the outlet in the long run. As a result, the Baltic Sea level should have been much lower. We may recognize here that while Östhammar/Öregrund's townspeople in 1491 identified the phenomenon as rising ground, it was defined two centuries later as a falling sea level. The townspeople probably considered their harbor dilemma to be entirely local, giving them the illusion of a land elevation [20].

So how could one judge whether the land went up or the water went down? Well, a solution might be to calculate the occurrence frequency for a long time over a larger area, in this case, across the entire Baltic Sea. This would basically give three possibilities [20]:

1. In the Baltic Sea, the same rate of change would suggest a general decline in water.
2. A higher rate of change in the north than in the south may suggest a decline in latitude-dependent water.
3. Different exchange rates in various parts of the Baltic Sea may suggest local land elevation.

As a result of global warming, a future rise in sea level will affect the coastal regions of the world. Although the speed of sea-level rise is not apparent, it will have severe and global implications. For relatively vulnerable developing countries, the effects of future sea-level rises are commonly investigated; however, a whole range of varying regions need to be considered in order to understand global consequences better.

The rate of rising in sea level is continuing to increase, according to IPCC [21]. A global mean rise in sea level of 0.63 m is likely to occur before 2100, with a practically assured continuous rise in sea level after this point [21]. On a millennium scale, the Greenland Ice Sheet's near-complete loss would cause an annual sea-level rise of 7 m with high confidence [21]. Consequently, the precise frequency and amount of future rise in sea level is highly uncertain [22]. In any scenario, the projected future increase in the sea level would flood areas along the coasts of the country, where we consider most of our communities and infrastructure (e.g. [23]). We are going to have to adapt. A first step in the adaptation process is to examine the impact on nature, human beings, and culture, including infrastructure, of sea-level rise, reversible, or irreversible.

Seawater intrusion into coastal aquifer systems would be a regular and potentially extreme consequence of the sea-level rise in coastal regions. For the Baltic Sea and elsewhere, several researches concentrated on the effects of climate change on the discharge of rivers [24]. Sherif and Singh [25] introduce one of the first studies on the effects of climate change on the accumulation of seawater in two coastal aquifers. Just relatively modest changes in mean sea level will be relatively far in the inland direction shift the toe position of the freshwater-saltwater interface of coastal aquifers. More specifically, studies indicate that the thickness and size of the Baltic Sea's coastal freshwater dams can be significantly reduced under increasing environmental conditions [26].

9 Adapting to Climate Change

The climate is changing throughout the world. Regardless of mitigation measures, i.e., greenhouse gas reduction initiatives, it will be essential to adapt to the changes already triggered by greenhouse gas emissions in order to meet the ecological, economic, and social implications anticipated by experts. Therefore, current climate policy is based on two pillars: reducing greenhouse gas emissions and responding to the already foreseeable effects of climate change.

Climate change mitigation was recognized at the national level in the Baltic States as an essential issue, and the first set of measures was adopted. In Estonia, Latvia, and Lithuania, however, the portfolio of adaptation steps is much more limited. This becomes particularly evident when comparing the Baltic States' already taken action on adaptation with other Baltic Sea area countries, such as Germany and Finland, which have established national adaptation plans and are already actively implementing climate change adaptation measures.

Addressing adaptation to climate change is essential, not only in order to be consistent with EU goals and priorities but also because some Baltic States regions are already experiencing first changes in the natural environment. In coastal areas, for example, climate-related changes such as rapid sea-level rise, more rise in sea-level temperatures and more extreme weather events can be expected to have a variety of impacts [27]. For example, the storm of January 2005 had a major impact on all three

Baltic States [28] and Latvia, Lithuania and Estonia will become more vulnerable to coastal erosion and flooding as climate change increases the frequency and intensity of storms in the Eastern Baltic Sea region [27].

10 Problems Meet Solutions

It remains a challenging task to solve the current environmental issues as the scale of economic activity in the Baltic Sea rises from year to year. Strengthened maritime regulations that lead to fewer incidents in the future. However, it seems issues such as eutrophication or off-shore oil and gas industries are will stay and in some cases and places are growing. Smart solutions are needed to overcome the trade-related problems of fish resource exploitation and, at the same time, meet fish demand. Continuing the small-scale coastal fishing industry as an essential part of the coastal communities' lifestyle and identity is also important. Fisher–folk are looking for new ways of managing their resources as traditional fishing methods are no longer enough.

Climate change is a complex issue concerning problems such as rising sea level, changing weather and water temperatures, shifting patterns of distribution of species, intensifying bad weather, etc. It is a global challenge to address these issues, but each country has to do its part. They will significantly increase the likelihood of a successful outcome by working together, educating and encouraging each other, sharing good practices on how to reduce the effects of climate change.

One of the solutions to coping with the rapidly changing environment is renewable energy. Wind and wave turbines are becoming increasingly common, although ensuring that they do as little harm as possible to the environment is crucial.

Nevertheless, the adoption of new resource management strategies and marine environmental protection initiatives alone will likely not produce the desired result if the people of the Baltic Sea countries, who are the end-users of the many services that the sea offers, do not change their minds towards more sustainable ways of living and consuming resources.

11 Conclusions and Meeting Future Challenges

The Baltic Sea is a shallow semi-enclosed sea with an area of 415,000 km^2 and a maximum depth of 460 m. A heterogeneous wide area is the Baltic Sea Drainage Basin (BSDB). The drainage basin is shared by 14 nations, covering an area of 1,739,000 km^2 and nearly 84 million inhabitants. There are 14 larger international river basins within the BSDB, with an approximate area of 1,050,000 km^2. These river basins vary in size, a number of countries sharing basins, environmental issues encountered and how they are treated. More than 200 rivers flow into the Baltic Sea, producing a catchment and drainage area of nearly 1,700,000 km^2 that is about four times larger than the sea itself. This catchment area is considered to be part of the Large Marine Ecosystem of the Baltic Sea (BSLME).

As a result of global warming, potential sea-level rise would impact the world's coastal regions. Although it is not known how high the sea level rises, it will have significant and international consequences. So how could one judge if the land was going up or the water was going down? A solution could be to measure the rate of incidence over a broader area for a long time, in this case, throughout the Baltic Sea. Renewable energy is one of the ways to cope with the rapidly changing environment. Wind and wave turbines are becoming increasingly common, although it is vital to ensure that they harm the environment as little as possible. Nonetheless, the adoption of new resource management approaches and marine environmental protection programs alone will probably not yield the desired result if the citizens of the Baltic Sea countries, who are the end-users of the many services offered by the sea, do not change their minds towards more sustainable ways of living and consuming resources.

Resolving the current environmental issues as the level of economic activity in the Baltic Sea rises from year to year remains a challenging task. The improved maritime legislation is leading to fewer incidents in the future, but problems like eutrophication and offshore oil and gas industries are here to stay and develop in some cases and areas. Smart solutions are needed to overcome the trade-related problems of fish resource exploitation and, at the same time, meet fish demand. Continuing the small-scale coastal fishing industry as an essential part of the coastal communities' lifestyle and identity is also important. Fisher–folk are looking for new ways of managing their resources as traditional fishing methods are no longer enough.

Successful spatial planning for the Baltic Sea in the future relies on the following:

1. Sustainability. Spatial planning addresses economic prosperity, social well-being, and environmental targets at the same time and balances their respective needs.
2. Pan-Baltic thinking. Considers the whole Baltic Sea ecosystem and the whole Baltic Sea as one planning space.
3. Pan-Baltic topics that need to be addressed jointly include a healthy marine environment, a coherent pan-Baltic energy policy, safe, clean and efficient maritime transport, and sustainable fisheries and aquaculture.

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Overview of Water Resources, Quality, and Management in Baltic Sea Countries

Mahmoud Nasr and Abdelazim M. Negm

Abstract Recently, the region around the Baltic Sea has experienced stringent intergovernmental agreements and actions to regulate water resources among the Baltic countries. The region has also been influenced by various industrial, agricultural, and human activities, as well as several anthropogenic and natural inputs. In this context, multiple researchers have focused their work on understanding the water status and management among the Baltic Sea countries. The aim of this chapter is to represent a summary of the recent number of documents, states, and funding sponsors that contributed to the publications of "Water status in Baltic Sea countries". This survey is retrieved from the Scopus and Web of Science databases from 2001 to 2019. Further, the chapter gives an overview of the water status and standards of some Baltic Sea countries that control the environmental features within the region. The essential suggestions and findings are summarized in the recommendations and conclusions sections.

Keywords Baltic sea · Environmental condition · Literature survey · Water action plan · Water resources

1 Introduction

The Baltic Sea region consists of several EU and non-EU member states, viz., also known as developed and developing countries, such as Denmark, Poland, Germany, Finland, Sweden, and Russia [1]. Surface water and groundwater resources differ widely among these countries due to the existence of various rivers, lakes, streams,

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dams, drains, reservoirs, and aquifers [2]. These water resources control the water quality condition and the ecological and aquatic processes of the Baltic Sea [3]. Various anthropogenic and natural factors, in turn, affect the environmental conditions of related countries, which strongly connect to the water quality of the sea [4]. Moreover, in the past 10 years, several wastewater treatment plants, sewerage collection systems, and infrastructure projects have been constructed to handle a large amount of wastewater in the Baltic Sea region [5].

Due to the importance of the Baltic Sea resources, a number of studies have recently been conducted to cover the water status of the Baltic countries [6]. In addition, more studies have been performed to evaluate the ecosystem and water management within the Baltic region [7]. Although some Baltic countries have considerably succeeded in achieving the water-quality standards, various challenges still remain [8]. For this purpose, water and regulatory authorities attempt to raise consumer concerns and public awareness of water scarcity [9].

In this context, the current chapter gives an overview of the water status and features for the Baltic Sea countries. This objective is attained based on a systematic literature review method and an analysis of relevant documents and reports about the Baltic Sea Basin. Most information is collected from peer-reviewed journals available in the Web of Science, Scopus, and Google Scholar databases. Some recommendations that could be used to improve the Baltic Sea quality are considered. Lastly, a summary of the essential conclusions and perspectives for further researches is demonstrated.

2 Information from Scopus Database

Figure 1 shows the number of documents retrieved from the Scopus database using the research keywords "Water", "Baltic", and "Countries" (https://www.scopus.com/search/form.uri?display=basic). The total number of published documents was 140 during 2001–2010, which increased to 186 documents from 2011 to 2019 (Fig. 1a). The documents were managed by several publishers such as Elsevier, Taylor and Francis, Springer, and Wiley. During 2011–2019, the top countries that participated in the "Baltic Sea region" publications were Sweden, Finland, Poland, Estonia, Denmark, Latvia, Germany, and Lithuania with 47, 37, 32, 29, 28, 27, 25, and 25 documents, respectively (Fig. 1b). Hence, Sweden holds the highest national collaboration statistics. About 69.4% of the documents were an article type, followed by 14.5, 7.5, and 5.9% for conference papers, book chapters, and review manuscripts, respectively (Fig. 1c). The documents were funded by the European Commission, Academy of Finland, California Environmental Protection Agency, Norges Forskningsråd, and other sponsors (Fig. 1d). The peer-reviewed and highly reputable international journals include Agriculture, Ecosystems and Environment, Marine Pollution Bulletin, Ambio, International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management (SGEM), and Environmental Science and Pollution Research. These journals focus on the following areas (a) biological

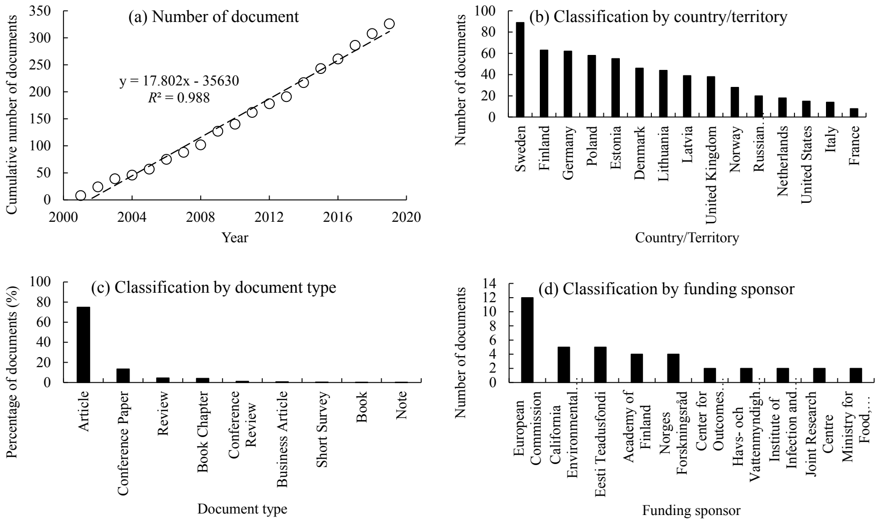

Fig. 1 Statistics of documents retrieved from Scopus database using research keywords "Water", "Baltic", and "Countries" during 2001–2019: **a** Cumulative number of documents, **b** Classification by country/territory, **c** Document type, and **d** Funding agency

and physical characteristics of agroecosystems, (b) global environmental changes including air pollution, climate change, and agricultural systems, (c) land, air, and water relationships, (d) aquatic biology and ecology, (e) environmental analyses and monitoring, and (f) environmental microbiology.

3 Information from Web of Science Database

The total number of documents obtained from the Web of Science (WOS) database using the research keywords "Water", "Baltic", and "Countries" is displayed in Fig. 2 (https://www.scopus.com/search/form.uri?display=basic). The cumulative number of published documents was 83 during 2001–2010, which considerably elevated to 243 documents from 2011 to 2019 (Fig. 2a). The publications were managed by various publishers such as Elsevier, Taylor and Francis, Springer, and Wiley. During 2011–2019, the main countries that contributed to the "Baltic Sea region" publications were Sweden, Finland, Germany, Poland, Estonia, Denmark, Lithuania, and Latvia with 75, 53, 44, 38, 36, 34, 32, and 28 documents, respectively (Fig. 2b). Similar to the Scopus database, Sweden retains the top national collaboration country. Almost 81.5% of the documents were an article type, whereas proceeding paper, review, and news item reported 9.1, 9.1, and 0.3% of the total documents, respectively (Fig. 2c). The major funding agency was European Union (EU) followed by Swedish Environmental Protection Agency, Academy of Finland, Ministry of Education and

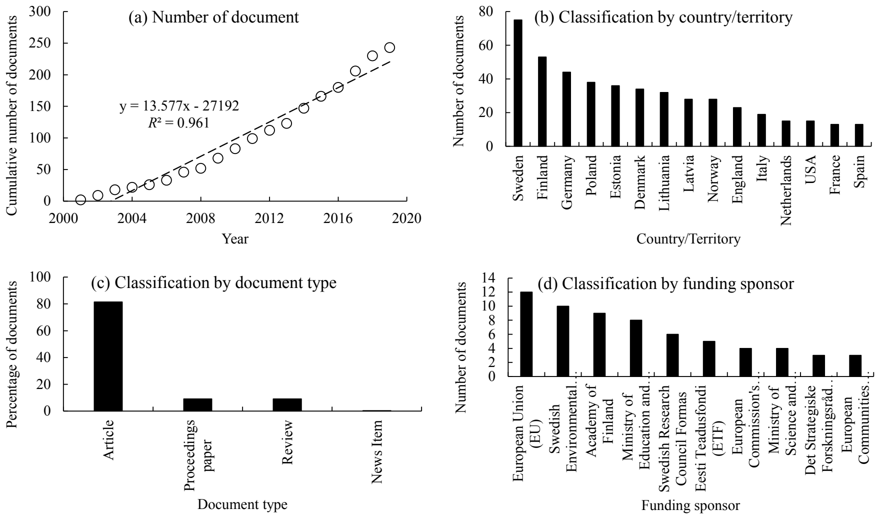

Fig. 2 Statistics of documents retrieved from Web of Science (WOS) database using research keywords "Water", "Baltic", and "Countries" during 2001–2019: **a** Cumulative number of documents, **b** Classification by country/territory, **c** Document type, and **d** Funding agency

Research Estonian, Swedish Research Council Formas, Eesti Teadusfondi (ETF), European Commission's Joint Research Centre, Ministry of Science and Higher Education Poland, Det Strategiske Forskningsråd (DSF), and European Communities (EC) (Fig. 2d). The peer-reviewed and highly ranked international journals that handled these publications include Marine Pollution Bulletin, Agriculture Ecosystems Environment, Ambio, Hydrobiologia, Ecological Economics, and Water Science and Technology. These journals focus on the following subjects (a) biological study in limnology and oceanography, (b) atmospheric sciences, (c) environmental engineering and biotechnology, (d) valuation of natural resources, (e) economic-ecologic interaction and harmony, and (f) policy, strategy, and management considerations of water quality.

4 Baltic Sea Overview

The Baltic Sea is recognized as a large brackish water body and a semi-enclosed sea located between central and northern Europe [10]. It is relatively shallow with an average depth of about 54 m, in which the sea depth significantly varies due to the presence of sills that control the sediment transportation and deposition situations [11]. The Baltic Sea is also known as a separate marine region characterised by a unique and large ecological system. It is linked to the North Atlantic and the North Sea via the Danish straits [3]. Recently, intensive anthropogenic and natural influences have seriously threatened the ecological situation of the sea. The destructive anthropogenic causes include solid waste, agricultural activities, petroleum products, and industrial and municipal wastewater. The main natural inputs are inadequate water exchange, biological processes in the aquatic environment, atmospheric processes, and large river discharges, introducing multiple pollutants into the sea [12]. The main environmental issues in the Baltic Sea comprise overfishing, deterioration of biological diversity and habitats, and eutrophication [13]. Furthermore, some coastal ecosystem services have been damaged because of dissolved oxygen depletion, fish kills, and the spread of toxic algal blooms.

5 Baltic Sea Region Overview

As reported by Manzhynski et al. [14], the Baltic region contains several countries that can be classified into (a) new EU countries such as Lithuania, Estonia, and Poland, (b) highly developed countries including Sweden, Germany, and Denmark, and (c) countries having large social and economic impacts on the region (e.g., Belarus and Russia). Russia, Lithuania, Estonia, and Latvia can also be defined as developing countries located in the Baltic Sea region, as reported in another work by Chang et al. [15]. These countries share different topographic, historical, social, political, and economic positions. The water quality and management of nine states in the Baltic Sea Region have been explored by Nainggolan et al. [5] and Vigouroux et al. [16].

The drainage basin of the Baltic Sea region covers about 1,720,270 km^2, which can be separated into two regions [17], viz., northern boreal and southern areas that drain into the Gulf of Bothnia and the rest of the Baltic Sea, respectively. The area of the drainage basin is considered four-folds the sea area, holding about 110 million people [18]. The catchment area of the Baltic Sea has unique topographic and biological characteristics, and it is surrounded by essential ecological boundaries. It contains around 200 rivers, which in turn increase the nutrient (phosphorus and nitrogen) loads and eutrophication issues due to surface runoff [19]. Moreover, the catchment area retains dense human activities and land-based practices, resulting in the release of huge quantities of domestic wastes into the sea [6]. Moreover, most of the Baltic countries are highly industrialized, and they are associated with major sources of water pollution in Northern and Eastern Europe. The sources of contamination include industrial facilities, sewage treatment plants, toxic air emissions, and marine aquaculture farms. As a result, the water quality of large parts of the central and coastal Baltic Sea area has been severely deteriorated over the last century [8].

6 Baltic Sea Regulations Overview

A series of international collaborations and European agreements have been agreed by the governmental authorities to secure the long-term protection of environmental quality. The national actions have also been adopted to obtain healthy ecosystems around the Baltic Sea region and to meet major challenges influencing the marine eutrophication [5]. For instance, the coastal countries of the Baltic Sea and the European Community declared the Helsinki Commission (HELCOM) Baltic Sea Action Plan (BSAP) in November 2007 to protect the marine environment of the Baltic Sea ecosystem [10]. The BSAP has been adopted and implemented to target the reduction of the nutrient loads from land into the Baltic Sea at various spatial and temporal scales [4]. The amounts of nitrogen, phosphorus, heavy metals, and chemicals should comply with international ecological standards. Moreover, the industrial wastewater discharged into the Baltic Sea should be significantly reduced or prevented [12]. However, due to the significant differences in the catchment features, socioeconomics, environmental legislation, land use/land change, and geosciences along the Baltic Sea region, the regulation and management of environmental issues are still challenging [12].

7 Water Status of Some Baltic Countries

Understanding the water status of the Baltic Sea region is an essential step as the relevant countries are strongly associated with sea quality.

7.1 Sweden

Sweden contains important streams, lakes, rivers, and waterfalls, which are valuable for most human activities. In Sweden, daily water consumption was about 183 litre per person in the years 2015 and 2016 [20]; however, the consumption of bottled water is minimal. Näsman et al. [21] mentioned that the drinking of bottled water was 10.8 L/person/year in 1993 and increased to 24.4 L/person/year in 2014. The Swedish Brewery's Association's [22] lists the status and statistics of drinking water in Sweden during the past 10 years. Sweden protects the quality of the Baltic Sea by avoiding the release of high nutrient loads and organic compounds into the sea [23]. This objective is achieved by developing nitrogen and phosphorus removal technologies into the wastewater treatment plants. The Baltic Sea action plans implemented to improve the water status in Sweden and to meet the international requirements and standards are given by the Swedish Environmental Protection Agency (http://www.swedishepa.se/).

7.2 Germany

In Berlin (Germany's capital), the total annual rainfall amounts to 570 mm [24]. Germany contains about ten main river basins, including Schlei-Trave, Rhine, Elbe, Weser, Danube, and Maas [25]. In Germany, there are approximately 9900 surface water bodies, which comprise 9070 rivers, 710 lakes, and 74 coastal waters [26]. The ecological status of 10, 30, 34, and 23% of these water bodies can be defined as 'High', 'Moderate', 'Poor', and 'Bad' quality, respectively; however, <3% are classified as 'Uncertain'. Germany also contains about 1000 groundwater bodies, which are considered important sources of drinking water. About 62% of groundwater bodies have attained 'High' status, regarding the quantitative (e.g., stability of groundwater levels) and chemical (e.g., pollutants) conditions [26]. The 'Low' to 'Moderate' water quality at some locations could be linked to the noticeable reduction in groundwater level and nitrate inputs from agriculture [26]. The presence of unfavourable and toxic constituents in the drinking water of Germany is summarized in a study by Umweltbundesamt [27]. The available water supply and water use in 2010 were approximately 188 billion m^3, representing 82.4, 11.0, 3.6, 2.7, and 0.3% for unused, thermal power plants, mining and manufacturing industries, public water supply, and remaining industrial and agricultural practices (https://www.umweltbundesamt.de/publikationen/). Around 33.1 billion m^3 of water were supplied from groundwater and surface waters to private house-holds in 2010. Germany also contains nearly 10,000 wastewater treatment plants, treating a total of 10 billion m^3 of wastewater [25]. Additional details of the wastewater treatment facilities and water services in Germany can be found in previous studies [9, 28].

7.3 Denmark

Copenhagen (Denmark's capital) has an annual rainfall of 525 mm [24], and the average water consumption in Denmark was about 158 L/person/day in 2015 and 2016 [29]. HOFOR, which provides water supply and sanitation services to about 90% of Copenhagen's population, is the main utility company in Denmark. Denmark has relied on over 30 years of aquatic action plans to solve the challenges of water quality, policies, and management. The strategies aim at reducing the pollutant levels, mainly nutrients, in water bodies [30]. Denmark does not have large rivers, and hence, a high portion of Danish drinking water comes from groundwater [31]. However, the quality of groundwater is influenced by chemical and toxic contaminants from the agriculture sector. Moreover, Danish people attempt to utilize most of the rainwater via the application of domestic roofs, rainwater harvesting systems, permeable urban infrastructure, and collection and storage tanks. The collected rainwater can be used after partial treatment for flushing, laundry, washing, and irrigation. For this purpose, the Danish government has reasonably increased the environmental awareness of the society and the public to maintain and push forward the "Green Space Branding" strategic plan [32].

7.4 Estonia

Tallinn is Estonia's capital, having an annual rainfall of 690 mm [24]. Tallinna Vesi (Tallinn Water) is the main water utility company in Estonia, offering water, wastewater, and sanitation services to about 90% of Tallinn's customers. Surface water, particularly the two Estonian lakes (Ülemiste and Raku), contributes to the most drinking water requirements [31]. However, the people of Estonia consumes a low amount of water, i.e., approximately 100 L/capita/day [33].

7.5 Poland

Poland is considered one of the Baltic Sea countries, having relatively poor water resources with low quantity and quality [34]. Almost 99.7% of the whole Polish territory is situated in the Baltic Sea drainage basin [35]. About 54 and 34% of the region of Poland belong to the drainage basins of the Vistula River and Oder River, respectively. A small area is covered by catchments of short rivers that discharge directly into the Baltic Sea. The freshwater resources in Poland are stored in lakes (almost 10,000 lakes in northern Poland) and reservoirs (in the southern part) [36]. The average annual freshwater resources in Poland was estimated as 59.9 km^3 (2000–2015). The entire amount of consumable groundwater resources coming from quaternary aquifers was 17.7 km^3/day in 2015. The available quantity of water per capita is 1600 m^3 per year; compared to 5000 m^3/capita/ year for most European countries [7]. The annual precipitation in Poland varies between 500 mm towards the central and northern regions (the lowlands) and 1200 mm at the southern mountainous regions, with an average value of around 600 mm. River water increases (excess water) in the spring, while it reduces (water deficits) during the autumn and winter seasons. The quality of surface water in Poland is negatively impacted by various anthropogenic factors, which have been reported by Szalinska [37].

7.6 Iceland

Recently, Iceland has developed national guidelines considering the principles of the World Health Organization (WHO) and the International Water Association (IWA) to maintain the concept of "Water safety plan" [38]. The Icelandic drinking water regulations include improvement of utility performance, protection of all water resources, regulation on public health, and supply of safe and acceptable drinking water [39]. Ministry of Industries and Innovation, Ministry for the Environment and Natural Resources, Ministry of Welfare, and Ministry of the Interior handle these objectives. Iceland comprises several freshwater resources in terms of rivers, lakes, ponds, and springs [2]. Drinking water is mostly obtained from aquifers in porous basaltic rocks [40], and about 95% of drinking water comes from groundwater [41]. Fresh groundwater withdrawals are treated by filtration followed by UV disinfection. The Icelandic water resource systems provide about 600 thousand m^3 of freshwater per person per year. Iceland includes almost a number of 31 water utilities that serve 81% of the residents [42].

7.7 Russia

Given the size of the Russian landmass, the water quality in Russia varies spatially due to different domestic and international consequences [43]. In Russia, the water supply system is strongly associated with various domestic (households), energy, irrigation, and industrial applications [44]. The main rivers in European Russia include Mezen, Onega, Lower Volga, Northern Dvina, and Don [45]. However, the freezing of rivers may damage hydraulic structures, roads, and bridges, as well as can cause multiple engineering problems [46]. The ice phenomenon in Russian rivers can also inhibit seasonal navigation on the rivers, raise the water levels, and cause flooding. Telichenko et al. [47] suggested green spaces and sustainable landscaping options to manage stormwater problems in Russia. The water status in Russia is also influenced by a number of dams and reservoirs such as Osa River Dam, Irigan Dam in Dagestan, Chirkeiskaya Dam, Cheboksary Dam, Kama Dam, and Bratsk Reservoir [48]. A large part of the Russian people employs household filters or utilizes bottled water to obtain a high quality of drinking water. Due to the installation of metering and modern plumbing systems, the water demand by Russian households has reduced from 300–380 to 180–200 L/person/day.

8 Recommendations

The current chapter gives an overview of the recent publications regarding the water status of the Baltic countries. Based on the literature survey, several recommendations should be considered:

(a) Small, remote, and rural communities should be supported by adequate infrastructure projects, minimum leakage systems, and wastewater collection structures.
(b) Advanced methods of wastewater treatment, with providing adequate training for staff, should be considered to meet the water quality standards regarding organics, nutrients, and anion and cation constituents.
(c) Stakeholders, decision-makers, and public and private ownership should engage under the water authorities of Baltic countries to maintain the "Water-Energy-Food nexus" strategy.

(d) Advanced water metering systems should be broadly implemented to sustain water reforms and tariffs.
(e) Promote the application of water safety projects, as well as maintenance and renewal of infrastructure.
(f) Conduct risk assessment studies and incorporate guidance on materials used for small water supplies and utilities.

9 Conclusions

This chapter aims at giving an essential overview of the water resources and conditions of the Baltic Sea countries. This objective is revealed based on the findings retrieved from the Web of Science and Scopus databases. It is concluded that:

(a) Intensive anthropogenic and natural inputs have seriously threatened the ecological situation of the Baltic Sea countries.
(b) Recently, research studies evaluating the ecosystem and water management within the Baltic region have considerably increased due to the importance of the Baltic Sea resources.
(c) During 2011–2019, the total number of publications reported using the keywords "Water", "Baltic", and "Countries" was 186 and 243 according to the Scopus and Web of Science databases, respectively.
(d) The available surface water and groundwater resources vary broadly among the Baltic countries due to the existence of multiple rivers, lakes, streams, dams, drains, reservoirs, and aquifers.
(e) A series of international activities and European agreements have been established by the governmental authorities to secure the long-term protection of the environmental quality in the Baltic region.
(f) The developed Baltic countries such as Sweden, Germany, and Denmark have adequate water resource management systems; however, some countries such as Lithuania, Estonia, and Poland still have some water resource challenges.

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Quality of Groundwater in Baltic Sea

Environmental Quality of Groundwater in Contaminated Areas—Challenges in Eastern Baltic Region

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Abstract The lack of water in the future will force society to find more sophisticated solutions for treatment and improvement of groundwater wherever it comes from. Contamination of soil and groundwater is a legacy of modern society, prevention of contaminants spread and secondary water reuse options shall be considered. The aim of the book chapter is to give oversight view on problems and challenges linked

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to groundwater quality in Eastern Baltic region whilst through case studies explaining the practical problems with groundwater monitoring, remediation and overall environmental quality analysis. The reader will get introduced with case studies in industry levels as credibility of scientific fundamentals is higher when practical solutions are shown. Eastern Baltic countries experience cover contamination problems that are mainly of historic origin due to former Soviet military and industrial policy implementation through decades. Short summaries for each case study are given and main conclusions provided in form of recommendations at the very end of the chapter.

Keywords The Baltic Sea basin · Case studies · Contaminated sites · Water pollution

1 Introduction

1.1 Scope of the Problem

The lack of water in the future will force society to find more sophisticated solutions for treatment of polluted water to gain secondary and tertiary usable water. It also applies to the improvement of groundwater that comes from contaminated zones. Contamination of soil and groundwater is a legacy of modern society. All around the world, contaminated areas cause environmental problems: degraded fields, landfills, old and existing industrial and military installations are contributing to pollutants spread to the outer environment [1]. During the 1960s, the ideas discussed by Rachel Carson in 'Silent Spring' marked a fundamental change in ecological thinking which should be based on the coexistence of the environment and industry [2]. The impact of human activities on the environment has changed completely. The natural environment is deteriorated through the use of natural resources contaminated with various chemicals.

The growing population of the coastal areas worldwide, including the Baltic Sea region, stand in front of new challenges. Agricultural, housing, industrial, and transport activities affect the environmental quality of water resources. The Eastern Baltic region also deals with the problems related to pollution with nitrates, phosphates, oil products, heavy metals that from a point and diffuse sources through the soil and groundwater are forwarded to the sea [3]. The legal instruments (such as directives and laws) lead to permanent solutions to prevent the groundwater quality from intensive contamination and promote the development and use of environmental technologies.

Contamination with organic and inorganic ecotoxic substances is among the important problems as bioaccumulation effects of such substances are inducing direct and indirect hazards to the environment and human health. For example, toxic heavy metal ions are non-biodegradable and tend to accumulate in living organisms causing severe disorders and diseases [4]. Thus, the quality of soil and groundwater is fundamentally important, and various technologies are used for the remediation of diffuse and point sources generated by industrial as well as natural contamination [5, 6].

Monitoring of pollution hand in hand with the planning of treatment are crucial to find and implement the strategies for improvement of groundwater quality. There are tens of thousands of areas in the Baltic Sea region that expect immediate corrective measures which differ in nature, cost, risk, and other factors. According to the European Commission, there are approximately 3–5 million potentially contaminated sites and 500,000 contaminated sites in Europe [7] of which a significant portion is located in Eastern Baltic.

Assessment of contaminated and potentially contaminated sites in the Baltic Sea region began slightly in the 1980s, but mainly after the collapse of the Soviet Block in the 1990s. Today governments of the Baltic states have prepared the priority lists of problem zones, for example, National Registry of Contaminated Areas in Latvia includes areas contaminated with various inorganic and organic pollutants. Sites are divided into the three categories: the first: around 250 contaminated sites (exceeding the threshold values 10 or more times); the second: >2600 potentially polluted sites and the third deals with areas additionally monitored or already remediated [8]. Although the environmental problems associated with historical pollution are relatively known, they are often a subject to political battles; social emotions and media catalysis often dominate them, which leads to a lack of strategic planning for sustainable management. The classification of problem zones is similar over the eastern Baltic region. Even in relatively rich Nordic countries, resources for restoration are limited and, therefore, the feasibility, objectives, and scope of corrective measures must first be assessed through detailed environmental studies.

Two categories of healing technologies exist: in situ and ex situ. On-site (in situ) technologies treat soils and groundwater with biological, physical, chemical, physicochemical, thermal and stabilization methods [8–10]. However, most dominant methods ex situ are simple excavation and pump-and-treat. Complex pollution recovery requires integrated solutions which always are expensive and complicated from the technological aspects.

1.2 Legal Framework

The European Union (EU) Waste Management [11], Water Framework [12] and Groundwater [13] Directives are incorporating the guidelines and rules how to treat the problems and improve the situation. From these main legal instruments, each country in the EU derivate their legal instruments through specifying problems with contamination and providing details of monitoring, assessment, analyses and remediation. Additionally, there are governmental and non-governmental organizations to support the remediation of contaminated land and groundwater. The European

Coordination Act for Effective Demonstration of Ground and Groundwater Rehabilitation—EURODEMO promotes sustainable and cost-effective ground and groundwater management technologies. In 2004, the EU adopted the Environmental Technology Action Plan to promote the development and use of broader environmental technologies including environmental remediation technology. EURODEMO cooperate, exchange experiences and develop common protocols, its efforts are seen as an important tool for achieving the priority objectives of the European Strategy for Sustainable Development, which sets out general objectives and concrete actions for key priorities [14].

1.3 Strategies and Criteria for Decision Making

The overall objective of the decision-making strategies for environmental actions is '*to identify and develop activities that will enable the European Union to further improve its quality of life in the long term through sustainable community development*'. General objectives for the rehabilitation of historically contaminated sites, therefore, are [15]:

- prevention or reduction of pollution and adverse impacts on human health, property, the environment and biodiversity, in particular through military and economic measures;
- improvement of the quality of soil, groundwater and surface water at contaminated sites;
- prevention of the ingress of contaminants into surface water and groundwater;
- rehabilitation and improvement of contaminated sites;
- environmental considerations should be taken into account in spatial planning;
- determination of the fair value of the land and the property tax based on the level of pollution.

In this way, the main ideas for the measures taken are to reduce, control, prevent and eliminate contaminants in the environment, including evaluation and assessment of facts and suspicions. Technology may play a key role in the location and treatment of contaminated areas and polluted groundwater [15].

Depending on the degree of pollution, the criteria for the geological and hydrological nature of the area can be supplemented by other factors, such as social, health, and environmental significance. Nowadays corporate social responsibility aspect (CSR in business) is of crucial importance. Analysis of the advantages and disadvantages of each approach helps decision making. Besides, the methods are designed for subgroups of contaminants such as heavy metals, inorganic salts, non-halogenated and semi-eluting substances, hydrocarbons, explosives, and others. Radioactive materials form a separate group, mainly from nuclear research, manufacturing and fuel cycle, and other sources. Heavy metals contain a group of metals and some metalloids (V, Cr, Fe, Co, Ni, Cu, Zn, As, Ag, Cd, Sn, Sb, Hg, Tl, and Pb) as environmental pollutants based on their ecological and toxicological significance. In anthropogenic environment, heavy metals form a significant group of soil, sediment and groundwater contaminants, as they cannot be destroyed, but in natural local conditions, heavy metals are converted into different chemical species. Concentration and type of contaminants, both organic and inorganic, pH and other environmental factors determine the problem size and approach settings [16, 17]. In order to reduce contamination, the following in situ and ex situ restoration methods are used [18]:

(a) in situ and ex situ technologies: biological regeneration, stabilization/solidification and separation/concentration;
(b) in situ ground wash technology, electrokinetics, barrier/walls for treatment, chemical treatment, soil improvement, and phytoremediation;
(c) ex situ technology—soil washing.

Important diffuse sources of excess supplies of nutrients and salts are agriculture and sea intrusions. With this, the problem stands in a different way as pollutants cannot be removed per se however, monitoring of sources and preventive actions are crucial.

Groundwater chemistry is the indicator of the quality of the surrounding environment. Thus, a groundwater sampling is one of the ways to determine environmental state of the area. Research and modelling are quite complex due to many factors, and analysis is mainly carried out through the monitoring actions. The exchange of surface water is fast, but in (artesian) deep water it is slow, this must be taken into account. Natural composition of groundwater in the Baltic Sea region is determined by geology, anthropogenic influence, environmental factors [4]. Pollution can penetrate deep into groundwater (artesian—confined water horizons). As most significant can be considered the impact of groundwater pollution on the drinking water quality in countryside where shallow groundwater is used for human consumption and most common is pollution with excess of nutrients [19], as well as for biggest cities where more diverse presence of pollutants in groundwater can be found [3]. With that said, surface water and soil should be protected preventively from various forms of pollution.

1.4 Invisible Contamination

The concept of emerging pollutants is becoming of growing importance understanding that many groups of materials and substances produced after World War II in industrial amounts and may have a possibly high impact on humans and environment. Common examples of emerging pollutants are pharmaceuticals, nanomaterials, and other groups of substances and materials. Nano-sized materials can be found in textiles, sunscreens, cosmetics, personal care products and cleaning agents, paints and coatings, plastics and polymers, in the food sector as additives, supplements, containers and packaging, in the energy sector as fuels and catalysts, in consumer electronics and semiconductors as well as in many other fields [20, 21]. Landfills and dumps pose significant risks to humans and environment as contaminants are leaching [22].

The one of reasons are also nanomaterials that combine nano-sizes and high chemical reactivity. Thus, the impacts on the environment and can be found even if the concentration of nanomaterials in the environmental media are very low, and simple wastewater treatment systems do not remove them completely. Further the transformations of nanomaterials due to their reactivity can influence, their transfer to other environmental media (soils, sediments, surface water), and further association with natural colloids (organic or minerals), also accumulation in some compartments. These properties govern the hazard that strongly depends on the exposure and speciation. This field has received a lot of attention from researchers and regulators [23]. There is an urgent need for broad and integrated studies that address the risks of engineered nanomaterials and other emerging pollutants including also their impacts on the waste composition, to consider them as the producers of dangerous leachates to groundwater [24]. In the context of assessing potential risks of engineered nanoparticles, life cycle thinking can represent a holistic view on the impacts of nanomaterials through the entire value chain of nanoparticles containing products from production, through use, and finally to disposal [25, 26].

At the same time, the problem of emerging pollutants is relevant not only in respect to possibly coming threats but also to already existing waste materials. A good example in this respect is nano-silica as its production started since the 1950s and has a worldwide production of several million tons [27, 28]. Modelling of possible nano-silica concentrations in surface water for the EU and Switzerland is predicted to be 0.12 μg/l. Also, waste tire rubber and rubber ash contain nano-sized material and can influence environmental quality [29]. As a prospective approach to use automotive waste tires as resources for the synthesis of SiC/Si_3N_4 nanocomposite has been reported [30] by using simultaneous pyrolytic reduction and nitration reaction using pyrolysed waste automotive tire char as carbon source and silicon dioxide as silica source. Such an innovative approach of using automotive tires as carbon source for synthesizing nanocomposites could be used to reduce the volume of wastes in landfills, decreases the risk of health concerns and also recovers valuable carbon resource. Further, there are many studies on possibilities to use nanomaterials for remediation of waste and treatment of groundwater [31].

2 Revealing Geological Background of Contaminated Areas in Latvia

Historical industrial and military sites are dominant source of pollution where intense monitoring, assessment, and remediation is the necessity. Industrial areas and ports in the eastern Baltic region have of biggest corporate-funded networks of groundwater monitoring and contains tens to several hundreds of monitoring wells which are used permanently for sampling purposes [32]. As an example of Latvia provides that almost half of the objects are located in Riga and few elsewhere (Fig. 1). The sites represent historical industry, oil terminals and factories, landfills/dumps and military

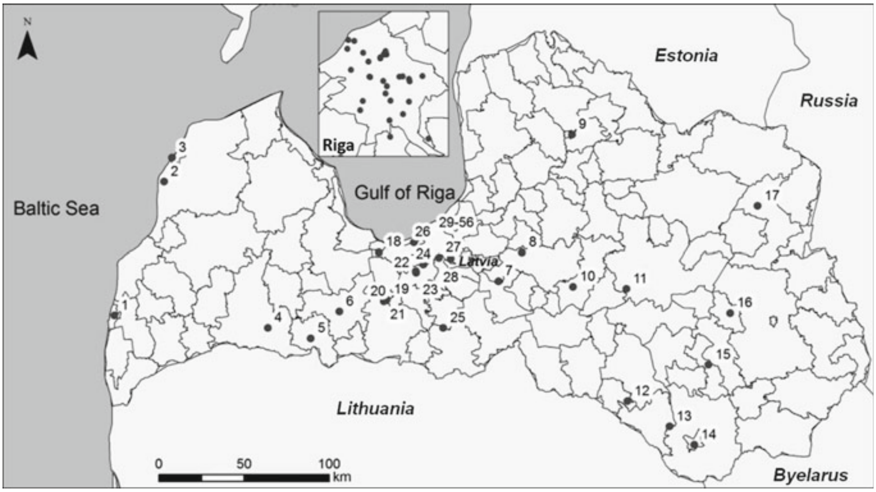

Fig. 1 The sites contaminated with heavy metals in Latvia [8]

objects of cold war past. As most of such objects are close to waterways, they pose a direct threat through leaching and stormwater washouts [8, 33].

To implement the EU strategies and Directives through the local legislative measures, monitoring is planned directly because of the legal necessity as well as via CSR measures, e.g., Freeports of Riga and Ventspils as well as gas station networks are performing. Samples regularly are taken for monitoring, and all kinds of parameters measured and tested to complete view that covers groundwater chemical characteristics. The upper geological section commonly is made by Quaternary sediments: technogenic (filled and urban soil), alluvial and limnic (sand, gravel, silty clay and sapropel), marine (Littorina and Post-Littorina sand, gravel, and mud), glacial (clayey sand and loam). Deeper layers in the eastern Baltic region are represented by different age Palaeozoic and Mesosoic, Tertiary bedrock—sandstone, siltstone, limestone, dolomite, and domerite. Hydrogeological factors are filtration characteristics of sediments and the closeness to rivers, lakes, and sea [34, 35]. Geological peculiarities play a major role in groundwater horizon development, depth, thickness, hydrogeological parameters, and mineralogical content. The first upper water horizon directly exposed to pollutants is Quaternary groundwater which flows mostly to the direction of water basins and is unconfined. Groundwater quality control includes sampling, laboratory testing, and data analysis. Flow modelling in concert with analysis of quality parameters provide valuable information on contamination control from historically polluted areas. The control of the quality determines the policy and regulations for environmental management. Deeper hydrogeological horizons at various depths mostly are confined aquifers and are exposed to surface contaminant intrusions due to geological unconformities, local tectonics, size and depth of contaminant inflows. Few sites in eastern Baltics has deep aquifer contamination threat as in former times pollution was pumped in special boreholes several hundred meters

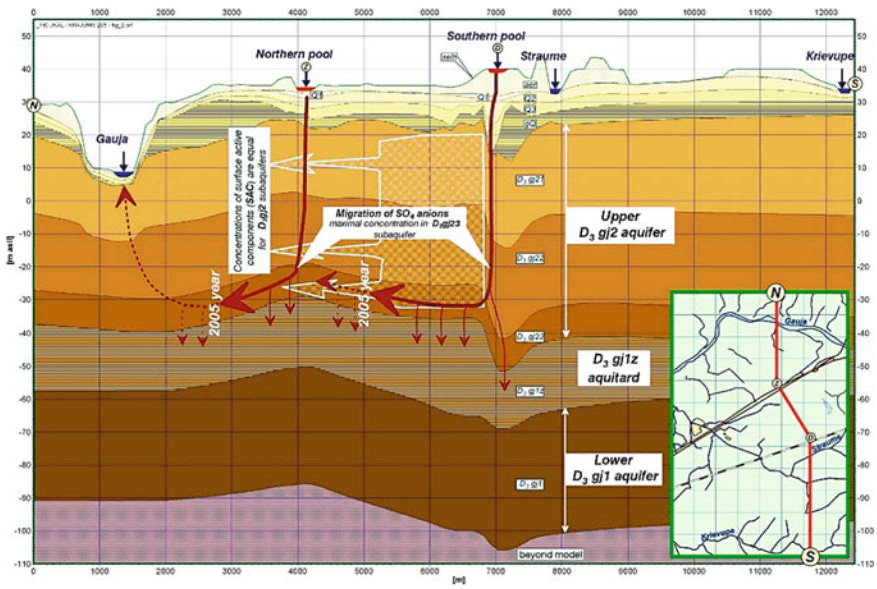

Fig. 2 Schematic block diagram of the contamination movement in Incukalns acid tar pond area [36]

underground expecting that it is the best solution of these times. However, in many cases this is not the case as boreholes are deteriorating and leaching is inevitable. As an example can be discussed Incukalns southern and northern acid tar ponds that are historically contaminated sites located 30–35 km from Riga (Fig. 2).

During 1950–1980, acid tar was a waste generated as the result of medical and perfumery oil production. Disregarding environmental protection measures acid tar and other chemical wastes were dumped in a sandy pit in a forested area. In 1986 the dump-site was closed. Remediation was performed 4 times with the last one still in operation during 2019 when shallow acid tar pond was removed. However, large part of the contamination plume is in confined artesian groundwater Upper Gauja sub-horizon (up to 60–90 m deep), less part of the contamination—in shallower groundwater. Parameters for upper groundwater are not completely understood neither for the deeper Gauja horizon. Contamination plumes are migrating in horizontal as well as vertical plane, thus polluting substances from the northern and southern ponds are getting closer to Gauja River and also threatening the groundwater resources of Riga city [37, 38]. Treatment of the upper groundwater is done via neutralizing, pump-and-treat and purification, while the residual mass was excavated, neutralized with lime and other chemicals mixed with fillers and delivered to the cement industry. Still deep aquifer problem is not yet resolved and doubtful that will be done in a short-time scale [38].

Short Summary: Geological and hydrogeological situation is main important aspect regarding analysis of contaminants potential migration and threats to groundwater. Remediation measures are chosen after careful regional and local studies.

3 Monitoring in Gas Stations

Monitoring network development is dependent on the type of commercial use, geology, form of contaminants, and legislation applied. In gas stations it is more specialized, and mostly oil products, as well as volatile BTEX (light toxic hydrocarbons) substances, are measured. Nevertheless, other contaminants often are on-site if the new commercial unit is built on historically contaminated masses. The eastern Baltic countries have practice of gas station monitoring that commonly has 3–5 monitoring wells—one for incoming flow blank control and 2–4 for outgoing groundwater flow. It guarantees standard basic information for necessary monitoring of oil product amount in groundwater. The regularity of sampling varies from 1 to 4 times in a season depending on the size of the station, historical contamination data and volume of sold oil products a year. Gas station supervision usually involves groundwater monitoring wells as well as additional wells of contaminated zones soil thermal treatment through air sparging (Fig. 3, left).

Fig. 3 Gas station monitoring and air sparging (thermal treatment) well-planning scheme in Riga gas station (left); Kleisti dump site before remediation—large dots drilling sites in waste mass, small dots monitoring wells for remediation planning (right)

Short Summary: Gas station networks that are relatively new and organized according to the environmental standards rarely create environmental hazards. However, some gas stations are established in territories formerly used for other operations the had leaching tanks. The monitoring of groundwater is the legislative necessity and must be done regularly to determine the environmental quality and to give the information for the control of pollution sources, migration and rates [39, 40].

4 Former Industry Sites and Dump Sites

Problems at industry sites and dumps often are linked with possible extermination of monitoring wells and damaging of those. Mostly the main sources of the pollution in industrial territories, dumps and ports have been inadequate storage places of oil products, acids, heavy metal-containing materials, etc. [39]. The worst environmental quality characterizes former military abandoned areas. The main sources of pollution are petroleum storage, gas refilling places, car repairing services, scrap-iron carving areas, unapproved wastages. Groundwater may include an excessive concentration of organic substances, surface-active substances, macrocomponents, nitrogen compounds [8].

Concern usually is dependent on the industrial-duty of the area. For example, complex treatment solutions are required where oil products (DNAPL and LNAPL) and other contaminants as heavy metals—Zn, Cu, Pb and As are present. Industry and continuous dumping without proper isolation through decades resulted in the infiltrating of pollutant substances in soil and heavy metals in high concentrations are sorbed in sediments dangerous for the environment [41]. The monitoring system has to be implemented during the initial assessment (Fig. 3, right) as well as in later aftercare period up to 30 years from the closure/remediation of a landfill. Preliminary initial assessment always has more research and denser monitoring/investigation wells for soil and groundwater quality control than during aftercare monitoring stage.

Other concern areas are oil terminals and logistical railway knots. Often dense and thick layers of oil products that can reach up to several meters LNAPL/DNAPL have been developed through the decades, like in case study at Ventspils Port on Baltic Sea eastern coast. Different solutions for groundwater treatment often are needed because of complicated hydrogeological conditions and manifold contaminants demanding distinct approaches for remediation. Various technologies of treatment can be used such as pump-and-treat, reactive barriers, chemical injections and other. Two systems were proposed for treatment of different age and fraction oil product contamination in groundwater of the Baltic Sea coastal area north from Ventspils City, in the western part of Latvia (Fig. 4).

Remediation should be performed after careful analysis of results of groundwater level and LNAPL fluctuations in the zone of direct influence of the open sea. Series of experiments using vacuum pumping system were performed in addition to the monitoring as one of the method for estimation of the close-to-sea hydrogeological conditions. Groundwater contamination, LNAPL monitoring and intensive pumping

Fig. 4 Location of remediation works in the northern part of Ventspils City (left); pump-and-treat circular flow treatment via carbon cassettes (right)

of contaminated groundwater under the strong influence of the sea was modelled, because common methodology by creating artificial groundwater surface depression by vacuum pumping for treatment is not very effective. During experiment efficiency of vacuum pumping treatment system for two different types of oil contamination under the strong marine influence conditions was successfully tested and implemented in pilot-scale later. Remediation plan was changed and as sandy sediments have good porosity, skimmer (density sensitive) pumping finally was chosen as an effective treatment for the continuous LNAPL of several hectares more than 1 m thickness in average removal.

Another case in the same area (Fig. 4, left, point No.2) involves the remediation works at oil pipeline route, located about 1 km from the Baltic Sea coast where the problem with pipeline rupture arose in 2010. The rupture at ~1.5–2.0 m depth from the ground surface was found when gasoline leaking from the rupture and became visible in the snow. Soil and groundwater were heavily contaminated with light petroleum products. The immediate plan was needed to organize the set of measures focusing on LNAPL dissemination and movement to the Baltic Sea. The accident happened while the light hydrocarbons were transported through the pipeline and overall, the 2500 m^2 big area of intense hydrocarbon spill pollution was calculated in the groundwater as well as in aeration zone. Installed groundwater monitoring wells have shown 0.32 to 0.73 m thick layer of floating oil in 2010. According to estimations, more than 150 m^3 of petroleum products leached during this one accident. Most likely, it brought together a mix of long-existing historical heavy hydrocarbon and fresh light hydrocarbon pollution. There were done remediation works by pump-and-treat technology, pollution was mainly made up of gasoline, concentration maintained at a very high level (BTEX 100–10,000 μg/L). Afterward pumping system through the absorbent material was projected in order to achieve necessary environmental remediation progress with the minimum of expenses (Fig. 4, right).

However, the most effective technology for contamination with oil products in aeration zone should be soil vapor extraction with implementation of dense network oxygen-enriched hot air injection holes. Thus evaporation of volatile hydrocarbons from soil and groundwater would be achieved by special recovery systems. Financial aspects, in this case, led to the use of pump-and-treat technology using special containers/cassette absorbents (Fig. 4, right). Groundwater was pumped through the absorbent layer in a special box designed to supply the so-called infiltration gallery and through a perforated horizontal tube (drain) re-routed into the ground for further pumping through the absorbent and rehabilitation. Carbon powder in cassettes is water repellent, absorbs oil, petroleum and chemical products. Absorbents soak up contaminant substances intensely that many times oversize own weight and successfully solves many problems of leakage [42]. Pumping then usually done from several wells 5–8 h a day, dislocation of the system in the whole former accident area periodically is changed in order to include whole area in remediation works.

Short Summary: The best-known way for easy tech-type remediation of hydrocarbon contaminated sites is the use of pump-and-treat technology nevertheless the best from environmental efficiency but cheapest and it provides the time frame for reporting the remedial progress to institutions. The environmentally sensitive Baltic Sea is under serious threat from hazardous industrial sites such as terminals, which often are producing contamination of various hydrocarbons in groundwater through continuous or accidental leaching in former times as well as nowadays [22]. Liquid petroleum products as the mobile layer of pollutants are moving towards the sea and thus increasing the size of environmental problems for the Baltic Sea, and that is not only the local problem anymore. Remediation projects often are formal and inefficient—a new approach is recommended in order to improve the situation. World-known successful technologies must be approved in practice, best available technologies for groundwater remediation, such as soil vapor extraction combined with groundwater lowering, reactive barriers and skimmer pump use must be implemented in order to achieve progress on environmental remediation.

The second most important group of contaminants are heavy metals which can be treated through sorption systems, phytoremediation, preventive measures of wetland construction [8, 43].

5 Seawater Intrusion in the City—Example of Liepaja, Latvia

Large part of world's population is living in coastal areas that are affected by seawater intrusion resulting in depleted freshwater resources. Extensive groundwater abstraction is the main cause for activation of seawater intrusions worldwide [44]. Seawater intrusions typically are affecting relatively small areas near coastal cities but have large negative impact on available freshwater resources. The city of Liepaja located next to the Baltic Sea in Latvia has encountered problem with saltwater intrusion from the Baltic Sea in confined aquifer due to extensive groundwater abstracting in former decades. This case is exceptional among typical saltwater intrusion cases (Fig. 5) because saltwater retreat during last years is observed with good amount of

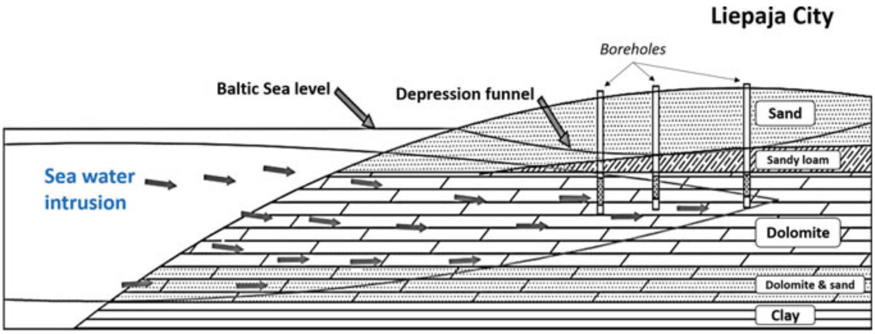

Fig. 5 Schematic overview on seawater intrusion in Liepaja city

monitoring data. The development and retreat of saltwater front can help to better understand the seawater intrusion and freshening possible processes.

Liepaja is situated in the western part of Latvia at the coast of the Baltic Sea (Fig. 6). Crystalline basement is more than 1 km deep in this western part of Latvia and several distinct aquifers can be found in a way down to this depth. Deepest Cambrian sandstone aquifers, as well as Lower Devonian aquifers, are strongly mineralized, therefore not acceptable for drinking water supply needs, thus shallower—Middle Devonian and Upper Devonian aquifers are typically abstracted [45, 46]. Devonian deposits are dipping South–South Eastwards and are covered by Quaternary sediments—till, clay and sand typically acting as confining unit with minor shallow groundwater resources. However, North–West from Liepaja city in Quaternary sediments are not present at the bottom of the Baltic Sea thus hydrological connection exist between confined Devonian aquifers and the Baltic Sea [47].

Up to the middle of IX century the shallow Quaternary groundwater was used in Liepaja, but later deeper wells were drilled in sedimentary aquifers—mostly Upper Devonian Muru-Zagares aquifer because of good quality and quantity. At the beginning of XX century, groundwater abstraction rates increased due to industrial development resulting in lowering the groundwater level in the aquifer. During the 1930s the first signs of depletion of groundwater quality was observed because of elevated chloride ions and new groundwater sources prospecting was started [47].

Hydrogeological mapping in scale 1:100,000 for Liepaja city and surroundings was done in 1947, and the authors insisted that the only useful source of the drinking water Naujoji Akmene-Middle Ketleri and Muru-Zagare artesian aquifers of the Upper Devonian can be used. Although deeper located Middle-Devonian Burtnieku aquifer has large groundwater resources and, probably lower vulnerability to seawater intrusion, the quality of it is inappropriate for drinking water needs because of elevated sulphates and hardness [47]. The system of drinking water extraction wells was recommended to be developed to the east from the Liepaja Lake between villages Grobina and Otanki [48, 49]. Following that, first, two experimental research-exploitation wells were drilled in this area in 1953, with depths of 102.8 and 117.0 m in Muru-Zagare aquifer. The analysis showed that the quality and capacity of this

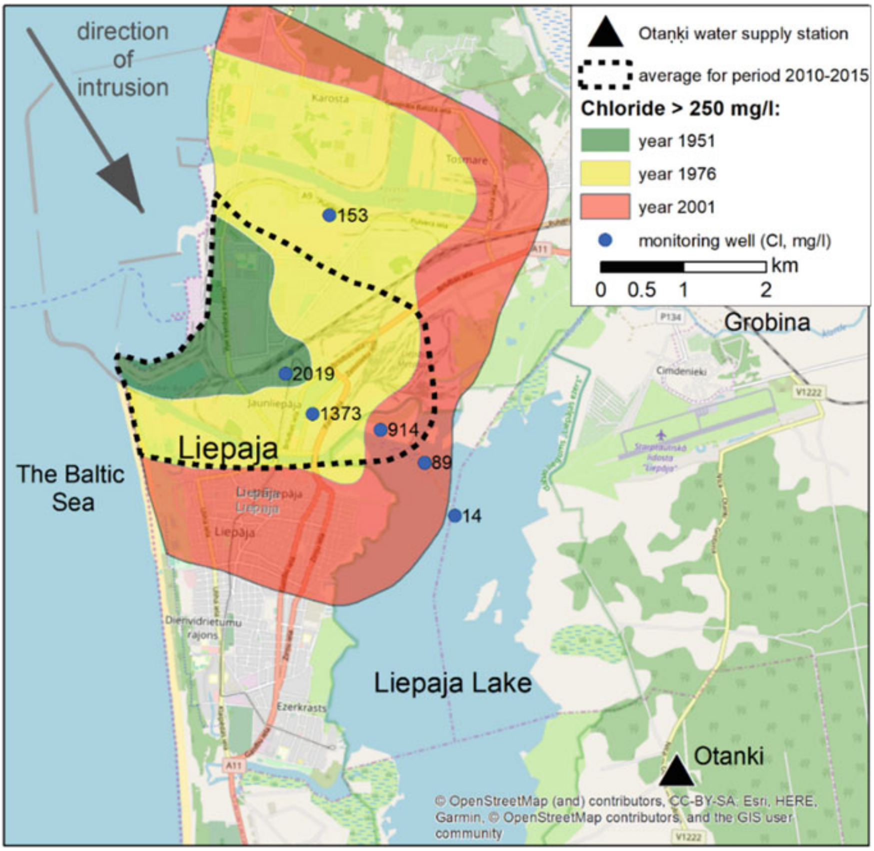

Fig. 6 Development of saltwater intrusion in the city of Liepaja over the last decades and chloride concentration in monitoring wells in 2016

aquifer was suitable for water supply needs and starting from the beginning of the 1960s groundwater abstraction increased in the established water supply station 'Otanki'. Since then active monitoring of groundwater levels and quality has been carried out.

The intensive and long-time exploitation of the Upper Devonian Muru-Zagare groundwater aquifer in Liepaja city and surroundings has caused the origin and further development of complicated hydrodynamic and hydrochemical situation: chloride rich seawater intrusion and shifting of deeper situated Eleja-Plavinas water horizons (with sulphates). The concentration of chlorides in groundwater of Muru-Zagare aquifer rose from 10–20 to 245 mg/L, but the concentration of sulphates averagely from 100 to 200 mg/L in 1944 as a result of seawater and deeper groundwater intrusions. Piezometric surface of this aquifer in 1944 was 2–3 m, ten years later 3–4 m below the sea level, but the concentration of chlorides rose up to 600 mg/L. From 1976 it was observed that the eastern part of seawater intrusion zone started

Fig. 7 Groundwater levels in Upper Devonian Muru-Zagare (D_3*mr-zg*) and Middle Devonian Burtnieku (D_2*br*) aquifers

to move in the direction of the groundwater prospect Otaņķi because of intensive groundwater exploitation [50]. The lowest levels of piezometric surface in Liepaja City were observed from 1985–1990 (more than −14 m.a.s.) when the exploitation of the Muru-Zagare aquifer was the most intense with abstraction rates up to 15,000 m^3/d [46].

At the beginning of the 1990s, when the Soviet Union collapsed, groundwater demand significantly decreased. The depression cone in aquifers steadily recovered since then and groundwater level in Muru-Zagare aquifer since 2009 is stable at 0.5 m.a.s.l. (Fig. 7).

Although groundwater tables in both aquifers are above present sea level and chloride ion concentration has decreased in the marginal zone of former seawater intrusion, high levels of chloride concentration are still observed in the central part of Liepaja [51]. A recent detailed investigation in 2017 showed that groundwater samples from Muru-Zagare aquifer in the central part of Liepaja has up to 50% composition of the Baltic Sea while wells from marginal zone of the intrusion show steady decrease in chloride concentrations [52]. Because of bad groundwater quality in the territory of Liepaja, new groundwater body at risk has been delineated for the needs of Water Framework Directive [51].

Short Summary: Recent studies [51, 52] show that saltwater intrusion in the city of Liepaja could eventually diminish as groundwater levels are higher than seawater level and groundwater quality is rising in recent years. However, precise predictions are hard to yield out because there are not many similar cases in the world when greatly affected aquifer by saltwater intrusion experiences rapid freshening. The seawater intrusion in the city of Liepaja has been well monitored during former times, and monitoring is still ongoing therefore this site could bring valuable knowledge on saltwater retreat in the future. The saltwater intrusion problem solution experience should be used for modelling of treatment of other contaminants intrusion for given geological circumstances [53].

6 Metropolitan Wastewater Crisis in St. Petersburg, Russia

The Gulf of Finland is one of the most problematic sea areas from the point of view of anthropogenic influence as the city of St. Petersburg situated in a mouth of the River Neva incorporates agglomeration of more than 6 million inhabitants, thus creating huge impact to the water quality through waste, wastewater, stormwater and industry (Fig. 8).

Nevertheless, the eastern Baltic coastline of Russia Federation is rather short, the influence is huge, it is monitored, and lot of efforts are made within the point source pollution control, treatment of waste and wastewater as well as promoting the regional legislation in north-east of Russia. This region also is included in the projects of the Baltic Sea region as well as the EU borderland activities in order to promote the achievement of sustainable goals, Blue Green growth, circular economy initiatives.

To fulfill the wastewater treatment, in average for the city of St. Petersburg every year 8–10 ha of sludge storage area must be devoted. Wastewater flows achieve millions of cubic meters per day producing more than 1500 m^3/day of dry matter.

Fig. 8 The map of dangerous for environment objects at the Gulf of Finland [54]

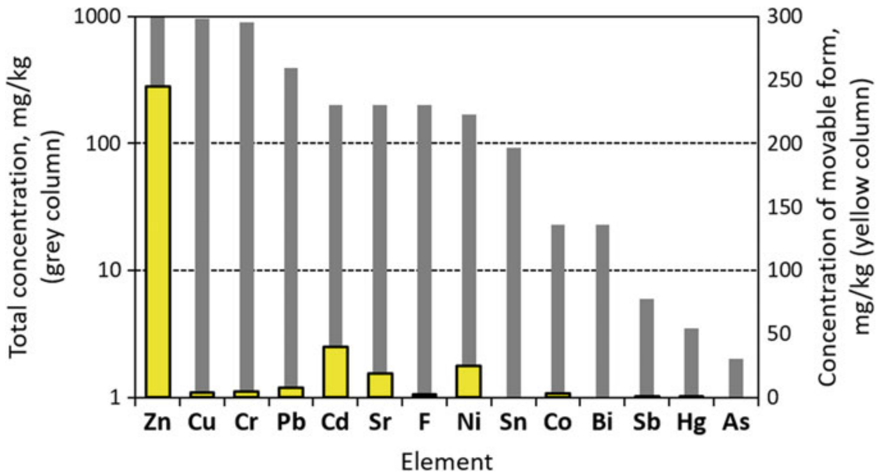

Fig. 9 The concentration of metals in sewage sludge at St. Petersburg, Novoselki wastewater treatment plant

With that said, it is clear that tremendous amount of ecotoxicants come into play, for example, in sewage sludge some potentially toxic metals such as Zn, Cd, Sr, Ni are prevailing in movable forms, while total concentration is significant for a range of metals (Fig. 9).

Needless to say that sooner or later the sludge amount may pose a threat of leaching of heavy metals or other contaminants as organic substances and pharmaceuticals, thus creating huge environmental problems in the sea as well as groundwater.

Another problem in the north-east Russian coastal areas is the excessive amount of nutrients feeding the Gulf of Finland and promoting eutrophication (Fig. 10).

Short Summary: Therefore, the government of Russian Federation and the authorities of Leningrad Oblast (Region), St. Petersburg municipality created strict rules to superintend the process of wastewater treatment, management of wastewater

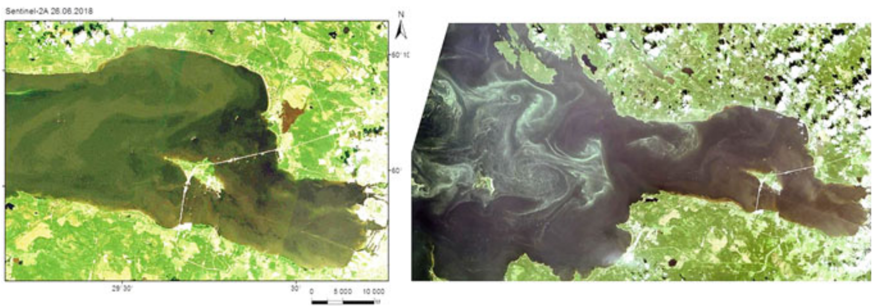

Fig. 10 Satellite SENTINEL 2a imaging of eutrophication in the Gulf of Finland on 26.06.2018. (left); suspended matter and development of blue-green algae in the gulf, Neva River mouth (right)

treatment residues, licensing of transport and landfilling in a proper way, technical normatives and standards for the reuse of residuals in agriculture as fertilizer and/or building material. The speciation and bioavailability of heavy metals in residuals are also crucial whether sludge can be useful as a soil amendment if it is not contaminated above the threshold [55].

7 Problems with Heavy Metals in Soil at Kroodi Stream, Estonia

The Kroodi Stream is situated near Tallinn, the capital of Estonia, in the north-eastern suburbs. This small river-like stream was excavated between Lake Maardu and Muuga Bay in 1893, and for a long time, large industrial areas were located on its banks—the Maardu industrial zone (and port) on the left bank and the territory of the former AS Eesti Fosforiit on the right bank.

Water quality of the Kroodi Stream was the worst in the 1960s and 1970s when even the most basic water protection measures were not taken. Compared with the second half of the last century, water quality has improved significantly, but the most important sources of pollution are the effluents and groundwater from the ancient Eesti Fosforiit at Maardu.

The Environmental Investment Center finances a number of environmental protection projects using Estonian environmental tax resources, revenues from the sale of carbon dioxide credits and the EU Structural Funds. Also, the Environmental Investment Center accepts special loan applications to carry out environmental projects. For 17 years, the state has supported over 20,000 environmental projects valued at over 1.2 billion Euros through the Environmental Investment Fund. Estonia carried out an 'inventory of residual pollution facilities' during which the production complex of the former chemical company AS Eesti Fosforiit was investigated. During the development of the most suitable solution for environmental safety, the sediments of the Kroodi Stream in the Maardu industrial zone were analyzed. The facility is located in the territory of Maardu City, Harju County. Potentially polluted waterways flow from Lake Maardu into Muuga Bay with its residual pollution was the result of earlier anthropogenic pollution of land and water—the collection of unused hazardous substances in the environment that endanger the health and wildlife of the surrounding area. This pollution covers an area of 8 ha where high concentrations of heavy metals and petroleum products were found. The water management plan for the Kroodi Stream in the West-Estonian river basin district has been identified as a pressure factor for residual pollution. A total of 144 wells were drilled in the reservoir, and pollutants were characterized and sampled. The concentration of heavy metals and metalloids such as As, Cu, Pb, Zn, Ni and Cd were exceeded [56].

Later, different ways of isolation measures for heavy metals containing soil that pollutes groundwater were investigated. The following methods were evaluated for the possible recovery of heavy metals: stabilization, electrokinetic soil cleaning, phytoremediation, biological treatment and landfill separation. Isolation from pollution was considered the simplest and cheapest way. The most interesting fact was that the Kroodi Stream was closed and opened later after treatment and isolation works by creating the bypass way for the waterflow (similarly like in road construction works). This is a typical site for pollution of industrial zones and/or ports, where the results of this project can be directly applied to other areas of the Baltic Sea region.

Short Summary: Excavation and transport of contamination is not always the case as the solution through moving of one mass to another place is senseless. Therefore, engineered solutions have to be used such as stabilization, isolation, and capping of contaminated soil to avoid the precipitation access to polluted soil and to avoid the leaching [57]. Contaminated soil in future might be extremely valuable source of secondary material [58]. Very important is to model groundwater flow and surface water streams as during remedial process, one may need to change the direction of existing waterways through creating new river and/or lake beds.

8 Multi-component Contaminated Objects

Contamination often is complex and consists of multiple hazardous constituents; a combination between oil products and heavy metals is very common [59]. As an example can be discussed the territory located in the northern part of Riga, about 5 km from the mouth of the Daugava River in the Gulf of Riga (Fig. 11).

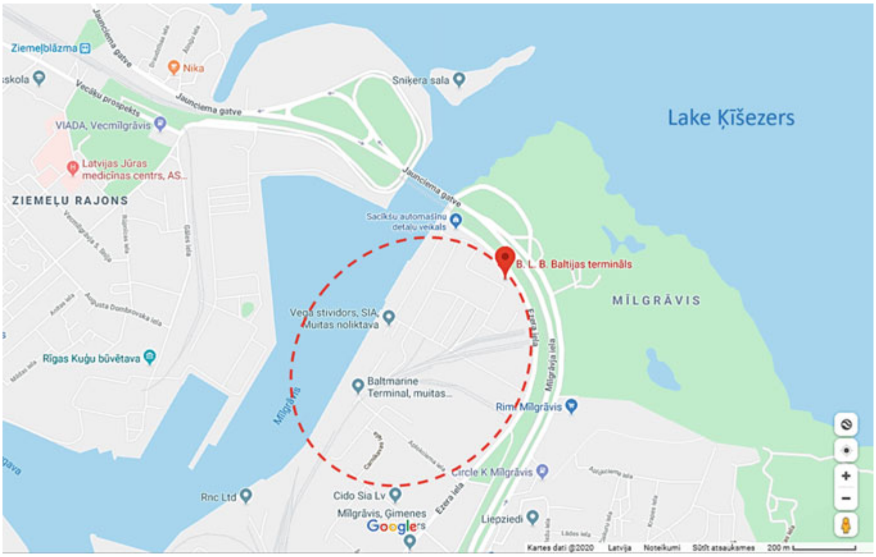

Fig. 11 Case study location at Riga Freeport BLB Oil Terminal

The study area has been economically active since the early XX century. In earlier years (1894–1967), the area was used for a variety of industrial activities, including the production of superphosphates, and an industrial dumpsite was developed nearby. Later, an oil storage, handling, and transit terminal was established in the area on the levelled surface of this sulfuric acid industrial dump-site. In the 1960s, there was a factory, but later it was covered by the territory of the oil terminal. The main source of soil pollution was the production of superphosphate (slag) waste, with the highest concentration of heavy metals and metalloids such as Pb, Zn, and As. The total amount of toxic heavy metals throughout the study was estimated at 1264 tons, or 15 kg per 1 m^2 of slag (755 t of Cu, 358 t of Zn, 66 t of As).

By geomorphology, the territory is slightly wavy and technologically changed. Formerly the Daugava branch glacier, it is now covered with a layer of sand, debris, glass, slag, and other civilization debris, filled with a layer of about 4 m thick technogenic layer. Filled soil is covered in 0.5 m thick mud and clayey sand in almost the entire area. Thick sea sand deposits of Littorina are below this layer.

Hydrogeologically, the first groundwater horizon is the upper groundwater, which is found in both filled soil and fine-grained marine sediments. In places where there is no dirt or clay sand, groundwater forms a common horizon for groundwater. Depending on the season, the groundwater level of the area is between 1.5 and 2.5 m. The wider amplitude of the level is visible in the filled soil layer (up to 0.6 m). The direction of groundwater flow into the Daugava River. The area's groundwater and groundwater are heavily contaminated with heavy metals, and some sections are also petroleum products. Investigations largely were performed with geophysical techniques [60].

Earlier studies have shown that pollution exceeds ~1000 tons of various metals [8, 61]. They are concentrated in the tailings of the sulfuric acid production process and are widespread in the area in the form of filled soil. The thickness of the roll is 1.0–4.5 m. Toxic heavy metals acquire high mobility as a result of precipitation and infiltration. Therefore, a reduction method must be selected to reduce the mobility of heavy metals [17].

For the beginning of studies, the drilling sites were selected after a thorough analysis of the historical research materials and after careful interviews of long-time workers of this >20 ha area.

Soil samples were taken from the upper part, covering a depth range of 0.5–2.0 m (to assess soil quality of the upper layer), but the second interval was from 3.0 to 4.5 m. The total area of soil samples was 1.82 ha for the pilot study.

Next step was the pilot study area selected based on the results of the first phase studies. The field of study was chosen for economic reasons (currently not used directly in industry). It was calculated that the pollution level of this part is more or less typical for the whole area. In the second step, 5 soil samples were taken to select a sample for stabilization as this was hypothesis accepted for high-intensity multi-component contamination.

All soil samples were analyzed in a Eurofins laboratory in Finland. Following concentrations of heavy metals were determined: Pb, Zn, Cu, Ni, Cd, Cr, Hg according to ISO 17294-2 [62] and by the As method according to NEN 6966 [63]. This aspect is important to know as practical field studies always should follow certain standards and analyses performed at accredited, licensed facilities.

Subsequently, in a second phase, leaching stabilization experiments were performed in the geotechnical laboratory. One of the five samples was selected for testing for possible stabilization. The sample was chosen because the soil contamination level was closest to the average level of 1.82 ha of the test area. The sample was mixed and then divided into three parts: one part was cemented with 5% cement, the other part with 13% cement, and the third was left uncemented (zero sample). A special leaching test BS EN 12457-2 was used to study the behavior of the solidified mass in the environment [64].

The final part of the experiment included geotechnical compaction tests to determine the intended parameters of stabilized/solidified soils (results not described in this study). Preliminary study results showed that the study area is contaminated with As, Cu, Zn, Pb, and some areas also contaminated with Cd, Ni, Cr and Hg. The average level of soil contamination is above the legal limit: 13.5 times As, 20.6 times Cu, 6.6 times Pb, and the allowable levels of Zn and Hg are achieved. Table 1 reveals the results of the site tests: the average concentration of heavy metals obtained from the analysis of 5 samples taken on an area of 1.82 ha, as well as the results of sample tests for leaching.

The average sample was taken to leaching test, and the main results of solidified soil of 5% and 13%, as well as of 'zero sample' are given in Table 2.

The leaching test showed that the leach form had unacceptable quantities of heavy metals (Cd, Cu, Ni, and Zn) but the leaching in stabilized solid form was reduced and was at an acceptable level. In addition, emissions of cadmium and nickel were

Table 1 Average concentration (mg/kg) of heavy metals in soil upper layer of the pilot study area

Parameter / Element	**Cd**	**As**	**Ni**	**Cr**	**Cu**	**Zn**	**Pb**	**Hg**
Average in pilot study area	2.26	255	6.85	9.35	1145	1455	620	0.475
Sample for S/S testing	2.3	350	8.1	13	2100	1200	400	0.54
Acceptable legal norms in Latvia	**8**	**40**	**200**	**350**	**150**	**700**	**300**	**10**

In pink boxes—values exceeding the legal norms

Table 2 BS EN 12457-2 leaching test results (mg/kg) compared to soil contamination

Element	Soil contamination in sample for S/S testing	Zero sample (pH 3.2)	5% cement addition (pH 10.5)	13% cement addition (pH 10.5)	Acceptable leaching level after the use of S/S method (Finland)
As	**350**	**0.02**	**0.02**	**0.08**	**0.5**
Cd	2.3	0.27	<0.002	0.002	0.02
Cr	13	<0.01	0.03	0.01	0.5
Cu	**2100**	**600**	**0.25**	**0.27**	**2**
Hg	0.54	<0.002	<0.002	<0.002	0.01
Ni	8.1	0.65	<0.01	<0.01	0.4
Pb	**400**	**0.02**	**<0.01**	**<0.01**	**0.5**
Zn	**1200**	**36**	**0.04**	**0.03**	**4**

In pink boxes—values exceeding the legal norms of leaching; in bold—values of concern in soil total concentration versus leached values leached more evenly, and their total amount is below the acceptable levels. The results indicated that the S/S healing process is highly effective for heavy metal removal. Since in this case, Hg and Pb are not very mobile heavy metals, as can be seen from Table 2 [65].

Further research is needed to improve the chemical composition of the binder needed to stabilize/cure the soil. After the recovery is complete, a risk analysis and monitoring network should be developed.

Short Summary: Careful analysis of historical information and archives shall be performed before any action, whether it is monitoring or assessment of the environmental quality or complex remediation strategy development. If possible, interviews with employees and study of enterprise materials in industry area shall be organized. Only after the initial stages of testing of soil and groundwater quality must be started. When contamination is quantified and zonation prepared, technical—economical analysis and technological studies may be started to choose the right remediation methodology to revitalize the area. Hydrogeological modelling is important and groundwater flow direction scrupulously known and studied. In situ and ex situ technologies are used to restore contaminated sites. Recovery of heavy metals is most often associated with excavation and ex situ recovery. For contamination of a large volume and high concentration, stabilization/solidification, electrokinetics, separation/concentration technologies are used. The leaching tests show whether leaching in stabilized soil is in stable form and leaching through groundwater at acceptable levels. This demonstrates the effectiveness of the treatment for environment. Physical stability of geotechnics is important if the treated area is supposed to be used for further economic activities.

9 Conclusions

(1) Environmental contamination of Eastern Baltic is mainly of historical origin. Remediation is compulsory according to national legislation acts where concentrations exceed the prescribed risk based on numerical criteria or standards.
(2) Dump sites constitute a large part of contaminated sites and specific technologies as modified pump-and-treat systems of leachate, landfill mining, phytoremediation as well as preventive engineering structures construction have been tested and implemented.
(3) Complex contamination usually is remediated stage-by-stage using various technologies depending on the land use activities, social aspects, contamination level and economic feasibility.

Recommendations

(1) Chosen remediation techniques, as well as monitoring of dangerous objects, shall be performed after careful geological and hydrogeological analysis.
(2) Gentle and passive remediation techniques are preferable where is such an opportunity. Excavation and landfilling of contaminated soil in hazardous landfill shall be the last option. The concept is to treat as much as possible solid and liquid matter in order to diminish the amount of hazardous masses.
(3) Careful historic data analysis, monitoring, collaboration among industry, authorities, and scientists (Triple helix approach) are keys for successful treatment approach decision making.

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Water Quality and Wetlands in Latvia

Water Quality Assurance with Constructed Wetlands in Latvia

Linda Grinberga

Abstract Constructed wetland is a well-known and widely used method over the countries to improve water quality. This chapter outlines the experience of Latvia in wastewater treatment and nutrient retention in constructed wetlands. In Latvia constructed wetlands as a domestic wastewater treatment systems were initially implemented in the year 2003. Wastewater from small villages with up to 1000 inhabitants was collected and purified in subsurface flow constructed wetlands with flow regime and dimensions adapted to site-specific requirements. Constructed wetlands can provide biochemical oxygen demand (BOD) reduction efficiency up to 98% without a frequent maintenance. Two pilot-scale constructed wetlands for nutrient retention were implemented in agricultural areas and monitored since the year 2014. The monitoring results obtained during the study period showed the reduction of the average concentrations of total nitrogen and total phosphorous by 53% and 89%, respectively. Basing on the initial results presented in this chapter, constructed wetlands could gain more trust to be implemented for water quality assurance as treatment systems for the wastewater from household and agricultural sectors in Latvia.

Keywords Constructed wetland · Nutrient retention · Water quality · Latvia · Wastewater · Treatment

1 Introduction

Constructed wetlands have been used all over the world as treatment systems since 60s [1] to remove nutrients, suspended solids and to improve water quality by reducing pollution from the various contaminated waters [2–4]. Available research articles show results of laboratory-scale and field-scale constructed wetlands with different constructions and design principles [4, 5]. The biological processes are well explained and constructed wetlands can be adapted to site-specific climate, hydrological and

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geological conditions. This treatment method is based on natural processes and can be cost-effective when compared with other energy consummating alternatives.

In Latvia the first documented constructed wetlands were built in the year 2003. Due to the building and exploitation failures, first experience of the constructed wetlands as a treatment plant in Latvia was not promising. Extra attention during the building process should be paid to the filter material of the wetland. The lack of the competences in this particular field most probably did lead to the low filtration capability in some wetland cases of Latvia when improper filter material was chosen and/or filter material was compacted with a heavy building technic while filled. However, some of the constructed wetlands for domestic wastewater treatment showed a lasting reduction in concentrations of BOD and chemical oxygen demand (COD) and total suspended solids (TSS) after wastewater treatment in constructed wetland when random water samples for testing purposes were analyzed. Water quality was ensured according to the current legal requirements.

Since year 2013 the additional attention was addressed to water quality from agriculture in Latvia. EU Nitrates directive designates the areas which are sensitive on contribution to water pollution with nitrates and indicates measures for limiting the risks of nitrate impact on open water bodies [6]. To achieve the requirements to good water quality in surface waters we should prevent nitrate leaching from agricultural areas. Low-energy and maintenance method is to use natural conditions and passive wastewater treatment in constructed wetlands. Two constructed wetlands were built and monitored in Latvia since June, 2014. The Cabinet of Ministers in Latvia has released the regulations valid since 31.10.2014. That state the criteria for environmentally friendly drainage systems and farmers can gain extra points to receive a financial support for investment in the development of agricultural and forestry infrastructure. To encourage the farmer interest to apply for this support several drainage systems suggested by the regulations were implemented in agricultural areas. Field-scale study sites helped us to gain the experience in exploitation considering the specific farming approach and to monitor the efficiency of suggested environmentally friendly drainage systems in nutrient retention. This chapter gives an insight in constructed wetland research installed as edge-of-field measures to reduce nutrient leakage from agricultural catchments.

2 Constructed Wetlands for Domestic Wastewater Treatment

Domestic wastewater systems in Latvia have to be designed, implemented and managed according to the actual legislation adjusted by valid regulations. The main regulations to be considered during wastewater management system design process are released by The Cabinet of Ministers of Latvia and are supported by the EU Urban Waste Water Directive [7] and the EU Water Framework Directive [8]. The Cabinet of Ministers of Latvia doesn't regalement any specific wastewater treatment method so engineers can customize it for the individual needs in the object if the result is in accordance with legislative rules.

The most widely used biological treatment method for urban domestic wastewater in Latvia is biological wastewater treatment with activated sludge and forced aeration. There are three most typical decentralized sewerage system types in Latvia—wastewater containers, septic tanks or individual treatment plants. The Administration of Latvian Environmental Protection Fund in a report in the year 2017 recommended choosing an individual treatment plant with electricity supported aeration and activated sludge for decentralized systems if storage or septic tanks are not appropriate solution [9]. The possible problems in wastewater flow or electricity supply interruption cases and limitations in pollutant concentrations in wastewater if the proposed biological treatment method is implemented are reasonably mentioned in this report. Regulations Regarding the Management and Registration of Decentralized Sewerage Systems by Republic of Latvia Cabinet states the requirements for the decentralized sewerage systems situated in the territories of villages and towns [10]. Regulation approves industrially manufactured wastewater treatment installations that discharge the treated wastewater into the environment and the total capacity whereof is below 5 m^3 per day, septic tanks and wastewater containers which collect untreated wastewater, septic tank sludge, feces, or sewerage system treatment waste [10]. It is approved that purified wastewater can be released into environment through the specially designed infiltration system—filtration fields, underground infiltration drains, sand and gravel filters, infiltration trenches and soak ways, cane fields. Basing on valid legislation in Latvia, constructed wetlands would qualify as infiltration system for treated wastewater after a septic tank or an individual treatment system.

To develop wastewater treatment methods and to introduce success stories of long-term research from other countries in Latvia, several constructed wetlands as an individual biological sewage treatment plants were implemented. Successful adaptation of a constructed wetland design to Latvian conditions would allow consumers to select a more appropriate wastewater management option in individual cases when the 3 options provided by the law do not work satisfactorily, especially in decentralized systems. The valuable benefits for the treatment plants besides the optimal water quality would be less resource requirement, low or zero energy consumption and simple exploitation.

Constructed wetlands are widely used as a treatment system to reduce pollution leakage to the environment. In subsurface flow constructed wetlands the biological activity appears inside the filter material as coarse sand, gravel or other suitable filter material saturated with wastewater. Initially, constructed wetland implementation was focused on the treatment of domestic and household wastewater [3], but nowadays subsurface flow constructed wetlands are frequently used for treatment of specific wastewater such as industrial wastewater from the food industry [3], chemical industry, textile industry [1, 11], coal industry, etc.

The volume and composition specifics of the wastewater requires to customize the construction and technical solution. The direction of the water flow in a subsurface constructed wetland can be organized horizontally or vertically up or down, all versions are widely applied and investigated [12, 13]. The technology of the inlet part of the constructed wetland can differ noticeably and the design basically depends on the surface conditions of the object. Wastewater can be discharged into the wetland if the terrain conditions are convenient or it can be pumped with the pressure. Depending on the climate conditions as precipitation amount and the lowest air temperatures, spreading of wastewater over the filter layer is possible or freezing protection for the pipes has to be provided. Latvia is located in a humid climate zone with a long-term average annual precipitation of 667 mm [14] where precipitation exceeds evapotranspiration resulting in an average annual runoff of 245 mm [15]. In Dobele meteorological station located in a middle part of Latvia, annual average air temperature in a period of 2014 to 2017 was observed 8.6 °C during vegetation period (April to September) and 7.7 °C during non-vegetation period (October to March) [16]. The air temperature was under the 0 °C on average 51 days in a period of 2014–2017 [16]. During the cold season, when the air temperature is below zero, biological processes slow down, but wetland activity does not stop and wastewater treatment continues under the ice [2, 17].

The activity of microorganisms in the filter provides a certain release of heat energy, but it is not completely safe protection against freezing throughout the winter and at any temperature. To ensure the optimal wastewater treatment during the cold period of the year, constructed wetlands in Latvia was adapted to perform safely in wintertime. The infiltration pipes were built inside the upper part of the filter and protected from freezing with a ground cover.

Several constructed wetlands for domestic wastewater treatment were implemented in Latvia since the year 2003. Four of them in Tervete, Birzi, Tinuzi and Valti are described in this chapter to demonstrate the experience in building and exploitation.

2.1 Sewage Treatment in Constructed Wetland in Tervete

Vertical subsurface flow constructed wetland was implemented to receive wastewater from Tervete Rehabilitation centre located in Zemgale region, Tervete Municipality as a pilot-scale demonstration object under the Sustainable Water Management and Wastewater Purification in Tourism Facilities (SWAMP) project activities. Tervete Rehabilitation centre creates domestic wastewater in an average amount of 58 m^3 per day. There is a joint sewerage system for domestic wastewater and stormwater from the roof area of 0.3 ha. The hydrotherapy unit provides water treatment services that create low-organic wastewater of 40 m^3 per day.

Raw wastewater from the Rehabilitation centre is directed to the overflow tray and then from the first septic tank with the volume of 60 m^3 is periodically pumped to the reed bed of constructed wetland with the surface area of 1200 m^2 (Fig. 1). Perforated infiltration pipes are installed into the upper part of the constructed wetland to evenly distribute influent over the filter layer. Drain pipes are built in the lower part of the filter and collect purified water to discharge it in the second septic tank. During the

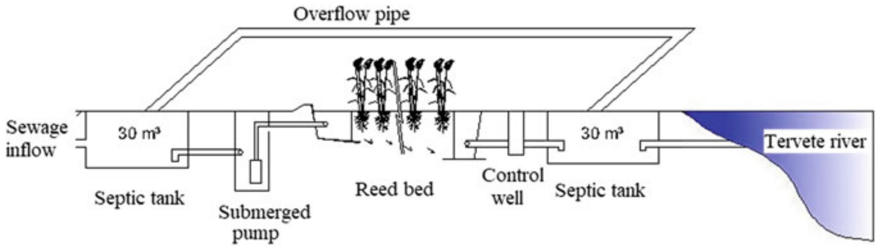

Fig. 1 Schematic drawing of the constructed wetland in Tervete Rehabilitation centre. *Author* Santa Voitehovica

storm events when the water level in the first septic tank is rising critically, water overflows though the pathway to the second septic tank and then to the Tervete river.

Common reeds *Phragmites Australis* on the surface of constructed wetland are mowed once per year and left above the filter during the winter. No specific exploitation issues as lasting accumulation of surface water or sudden odours were documented. A view of the Tervete constructed wetland in early spring showed in Fig. 2.

Water samples were taken once or twice per year during the period of the year 2012 and 2018 only to control if the treatment system meets the requirements of the

Fig. 2 A constructed wetland in Tervete Rehabilitation centre. *Author* Santa Voitehovica

actual legislative requirements in Latvia. The inflow concentrations of the BOD and COD were observed 440.6 and 731.3 mg per liter on average, respectively, during the exploitation period. BOD and COD concentrations at the outlet were 1.5 and 14.5 mg per liter on average, respectively. The treatment efficiency of the constructed wetland was 99% for BOD and total suspended solids (TSS) and 98% for COD. The retention efficiency of the constructed wetland was 84% for total nitrogen (TN) and 98% for total phosphorous (TP) if occasional grab samples once or twice per year were taken. Regular monitoring should be carried out to observe the wetland performance and to determine the dependence of wetland efficiency on site-specific factors.

2.2 Sewage Treatment in Constructed Wetland in Birzi

Birzi village has 250 inhabitants and total amount of domestic wastewater of 67.5 m^3 per day was calculated. A centralized sewage system passed wastewater to the biological wastewater treatment plant where a system of several biological treatment methods with low energy consumption were used. Treatment system started with two-stage sedimentation ponds with a retention time of two and five days. After mechanical sedimentation wastewater flowed into biological pond where biological treatment was started accordingly the biological activity of microorganisms and bacteria. After a partial treatment wastewater was discharged in a surface flow constructed wetland that was built by transforming the old biological treatment plant with aeration and activated sludge and using the old concrete basins as a wetland base. Common reeds *Phragmites Australis* were planted in a bottom of the wetland. The depth of the open water layer was 0.05–0.5 m. The outflow was covered with a gravel coating to prevent plants from erosion. Purified wastewater was repeatedly settled in a post-treatment sedimentation pond and discharged in natural watercourse Birzupe.

The wastewater treatment system with a biological pond and constructed wetland was under exploitation since the year 2005. Any performance failures were not observed and regular water quality and performance monitoring were not realized. Though the yearly manually taken water samples since year 2012 was analyzed to prevent any risks of pollution leakage. Figure 3 shows a treatment system in Birzi with a biological pond in a front and planted constructed wetland in behind.

The treatment efficiency of the treatment system with biological pond and constructed wetland was 89, 81 and 92% for BOD, COD and TSS, respectively. The concentrations of TN and TP was reduced on average by a 76%, and 56%, respectively. These results show only a tendency of treatment level in all system. To reasonably measure the performance of the surface flow constructed wetland and to evaluate factors influencing the treatment efficiency, regular monitoring should be carried out and water samples at the inflow and outflow of the wetland particularly should be taken.

Fig. 3 A biological pond and constructed wetland in Birzi. *Source* Vigants Ltd. Archive

2.3 Sewage Treatment in Constructed Wetland in Tinuzi

Within the cooperation project between Latvian and German companies in the year 2003 a constructed wetland in Tinuzi at the Ikskile county was built. Tinuzi village with 300 person equivalent (PE) created domestic wastewater in amount of 56.3 m^3 per day including side waters. Wastewater from the centralized sewage system was discharged into the open sedimentation pond with a water depth of 1.5 m. Wastewater with the pressure was directed to the two vertical subsurface flow constructed wetlands with total surface area of 960 m^2 and distributed through the infiltration pipes. The infiltration pipes were supplemented with additional 4 mm holes on every length meter. Half of the constructed wetland was covered with 0.6 m high ground layer during the winter to ensure the optimal wetland performance in the cold periods with the air temperature below 0 °C. Both vertical subsurface flow constructed wetlands showed in Fig. 4.

The inflow concentrations of the BOD and COD were observed 192.8 and 500.2 mg per liter on average, respectively, during the exploitation period. BOD and COD concentrations at the outlet were 4.7 and 44.4 mg per liter on average,

Fig. 4 Two vertical subsurface flow constructed wetlands in Tinuzi. *Author* Ugis Plaudis

respectively. The treatment efficiency of the constructed wetland was 98, 91 and 97% for BOD, COD and TSS, respectively.

The inflow concentrations of the TN and TF at the inflow and outflow of constructed wetland in Tinuzi was on average 94.6 and 11.55 mg per litre, respectively when grab samples once per quarter were analyzed. In January of 2014 an event with higher TN concentrations at the outlet was observed. All other cases show a reduction of TN and TP concentrations at the outflow. The treatment efficiency of the constructed wetland was 31 and 42% for TN and TP, respectively.

Environmental review of Developed in the Strategic Environmental Assessment Framework for Ikskile County Spatial Planning 2011–2023 defines Tinuzi constructed wetland as experimental wastewater treatment system. The wetland was considered as one of the best technical solutions for the wastewater purification. The technology was rated as economical and environmentally friendly. No chemicals or other specific materials were used in the operation of these wastewater treatment plants, they did not produce pronounced odors there were no noise sources.

2.4 Sewage Treatment in Constructed Wetland in Valti

Horizontal subsurface flow constructed wetland was designed for stormwater and domestic wastewater treatment form the farm "Valti" located in the mid-western part of Latvia, Skrunda Rural territory. Stormwater forms mainly in the farmyard area with living house and livestock housing, machinery shed, silo tank, paved walkways and grassland. Stormwater amount calculated by the maximum intensity method [18] was 31.5 L s^{-1}.

Valti constructed wetland was mainly designed as stormwater treatment plant with an opportunity to connect the existing sewage system and purify pre-treated domestic wastewater from the living house. The existing domestic wastewater from the living house was concluded in the septic tank and was regularly pumped out after sedimentation. Primary sedimentation usually does not ensure a sufficient reduction of pollutants and holds the risk of polluting the environment. The farmer also hosted a public open-air events for up to 40 participants. The design of the constructed wetland considered the possibility to connect the existing non-pressure sewage system. Maximal daily domestic wastewater discharge was calculated [18] 0.96 m^3 per day.

The construction type of the wetland was selected to purify the wastewater with the highest contamination level in the particular object. In this case it was based on the typical domestic wastewater with BOD (Biochemical Oxygen Demand) concentration 150–350 mg L^{-1} [19]. Constructed wetland with subsurface flow with horizontal water flow in the filter was selected for wastewater treatment. The size of the wetland was adapted to the total maximum amount of wastewater, with the surface area of the filter 150 m^2. The material for filter layer of the wetland was porous sand and thin gravel layer around infiltration and drainpipes to provide better water filtration. Common reeds *Phragmites australis* [20] were planted on the top of the sand filter. The building process demonstrated in Fig. 5.

During the exploitation period of the year 2015–2019 water quality was not monitored as the object qualifies as a private wastewater treatment system in rural area. No leakage of dirty waters at the outlet was observed, no remarkable smells or durable surface waters above the wetland filter appeared. Wetland was under the water periodically after the heavy rainfalls. Lack of moisture has caused reed destruction as noticeable rain events have not been often enough. Basing on the interview of the owner and operator, constructed wetland has been a comfortable treatment method for domestic wastewater.

3 Constructed Wetlands for Water Treatment from Agricultural Catchments

Each type of wastewater has different and specific content and concentrations of pollutants and elements depending on its origin. The parameters of constructed wetlands should be adjusted [13] depending on the nature of the wastewater and the degree of

Fig. 5 The building process of the constructed wetland in Valti. *Author* Vanda Valtenberga

contamination, just like any other treatment plant. Agricultural runoff may result in leakage of plant nutrients in excessively high concentrations, as well as suspended particles, possibly pesticides, or other substances depending on the type of farming. Uncontrolled agricultural run-off released into natural watercourses increases the risk of overgrowth, which has a number of negative effects. Constructed wetlands with variable construction can serve as a buffer zone, preventing the leakage of contaminants and nutrients from agricultural areas and preventing their release into the environment.

The regulations released by The Cabinet of Ministers in Latvia state the criteria for environmentally friendly drainage systems and constructed wetlands are defined as one of the supported drainage elements. Regulations determine constructed wetlands as artificially created surface or subsurface flow wetlands for capturing water pollution Measurable criteria are as following:

- Artificially implemented wetlands that have not existed before and that have been created as a result of the project;
- Construction site should be as close to the inlet of a regulated watercourse and/or natural watercourse as possible;
- Natural plant filters (reeds, etc.), wood chips, gravel, sand is used for water filtration in a subsurface flow constructed wetlands;

- A water depth of the surface flow constructed wetland should be no more than 1.5 m from the base to the water level [21].

A climate in Latvia is with moisture surplus which occurs as a surface runoff 250 mm on average per year [15]. This chapter focuses on the surface runoff, drainage runoff and runoff from open ditches from agricultural areas.

A runoff occurring in agricultural areas can contain polluting elements as phosphorus and nitrogen that increase overgrowth and eutrophication when entering into the natural waters. As it is undesirable for natural water ecosystems, we should keep pollutants within the limits of control. The runoff that contains polluting and biogenic elements from agricultural areas is transported by drainage system through the drains and open ditches to natural water bodies, and it promotes the growth of aquatic plants. The appropriate solution for purifying this type of water is widely applied in constructed wetlands. Their operating principle imitates natural processes, construction and operation is relatively simple and does not require a large financial investment, wetlands are adaptable for a wide range of wastewater.

There is a good approach to intercept and purify agricultural runoff from small catchments via individual local solutions such as barriers or thresholds with a simple stone-wood or stone construction. This bottom dam is built in an open drainage ditch with the purpose to increase the water level, reduce the flow rate and detain and settle suspended solids, thereby reducing the nutrient load on natural waters. The settling pond established upstream the bottom dam operates on similar principles as constructed wetlands. It uses the natural self-purifying ability of water, detains nutrients and suspended solids and promotes nutrient uptake through the aquatic plants. Considering that the drainage system is made to remove an extra moisture from the soil from an agricultural area, uncontrolled flooding of tile drains or any disorders of drainage system are prohibited. The practical teaching farm “Vecauce” of Latvia University of Life Sciences and Technologies has built twelve bottom dams in open drainage ditches in agricultural areas. Monitoring results from the period of 2014–2018 showed the retention of TN and TP up to 5 and 25%, respectively. Suspended solid were retained by up to 86% on average during the study period. In some cases increase in the nutrient and suspended solid concentrations was detected. The main conclusion after investigating bottom dams on the site was that the efficiency was dependent on the location of the element.

This chapter provides an overview of experience in nutrient retention in constructed wetlands implemented in Latvia. Three constructed wetlands with different design parameters and technologies in agricultural catchments were implemented to reduce nutrient loads on natural watercourses.

3.1 Nutrient Retention in the Constructed Wetland in Mezaciruli

Surface flow constructed wetland showed in a Fig. 6 was installed at the farm Mezacir-

Fig. 6 Surface flow constructed wetland in farm Mezaciruli. *Author* Linda Grinberga

uli, Zalenieki county, Jelgava region, Latvia located within the Nitrate Vulnerable Zones designated according to the criteria of the EU Nitrates Directive [6]. Constructed wetland received surface and drain runoff from an agricultural catchment and was designed as an in-stream measure. The catchment area of the constructed wetland was 73.6 ha. The wetland was built by transforming an existing open drainage ditch to ensure a surface area of the constructed wetland/catchment area ratio 0.5% [22]. The maximal water depth of the wetland was 1.45 m, the surface width was from 6 to 42 m and total length was 240 m. The water level was regulated with a concrete dam and measured with a V-notch weir.

Water samples were analysed for concentrations, mg per litre, of nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_4-N), TN, orthophosphate-phosphorus (PO_4-P), TP and TSS. Water samples were collected using a grab sampling technique at the inlet and outlet of the wetland, once or twice per month depending on water discharge to evaluate the efficiency of the treatment system [23].

The constructed wetland reduced the concentrations of TN by 19% on average. The seasonal impact on nitrogen transformations was demonstrated by the increase of NH_4-N concentrations and decrease of NO_3-N concentrations during the vegetation period. NH_4-N concentrations were increasing during the vegetation period, but decreasing during the non-vegetation period. The retention efficiency of the constructed wetland for total phosphorous was 43% higher during the vegetation period.

Several cases showed an increase of PO_4-P and TP during the non-vegetation period. The retention was 43% for suspended solids and 46% for TP.

The surface flow constructed wetland was able to retain nutrients overall in the study period with a slight trend to higher treatment efficiency during the vegetation period.

3.2 Stormwater Treatment in Constructed Wetland in Mezaciruli

The research in a study site of farm Mezaciruli focused on the runoff from the farmyards. There are regulations in Latvia for the cities which determines the limits and admissible amounts of pollutant concentrations entering into the natural watercourses. Determinations for the water quality from agricultural catchments included in EU regulatory documents as Nitrate Directive 91/676/EEC [6] and Water Framework Directive [8]. But there are still a lack of regulations and solutions offered for countryside and especially for farmyards. Often the farmyards serve as a transit territory for agricultural technics and equipment, possibly some animal moves through the farmyard territory. And to ensure that all this movement is satisfactorily organized if this area was planned as a transportation corridor, there possibly should be a hard, waterproof surface covering. We can imagine what happens when the soil is mixed with stormwater and some agricultural heavy equipment is moving around and then a mass of cattle is transported across it. Runoff occurring in such area results with the bad quality water with possible high amount of organic matter or nutrients and suspended solids as well as other pollutants.

This research object showed that the farmyards need special attention regarding surface runoff management and there are several possible solutions to capture and purify stormwater from the hard surfaces from the farmyards. In addition these solutions should be as possibly simple, low expensive during building and exploitation and easy to maintain with a small exploitation effort without any specially qualified stuff. These issues will attract farmers and will ensure them to agree when stronger rules in water quality would be considered. And the most important the treatment method should be effective enough to purify the incoming wastewater. The solution should be found considering the specifics of the stormwater when the wastewater occurs irregularly, with possible peak amounts and with possible long dry periods, and differing concentrations of chemicals, possibly high concentrations in the case of farmyards. This chapter illustrates one of the examined solutions to improve the water quality from the farmyards before entering in natural open watercourses (Fig. 7).

Horizontal subsurface flow constructed wetland was installed at the farm Mezaciruli, Zalenieki county, Jelgava region, Latvia in the year 2014. A stormwater was discharged and accumulated in a sedimentation pond as a pretreatment plant, then periodically pumped to a horizontal subsurface flow constructed wetland with the

Fig. 7 Subsurface flow constructed wetland in farm Mezaciruli. *Author* Linda Grinberga

surface area of 160 m^2. Water samples were taken manually once or twice per month depending on the water flow.

The existing monitoring data [23] showed the average concentrations of TN and TP at the inlet of sedimentation pond were 14.87 and 7.07 mg L^{-1}, respectively. All of the monitored water quality parameters showed a reduction. During the study period the concentrations of TN and TP were reduced on average by a 53%, and 89%, respectively [23]. Suspended solids were retained on average by 63% during the study period.

3.3 Nutrient Retention in Constructed Wetland in Sodite

The catchment basin of Sodite stream was occupied with tile-drained agricultural area of 85%. There was a summer village in a downstream of the Sodite stream. A section of 3.75 km was rebuilt as a two-stage ditch. Forth a chain of two surface flow constructed wetlands were implemented before entering drain water into the Tervete River. Wetlands were designed with a total surface area of 60 m^2, water layer was up to 1.2 m deep. Two small islands were implemented at the inflow of the first and at the outflow part of the second wetland to split the water flow track and to distribute water flow over the wetland area. No plants were planted during the construction works, but vegetation occurred naturally during the exploitation as the appropriate conditions were set (Fig. 8).

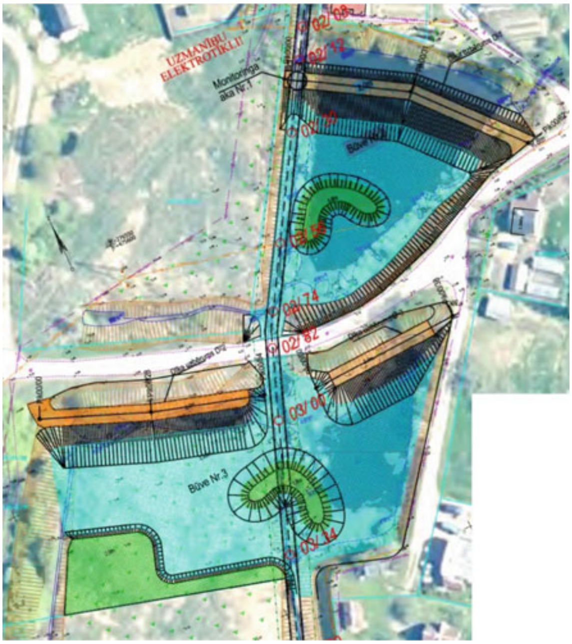

Fig. 8 A schematic plan of two surface flow constructed wetlands in Sodite. *Source* Jelgava district municipality archive

Water samples were collected for the 9 month period in year 2018 twice per month to analyze a concentrations of nutrients and suspended solids. Interesting results showed NH_4-N concentrations by increasing 6% on average. Uncontrolled discharge of domestic wastewater into the wetland was possible. During the study period the concentrations of TN and TP were reduced on average by a 3%, and 9%, respectively [23]. Suspended solids were retained on average by 34% during the study period. As the monitoring was carried out directly after implementation and data series was less than a year long, the results are likely to change during the exploitation period.

4 Conclusion

Constructed wetlands for wastewater treatment are not broadly used in Latvia however most pilot-scale wetlands show a good potential in water quality assurance. There are an examples of in-stream practice of surface flow constructed wetlands for treatment of domestic wastewater and runoff from agricultural catchments as well as an examples of subsurface flow constructed wetlands for the treatment of domestic wastewater and stormwater in climate and management conditions of Latvia. The highest reduction level was detected for TN and TP by 99 and 98%, respectively, at Tervete constructed wetland which could be explained by higher nitrogen concentrations at the inlet and appropriate wetland parameters according to the treated wastewater. A regular monitoring and wider studies would lead us some way towards enhancing our understanding of site-specific factors influencing the treatment and nutrient retention efficiency of constructed wetlands.

5 Recommendations

1. The functions of the constructed wetland should be adapted according to composition of the wastewater content and amount to improve water quality.
2. The calculations of specific parameters of constructed wetland should be made following previous studies and governmental regulations.
3. Building process should be considered to manage according to the design project and recommendations of an engineer.

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Potential Management of Water Contaminates in Germany

Phosphorus Fluxes in the Baltic Sea Region

Judith Schick, Sylvia Kratz, Elke Bloem and Ewald Schnug

Abstract Phosphorus (P) budgets and flows in particular regions or countries are assessed and suitable strategies discussed to identify and improve the P use efficiency in these countries. These strategies will help to reduce P losses, close the P cycles and protect vulnerable waters, such as the Baltic Sea, from further eutrophication. The P budgets and flow analyses show that in most of the Baltic Sea Region (BSR) countries P inputs exceed outputs, and a high amount of P that entered the system is retained, especially within the soils of the agricultural production sector. The continuous accumulation of P in the soil results in excessive P surpluses and increases the risk of P losses and eutrophication in the long run. Various suitable measures to help to minimize these P losses are proposed, including more stringent recycling of wastewater P (communal sewage sludges and their ashes; struvite and related precipitation products from wastewater treatment), biodegradable solid wastes (biowaste compost) and incinerated slaughter residues. However, the commercial implementation depends on the overcoming of considerable obstacles which include the development and implementation of adequate technology, the adjustment of existing and creation of new governmental regulations and promoting social acceptance of the necessary changes. Furthermore, the monitoring of P fluxes needs improvement in order to generate more consistent and comparable results. It is recommended that fluxes are modelled not only on a national but also on a regional scale in order to be able to account for the specific geographical condition of each country. Also, the P status of agricultural soils with its changes over time and some key soil characteristics need to be considered on a sub-national/regional scale to assess the actual risk of P loss

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via erosion/run-off/leaching from a particular area/region. Finally, P flow analyses should comprise several years to monitor long-term developments and trends in P flows.

Keywords P fluxes · P budgets · Nutrient surpluses · Baltic sea

1 Introduction

Phosphorus (P) is an essential major plant nutrient for all living organisms. To maintain the growth of healthy crops and receive optimum yields, a sufficient P level in the soil has to be maintained by using organic and/or inorganic P fertilizers.

On the other hand, excessive inputs of P (and N) into the environment are the major drivers for the regular eutrophication of the Baltic Sea. As a result from significant nutrient inputs, especially N and P, eutrophication induces massive algal blooms and has a negative effect on the water quality.

These nutrient inputs either originate from point sources (e.g. wastewater treatment plants, industries and aquaculture) or from diffuse sources (e.g. agriculture, managed forestry, scattered dwellings, storm overflows etc.) [1]. The sector agriculture is said to be responsible for 60–80% of the diffuse anthropogenic P losses to the Baltic Sea [2]. Within the sector agriculture, the major contributors for high P loads from agriculture are high livestock densities and the immoderate use of fertilizers in conventional farming systems [3, 4].

According to the Swedish Environmental Protection Agency, eutrophication is the worst threat to the Baltic Sea [5]. To improve the situation of this inland sea, maximum allowable inputs (MAI) have been adopted by the 2013 HELCOM Copenhagen Ministerial Meeting. These values determine the maximum tolerable inputs of water- and airborne P (and N) to Baltic Sea sub-basins to achieve the targets for a non-eutrophic sea [6].

To document the trend of nutrient inputs into the Baltic Sea, data on the quantity of nutrient inputs must be collected. For the identification of those nutrient sources responsible for the pollution of the Baltic Sea, additional information on land-based sources and retention within the catchment are important. Furthermore, such data could also be used to assess the efficiency of strategies implemented to reduce the pollution inputs. Thus the collection of quantified data on nutrient inputs is an important factor for the interpretation, evaluation and prognosis of the condition of the marine environment and the related changes of the open sea as well as coastal waters [1]. Accordingly, quantitative assessments and a better understanding of P flows within different systems (e.g. on regional or on a country scale) can be used for the implementation of more effective policy strategies to ensure a more sustainable, site-specific P management [7].

Within the frame of the EU research project "PROMISE-Phosphorus Recycling of Mixed Substances" data available on P fluxes of the riparian countries of the BSR was collected and analyzed. The results of this data analysis will be presented in this chapter.[1] While only 9 countries (Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland and Germany) share a direct coastline to the Baltic Sea, five additional countries (Belarus, Ukraine, Czech Republic, Slovakia and Norway) indirectly contribute with waterborne inputs to it. Data on Russia, as well as the indirect contributors, however, is very scarce. Therefore the focus here is on the 8 European direct contributors.

2 Calculation of P Fluxes in the BSR

The P cycle is a very complex mechanism. Studies investigating P flows in different countries differ regarding data included (mainly due to their availability), specific methodologies, flow diagrams used, outcomes etc. Thus, it is very difficult to compare data obtained for different countries and from different researchers [1, 9, 10]. Furthermore, lessons learned and strategies implemented basing on data on P fluxes for one particular country can hardly be transferred to another one because P outflows vary in nature and magnitude from one country to another [7, 9].

2.1 The Gross P Budget

Nutrient budgets are often used to identify those areas which are vulnerable to nutrient leaching. The calculation of the gross P budget provides an insight into the links between agricultural P use, losses of P to the environment via soil surface erosion/run-off or leaching, and the sustainable use of soil P resources and indicates the total **potential risk** of agricultural P to the environment, comprising both water and soil [11]. In contrast, the **actual risk** of P leaching, run-off or changes in soil stocks of P depends on many factors including climate conditions, soil type and soil characteristics, soil P saturation, management practices such as drainage, tillage, irrigation etc. Thus, additional information on the vulnerability of the soil to P leaching and run-off, as well as data on the state and accumulation or depletion of P stocks in the soil, are necessary to assess the risk of P to water but are currently not available.

In order to make comparisons between countries, and to develop EU wide political strategies and policies for protecting the environment from nutrient leaching and eutrophication, Eurostat/OECD have been working on establishing a common robust and feasible methodology for calculating P (and N) budgets. The EU member states, Norway and Switzerland have agreed to follow the **land budget approach** and have published their harmonized methodology in a handbook in 2013 [11]. Based

[1]This text is based on the BONUS PROMISE Deliverable 3.5 „Report on meta data analysis of P fluxes" by [8], which was edited and shortened by the authors. Available online at: https://portal.mtt.fi/portal/page/portal/mtt_en/projects/promise/Publications/Report%20on%20meta%20data%20analysis%20of%20P%20fluxes.pdf.

on this handbook, Eurostat has requested all EU countries (and additionally, Norway and Switzerland) to report yearly N and P budgets, and compiled them in an online database, dating back as far as 1985. According to EU methodology, the "gross P budget (formerly called "balance") in agricultural land" estimates the **potential surplus of P on agricultural land**. This is done by calculating the balance between P added to an agricultural system and P removed from the system per hectare of agricultural land. The indicator accounts for all inputs to and outputs from the country's agricultural sector. The **inputs** consist of the amount of P applied via mineral fertilizers and animal manure as well as organic fertilizers such as sewage sludge, urban compost, industrial waste products and other products used as agricultural fertilizers. Other minor inputs such as atmospheric deposition, or seeds and planting material are also accounted for. The P **output** is contained in the harvested crops and fodder, crop residues removed from the field and uptake by grazing livestock. The **area (agricultural soils)** to which the balance refers is the total of arable land, land under permanent crops and permanent grassland as defined in the Crop Production Statistics (land use), while extensive areas should be excluded. As pointed out on the Eurostat web page on Agricultural Nutrient Balances [12], the national P budgets compiled and presented by Eurostat/OECD are the outcome of a set of calculations provided by the countries. Countries use several data sources to estimate the balances. The basic data used include the consumption of fertilizers, livestock population, manure imports, exports and treatment, crop and fodder production, crop residues, seed production, the area of leguminous crops, the area of arable land, land under permanent crops and permanent grassland. Countries may have used different types of data sources for these data. For instance, some countries use estimates of the livestock population based on data from the Livestock Surveys, or they have used other data sources like national registers on livestock [12].

Data sources that are used available in Eurostat include Crop Production Statistics (production and land use), Livestock Statistics (livestock numbers), FSS (Farm Structure Service; livestock numbers). Countries have estimated their own nutrient coefficients based on measurements, scientific research, expert judgment, default values etc. Therefore, the conversion from material amounts (tonnes of seed, yield, animals, manure etc.) into P (and N) amounts is not done in a uniform way throughout Europe. The practical implementation of calculating national nutrient budgets was a compromise between the ideal budgets and what can be reasonably achieved with the limited resources each country can allocate for this task. Thus, problems in data availability and quality have lead to the exclusion of certain nutrient flows, such as atmospheric deposition of P, or crop residue inputs. Other flows were defined as optional in the reporting to the EC, and are thus reported only by some countries, e.g. use of organic fertilizers other than manure, manure treatment, and non-agricultural use of manure [11]. Figure 1 presents an overview of the ideal and the practical (implemented) version of the Gross Phosphorus Budget.

While country-specific differences still limit the comparability between countries, the Eurostat compilation provides an excellent basis for a first assessment of the potential risk of P eutrophication emanating from the participating member states' agricultural sector.

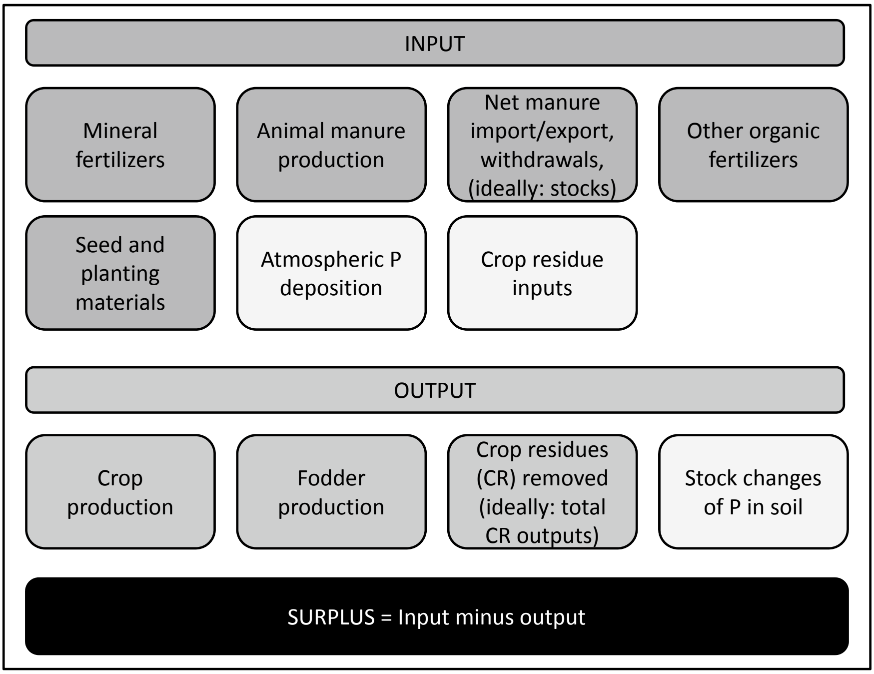

Fig. 1 Ideal and practical version the Gross Phosphorus Budget according to the Eurostat/OECD Handbook on Nutrient Budgets (after [11]) (dark grey: practical implementation, light grey: additional flows to be included in ideal version)

As displayed in Fig. 2, the gross P budgets of the riparian countries of the BSR vary significantly. Only Germany and especially Estonia showed negative budgets for 2015[2] and the budget for Sweden was 0. In contrast, Denmark displayed considerable P-surpluses and the numbers for the other countries of the Baltic Sea Region also demonstrate that usually more P enters the soil than is removed. This indicates that in nearly all countries of the BSR there is a potential risk of agricultural P to the environment, and at the same time, the potential to reduce P inputs into the soil and thus curb P losses to the environment.

However, the development of the gross P-budgets of the 9 HELCOM-countries (Fig. 3) from 1990–2015 shows that the surpluses were drastically higher more than 20 years ago and that a significant decrease of the surpluses has been achieved, so far.

[2]No complete dataset for all BSR countries was available for 2016 or more recent years in the Eurostat database.

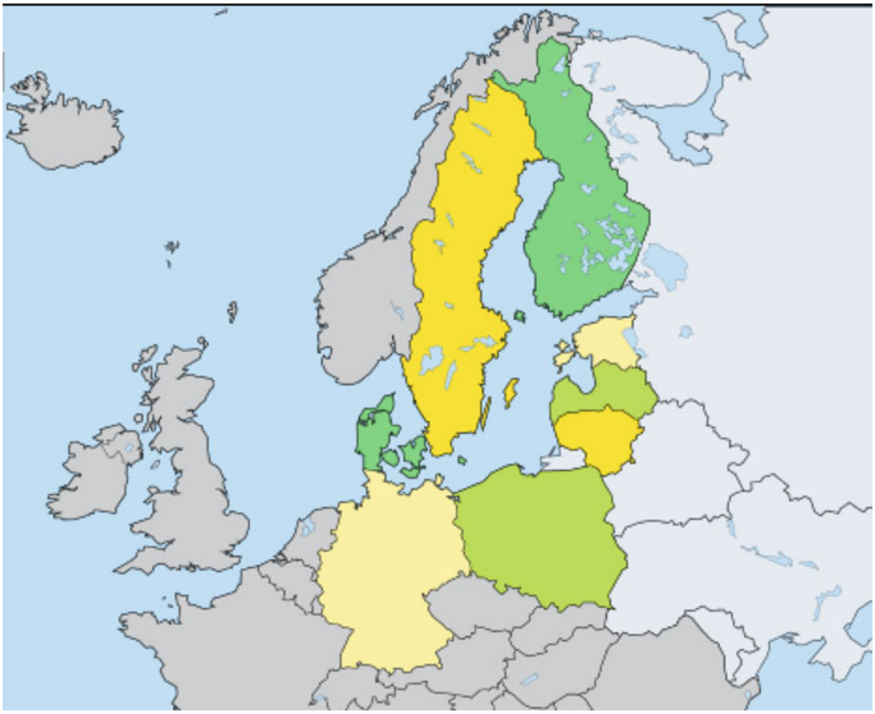

Fig. 2 Gross P budget of Denmark (7.0)[e], Germany (−2.0), Estonia (−7.0)[e], Latvia (2.0)[e], Lithuania (1.0)[e], Poland (2.0), Finland (4.0) and Sweden 0) in 2015 (*Source* EUROSTAT; map generated on 04.09.2018). e = estimated values

2.2 P Flow Analyses (PFA)

As is obvious from the above chapter, agricultural P budgets/balances are limited to quantifying the inputs and outputs of an agricultural system (farm, region, country). However, they do not provide insights into how nutrients flow through the system. In contrast to this, P flow analyses aim to comprise P flows throughout the entire society, taking different subsectors and internal flows into consideration, thereby giving evidence of how a population uses and reuses P, and how P is lost to the environment on different spatial scales [7, 10]. Thus, on the one hand, PFA look at internal flows and losses within the agricultural sector (including soil accumulation, leaching, run-off/erosion and incineration of organic wastes such as rendering by-products). At the same time, on the other hand, PFA results have uncovered that large amounts of P are lost outside agriculture, and that important output flows from the system exist in the industrial, consumption and waste handling sectors, via wastewater and biodegradable solid waste [10]. This knowledge is an important prerequisite when political measures and strategies are developed to minimize nutrient losses and prevent eutrophication of rivers, groundwater and oceans such as the Baltic Sea.

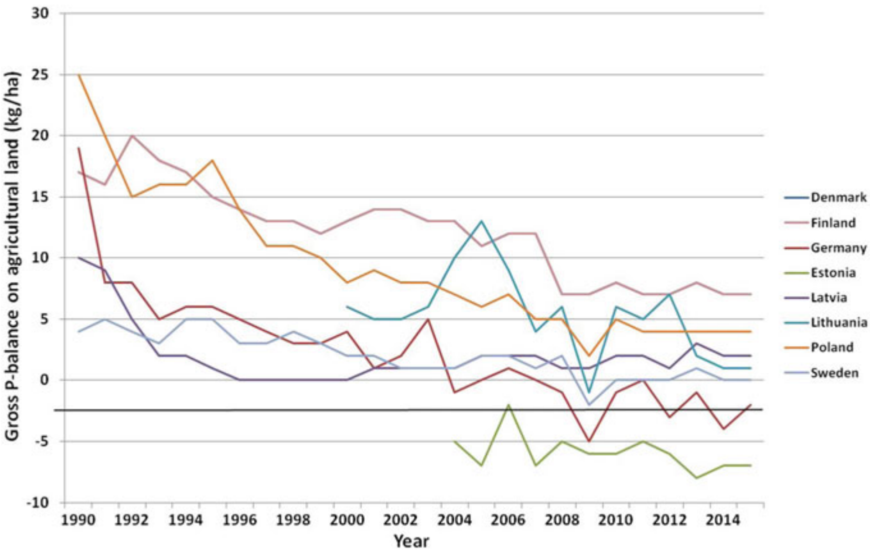

Fig. 3 Development of the gross P-budgets of the 9 HELCOM-countries from 1990–2015 (*Source* EUROSTAT; graph generated on 11.09.2018). Estimated values for: Denmark: 1990–2015; Estonia: 2015, Latvia: 1990–2015, Lithuania: 2000–2015

2.2.1 P Flows in the EU-27

Probably the most extensive P flow analysis for the EU-27 (based on individual calculations for each member state) was carried out by Van Dijk et al. [10]. Their system included the following sectors:

- Crop production (CP): arable and grassland, seed industry
- Animal production (AP): livestock, fish culture (aquaculture), feed processing industry
- Food processing (FP): processing of crops, milk and eggs, slaughtering of livestock, catches of wild fish and other wild animals
- Non-food production (NF): fiber, forestry, pet food and detergent industries
- Human consumption (HC): societal consumption of plant and animal based food products and non-food products (fibers, tobacco, skins/hides, pet food, detergents, wood and paper)
- Human consumption output: handling of related communal liquid and solid waste flows (wastewater, municipal solid waste, bio and green waste, pet excreta, wood and paper wastes)
- All other non-communal waste flows were situated in the concerning sector (e.g. stable manure in the AP sector).

The base year for these calculations was the year 2005; input data came from databases of the United Nations Food and Agriculture Organization (FAOSTAT) and the European Union (Eurostat).

With regard to the entire EU-27 as a reference area, the following findings were gained by Van Dijk et al. [10]:

- P imports to the EU-27 consisted mainly of primary P (74% of total P imports), with 78% of primary P entering the system via crop production in the form of mineral fertilizer, 14% imported via animal production for inorganic feed additives, 6% for detergent production, and 1% for inorganic food additives.
- About half of the net P import accumulated in agricultural soils in crop production, while the other half was lost from the system in solid and liquid wastes from the different sectors.
- Annual accumulation of P in agricultural soils was 4.9 P kg/ha in 2005, with a wide range between countries, attributed both to differences in management practices, weather conditions and governmental policies as well as lack of quality in the input data.
- More than half of total annual losses were attributed to human consumption, mainly the lack of reuse of wastes from the wastewater system (54%), food waste originating from households, retail and food services (27%), and pet excreta (11%).
- About 28% of the total annual losses were attributed to the food processing sector, mainly by sequestration of P in ashes of incinerated slaughter residues, the rest was shared almost equally between crop production, animal production and non-food production.
- 17% of the total annual losses were identified as emissions of P to the hydrosphere.
- Except for animal manure, which was almost fully recycled, there was relatively little P recycling in the EU-27. Generally, there was better waste management in Western Europe, compared to the Eastern European countries.
- P use efficiency of the system and sectors, in general, was relatively low (between 20 and 80%).

2.2.2 P Flows in the Riparian Countries of the BSR

In this sub-section, a closer look is taken at the 8 individual riparian countries of the BSR analysed byVan Dijk et al. [10].[3] The heterogeneity of these countries is already reflected by the total numbers for P inputs, outputs and the P balance (Table 1). Apart from Estonia and Latvia, all countries showed a positive P balance for the year 2005. However, the relative shares of the surpluses in % of the total P inputs differed significantly, making up as much as half of the total inputs for Poland, and roughly a third for Denmark and Finland, while they were considerably lower for Lithuania (11%), Germany (9%) and Sweden (3%).

The distribution of P imports into the different sectors did not show a consistent pattern for all countries of the BSR (Table 2). Similar to the findings for EU-27, the

[3] P flow diagrams for each country discussed in this report can be found in the supplementary information (SI) attached to the online-publication of [10].

Table 1 Total inputs and outputs (t P/a) of the 8 riparian countries of the BSR in 2005 (*Source* [10])

	$Input_{total}$	$Output_{total}$	Surplus/deficit[a] (total)	Surplus/deficit in % of $input_{total}$
Denmark	83,360	56,200	27,160	33.0
Estonia	6400	7330	−0930	15.0
Finland	48,230	31,330	16,900	35.0
Germany	337,270	307,120	30,150	8.9
Latvia	9340	10,930	−1580	17.0
Lithuania	18,760	16,620	2140	11.0
Poland	238,560	119,300	119,260	50.0
Sweden	52,620	51,060	1560	3.0

[a]Estimated to accumulate in agricultural soils

Table 2 Relative shares (%) of total P imports (t P/a) into different sectors for the 8 riparian countries of the BSR in 2005 (*Source* [10])

	$Input_{total}$	Share of $input_{total}$ (%)			
	(t P/a)	NF	FP	AP	CP
Denmark	83,360	2.5	25	50	23
Estonia	6400	33	34	20	13
Finland	48,230	32	11	12	45
Germany	337,270	6.5	32	25	37
Latvia	9340	45	25	15	15
Lithuania	18,760	13	18	13	56
Poland	238,560	8.0	6.3	14	72
Sweden	52,620	39	19	12	29

NF non food, *FP* food processing, *AP* animal production, *CP* crop production

highest share of imported P was allocated to ***crop production*** (mainly as mineral fertilizer P) in the cases of Poland (72%), Lithuania (56%), Finland (45%) and Germany (37%). In contrast to this, Denmark, Estonia, Latvia and Sweden had considerably lower imports into the crop production sector. For Latvia and Sweden, the highest share of P imports was identified for the ***non-food production*** sector, with 45% of total imports (mainly as detergent raw materials) for Latvia, and 39% (mainly as forestry products and detergent raw materials) for Sweden. Denmark imported the highest amounts of P (50%) as animal- or plant-based feed or inorganic feed additives for the ***animal production sector***, whereas the highest imports for Estonia could be attributed to the ***food processing sector*** (34%, mainly as crops and processed products).

Like EU-27, Poland **lost** about half of its P imports in the form of **solid and liquid wastes**, while the other half **accumulated** in **agricultural soils** in crop production.

Finland and Denmark also showed comparatively high levels of P accumulation in their soils (35 and 32% of total P imports, respectively), while accumulation in the remaining 5 countries was significantly lower, or, as in Estonia and Latvia, did not occur at all (Table 3). Similar to EU-27, Finland, Germany and Lithuania lost around half of their imported P from the system. An even higher degree of loss was recorded for Estonia, Latvia, and Sweden with 65, 74 and 66% of imported P, respectively; indicating that in these countries, there may be high potentials for P-recovery. In contrast to this, Denmark only lost a third of its total P imports.

Similar to the findings for EU-27, in most of the countries of the Baltic Sea region the major share of P-losses was attributed to the ***human consumption*** sector (Table 4). Only in Sweden and Denmark, considerably higher losses were found in the sector of non-food-consumption (resulting from wood industry waste), and food production (mainly slaughter waste), respectively, while in Finland, the losses from HC and NF (wood industry) were in the same range.

Looking at the share of direct P emissions into the hydrosphere in total annual P losses from all sectors, the BSR countries present a rather heterogeneous picture, ranging between 5.4 and 24% of total losses (Table 5). Direct emissions into the hydrosphere mainly occur through wastewater from human consumption and, as discussed above, through leaching, drainage, runoff and erosion from the crop production sector (see [10], SI—Table S1).

The mean annual P accumulation rate is calculated as input-output P balance of agricultural land, and it is assumed that it is equal to the agricultural P balance (= the soil P balance) [10]. For 2005, the mean annual P accumulation rate was below that for EU-27 in all 8 Baltic countries (Table 6). However, a wide range was identified. The highest accumulation occurred in Denmark (10 kg P/(ha*a), followed by Poland and Finland with 7.5 kg P/(ha*a) each. The accumulation rate for Germany, Lithuania, and Sweden was below the mean rate calculated for the Baltic countries

Table 3 Accumulation und losses (t P/a) and their relative shares (%) of total input (*Source* [10])

	$Input_{total}$ (t P/a)	Accumulation[a]		Losses[b]	
		Total (t P/a)	(%) of input	Total (t P/a)	(%) of input
Denmark	83,360	27,160	**32**	27,750	33
Estonia	6400	−930	−15	4160	**65**
Finland	48,230	16,900	**35**	22,260	46
Germany	337,270	30,150	8.9	163,860	49
Latvia	9340	−1580	−17	6680	**74**
Lithuania	18,760	21,400	11	9200	49
Poland	238,560	119,260	**50**	95,880	40
Sweden	52,620	1560	3.0	34,730	**66**

[a]surplus/deficit from Table 1

[b]For a detailed description of which subflows are defined as losses from the different sectors see supplementary information (SI) in [10]

Bold represents the three highest rates of accumulation/loss

Table 4 Relative shares (%) of total losses for different sectors in the 8 riparian countries of the BSR in 2005 (*Source* [10])

	$Losses_{total}$ (t P/a)	Share of $losses_{total}$ (%)				
		NF	FP	AP	CP	HC
Denmark	27,750	3.0	**61**	5.1	8.0	23
Estonia	4160	31	11	5.0	1.1	**51**
Finland	22,260	**41**	15	2.7	2.2	39
Germany	163,860	3.0	33	4.4	3.1	**57**
Latvia	6680	37	7.8	5.2	2.4	**47**
Lithuania	9200	15	16	6.2	7.9	**55**
Poland	95,880	7.8	22	6.6	6.4	**57**
Sweden	34,730	**47**	12	2.9	2.4	36

NF non food, *FP* food processing, *AP* animal production, *CP* crop production, *HC* human consumption
Bold represents numbers for the sector with the largest relative share in the respective country

Table 5 Relative share of direct P emissions into the hydrosphere in total annual P losses for all sectors in the 8 riparian countries of the BSR in 2005 (*Source* [10], SI—Table S12)

	P emissions into the hydrosphere from HC		P emissions into the hydrosphere from CP		P emissions from HC + CP
	t P/a	% total losses	t P/a	% total losses	% total losses
Denmark	830	3.0	2223	8.0	11
Estonia	357	8.6	46	1.1	9.7
Finland	961	4.3	500	2.2	6.6
Germany	3870	2.4	5016	3.1	5.4
Latvia	834	13	158	2.4	15
Lithuania	1150	13	725	7.9	20
Poland	16,407	17	6141	6.4	24
Sweden	1232	3.5	820	2.4	5.9

HC human consumption, *CP* crop production

(3.3 kg P/(ha*a), while, as mentioned before, Estonia and Latvia were experiencing P depletion in their agricultural soils.

The gross P budget calculated by Eurostat [12] for 2005 differed from the annual P accumulation rate given by Van Dijk et al. [10] in some cases (see Table 6): The deficit for Estonia was significantly higher according to Eurostat, while for Latvia, Eurostat was calculated a surplus instead of a deficit for 2005. Furthermore, the P surplus estimated by Eurostat for Lithuania was significantly higher than the accumulation rate calculated by Van Dijk et al. [10].

This indicates the fragility of these different approaches to calculate P flows and balances which often base only on assumptions and different data sets.

Table 6 Annual P accumulation rate in agricultural soils in 2005 (kg P/(ha*a)) [10], compared to gross P budget (kg P/(ha*a) in 2005 and 2015 [12]

	Annual accumulation rate	Gross P budget	
	2005	2005	2015
Denmark	10.1	11[e]	7[e]
Estonia	−1.1	−7	−7[e]
Finland	7.4	6	4
Germany	1.8	0	−2
Latvia	−0.9	2[e]	2[e]
Lithuania	0.8	13[e]	1[e]
Poland	7.4	5	2
Sweden	0.5	2	0
Baltic countries, mean	*3.3*	*4.3*	*1.8*
EU 27	*4.9*		

[e]estimated values

When comparing the gross P budgets for 2005 and 2015, Denmark and Finland are still the countries with the highest surpluses; however, they reduced their surplus considerably by 2015. Poland also reduced the surplus significantly within the observed time span. According to the numbers from Eurostat, Lithuania reduced its surplus drastically within the 10 years covered here by 12 kg P/(ha*a). Since an explanation of this reduction cannot be offered at this point and the data provided by Eurostat for this country are estimated, it is suggested that the values for Lithuania are handled with care. Estonia's negative balance and Latvia's surplus remained stable within the time span observed. Sweden went from a small surplus in 2005 into a zero balance in 2015, while Germany's P balance went from a zero balance into a slight deficit.

3 Identification of Options to Improve P Use Efficiency in the BSR

The P budgets and flow analyses presented in the previous chapter reveal that in most of the BSR countries, P inputs exceeded outputs and a high amount of P that entered the system was retained. In general, a significant amount of the total inflow of P is stored within the soil of the ***agricultural production sector***. While this is not a direct loss from the system in the short term, the **accumulation of P in the soil** over several years results in excessive P surpluses and increases the risk of P outflow as soil erosion, leaching or as particulate or dissolved P in runoff water in the long run.

For Germany, it was calculated that 21% of P stored in the system was applied by mineral and organic fertilizers and accumulated in the soil. Another 13% resulted from the excretion of livestock animals [13]. For Denmark, an even higher amount, 68% of the total P remaining in the system, was estimated to accumulate in agricultural soils [14].

One major reason for the accumulation is the common practice to apply P without considering the current status of the soil and the actual demand of the crop [7]. Thus, a **balanced and targeted fertilization practise** is one of the key strategies to reduce unnecessary P inputs into and, as a consequence, losses from agricultural soils.

Chowdhury et al. [7] reviewed a number of reports on recent substance flow analyses for P carried out on city, regional and country scales. In most of the country scale studies, the **import of mineral ores (primary P) or chemical P fertilizers** was observed to be the ***main inflow*** into the system, particularly if the countries had only low or no own rock phosphate reserves.

The case studies for the 8 individual countries, with Finland being the only one of them owning native rock phosphate deposits, did not confirm this observation unequivocally (see Chap. 4, Table 2). In line with [7], the highest share of imported P was allocated to crop production (mainly as mineral fertilizer P) in the cases of Poland (72%), Lithuania (56%), Finland (45%) and Germany (37%). In contrast to this, Denmark, Estonia, Latvia and Sweden had considerably lower imports into the crop production sector.

More recent case studies for Denmark, Sweden and Germany complete this picture: In the year 2011, for Denmark the imports of food products and feed P (79% of the total P-import) still significantly exceeded the import of mineral P (21% of total P-import) [14]. These numbers are in good agreement with those from 2005 (cf. Table 2). The high share of the P import with feedstuff (63% of the total P-import) is essential to maintain the intensive animal husbandry in Denmark [14].

In Sweden, the use and thus the import of mineral P decreased from 2005 till 2010 by 30% and was only slightly higher (39% of the total imported P) than for imported fodder and feed minerals (30%), for which an increased import over the last years has been observed [15]. The trend of reduced imports of mineral P might to some extent result from the development of prices for mineral P in 2008, which increased by 700% within one year [16].

In Germany, P imports were still dominated by primary P/mineral fertilizers in 2010: 39% of total P import could be attributed to mineral fertilizers (26% for processing in the fertilizer industry and 13% imported as mineral fertilizer), while only 23% of the amount of imported P were raw materials for the feed industry and feed for livestock husbandry [13].

The comparatively low amounts of imported mineral P for fertilization purposes in most of the BSR countries might be the result of the **high accumulation of manure** in the particular countries. Manure has been identified as being the most important P input to crop production and is usually one of the major P flows in substance flow analyses [9]. In recent times, there has also been a change in the perception of manure as a valuable nutrient source. Nowadays, it is regarded in many countries (e.g. in Sweden) as having the same fertilizer value as mineral fertilizers

Table 7 Livestock density, amounts and relative shares of mineral fertilizer and animal manure as P source for fertilization in the BSR countries in 2005 (*Source* [10])

	Livestock density (LAU/ha)	Mineral P (1000 t P/a) (= Input CP)	Animal manure P (1000 t P/a) (= Flow AP − CP)	Total P (1000 t P/a) (mineral + manure)	Mineral P (% total P)	Manure P (% total P)
Denmark	1.8	19	48	67	28	**72**
Estonia	0.52	0.8	4.5	5.3	15	**85**
Finland	0.77	22	16	38	**57**	43
Germany	1.4	124	247	371	33	**67**
Latvia	0.39	1.3	7.0	8.3	16	**84**
Lithuania	0.53	11	13	24	44	**56**
Poland	0.84	172	105	277	**62**	38
Sweden	0.88	16	29	44	35	**65**

Bold represents relative shares > 50%

[15]. An explanation for this can be found in the fact that, since concentrated animal feeds based on imports such as soybean cake were introduced in intensive animal production, P contents in animal manure increased considerably, making manure a viable alternative P fertilizer which can replace the use of mineral P [10].

In all 8 BSR countries, the animal manure which was generated was almost fully recycled (recycling rates between 94–97%, calculated based on Table S12 (SI) from [10], i.e. applied to agricultural land. In Denmark, Estonia, Germany, Latvia, and Sweden, P applied with manure significantly exceeded the amount of imported mineral P in 2005, ranging between 65 and 86% of total fertilization (Table 7). Although it decreased to 50% in 2012, the amount of P applied with manure in Germany still significantly exceeded the amount mineral P, which accounted for only 25% [17].

In Lithuania, manure inputs only slightly exceeded mineral P inputs. At the same time, livestock densities, which should give a first indication about the degree of manure accumulation to be expected in a country, varied considerably: While countries with intensive animal production reached stocking densities as high as 1.8 large animal units (LAU) in Denmark, and 1.4 LAU in Germany, Sweden had a medium density of 0.88 LAU. Countries with more extensive animal production kept their stocking density as low as 0.53 LAU in Lithuania, 0.52 LAU in Estonia (0.86 if data for broiler chicks at the beginning of 2006 is included) and 0.39 LAU in Latvia (calculations for Table 7 are based on livestock numbers for 2005 according to Eurostat, 2006 and LAU conversion factors for Germany according to [18]).

The country with the largest share of mineral P inputs was Poland (62% of total inputs), displaying a medium livestock density of 0.84 LAU, followed closely by Finland (57%), the only country owning native phosphate rock mines, and with a livestock density of 0.77 LAU. For Poland, the high share of mineral P inputs was still observable between 2012 and 2014, when 11.4 kg P/(ha*a) (ca.60%) were applied with mineral fertilizers, and only 6.8 kg P/(ha*a) were added with manure [16].

In other words: some countries with comparable livestock densities, such as Sweden, Poland and Finland, practiced quite different fertilization schemes, with animal manure and mineral P fertilizers playing rather different roles in terms of their relative importance. Obviously, there are other additional drivers determining an increased share of mineral P in crop production. In Finland, for example, the mere availability of primary P sources inside the country's own borders is an important driver. Another driver common to a number of European countries is an intensive crop production sector requiring a higher P supply which cannot be satisfied by the manure generated in the country's animal production sector. In Poland, the high share of mineral P used can be attributed to a long established fertilizer industry which can be traced back to the second half of the 19th century. Later, in the central planned economy, the fertilizer industry was a major part, and the production and distribution were even subsidized by the state. Since the amount of produced fertilizers matched the demand of Polish agriculture, almost no fertilizers were exported [19].

Manure is usually applied according to the N-content. However, the N:P ratio in many manures does not match the nutrient requirements of most crops. Thus, in regions with a high livestock density, where manure accumulates, high P surpluses in the soil have been identified. On the other hand, in regions with intensive crop production, agricultural soils often show P deficits. This condition has been reported for all countries of the Baltic Sea Region. The uneven distribution of manure P is mainly a problem of transport. While dry broiler or layer litter can be relatively easily transported to where it is needed, the transport of liquid manure (slurry) from cattle and swine is very expensive due to its high water content and the related lower nutrient concentration compared to solid manure. One promising solution is the **mechanical separation of slurry** into a solid and a liquid phase. That way, the liquid N-rich phase can be used nearby (on-farm), whereas the solid P-rich phase can be transported to areas further away from the farmstead, where crop production dominates, and the P demand is high, enabling efficient recycling. The solid fraction also has a high energy content and can, therefore, be used for incineration or biogas production. Manure separation is becoming more and more popular in some Western European countries with high livestock densities such as Denmark, where several physical and mechanical separation techniques have been developed and even combined with the addition of several chemical additives, flocculants and/or coagulants to more effectively remove nutrients from the liquid phase [20, 21]. However, the implementation of this technique still needs to be spread and established more widely in other countries of the BSR, particularly in those with intensive animal production, like Germany.

One major ***loss of P from the system*** occurs in the **human consumption sector (HC)**, from **wastewater**, **biodegradable solid waste**, and **pet excreta** [7, 10]. This was also found true for most of the BSR countries (see Sect. 2.2.2—Table 4, and [10], SI—Table S12). Therefore, increasing the **recycling rate** in this sector is crucial when it comes to the implementation of strategies to achieve a more sustainable and efficient use of P. By far the largest losses from HC in the BSR countries (between 28 and 56% of total losses from HC) can be attributed to municipal sewage sludge not used on agricultural land (and [10], SI—Table S12). Recycling of sewage sludges from municipal wastewater treat via a direct application on agricultural land decreased considerably in some of the BSR countries over the last decades of the twentieth century. Thus, in 2005, recycling rates of communal sewage sludge on agricultural land varied between less than 3% in Finland and close to 60% in Denmark (Table 8).

However, Fig. 4 illustrates a more or less stagnating trend in the agricultural use of sewage sludge between 2005 and 2013 for the majority of the Baltic Sea Countries.

The decrease in the direct application of municipal sewage sludges to agricultural land by the end of the twentieth century occurred with the aim of protecting the environment from unwanted harmful substances (organic and inorganic pollutants). However a modern and sustainable recycling strategy for this P source, including the transfer of its nutrients into a plant available form, is highly desirable. Especially the demand for mineral P fertilization can be decreased by realising consistent recycling from secondary raw materials. Currently, there are a number of techniques available for P recovery and recycling from wastewater treatment (e.g. struvite precipitation, mono incineration of sewage sludge and P recovery from the ashes or treatment of ashes to turn them into effective P fertilizers), however, they need further development to turn them into reliable and cost-effective options on a large scale.

Another viable option to reduce P loss in the HC sector is to enhance the recycling of solid organic wastes. This can be done by reducing food wastes from households, retail and food services, which make up the second largest share of HC losses in all BSR countries (20–30% altogether, own calculation based on data from [10]), as well as by improving the organic waste separation and collection in order to generate a high quality compost suitable for agricultural use [10]. Data on compost recycling was only available for 4 of the BSR countries for 2005: Apparently, recycling of compost on agricultural land was quite common in Germany and Denmark, with 57 and 47% of total compost P production used for fertilization, respectively. Finland

Table 8 Recycling rates of communal sewage sludge via direct application on agricultural land (*Source* [10], SI—Table S12)

	P from communal sewage sludge (t P/a)			Recycling rate
	Applied to land	Not applied to land	Total	% of total
Denmark	3143	2222	5365	59
Estonia	119	846	965	12
Finland	108	3678	3786	2.9
Germany	20,930	51,710	72,640	29
Latvia	554	931	1485	37
Lithuania	752	1575	2327	32
Poland	3195	15,708	18,903	17
Sweden	911	5466	6377	14

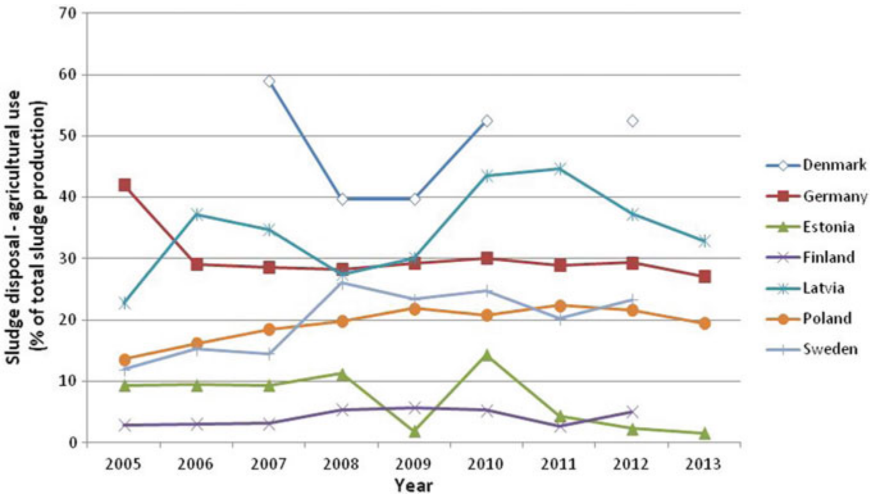

Fig. 4 Development of agricultural sludge-re- use (% of total sludge production) in the Baltic Countries between 2005 and 2013 (data for Lithuania not available) (*Source* EUROSTAT, graph generated on 04.04.2017)

used 20% of its compost P on land, while Sweden used only 5% (calculation based on data from [10], SI—Table S12). For Estonia, Latvia, Lithuania and Poland, no data was available. However, based on the numbers given, there is a considerable potential for more effective compost recycling for fertilization.

A high share of the total annual losses of P also takes place in the **food processing sector**, mainly by sequestration of P in **ashes of incinerated slaughter residues** (representing the main flow of losses in Denmark with 61% of total losses, but also an important flow in Germany and Poland, with 33 and 22% of total losses, respectively, see Sect. 2.2.2, Table 4). The re-use of these ashes for fertilization, after a suitable treatment to make their P contents more plant-available, is a necessary step to work towards closing the P cycle.

Direct P losses from the crop production sector (to the hydrosphere) were found to be comparatively low in the BSR countries, ranging between 1.2 and 8% of total annual P losses (see Sect. 2.2.2, Table 4). However, with regard to crop production, the accumulation and storage of P in agricultural soils, even if it is not a direct loss from the system, is one of the main risk factors for the eutrophication of rivers and oceans in the long run. Therefore, further options to improve P use efficiency in these sectors shall also be mentioned here, following the recommendations given by Van Dijk et al. [10]:

- Crop production: (1) balanced and targeted fertilization by adjusting P supply to actual crop demand; (2) the “five R of plant nutrition” according to [22], i.e. right timing, placement and type of fertilizer, right application method, right fertilizing management; and (3) improvement of crop breeds to increase their P uptake and internal P use efficiency.

- Animal production: minimizing the oversupply of P in feed by (1) increasing feed P availability and thus animal P uptake, (2) reducing feed P content by biorefinery of feed ingredients, and (3) lower supplementation of inorganic P additives.
- Food production: more efficient processing, with fewer food losses and additional biorefinery steps.

As mentioned earlier, the data collected and assessed in different years, for different countries, by different authors and with different methods are hardly comparable. This makes it difficult to develop supranational strategies to reduce the P surplus and P losses. Therefore [9] propose a "**standardized material flow format**" to be used for all future flow analyses. According to the authors this will:

(a) increase the comparability of data between different countries considering patterns of P flows and P losses, as well as the efficiency of the P management.
(b) allow to classify and cluster countries with view to their P flow structures. This, in turn, helps to formulate supranational strategies and policies.
(c) provide a basis for substance flow analysis on national levels.

4 Outlook: Future Obstacles and Necessities for Change

In Sects. 2 and 3, P budgets and flows of the BSR countries were analysed, and strategies were discussed to improve the P use efficiency in this country, aiming to work towards reducing P losses, closing the P cycles, and protecting the Baltic Sea from further eutrophication. However, before all the suggested measures can be put into practice, considerable obstacles have to be faced, including the further development and implementation of adequate technology, the adjustment of existing and creation of new governmental regulations, and, often underestimated in its relevance, promoting social acceptance of the necessary changes. Educating farmers to achieve similar yields with reduced nutrient inputs is one important aspect of this latter point [23]. Here the increase of organic farming could be one promising option.

Several authors, including [10, 23–26], also suggest to promote the change of populations' eating habits, moving from a meat- to a vegetarian-based diet, which could reduce anthropogenic P consumption considerably. As elaborated by these authors, the excess intake of P which is common in the majority of the developed and wealthy European (and North American) countries should be reduced to the actual intake recommendations. This can most easily be realised by reducing the consumption of animal products and increasing the intake of plant-based products. Metson et al. [27] quantified the role of diet in sustainable P management for a globally distributed set of countries over the period between 1961 and 2007. They argued that meat consumption drastically amplifies the requirement for P fertilizer inputs due to the inefficient process of converting plant-based feed into meat, which is associated with P losses during feed production as well as losses in excrements. Their calculations clearly showed that meat, egg and dairy consumption account for the majority of an individual's P footprint. On average, about 72% of the global average dietary P footprint between 1961 and 2007 was due to the consumption of animal-based food groups.

Regarding the production of data to assess and monitor P fluxes, either within a country or in a supra-national region (e.g. the BSR) there is also a need for improvement. In line with [7], it is recommended that examination of fluxes is carried out not only on national but also on a regional scale in order to be able to account for the specific geographical layout and structure of the agricultural production sector of each country. In addition to regional fluxes, the P status of agricultural soils with its changes over time, as well as some key soil characteristics determining the P retention capacity of the soil, need to be considered on sub-national/regional scale in order to assess the actual risk of P loss via erosion/run-off/leaching from a particular area/region. Finally, P flow analyses should comprise several years, since the study of one single year only presents the actual state, while it does not allow to critically appreciate long-term developments and trends in P flows.

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Regulatory Scenarios to Counteract High Phosphorus Inputs into the Baltic Sea

Elke Bloem, Silvia Haneklaus and Ewald Schnug

Abstract High phosphorus (P) inputs into environmental system such as the Baltic Sea are a topic of growing concern as eutrophication is endangering this natural ecosystems in its function as a habitat for sea life. The high P inputs are caused to a significant proportion from agriculture. Farmyard manure, sewage sludge, biogas digestates or animal by-products are regularly used as organic fertilizers in agriculture. Numerous studies show that the P balance of farms, particularly those of livestock farms, is very often excessively high. P accumulates in surface layers of agricultural soils when fertilized in excess via manure application and contributes to the eutrophication of both inland and coastal water bodies favorably by surface run-off and erosion. The Baltic Sea is one of the most polluted and endangered marine ecosystems. In the current chapter different options were compiled and discussed, which have the potential to reduce the pollution of the Baltic Sea significantly in future. These different options are intertwined so that each action alone will never achieve the same efficacy in reducing P losses to water bodies as the implementation of the full range of options.

Keywords Phosphorus (P) · Nitrogen (N) · Nutrient-surplus · Regulatory options · Baltic sea

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1 Introduction

The Baltic Sea represent only 0.1% of the whole sea and is especially endangered because of its specific conditions. The Baltic Sea is an inland water surrounded by land receiving fresh water from different rivers and salt water from the North Sea resulting in brackish water in the Baltic Sea. There is only a very small connection between North Sea and Baltic Sea via Kattegat and Skagerak. As a result there is an extremely low water exchange of oxygen—rich saline water from the North Sea against oxygen-depleted water from the Baltic Sea [1]. Therefore nutrients and contaminants that enter the Baltic Sea have the potential to stay there for a long time (in medium 25–35 years) and unfold there negative effects such as algae blooms, oxygen depletion in sediments and species extinction in this special environment. That mean that also measures to clean the Baltic Sea will need some time before they will show any effect. Today the Baltic Sea is one of the most polluted and endangered marine ecosystems despite of the fact that already in 1974 the HELCOM Commission was founded with the target to substantially improve the environmental conditions of the Baltic Sea. Especially with respect to the nutrient inputs, agriculture was identified as one significant contributor [2] and comprises about 60–80% of the diffuse anthropogenic losses of phosphorus (P) into the Baltic Sea [3]. High livestock densities in combination with the immoderate use of fertilizers especially that of farmyard manures cause high nutrient losses in conventional farming systems [4].

The Baltic Sea Action Plan (BSAP) was ratified in 2007 by all riparian states of the Baltic Sea with the target to restore a good ecological status of the Baltic marine environment by 2021 [5]. One of its four priority areas is to reduce eutrophication beside of the reduction in hazardous substances, the improvement of biodiversity and environmentally friendly marine activities. The ecological objectives of the BSAP comprise clear water, nutrient concentrations close to original levels, natural extend of algae blooms, natural distribution of plants and animals and natural oxygen levels [5, 6]. Nutrient surpluses of nitrogen (N) and P entering the Baltic Sea and difference in the ratio of dissolved inorganic N to dissolved inorganic P are mainly responsible for growing proportions of algae blooms, oxygen depletion and extending zones of oxygen depleted sediments so called ‘death zones’ [1, 5]. The Baltic Sea is divided into several sub-basins and most of them were categorized and classified as ´problem areas´ with view to eutrophication such as the Kattegat, the Danish Straits, the Gulf of Finland, the Baltic Proper and the Gulf of Riga [7]. Therefore, the reductions of N and P discharges into the Baltic Sea are one priority action, which have been agreed on in the BSAP. Medium N and P discharges from 1997–2003 are shown in Fig. 1 and the required reduction is shown as a percentage in red color.

The data behind Fig. 1 reveal that 42% of the total P (15,250 from 36,310 t P/yr discharge in total) and 18% of the total N loads (135,000 from 736,714 t N/yr discharge in total) need to be reduced. In the sub-basin Baltic Proper this value is as high as 65% of the total P load equaling 12,500 t P [6]. Specific measures to achieve this target have been summarized by the Helsinki Commission (HELCOM). In the public sector, they imply the efficient treatment of wastewaters from municipalities,

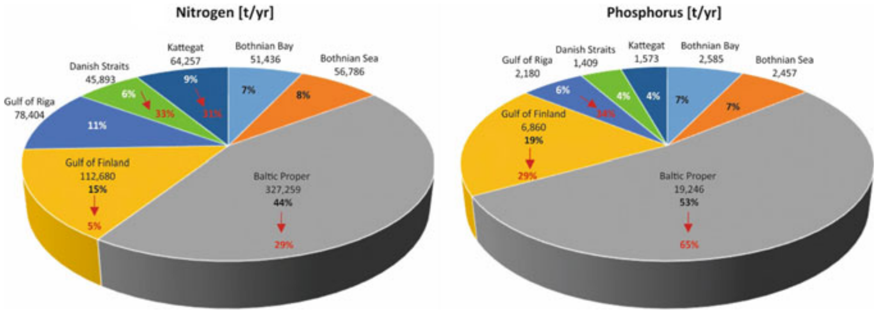

Fig. 1 Nitrogen and phosphorus discharges into sub-basins of the Baltic Sea (from 1997–2003) and required percentage of reduction (in red) that is necessary in order to achieve'clear' water [t/year] (Data from Laamanen [6])

scattered settlements and single-family homes as well as P-free detergents. In the agricultural sector, the focus is on manure handling and fertilization with a special view to livestock farms.

Since the BSAP was released, some progress has been made but the Baltic Sea is still far away from a clean environment. Still the whole Baltic Sea area is classified as 'endangered environment' [1]. Only the Bothnian Bay and the northeastern part of the Kattegat show lower nutrient inputs; all other areas of the Baltic Sea still show a high eutrophication level [8]. More recently collected data from 2013 even indicate that no area of the Baltic Sea reveal good environmental conditions with respect to eutrophication [9].

Therefore, in the following section some options are summarized with special view to the target to reduce the P but also the N discharge into the Baltic Sea. The options discussed in the next sections were elaborated within the EU-project "Phosphorus Recycling of Mixed Substances" (PROMISE) [10].

2 Measures to Reach the Target of the BSAP to Reduce Nutrient Discharge into the Baltic Sea and by This Reduce the Extent of Eutrophication

Nutrient discharge into the Baltic Sea originate from atmosphere, from rivers and from direct discharge. Industries or wastewater treatment plants as point source contribute to the pollution as well as agriculture and rivers as diffuse sources. About 75% of the N loads and at least 95% of P enter the Baltic Sea via rivers or as direct waterborne discharge [5]. Therefore, reduction of the nutrient discharge by these sources will have a strong effect on the total nutrient input. About 25% of the N entering the Baltic Sea originates from atmospheric deposition while this proportion is much lower for P. Hence, it is a greater challenge to regulate the N inputs efficiently in comparison to P. In the following subchapters, different strategies are discussed with the potential to contribute effectively to a reduction of P losses to the Baltic Sea in the next decades. To a lower extend also the N discharge can be reduced by the discussed options. Each option is an essential step to a genuinely sustainable P management on its own, but only all options together could presumably make a real difference for a contemporary P management.

2.1 EU-Wide Harmonization of Analytical Methods, Algorithms and Fertilizer Recommendations

The main target of fertilization is feeding agricultural crops with essential plant nutrients in a balanced way and in sufficient amounts and by this maintaining crop productivity, crop quality and plant health. Fertilization is conducted according to fertilizer recommendations based on soil analyses. Pollution of atmosphere and water-bodies with N- and P-containing compounds and the loss of N and P from agro-ecosystems are common challenges and indicate to significant shortcomings in the fertilizer practice and in the recommendations.

Beside of mineral fertilizers different organic nutrient source such as sewage sludge, farmyard manures, digestates or composts are used and application amounts are regulated by law.

In Europe and also in the Baltic Sea Region (BSR) different methods are employed to determine the soil P status and the plant available P fraction in the soil, which is the background for the P fertilizer recommendation [11]. The different extraction procedures make a direct comparison of data difficult as the different methods extract slightly different P fractions. Additionally, the threshold values for evaluating the soil P status proved to be not congruent in the different countries and recommended fertilizer rates can deviate highly [11]. If the same soil sample is analyzed by a laboratory in Germany and in Sweden, both laboratories will come up with a different assessment of the soil test P classification, which may deviate by up to two classes. In addition to the diverging assessment of the soil P status the recommended fertilizer rates for optimum P supply may deviate by up to 28% for grain crops and 37% for sugar beet [11]. In the worst case, three and four times higher application rates to sugar beet and cereals may be advised to a German farmer in comparison to a Swedish one. There is an urgent need for harmonization of analytical methods, interpretation of data (critical P values in soils and plants) and procedures to establish fertilizer recommendations in the BSR countries. An EU-wide harmonization of analytical methods, algorithms and fertilizer recommendations has a high potential to significantly reduce excess P application to agricultural soils.

2.2 Balanced Phosphorus Fertilization

A prerequisite for a sustainable P use in agriculture is a balanced P fertilization where inputs equal outputs. The concept of 100% utilization expresses that plants utilize transformation products from previous fertilizer applications despite a decrease in their solubility over time if P has been applied originally in easily plant-available form [12]. Following this approach, mobilization and immobilization processes are kept in a dynamic balance. In soils under humid conditions where the plant available P content is so high that additional P rates yield no increase in crop P content, the fertilization rate can be calculated solely via the P off-take by the harvest products [12]. The basic requisite for the validity of the hypothesis and the 100% concept is that the entire fertilizer P is soluble in the year of application. Then the whole P application can be fully taken into account in the site-specific P dynamics, and the long-term utilization rate will be 100% so that fertilizer rates can follow the off-take by harvest products [12].

A comprehensive survey in the BSR revealed that the soil P status was in the surplus range in four countries in relation to fertilizer form and origin of manure. The only exception was on sites in Finland, where cattle manure was applied, and where the P supply was in the optimum range [11]. The results revealed that the 100% concept can be applied and manure rates can follow the P off-take by harvest products, which is on an average 22 kg/ha $\times$ yr P.

Alternatively, on-farm experimentation employing Precision Agriculture technologies can be used to balance the P fertilization as this technique delivers truly site-specific threshold values and response curves to nutrient input, which can be translated into variable rate manure application maps [13]. The latter aspect is of crucial relevance on livestock farms with a view to balancing the soil P level.

A sustainable P use requires a truly balanced P fertilization, which adjusts P rates and expands recycling of P from anthropogenic and agricultural sources. Nationwide digital agro-resource maps showing the spatial variation of the soil P status and P demand for crops in the Baltic Sea Region (BSR) based on harmonized assessment methods (see Sect. 2.1) will assist in directing P fluxes. On soils where P is a proven yield limiting minimum factor, the optimum P fertilizer rate needs to be determined in response trials to optimize the P fertilization.

2.3 Statutory Provisions Related to Maximum N and P Application Rates

As mention in the section before, many European soils are ‘over-fertilized’ with P, and additional P fertilization is not necessary to achieve or to maintain high yields. Especially soils of livestock farms receiving manure on a regular basis accumulate P and show a high potential for surface run-off and erosion of P to adjacent water bodies [14, 15].

Table 1 Medium N and P contents in manures derived from different animals and indirect N or P application when fertilized according to N or P limit values, respectively (from Bloem and Haneklaus [10] based on data derived from Kratz and Schnug [16])

Animal manure		Medium N content (% DM)	Medium P content (% DM)	N:P ratio	P input (kg/ha) per 170 kg/ha N	N input (kg/ha) per 22 kg/ha P
Pig	Slurry	8.7	2.4	3.6	47	80
	Solid manure	3.0	2.8	1.1	159	24
Cattle	Slurry	9.7	0.8	12.1	14	267
	Solid manure	2.8	0.9	3.1	55	68
Poultry dung	Solid manure	4.7	4.7	1.0	170	22

To date, the European countries have different national regulations about the application of manure to agricultural soils. Some member states permit the application of farmyard manures on the basis of its N content with a maximum rate of 170 kg/ha × yr N while others put the focus on the P input. For example, in Sweden, an application rate of 22 kg/ha × yr P with manure must not be exceeded. Still, both regulations may cause an oversupply either by N or by P (Table 1). Nutrient ratios are highly variable in manure in relation to animal species and weight, feedstuff quality and quantity, housing management, storage time and conditions, and water content. If the N rate is the limiting factor, the application of solid pig manure and poultry dung will cause an extremely oversupply with P (Table 1). When cattle manure is spread according to its P content, excessive N rates can be applied even if the P input is limited to 22 kg/ha × yr P (Table 1). These simple calculations stress the need for combined maximum limit values for N and P with farmyard manure in all riparian states of the Baltic Sea.

Therefore the claim should be that manure application should be regulated uniformly in the EU according to legally regulated maximum application rates of 170 kg/ha N and 22 kg/ha P per year. Compliance with these specifications will cause an over-production of manures in some regions where livestock farming is concentrated. Consequently, a recycling chain for excess manure is required to utilize organic fertilizers in a sustainable way and to recycle the contained nutrients (see next section).

2.4 *Recycling of Sewage Sludge and Farmyard Manures*

The first three measures to reduce eutrophication of the BSR will most likely result in excessive amounts of manure, which must not be used on fields close to the farms where they accrue. Alternatively, these materials can be used for energy production

Table 2 Concentration of P in animal manure and sludge, monetary values of nutrients and maximum transport distance before transportation costs exceed the value of nutrients (Knudsen and Schnug [18] compiled from Petersen [19] and Poulsen [20])

Source	Manure type	kg P/t	Monetary nutrient value (€/t*)			Maximum distance of transport (km)	
			P	N, K	Total	P	N, P, K
Dairy cows	Slurry	0.7	0.92	5.49	6.40	7	48
Slaughtering pigs	Slurry	1.2	1.62	5.75	7.37	12	55
Chicken	Solid manure	7.0	9.38	26.5	35.9	70	266
Sludge	Solid	5	6.74	6.20	12.9	50	96
Triple-superphosphate	Mineral fertilizer	200	270	0.00	269		

*calculated from prices of mineral fertilizer in October 2014; 70% utilization of N and 100% utilization of P and K

in biogas plants, and the digestates can be sold as fertilizer materials. Still then excessive amounts of digestates will pile up in these regions.

A major problem of P in animal manure as well as in digestates or sewage sludge is the low dry mater content in combination with low P and nutrient concentration in the material. Therefore, transportation costs are high when compared to the value of nutrients [17]. Knudsen and Schnug [18] calculated the profitability of transport distances of different organic fertilizers in relation to their nutrient concentrations (Table 2). With respect to the P concentration, the maximum economic transport distance for farmyard manures and sewage sludge is much lower than 100 km, which stress the problem of areas with concentrated livestock farming. Transport of dry materials, like thermo-chemically treated ash can be operated economically over much longer distances of about 500 km [17].

The prerequisite of selling manure and digestates is the willingness to pay for the nutrient value. Prices can be regionally different depending on supply and demand for manure/digestates. Usually, in regions with a high animal density, the customer of manure only pays the costs for spreading [18]. Such hot spots of manure and digestates develop around animal production sites and as well as hot spots of sewage sludge develop close to sewage treatment plants especially in bigger cities. Hot spots of manure production may become critical if animal production sites are concentrated in certain areas like it is the case in Germany. In comparison, in the UK the animal production sites are more evenly distributed over the country. Transportation distances and costs to fields with a higher P demand are accordingly lower [21].

In case of sewage sludge, the concern about contaminations with organic and inorganic contaminants such as heavy metals and radioactivity or hazardous organic compounds, pharmaceuticals and infectivity is yet another reason for its limited acceptance by farmers as a nutrient source. It is important to note that most of these problems are transferred to biogas plants and their residues. Here, the thermo-chemical treatment offers the advantage to eliminate the organic pollutants almost completely.

The number of biogas plants is continuously increasing all over Europe, for example in Germany from 1050 in 2000 to 5905 in 2010 and up to 9300 plants in 2017. The most commonly used substrates are manures or sewage sludge in combination with corn. During the biogas process, the biomass is reduced by 2.3–75% in dependence of the substrate, and CO_2 and CH_4 are removed [22]. Also, ammonia gets lost during gasification, and the N to P ratio in digestates may be even narrower than in the original substrate. This will result in higher P surpluses when this material is fertilized according to its N content. Thus, it must be stressed again that for digestates as well as for manures it is vital that the field application rate is adjusted to both, the N and P content.

One possibility to produce recycled fertilizer products from organic nutrient sources is the precipitation of products such as struvite ($MgNH_4PO_4$) from the liquid phase. Struvite and other precipitates are produced during wastewater treatment from municipal and industrial wastewater. Such products have a high potential as fertilizers in agriculture, as the risk of introducing contaminants is distinctly lower than in the original material, P is contained in high concentration and in a highly plant available form and transportation costs are comparable to that of mineral fertilizers [17].

The direct application of sewage sludge is discussed controversial as it exhibit a critical composition of organic contaminants such as antibiotics and endocrine substances [23], heavy metals and pathogens [17]. Ideally, regulatory rules for the use of sewage sludge in agriculture would be congruent in the EU. Today the agricultural utilization of sewage sludge varies across Europe from 0% to more than 90% of the total sludge production from which in total around 45% was used in agriculture in 2012 [24]. In some European countries for instance Switzerland utilization of digested sludge is prohibited [25] or a great proportion is incinerated (e.g. Germany, Netherlands, Austria), whereas in others (e.g. Ireland, Spain, France, Portugal) application of sewage sludge to agricultural fields is common practice and account for more than 50% of the total amount of sludge in the country. The share of sludge, which is incinerated in the EU-27 is about 20% with further increasing tendency [25] as this is the current trend. Mono-incineration of sewage sludge and further treatment can be seen as an alternative option to produce recycling fertilizers for agriculture and to reclaim the P from the sludge.

Recycling of sewage sludge and manures by thermo-chemically treatment offers the advantage that organic contaminants are destroyed and that the product is free of pathogens. Therefore, an ash-derived product can be rated as safe and versatile and competitive with mineral P fertilizers if the P is in a complete plant available form so that P can be utilized to 100% on a long-term basis (see above). For conditioning, the original wet materials need to be dried before being suitable for transportation over longer distances. Here, equipment is available, which is rather simple, cost-effective and easily implementable to anaerobic digesters [17].

A further advantage of the thermo-chemical process is the possibility to reduce the heavy metal content of certain elements such as Cd, so that its content is even lower than in mineral P fertilizers. Moreover, ashes might be deposited for some time as a P source and may be further processed if advanced technologies are available or fertilizer prices for mineral products increased because of worldwide finite deposits. With mineral P fertilizers about 110,000 tons of P are applied in Germany each year to agricultural fields. It was estimated that treated sewage sludge ashes could provide approximately 66,000 tons of P annually. Thus this P source might replace up to 60% of the mineral P fertilizer input if fully recovered in a plant available form what is still a challenge [23]. Urban mining of P and its beneficiation into a suitable fertilizer product will not only contribute to alleviating P supply bottlenecks and price volatility of mineral P fertilizers but also preserve natural phosphate rock deposits.

2.5 Differentiation Between Big Livestock Enterprises and Livestock Farms

Intensive livestock farming still is the primary source for non-point nutrient pollution of water bodies and the atmosphere [26] and need to be regulated in a useful and sustainable manner. Even if the number of animals matches recommended figures of a maximum of two livestock units per hectare, actual application rates are manifold higher, because manures are often disposed as ‘wastes’ on much smaller areas in order to reduce disposal costs. Political decisions rather than scientific solutions are required to solve this problem. It is necessary to emphasize that not ordinary arable and livestock farmers are a threat to the environment, but the big livestock enterprises where manure is rather a waste than a fertilizer product. In this context, it is important to note that the majority of livestock farms is still run by familiar smallholders [27].

In principle, there are two options to solve the problem. Firstly, big livestock units could lose the status “farm” and become industrial units. This would make them accountable for acts and decrees and in case of violation of laws, clean-up costs could be charged.

Secondly, the distribution of livestock farms could be regulated so that minimum distances are defined by law in relation to animal numbers. The target should be to attain a more even distribution of livestock farms over the country. Such regulations should also include associated industries such as big slaughterhouses that have an influence on the settlement of new livestock farms.

The behavior of customer’s could also affect livestock farms when customers change in such a way that less meat and milk products are consumed and less food is disposed. In theory with a decreasing demand, livestock numbers could decrease. Practically it is fair to assume that consumer behavior will hardly influence livestock numbers as export to countries with a growing demand for meat such as India and China would prosper.

3 Discussion

The actual condition of the Baltic Sea is still alarming: In particular, N and P discharge from agriculture and other sources, which result in eutrophication, have a substantial impact on the highly sensitive ecosystem. On November 2007, the member states of the Helsinki Commission (HELCOM) for protecting the Baltic Sea decided in Krakow on a Baltic Sea Action Plan (BSAP) for reducing nutrient inputs into the Baltic Sea, implying amongst others, the distribution of countrywide quota for upper nutrient loads [5].

Ekardt et al. [28] summarized that "currently neither European nor German fertilizer legislation and soil conservation legislation provide adequate regulatory approaches for a sustainable use of P in agriculture. A precautionary concept on the European level is basically non-existent. Existing regulations lack specificity, real enforcement, precautious measures against relocation of problems, and protective measures for limiting P usage.

It is the sum of multiple minor actions of farmers, industries and consumers that can lead either to ecologically and resource-related fatal consequences or if a rethinking takes place and some of the discussed measure were implemented can cause a real shift to a cleaner BSR.

The presented options have the potential to improve the P management in the BSR in such way that nutrient losses to surface and marine water bodies are significantly reduced while at the same time the valuable nutrient P is recovered and can contribute to closing the P cycle in agriculture. Up to date voluntary, negotiated environmental agreements such as the implementation of good agricultural practices (GAP) codes did not yield a strong effect. Though the nutrient surplus of livestock farms is the major problem, there are other obstacles, which need to be overcome to achieve sustainable P management in the BSR. The options start with the claim for harmonization of methods, critical values and fertilizer recommendations in the riparian states. Such a procedure would be a breakthrough for sustainable P use as the background of algorithms would be the same in each country. A balanced fertilization is often claimed, but rarely performed. A basic rule of balanced fertilization is that the nutrient input matches the demand of the grown crop. Here, the problem arises that many soils of livestock farms are already overloaded with P. A mandatory limitation of the total (organic and mineral) P input to 22 kg/ha P and organic N input to 170 kg/ha per year is necessary. Consequently, alternative ways for the utilization of manure are required, livestock densities have to be reduced, or the acreage where manure is applied has to be extended [29]. A combination of biogas plants for energy production and equipment for drying and/or combustion of manures could deliver fertilizers, which can be transported over longer distances. The processing of sewage sludge should be carried out by mono-incineration in order to eliminate organic contaminants as well as pathogens and to yield P-rich ashes for further processing. The so-called thermo-chemical process aims at removing heavy metals such as Cd and delivering a fertilizer product with P in a plant available form. Facing limited global P reserves recycling of P should be obligatory. Last but not least it is time to question whether big livestock enterprises should have the same status as an ordinary agricultural farm as these show regularly the highest P surpluses in the nutrient balance [30]. Charging all farmers for environmental clean-up has been suggested by Mc Bratney [31], but such a procedure would punish favorably those, who obey the rules of good agricultural practice. Alternatively, intensive livestock units could be charged to implement Precision Agriculture technologies if by legal order the whereabouts of animal manures and slurries must be proved [13].

4 Conclusion

10 years after the BSAP was ratified still no significant progress can be reported with respect to the nutrient discharge into the Baltic Sea region and the eutrophication level is still alarming. Therefore, the goal to have clean water in the Baltic Sea by 2021 has failed. Comparable to the climate targets it is obvious that substantial progress cannot be achieved if legal rules are missing. Without such rules, it is hardly possible to achieve the proposed goals. Therefore, in this chapter different possible options are discussed, by which the extent of eutrophication of the Baltic Sea can be reduced in future if the discussed options will be implemented in EU legislation. Each measure alone will help to reach the target but implementation of the whole set of measures will have a much higher potential to reach the goal to change the Baltic Sea from an endangered polluted environment into an ecological one with a high biological biodiversity and an even higher touristic value as today. Agriculture is the largest user of P and the most significant source for P losses by environmental dispersion (surplus enrichment in soils, erosion) and irreversible fixation (meat and bone meals and ashes). Consequently, it should be a prime task to develop and verify strategies, which avert or reduce these undesired side effects to an unavoidable minimum.

5 Recommendations

The following flow chart (Fig. 2) shall deliver recommendations for policy planners and decision makers by summing up the variable actions discussed in this chapter to reduced nutrient surpluses in the Baltic Sea region. The chosen nutrient sources are exemplary as they are of the greatest concern today. Comparable regulations can be applied for other nutrient sources such as meat and bone meal or household wastes and composts. Whenever harmful substances such as organic contaminations, pathogens or prions can be enclosed, recycling by thermo-chemical treatment is a viable option.

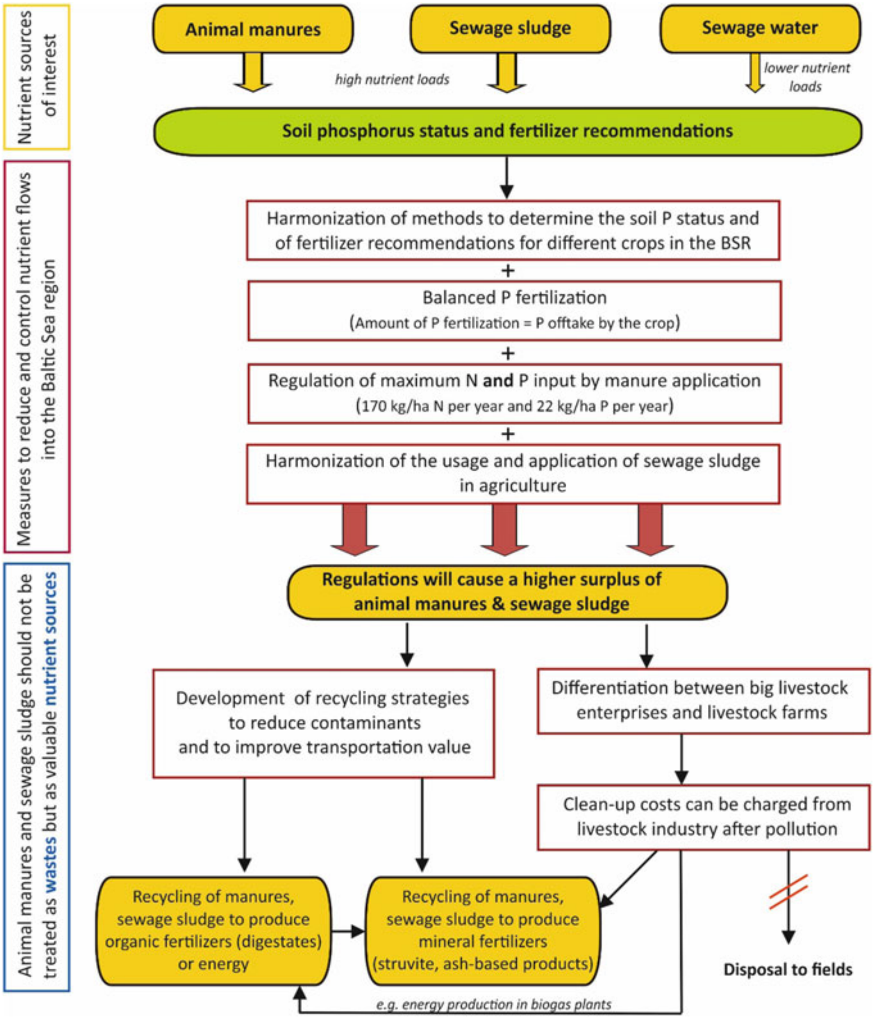

Fig. 2 Flow chart on the most important measures to reduce phosphorus (P) surpluses entering the Baltic Sea region

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Challenges of Flood Risk Management at the German Coast

Helge Bormann, Jenny Kebschull and Frank Ahlhorn

Abstract The anthropogenic land use of low lying coastal areas requires efficient protection against the sea as well as efficient drainage management to cope with storm floods and inland excess water at the same time. While dimensioning of technical solutions, such as dikes and pumping stations, is usually based on statistical analyses of historical data, such data is not available for strategic planning processes of non-stationary environments. To provide planning criteria, a scenario-based approach is introduced to be used as a basis for strategic planning of future coastal drainage concepts along the German coast. Such an approach can support integrative coastal risk management. Another challenge is the traditional perception of the efficiency of such technical installation and accordingly planning which is focusing on physical protection and safety. In contrast to well-established safety based approaches in Germany, the EU-floods directive asks for concepts assisting the management of flood risks. The floods directive demands for combining protection against, prevention of and the management of water-related risks. Since in many cases current national and state rules still rely on the safety based approach, a new perception is, therefore, necessary, taking into account the remaining risks. People must be willing to deal with residual (flood) risk related risks.

Keywords Coastal protection · Drainage management · Scenario approach · Risk management · Adaptation planning

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1 Introduction

Worldwide, more than one billion people live in low lying coastal areas. The pressure on those regions is high due to the high productivity of those regions and the favorable situation with regard to transportation and trade. As a consequence, humans have been modifying coastal ecosystems for a long time [1, 19]. Coastal ecosystems are undergoing increasing degradation in many parts of the world. At the same time, human activities create economic values in coastal regions which are worth being protected against the sea (e.g., storm tides).

In addition to the above mentioned direct anthropogenic use and degradation of the coastal zone, climate change and sea level rise will severely affect coastal regions in the coming decades [13]. As a consequence, climate change effects will require adaptation even if climate change mitigation will be successful [14]. This includes technical measures as well as the ability of the societies to deal with flood-related risks and to maximize synergies of spatial planning and flood prevention [2].

Dealing with change also requires to take instationarity into account while dimensioning coastal protection structures and organizing adaptation processes. One possible option is the scenario approach which explicitly describes different development paths for the future. Subsequently, decisions can be taken based on the spectrum of plausible model projections. While climate change impacts have been quantified for diverse regions [e.g., 8], the challenge remains how to deal with the underlying uncertainties, and how to agree on joint action with the regional decisions makers [5].

In the year 2007, a common framework for flood risk management was established across Europe by implementing the EU floods directive [11]. Nevertheless, different strategies were developed in the Member States of the European Union to deal with climate change-related impacts and risks. Differences in the strategies can be explained by different cultures how to deal with risk. Moreover, they are also due to different historic experiences and developments which resulted in different flood protection strategies and dimensioning approaches [2].

This contribution highlights the water management challenges of coastal regions as well as challenges due to climate change impacts, (imperfect) flood protection systems and missing risk awareness. Based on the results of two case studies it emphasizes the necessity to come up with integrative risk management approaches which are based on multiple scenario studies, and which involve as many as possible actors affected in order to share responsibility and come to a joint strategy.

2 Challenges at German's Shallow Coasts

2.1 Hydrological Boundary Conditions

Due to a humid climate, most of the coastal regions are characterized by a positive water balance. As for the North Sea Region in central Europe, the annual precipitation exceeds the annual evapotranspiration. The resulting excess water either generates runoff or is temporally stored in the hydrological system. If such regions are used for agriculture, settlements or business, the area needs to be drained. The drained water must be removed, e.g., by conveying the water to the sea. Due to small elevation difference, slow hydrological flow processes dominate the hydrological system. Usually, in flat terrain subsurface flow processes are more important than surface runoff. An exception is the case of soil saturation. Then, water accumulates at the surface and may generate surface runoff. Efficient drainage of such regions requires methodologies to accelerate water flow in order to keep the regions dry [6].

At the seaside, the diurnal tidal oscillation is a key boundary condition influencing the water cycle of coastal areas. Caused by gravitational forces, the sea water level periodically increases and decreases, approximately twice a day shaped like a sine wave. The oscillation of the sea water level leads to a fluctuating gradient of the water level in estuaries and along the coastline. During high tides, inland water is impounded, and if the sea level exceeds the water level of the river, sea water can even flow upstream. Low lying flat areas directly connected to the tidal rivers or the sea are regularly inundated if they are located below average high water level. In addition to the diurnal tides, storm tides are a key risk for coastal areas. In periods of strong onshore winds, the high tide water levels can be significantly increased by the wind. If such storms persist several tides, each high tide accumulates more water resulting in further raised high water levels. Storm tides are characterized by extreme water levels, strong winds, high waves and strong physical forces which affect the coastline. These different factors are the reason for the high risk of storm tides. In addition to coastal erosion, inundation of usually dry areas entails a high damage potential [6].

The diurnal oscillations of the water level, including inundations and tidal storm floods, make use of those areas, which are influenced by this dynamic, difficult. In the past, the human strategy therefore was—and in large parts of Europe still is—to prevent the natural hydrological dynamics, including regular inundations and wet conditions, and to control the hydrological processes of such regions. In the North Sea Region, sea walls have been built for 1000 years, and due to the positive water balance, drainage systems have been developed. Implications for water management, which are directly connected to coastal protection measures, are to protect the respective areas against tides and storm tides while ensuring water drainage through technical solutions. Possible technical solutions are the construction of dikes (sea walls) to prevent the landscape against tidal inundations, the construction of sluices and pumping stations to convey the excess water from the hinterland to the sea and to build storm surge barriers to protect the tidal rivers against stormwater levels.

In terms of flood risk, the respective areas are protected by the sea walls, allowing for anthropogenic activities and long-term investments. However, 100% safety through such technical protection systems does not exist. Therefore, according to the European Floods Risk Management Directive [11], these coastal areas are classified as high-risk areas. In case of failure of the protection systems, large areas will be flooded.

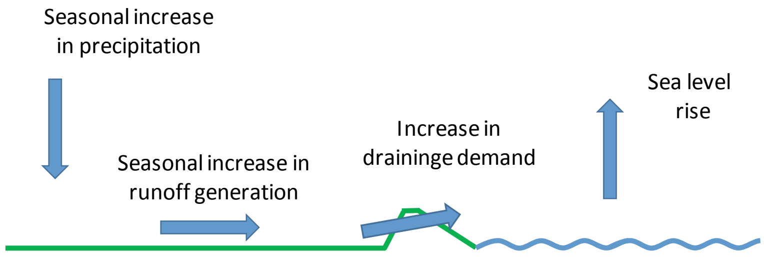

Fig. 1 Hydrological change and drainage challenges in shallow coastal regions

In addition to today's water management challenges, climate change is expected to aggravate efficient water management [7, 8]. At the coast, different climate change effects can add up to new problems. Regional models project sea level rise, overlain by land subsidence, intensification of storm surges, and also an increase in heavy rainfall events (in frequency and intensity) for the North Sea region (Fig. 1). Therefore, it can be assumed that the existing drainage infrastructure will not be sufficient on the long term. It is expected that it will not be able to deal with increasing drainage demand.

As a consequence, adaptation to climate change is required at an early stage, and traditional water management needs to be reviewed against future drainage requirements, taking into account innovative solutions [9].

2.2 *The Illusion of Safety*

The above mentioned different cultures and historical experiences of North Sea countries have led to different approaches to flood risk management along the North Sea coast. While, for example, in Lower Saxony (Germany), dikes are dimensioned by combining worst-case scenarios of storm tides with secular sea level rise and a safety margin [18], in the Netherlands, the dimensioning of dikes is based on a risk concept, combining "acceptable" flood probabilities and economic values that are to be protected by a dike [22]. Risk is thereby defined as the product of the probability of occurrence and potential damage as presented in Eq. (1):

$$Risk = probability\ of\ occurrence \times potential\ damage \tag{1}$$

As a consequence, in Northern Germany, the dimensioning leads to homogenous safety standards along the coastline which are independent of the protected values. In contrast, in the Netherlands the dimensioning leads to dike ring areas which safety standards depend on the protected economic values: the higher the potential damage, the higher the safety standard [17, 21].

The current strategy of dimensioning dikes has resulted in generally high safety standards along the German North Sea coastline. Finally, it is a safety standard for the technical structure "sea wall" [4, 15]. In contrast to the idea of the Dutch practice of coastal protection, the potential damage due to dike failure is not considered. Therefore it can be interpreted as a safety-based approach which is not consistent with the risk management approach the EU floods directive [11].

Organizing the dimensioning of dikes consistently with the related flood risk management would require to consider different fields of action, e.g., according to the German flood risk management cycle, as introduced by the German Working Group on water issues of the Federal States and the Federal Government (LAWA, Fig. 2) [16] or to the Dutch Multi-Layer-Safety approach (MLS) [17]. Both concepts consider preventive measures, including the technical flood protection, but also spatial adaptation measures reducing exposure and vulnerability to floods as well as emergency management while a flood happens. In addition to the MLS-concept, the flood risk management cycle from the LAWA [16] already considers recovery activities to reduce damage by quick and appropriate action after a flood event (Fig. 2: rebuilding and reconstruction aid).

The implementation of the EU floods directive provides the opportunity to introduce risk-based approaches also in related fields of action such as coastal protection. Such cultural adjustment is a real challenge since all involved actors necessarily have to jointly reshape understanding, concepts, and processes. However, introducing risk-based concepts offers the opportunity to deal with instationarity and change.

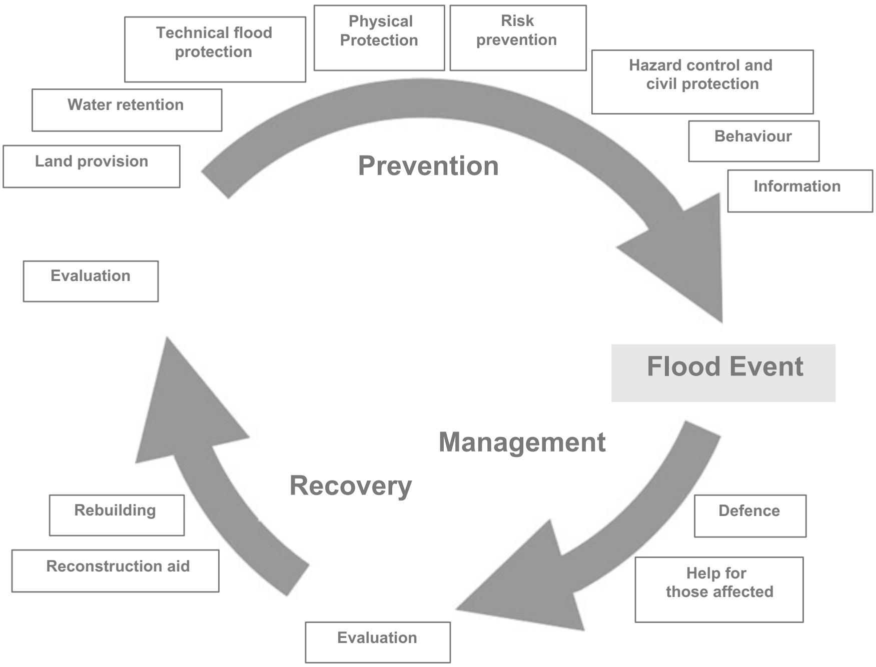

Fig. 2 Flood risk management cycle according to the LAWA; modified after [16]

The climate change adaptation challenge can be accepted by introducing the scenario approach, by comparing different approaches for the quantification of impacts, and finally by translating the different combination of scenarios and methodologies into a probability framework. Then, the underlying uncertainty can directly be considered for the decision making process. While, nevertheless, a 100% safety remains an illusion, the risk acceptance level can be defined with community-based approaches, and management of residual risks can be organized.

3 Case Studies

3.1 Scenario-Based Assessment of Future Drainage Demands in East Frisia (Lower Saxony)

Successful adaptation to climate change requires knowledge about the future development of climate variables and their impact on the environment. Since anthropogenic forcing and the exact implications are unknown, predictions are not possible. Instead, scenarios were developed to describe different possible development paths, as accomplished by the IPCC in the SRES report [12]. Such development paths are based on emission scenarios of greenhouse gases, which are translated into different radiative forcing to be used for global (GCM) and regional climate models (RCM). The spectrum of radiation forcing ranges in the latest IPCC reports from a commitment scenario (RCP2.6), representing a successful climate mitigation policy, up to business as usual scenario (RCP8.5) representing further intense use of fossil energy sources (Fig. 3).

Based on different emission scenarios, resulting in representative concentration pathways as introduced by IPCC [13], climate models are used to calculate impacts on global and regional climates. Subsequently, hydrological models can be used to quantify the regional scale hydrological impacts of climate change [e.g., 8]. Applying such a model chain finally results in a set of plausible hydrological projections. The challenge for sectoral and integrative climate change adaptation then is to deal with the so-called "Spaghetti plots", representing different plausible development paths for the future.

Essential variables for hydrological model applications in flat coastal regions are regional projections for temperature, precipitation and sea level rise.

A large part of East Frisia, the target area of this case study, is a low lying marsh area, used for agriculture, residential and commercial purposes. Therefore, adequate drainage is an essential requirement. Since drainage infrastructure sometimes reaches its capacity already under current climate conditions, limitations are expected for the future.

Regional temperature projections and sea level rise were used for hydrological model application to the target area of the KLEVER project (East Frisia), as presented

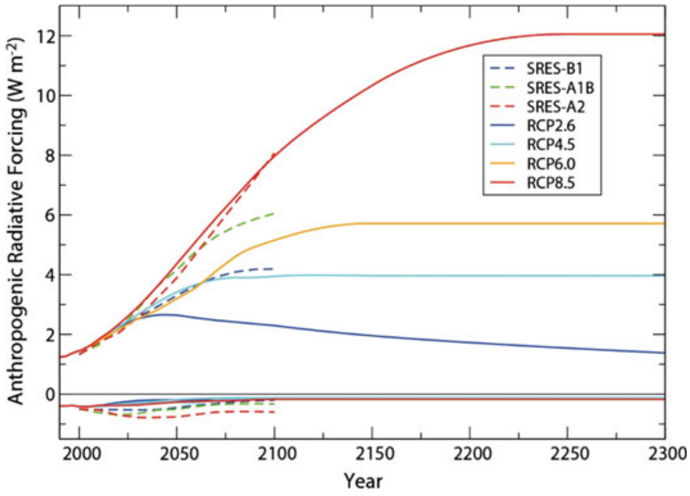

Fig. 3 Spectrum of the radiative anthropogenic forcing of different IPCC scenarios [13]; the curves below zero show the negative effects by aerosols

in Figs. 4 and 5 (changed after [8]). Realistic (e.g., RCP8.5, A1B, A2) and optimistic scenarios (e.g., RCP 4.5, B1) were used for the investigation.

Such regional specific information generated by regional-scale climate models (RCM) was used for hydrological model-based calculation of catchment-wide runoff

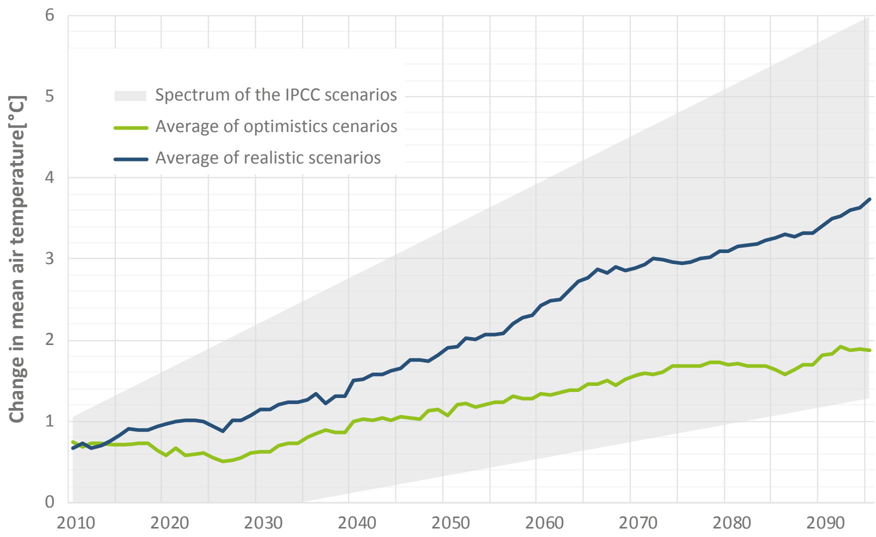

Fig. 4 Projected changes in annual mean temperature compared to control period for optimistic (green) and realistic emission scenarios (blue); changed after [8]

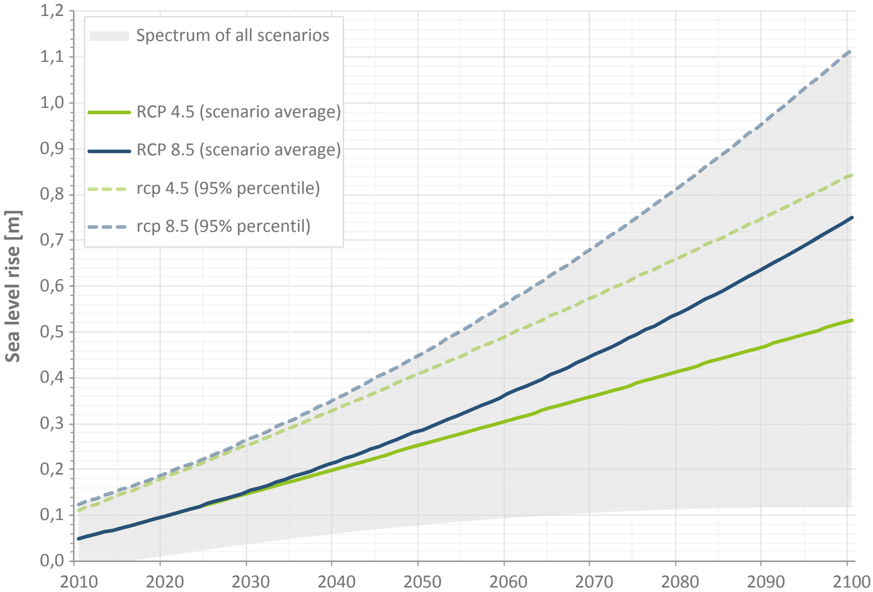

Fig. 5 Evaluation of the IPCC ensemble of regional sea level rise in the North Sea (German Bight); changed after [8]

generation, representing the drainage demand (Fig. 6), and the projected ability to use sluices for energy free drainage in the future (Fig. 7).

From the results of the simulations, it can be derived that future runoff generation is going to increase in the coming decades, inducing an increasing drainage demand in the winter time. Similarly, sluice potential will significantly decrease increasing the pumping requirements if the drainage shall at least be kept constant.

However, the main challenge of applying such model-based scenario analysis is how to deal with the remaining uncertainty behind the scenario calculations. Since scenarios do not have probabilities (all scenario should describe plausible story lines of the future), all scenarios can happen depending on future boundary conditions. Dimensioning dikes and drainage infrastructure, therefore, cannot solely be based on one statistical calculation as done in the quasi "stationary" past. Risk acceptance levels defined by the actors can help to select the appropriate safety level (or accordingly failure level). In the KLEVER project, actors finally agreed on using the 95% of the ensemble calculations instead of the 50% (= average) which is mostly used in political discussion. Doing so, they started to move from traditional safety based thinking towards a risk-based approach.

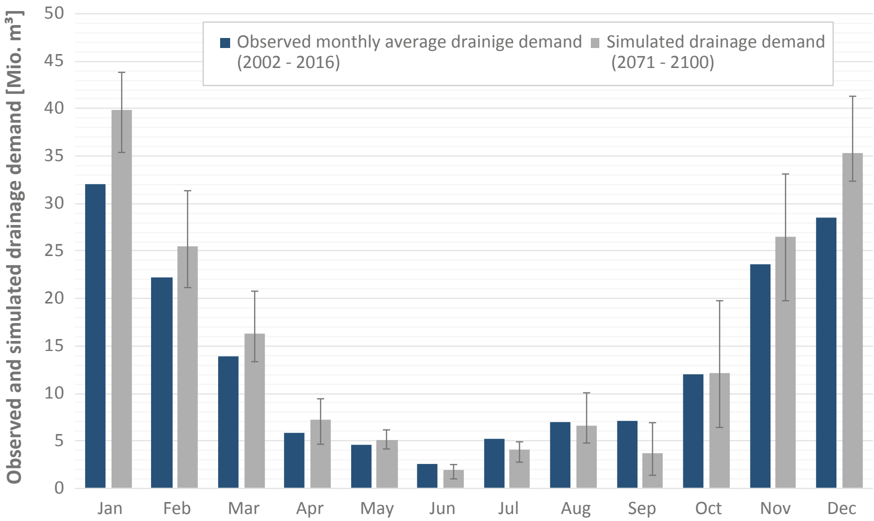

Fig. 6 Observed (2002–2016) and simulated (2071–2100) drainage demand for East Frisia. (Observation: sum of historical sluice and pump rates; Simulation: Model-based runoff generation); changed after [8]

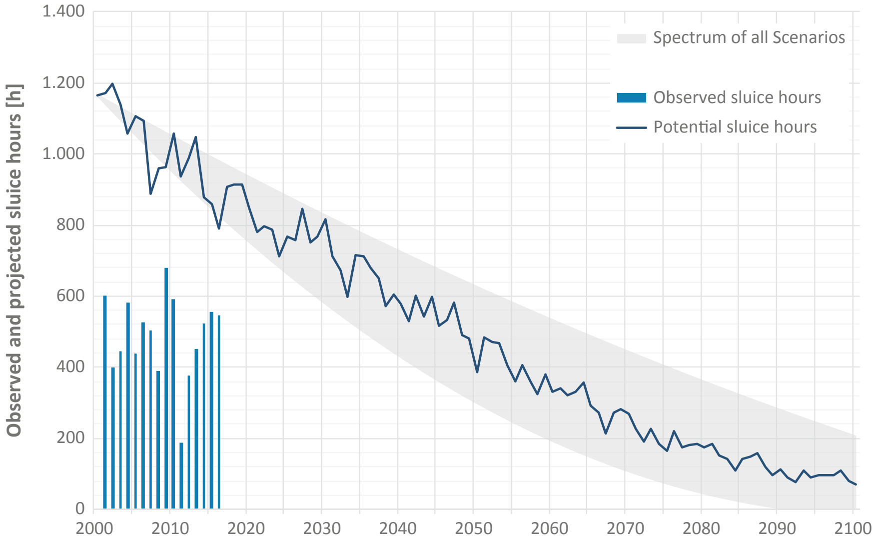

Fig. 7 Projected sluice efficiency due to sea level rise based on regional scale sea level projections; changed after [8]

3.2 Risk Perception in the Wesermarsch (Lower Saxony)

Implementing a risk-based flood management concept including different fields of action (e.g., prevention, protection, and preparedness) requires a clear definition of roles and responsibilities of all actors. Since the implementation of the EU floods directive, it is generally accepted that technical measures cannot guarantee 100% safety. Therefore the risk awareness of all actors is crucial.

While such risk awareness can be assumed for professional actors and voluntary aid organizations, the risk awareness of the general public is an issue. Although they do not play an official role, citizens can significantly reduce the damage of a flood event. Analyses of past flood events in the Rhine catchment revealed a damage reduction of about 50% due to increased awareness and preparedness of the population [10]. Due to the increasing safety standards, we assume that the flood risk awareness of the public generally decreased in the past decade. If so, tailored concept is needed to raise the awareness again.

In the focus of the FRAMES EU-Interreg project, the Wesermarsch county in Lower Saxony, coastal protection is vital. The marsh area is low lying, and coastal protection was and still is the precondition for the cultivation of the landscape. While flood risk awareness was very high after the historic storm surges in 1953 and 1962, recent informative meetings in the Wesermarsch revealed that flood risk awareness decreased and that people rely on authorities.

To assess the current awareness of the population along the North Sea coast in the Wesermarsch (Lower Saxony), [3] surveyed on risk perception, individual concernment, information demand and willingness for self-preparedness (24 questions in total) in the framework of the FRAMES EU-Interreg project. Two hundred eighty inhabitants from the Butjadingen Municipality (~5% of the population) completed the survey, resulting in a sampling error of 7.5% and a confidence interval of 95%.

The evaluation of the results revealed that general awareness to flood risk in coastal regions is high (Fig. 8). Storm tides, river flooding and climate change are perceived as central policy topics, and especially old people feel threatened by floods and storm surges. Older inhabitants felt more vulnerable than young inhabitants. This may be due to their reduced willingness to take risks compared to the younger generation and due to their experience from historical flood events.

Despite such high-risk awareness, most of the inhabitants mainly rely on the action of public authorities for both, the preparation for as well as the emergency management during a flood event. Individual preparedness and mutual assistance were rated high only by those people who had personal experience with floods (Fig. 9).

Highly correlated to these findings, the interest of the older generation in flood protection measures was higher compared to the young generation (Fig. 10). The reason behind seems to be that young respondents trust more in the existing infrastructure. They have not experienced severe damages due to floods and rely on the system of how coastal and flood protection is organized in our days.

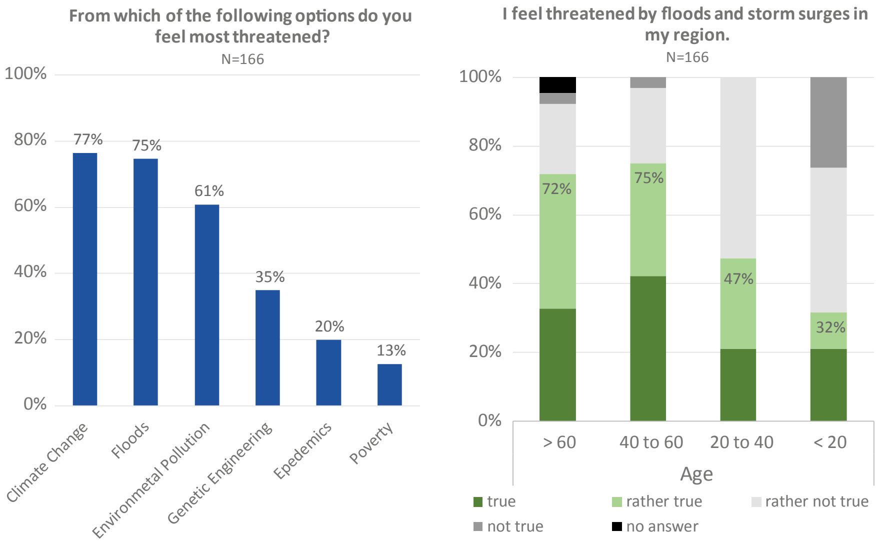

Fig. 8 Perception of the inhabitants of the Butjadingen municipality (Lower Saxony) on being threatened by floods and storm surges (a subset of all respondents according to the age pattern of the local population); changed after [3]

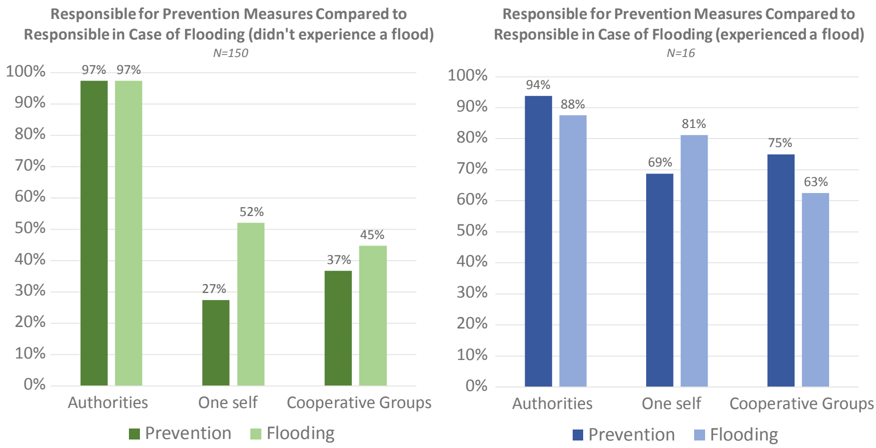

Fig. 9 Responsibility for action in case of a flood as perceived by the inhabitants of the Butjadingen municipality (Lower Saxony); changed after [3]

A high percentage of the respondents (~80%) rated the efficiency of those measures high which everybody should be able to implement him-/herself (e.g., phone lists, rescue package, essential equipment, etc.). While also the effort for implementation was assessed to be relatively low, the probability whether to implement or not to implement such measures significantly depended on age. Respondents older than

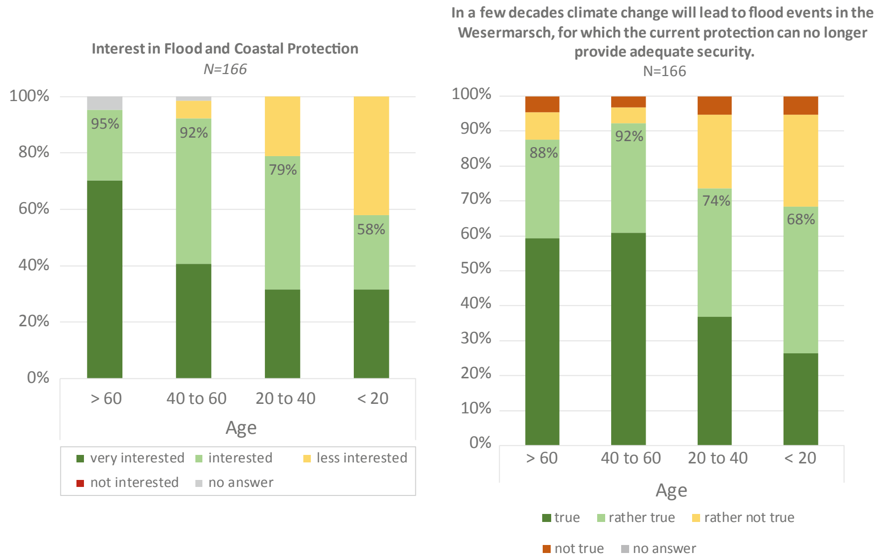

Fig. 10 Interest in flood protection activities and trust in the available flood protection infrastructure as perceived by the inhabitants of the Butjadingen municipality (Lower Saxony); changed after [3]

60 years rated such probability double as high as respondents younger than 20 years. Information, therefore, should be provided in a tailored way depending on the target groups.

In addition to the general awareness and preparedness, in case of an emergency, it is essential to be informed about the current status and recommendations for action. Asked for their preference on information channels, traditional information channels such as radio, TV or internet were preferred by all respondents independent of age (Fig. 11). This is good to know since the radio is a robust and reliable information source and can be used without an external power supply.

However, the survey also revealed that the interest in and the experience with active participation formats (e.g., round tables, workshops) is significantly lower for the younger generation. Therefore, suitable information formats are needed to be able to reach those groups who are interested in the flood risk topic but do not actively gather information on that topic (e.g., using social media). This is important because for both, for fostering general awareness and in the case of emergency, all groups need to be reached efficiently.

In general, based on the results of this survey, it can be concluded that the majority of the coastal population is aware of the risks due to flooding and storm surges. However, it remains a challenge to reach the young generation and to motivate the population to be actively prepared for catastrophic flood events. For this purpose, tailored information channels are crucial to increase the general preparedness as well

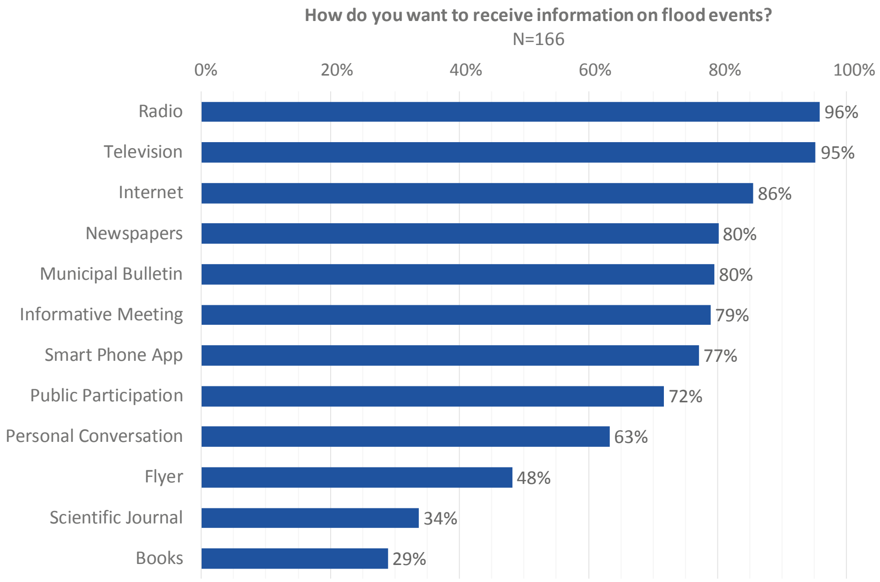

Fig. 11 Preferred information channels on floods, as perceived by the inhabitants of the Butjadingen municipality (Lower Saxony); changed after [3]

as to distribute information in case of an emergency to those people living in a flood-prone are. Therefore, action urgently needs to be taken to make the coastal citizens aware of the risk and to support that part of risk management on one's responsibility.

4 Lessons Learned and Conclusions

Based on the introduced case studies some main challenges of coastal regions along the German North Sea were identified which limit integrative strategic planning. Essential challenges are:

- A modern understanding of dealing with floods and coastal development requires an integrative risk-based approach. While good practice examples exist [17] and the EU floods directive explicitly demands such approaches, they are not yet implemented along the German North Sea coast.
- According to the definition of risk, the implementation of a risk management approach requires the consideration of economic values and potential damages. The idea of equal safety for a heterogeneous area is no longer appropriate [2].
- Since dimensioning of dikes due to climate change assumptions directly affects the coastal drainage system, integrative planning and dimensioning of coastal protection and drainage system is essential but not yet common practice in North-West Germany. This includes funding schemes which are not yet available [20].

- Taking decisions for an uncertain future requires explicit consideration of uncertainties, e.g., by applying scenario-based impact assessments to adapt coastal protection and drainage.
- Moving from a safety-based approach to a risk management approach demands for activities in multiple fields of action such as prevention, spatial measures and emergency management [17]. Since different actors are responsible for these topics, multiple actors also need to be mobilized and involved, including public organizations, aid organizations and citizens. Available investigations for North-West Germany show that not all actors are sufficiently aware of their responsibilities.

Based on these challenges and the case studies collective action is recommended for the implementation of a risk-based management approach in coastal regions. Such action is explicitly needed in North-West Germany but will generally assist adaptation in other coastal regions, as well.

Acknowledgements The authors thank the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety for funding the KLEVER project (climate optimized drainage solutions for East Frisia) contributing to the DAS program (German climate adaptation strategy) as well as the EU for funding the FRAMES project (Flood Risk Management and Multi-Layer(ed)-Safety) in the framework of the Interreg VB North Sea Region program.

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Potential Stresses on Water Resources in Russia

Water Resources of the Russian Part of the Baltic Sea Basin and Their Possible Changes Under Global Warming

Mikhail V. Georgievsky and Maria A. Mamaeva

Abstract The chapter presents the results of studies on the assessment of streamflow in the rivers of the Russian part of the Baltic Sea basin, carried out by specialists from the State Hydrological Institute in different years, including assessments for the territory of the former Soviet Union. An overview of monographs and other reference publications on the country's water resources assessment, with an emphasis on water resources estimates defined for the Baltic Sea basin. The changes in water resources and hydrological regime of the rivers occurring since the end of the 70s—the beginning of the 80s of the last century on the territory of Russia under the influence of climate change are described. Predictive estimates of possible changes in river streamflow made at the State Hydrological Institute are presented. Finally, conclusions are given regarding the prospects for solving problems in the study of water resources presented at the last VII All-Russian Hydrological Congress.

Keywords Water resources · Water balance · Forecasting estimates · Baltic Sea basin · Climate impact (change)

1 Introduction

The problem of assessing water resources and their use is not only of exceptional importance and relevance from a scientific point of view, but also acquires a strong socio-economic and political character in the last decades. On the one hand, that is due to the increasing role of anthropogenic factors related to water consumption for needs of population, industry and agriculture, as well as the impact on the conditions

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of the river flow formation. On the other hand, that is due to the factors caused by more noticeable changes in global and regional climate.

The Baltic Sea is the most substantial transboundary water body in Europe. It washes the shores of countries such as the Russian Federation, Estonia, Latvia, Lithuania, Germany, Finland, Sweden, Norway and Poland. More than 85 million people live in the basin, of which almost 15 million people live in a coastal zone of 10 km wide.

The Russian part of the Baltic Sea basin is challenging subject of research concerning distribution and formation of water resources, as well as its geographical location. Serious changes in the main factors determining the fluctuations of water resources and their change in time and territory have occurred in Russia over the last thirty years. That is why, the need for a modern assessment of renewable water resources and an assessment of their probable changes in the future for the territory of the Russian part of the Baltic Sea basin is an urgent task.

The purpose of this chapter is to summarize the results of studies carried out in Russia, and first of all at the State Hydrological Institute (SHI). It is also aimed at presenting an objective assessment of surface water resources, taking into account their changes under the climate impact for the case of the Russian part of the Baltic Sea basin, including estimates for the territory of the USSR.

SHI scientific school for the study of water resources and their use in the present and future is widely known among the world hydrological community. Since 1919 SHI scientists have been conducting complex researches, develop methodological approaches and periodically perform quantitative assessments of water resources and water balance of the territories of the former USSR and Russian Federation, which form the official basis for calculating the water supply of the population and the development of water-consuming industries of the country.

In different years SHI, in the framework of the different UNESCO and WMO projects, comprehensive studies and quantitative estimates of the world's water resources and their use were completed, which were published by UNESCO in the monographs «World Water Balance and Water Resources of the Earth» (1974) [1], «World Water Resources at the Beginning of the 21st Century» (2003) [2] and in WMO «Water Resources as a Challenge of the Twenty-First Century» (2004) [3]. These monographs are published in English, widely known in the world and used by scientists in many countries.

2 Estimates of the Water Resources of the Baltic Sea Basin Carried Out in Different Years at the State Hydrological Institute

In the second half of the twentieth century, significant attention was paid to the assessment of water resources and the water balance of river basins and administrative territories in Russia and in the world. The Soviet Union was a leading scientific power

Table 1 Water balance of the Baltic Sea (1967)

Basin area (thous. km^2)	Water balance elements						Runoff Coefficient
	Volume (km^3)			Depth (mm)			
	Precipitation	Runoff	Evaporation	Precipitation	Runoff	Evaporation	
661	506	171	335	765	259	506	0.34

in the field of hydrometeorology, which for the first time estimated the water balance and water resources of the state as a whole and the territories of river basins, sea basins, economic regions, union republics and administrative territories in it, based on observations of the Hydrometeorological Service till the year 1960 inclusive. All works were performed by a large group of staff of the State Hydrological Institute under the supervision of A. P. Bochkov and K. P. Voskresensky. The results were published in the monograph «Water Resources and Water Balance of the Territory of the Soviet Union» [4] issued in 1967. The monograph provided the methodological basis for calculating elements of the water balance of the Soviet Union at the current level of hydrological and meteorological knowledge of the country.

For the first time, water balance estimates for the basins of the seas, including the Baltic Sea basin (see Table 1) were presented. The water resources of the main rivers of the Baltic Sea basin (for 153 hydrological posts) and the water balance of rivers over an extended period (for 145 hydrological posts) were also estimated. Tables 2 and 3 present the data on water resources and water balance of the most significant rivers of the Baltic Sea basin.

In subsequent years in the USSR works on the study and calculation of water balance and water resources have been further developed. This was due to intensive water management construction, a huge increase in water consumption, the economic development of many new areas, the reconstruction of large river systems and other water use activities that require reliable hydrological justification.

In connection with these circumstances, in 1987 the State Hydrological Institute prepared a monograph «Water resources of the USSR and their use» [5], which published updated data on water resources and water balance of river basins and administrative-territorial units, as well as on use of surface and ground waters and surface water quality assessment.

This was the first interdepartmental joint edition of the State Water Cadastre. It was intended for use by the different level authorities, project and scientific organizations while addressing issues of rational use of the USSR water resources, planning and implementation of water management activities.

According to the data presented in the monograph, 1987, the flow of the Baltic Sea basin rivers, formed within the territory of the USSR, 568.2 km^2, was equal to 142.7 km^3, and taking into account the flow from the foreign territory, 637.9–161.2 km^3. Table 4 shows the average annual water balance of the largest lakes in the Baltic Sea basin, taken from the monograph, 1987.

A distinctive feature of the monograph, 1987, was that for the first time the surface and underground water resources and their use were considered in their unity and

Table 2 Water resources of the main river of the Baltic Sea basin (1967)

No.	River—Gauging station	Basin area (km^2)	The average annual flow rate (l/s, km^2)	Annual runoff							
				Average		75%		90%		95%	
				km^3	m^3/s	km^3	m^3/s	km^3	m^3/s	km^3	m^3/s
The Neva River Basin											
1	Neva at outlet	281,000	9.0	79.7	2530	70.1	2230	63	2000	59	1870
2	Neva—Petrokrepost'	276,000	9.0	78.1	2480	68.7	2180	61.7	1960	57.8	1840
3	Mga—Goryi	709	8.0	0.18	5.66	0.14	4.4	0.11	3.56	0.1	3.13
4	Tosno—Tosno	1300	7.6	0.31	9.85	0.25	8.02	0.21	6.76	0.19	6.08
5	Vuoksa—HPP X	61,500	9.7	18.5	588	16	509	14.2	451	13.2	417
6	Svir—HPP XII	66,100	9.3	19.4	617	17.1	542	15.3	486	14.4	456
7	Oyat—Shanginichi	4930	10.2	1.58	50.2	1.26	40.1	1.05	33.3	0.94	29.7
8	Pasha—Chasovenskoye	5710	10.4	1.87	59.3	1.52	48.2	1.28	40.7	1.15	36.5
9	Syas—Jahnovo	6230	8.7	1.7	54.1	1.37	43.6	1.15	36.4	1.03	32.6
10	Volkhov—HPP VI	79,800	7.4	18.5	586	15.3	485	13.1	414	11.9	377
The Luga River Basin and the Gulf of Finland's basin from the northern border of the Luga River basin to the southern boundary of the Neva River Basin											
11	Luga—Kingisepp	12,200	8.1	3.12	99.1	2.44	77.6	2	63.4	1.76	56
12	Oredezh—Morovino	2700	7.9	0.68	21.4	0.56	17.5	0.44	14	0.38	11.9
13	Saba—Raikovo	1280	7.5	0.3	9.6	0.25	7.95	0.21	6.79	0.19	6.18
The Neman River Basin and the Russian part of the Baltic Sea basin in the Kaliningrad region											
14	Neman at outlet	98,200	7.0	21.5	685	18.8	598	16.7	533	15.6	497
15	Sheshupe at outlet	6120	6.3	1.22	38.6	0.96	30.3	0.78	24.7	0.69	21.8
16	Pregolya—Gvardeysk	13,600	6.1	2.61	83	2.12	67.6	1.79	56.9	1.61	51.2

(continued)

Table 2 (continued)

No.	River—Gauging station	Basin area (km^2)	The average annual flow rate (l/s, km^2)	Annual runoff							
				Average		75%		90%		95%	
				km^3	m^3/s	km^3	m^3/s	km^3	m^3/s	km^3	m^3/s
17	Angrapa—Berestovo	2460	5.8	0.45	14.3	0.36	11.3	0.29	9.31	0.26	8.27
18	Pissa—Zeleny Bor	1360	5.9	0.25	8.02	0.21	6.64	0.18	5.68	0.16	5.16
19	Lava—Rodniki	7020	5.2	1.15	36.5	0.96	30.5	0.83	26.3	0.76	24
The Narva River Basin (Russian part)											
20	Narva—Narva	56,000	7.4	13.1	415	10.8	343	9.28	294	8.41	267
21	Plyussa—Brod	5090	7.8	1.25	39.7	1.03	32.6	0.87	27.6	0.79	25
22	Velikaya—Pyatonovo	20,000	6.6	4.16	132	3.35	106	2.8	89	2.51	79.7
The Zapadnaya Dvina River Basin (Russian part)											
23	Zapadnaya Dvina—Zapadnaya Dvina	2180	10.8	0.74	23.5	0.59	18.8	0.49	15.6	0.44	13.9
24	Mezha—Taborishche	5220	7.8	1.29	41	1.06	33.7	0.9	28.5	0.81	25.8
25	Obsha—Bely	1590	7.2	0.36	11.5	0.29	9.36	0.25	7.89	0.22	7.1

Table 3 Water balance of the main rivers of the Baltic Sea for a long-term period (1967)

No.	River—Gauging station	Basin area (km^2)	Water balance elements					
			Volume (km^3)					
			Precipitation	River runoff			Evaporation	Infiltration
				Total	Surface	Underground		
The Neva River Basin								
1	Neva at mouth	281,000	212	79.7	–	–	132	–
2	Neva—Petrokrepost	276,000	208	78.1	–	–	130	–
3	Mga—Goryi	709	0.52	0.18	0.14	0.04	0.34	0.38
4	Tosno—Tosno	1300	0.97	0.31	0.25	0.06	0.66	0.72
5	Svir—HPP XII	66,100	51.6	19.4	–	–	32.2	–
6	Oyat—Shanginichi	4930	4.03	1.58	1.21	0.37	2.45	2.82
7	Pasha—Chasovenskoye	5710	4.52	1.87	1.48	0.39	2.65	3.04
8	Syas—Jahnovo	6230	4.76	1.7	1.31	0.39	3.06	3.45
9	Volkhov—HPP VI	79,800	61	18.5	–	–	42.5	–
The Luga River Basin and the Gulf of Finland's basin from the northern border of the Luga River basin to the southern boundary of the Neva River Basin								
10	Luga—Kingisepp	12,200	9.16	3.12	2.19	0.93	6.04	6.97
11	Oredezh—Morovino	2700	2.02	0.68	0.45	0.23	1.34	1.57
12	Saba—Raikovo	1280	0.96	0.3	0.23	0.07	0.66	0.73

(continued)

Table 3 (continued)

No.	River—Gauging station	Basin area (km^2)	Water balance elements					
			Volume (km^3)					
			Precipitation	River runoff			Evaporation	Infiltration
				Total	Surface	Underground		
The Neman River Basin and the Russian part of the Baltic Sea basin in the Kaliningrad region								
13	Neman at mouth	98,200	75.1	21.5	–	–	53.6	–
14	Sheshupe at mouth	6120	4.68	1.22	–	–	3.46	–
15	Pregolya—Gvardeysk	13,600	10.8	2.61	1.97	0.64	8.19	8.83
16	Angrapa—Berestovo	2460	1.9	0.45	0.3	0.15	1.45	1.6
17	Pissa—Zeleny Bor	1360	1.03	0.25	0.16	0.09	0.78	0.87
18	Lava—Rodniki	7020	5.96	1.15	–	–	4.81	–
The Narva River Basin (Russian part)								
19	Narva—Narva	56,000	45.2	13.1	–	–	32.1	–
20	Plyussa—Brod	5090	3.84	1.25	0.79	0.46	2.59	3.05
21	Velikaya—Pyatonovo	20,000	14.6	4.16	3.02	1.14	10.4	11.6
The Zapadnaya Dvina River Basin (Russian part)								
22	Zapadnaya Dvina—Zapadnaya Dvina	2180	1.8	0.74	0.51	0.23	1.06	1.29
23	Mezha—Taborishche	5220	4.08	1.29	1.06	0.23	2.79	3.02
24	Obsha—Bely	1590	1.27	0.36	0.27	0.09	0.91	1

(continued)

Table 3 (continued)

No.	River—Gauging station	Water balance elements							Runoff coefficient	Infiltration coefficient (ratio of infiltration to precipitation)	Percentage of ground runoff relative to total runoff
		Basin area (km^2)	Layer (mm)								
			Precipitation	River runoff			Evaporation	Infiltration			
				Total	Surface	Underground					
The Neva River Basin											
1	Neva at mouth	281,000	755	284	–	–	471	–	0.38	–	–
2	Neva—Petrokrepost	276,000	755	283	–	–	472	–	0.37	–	–
3	Mga—Goryi	709	735	254	191	63	481	544	0.35	0.74	25
4	Tosno—Tosno	1300	743	238	191	47	505	552	0.32	0.74	20
5	Svir—HPP XII	66,100	780	293	–	–	487	–	0.38	–	–
6	Oyat—Shanginichi	4930	818	320	244	76	498	574	0.39	0.7	24
7	Pasha—Chasovenskoye	5710	791	327	258	69	464	533	0.41	0.67	21
8	Syas—Jahnovo	6230	764	273	210	63	491	554	0.36	0.73	23
9	Volkhov—HPP VI	79,800	765	232	–	–	533	–	0.3	–	–
The Luga River Basin and the Gulf of Finland's basin from the northern border of the Luga River basin to the southern boundary of the Neva River Basin											
10	Luga—Kingisepp	12,200	751	256	180	76	495	571	0.34	0.76	30

(continued)

Table 3 (continued)

No.	River—Gauging station	Water balance elements								Runoff coefficient	Infiltration coefficient (ratio of infiltration to precipitation)	Percentage of ground runoff relative to total runoff
		Basin area (km^2)		Layer (mm)								
				Precipitation	River runoff			Evaporation	Infiltration			
					Total	Surface	Underground					
11	Oredezh—Morovino	2700		750	252	167	85	498	583	0.34	0.78	34
12	Saba—Raikovo	1280		751	234	177	57	517	574	0.31	0.76	24
The Neman River Basin and the Russian part of the Baltic Sea basin in the Kaliningrad region												
13	Neman at mouth	98,200	–	765	219	–	–	546	–	0.29	–	–
14	Sheshupe at mouth	6120	–	765	199	–	–	566	–	0.26	–	–
15	Pregolya—Gvardeysk	13,600	8.83	797	192	145	47	605	652	0.24	0.82	24
16	Angrapa—Berestovo	2460	1.6	773	183	123	60	590	650	0.24	0.84	33
17	Pissa—Zeleny Bor	1360	0.87	761	184	115	69	577	646	0.24	0.85	38
18	Lava—Rodniki	7020	–	849	164	–	–	685	–	0.19	–	–
The Narva River Basin (Russian part)												
19	Narva—Narva	56,000		808	234	–	–	574	–	0.29	–	–
20	Plyussa—Brod	5090		754	246	155	91	508	599	0.33	0.79	37
21	Velikaya—Pyatonovo	20,000		731	208	151	57	536	580	0.28	0.79	27
The Zapadnaya Dvina River Basin (Russian part)												
22	Zapadnaya Dvina—Zapadnaya Dvina	2180		827	339	235	104	488	592	0.41	0.72	31
23	Mezha—Taborishche	5220		782	247	203	44	535	579	0.32	0.74	18
24	Obsha—Bely	1590		800	226	172	54	574	628	0.28	0.78	24

Table 4 Average annual water balance of the largest lakes of the Baltic Sea basin (1987)

Lake	Calculation period	Inflow (surface and ground)		Precipitation		Total input	Outflow (surface and underground)		Evaporation		Total output	Volume change	Level change during a period
		km^3	%	km^3	%	km^3	km^3	%	km^3	%	km^3	km^3	m
Ladoga	1932–1980	69.8	88	9.3	12	79.1	72.7	92	6.7	8	79.4	−0.32	−0.88
Onega	1969–1980	15.2	75	5.1	25	20.3	16.6	81	3.8	19	20.4	−0.12	−0.15
Peipsi	1953–1980	9.09	81	2.13	19	11.22	9.29	83	1.85	17	11.14	0.08	0.63
Ilmen	1966–1980	15	96	0.66	4	15.66	14.8	95	0.71	5	15.51	0.15	2

Table 5 Potential and approved operating storage of groundwater and the degree of their exploration (as of January 1, 1983) (1987)

River	Useful groundwater resources					Storage-to-resources ration (%)
	Potential			Approved		
	thou. km^3/day	km^3/year	Including surface water (km^3/year)	thou. km^3/year	km^3/year	
Neva	8640	3.2	1.9	236.6	0.09	2.6
Western Dvina	11,200	4.1	2.2	1307	0.48	11.7
Neman	12,770	4.7	3	1989	0.73	15.6

interrelation (see Table 5), as well as the quality of surface waters in the present (1987) and in the near (1990) and remote (2000) perspectives.

The last collective monograph devoted to the problems of studying and evaluating the renewable water resources of Russia, carried out by SHI experts and edited by I. A. Shiklomanov, is a monograph «Water resources of Russia and their use» [6], published in 2008. The main purpose of the monograph is to summarize results of the studies carried out for the last two decades in Russia and first of all in the State Hydrological Institute since the publication of the previous monograph in 1987. The monograph was also aimed at objective quantitative assessment of water resources (surface and ground), taking into account their quality and changes under the influence of economic activity and climate in different regions for the current period and the near future.

According to the information, presented in this monograph, the average long-term water resources volume, formed within the Russian part of the Baltic Sea basin, in the Baltic States and partially in Finland (the Vuoksa River) is equal to 129 km^3 (1930–2005).

The inflow from the given foreign territory is 46.2 km^3. Most of the water resources of the Baltic Sea basin is the Neva river flow (75.7 km^3, or 58.7% of the total water resources of the sea basin).

Table 6 provides water resources estimates before the dissolution of the Soviet Union and for 2008, as well as their changes, presented in the monograph.

In addition to the above publications, in which the analysis of the entire country water resources was carried out, the State Hydrological Institute published several monographs on the assessment of the resources of certain geographic regions, administrative areas or water basins. Among them is «Water resources of the non-chernozem zone of the RSFSR» [7], which also contains estimates of water resources for territories of the Baltic Sea basin.

It is necessary to especially note the annual reference publication «Surface and groundwater resources, their use and quality», the main purpose of which is to promptly provide consumers with an overview and integrated information on the quantity and quality of the country's water resources and their use in the past year.

Table 6 Water resources of the Baltic Sea basin and their changes (2008)

Estimates before the collapse of the USSR				Modern data (until 2008)				Changes in modern water resources in relation to the "norm" (%)*
Basin area (thou. km^2)		Water resources (km^3)		Basin area (thou. km^2)		Water resources (km^3)		
Russian part	Including foreign territories	Russian part	Including foreign territories	Russian part	Including foreign territories	Russian part	Including foreign territories	
568.2	637.9	143	161	257	414.5	82.7	129	−42

*Changes in water resources mainly due to changes in the basin area

This reference edition is one of the information products of the Water Cadastre of the Russian Federation and is prepared by specialists of the State Hydrological Institute.

The publication is intended for the authorities of the RF, its federal districts and constituent entities, as well as for organizations involved in the planning of water management and environmental activities at the level of the RF constituent entities and above.

The current model of the publication includes information on the resources, quality and use of surface and ground waters of the Russian Federation as a whole, its entities, federal districts, the main river basins and their sub-basins, as well as information on water and water levels in the largest reservoirs of the country. Now issues have been published for the years 1981–2016.

Tables 7, 8, 9, 10 and 11 contain data on the water resources of the main rivers and lakes of the Baltic Sea basin, their use, as well as the contamination of surface waters presented in the last, as of the time of writing this chapter, reference book of 2016 [8].

It should be noted that published data on surface and groundwater resources are regularly specified in the subsequent issues. In this regard, it is not recommended to use them for generalizations over long-term periods.

The latest issues of the reference book are available for download on the website of the State Hydrological Institute: http://www.hydrology.ru/ru/izdaniya_ggi_New.

3 River Water Resources of the Russian Part of the Baltic Sea Basin in Schemes of Integrated Use and Protection of Water Bodies

3.1 Schemes of Integrated Use and Protection of Water Bodies (Schemes)

Schemes of integrated use and protection of water bodies are developed in pursuance of the: Water Code of the Russian Federation (Article 33) [9] and Decree of the Government of the Russian Federation No. 883 of December 30, 2006 «About the procedure for developing, approving and implementing schemes of integrated use and protection of water bodies». They are also required for the implementation of the «Water Strategy of the Russian Federation for the period up to 2020» [10, 11], approved by the RF Government Decree No. 1235-p of August 27, 2009.

The state authorities and local governments implement schemes through planning on their basis and executing water management activities and water bodies protection measures. They are aimed at meeting the actual demand and the need for water resources in the future, systematic reduction of human impact on water bodies, ensuring rational use and protection of water bodies, as well as prevention of negative impacts of water. Schemes, in accordance with the Water Code of the

Table 7 River water resources of the Baltic Sea basin, km^3 (2016)

River basin section (outlet)	Long-term runoff characteristics					Annual runoff			
	Average value	Largest value	Year of largest value	Smallest value	Year of smallest value	Observed		Reconstructed	
						Value	Gradation of water content*	Value	Gradation of water content
Neva—Novosaratovka	74.3	104	1958	42.3	1940	73.8	A	73.8	A
Outlet	74.3	104	1958	42.3	1940	73.8	A	74.4	A
Narva—HPP Narva	11	16.1	1957	6.5	1973	11.3	A	11.3	A
Outlet	11	16.1	1957	6.5	1973	11.3	A	11.3	A
Zapadnaya Dvina—Vitebsk	6.73	11.4	1962	3.19	1939	5.71	ML	5.71	ML
Neman—Smalininkai	16.8	24.4	1958	11.2	1969	16.5	A	16.5	A
Outlet	19.3	28.1	1958	12.9	1969	19	A	19	A

**A* Average water content (probability of 40–60%); *ML* Moderately low water content (probability of 60–80%)

Table 8 Use of water resources of rivers and ground waters in the Baltic Sea basin, km^3/year (2016)

River basin section bounded by upper and lower river sites	Volume of collected water				Volume of discharged water			Total change in runoff
	From river network		From underground sources		In river network		In underground horizons, accumulators, agricultural irrigation fields	
	Total	Including for runoff transfer	Total	Including input from surface water	Total	Including runoff transfer		
Neva—Novosaratovka	0.091	0.000	0.031	0.000	0.115	0.000	0.001	−0.024
Outlet	0.762	0.000	0.000	0.000	0.202	0.000	0.001	0.560
Total	0.853	0.000	0.031	0.000	0.317	0.000	0.002	0.536
Narva—HPP Narva	0.015	0.000	0.004	0.000	0.009	0.000	0.000	0.006
Outlet	0.003	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Total	0.018	0.000	0.004	0.000	0.012	0.000	0.000	0.006
Zapadnaya Dvina—Vitebsk	0.005	0.000	0.005	0.002	0.005	0.000	0.001	0.002
Total	0.005	0.000	0.005	0.002	0.005	0.000	0.001	0.002
Neman—Smalininkai	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Outlet	0.004	0.000	0.003	0.003	0.009	0.000	0.001	−0.002
Total	0.004	0.000	0.003	0.003	0.009	0.000	0.001	−0.002

Table 9 Changes in water availability and water levels of the largest lakes in the Baltic Sea basin (2016)

Lake	Average long-term water storage (km^3)	Average long-term water level (m)	Water storage (km^3)			Water level (km^3)		
			On January 1, 2016	On January 1, 2017	Annual change	On January 1, 2016	On January 1, 2017	Annual change
Ladoga	911	5.1	888.6	900.6	12	3.86	4.53	0.67
Onega	292	33.0	292.81	293.62	0.81	33.09	33.18	0.09
Ilmen	2.92	18.0	2.19	3.8	1.61	17.28	18.76	1.48

Table 10 Water use in the basins of the largest lakes in the Baltic Sea basin, km^3/year (2016)

Lake	Average long-term inflow	Volume of collected water in the lake basin				The volume of discharged water into the lake basin	
		From river network		From underground sources			
		Total	Including for redistribution of runoff	Total	Including input from surface water	Total	Including for redistribution of runoff
Ladoga	69.8	0.526	0.000	0.018	0.000	0.487	0.014
Onega	15.2	0.084	0.000	0.026	0.000	0.171	0.000
Ilmen	15.0	1.058	0.001	0.051	0.000	0.335	0.247

Russian Federation, should become the basis for implementing water management measures and measures for the protection of water bodies in river basins.

It should be noted that at the moment eight Schemes of integrated use and protection of water objects in the Baltic Basin District have been approved (the basin district consists of river basins and associated groundwater bodies and seas) [12–19].

Five of the eight Schemes [12–15, 17], which are the main ones regarding the volume of water resources in the Baltic Sea basin, were developed by the State Hydrological Institute. Below is a summary of the hydrography and river water resources presented in these Schemes.

3.2 *The Gulf of Finland Basin from the Border of the Russian Federation with Finland to the Northern Border of the Neva River Basin*

The basin is a part of the North-West Federal District and is located on the territory of two constituent entities of the Russian Federation—the Leningrad Region and St. Petersburg. The basin is located in the southwestern part of the Karelian Isthmus, in

Table 11 Surface water pollution in the Baltic Sea basin (2016)

Main pollutants in river basins and sources of pollution	Number of samples analyzed	Average annual concentration in MPC		The largest concentrations of MAC in the year and their dates					
		Arithmetic	Median	First concentration	Date	Second concentration	Date	Third concentration	Date
Neva—St. Petersburg, hydrological section, Novosaratovka village									
$BOD_5(O_2)$ (mg/l)	32	1.21	1.00	3.7	01.02	2.6	10.11	2.40	01.03
COD (mg/l)	32	22.9	22	41	01.08	31	05.04	29.0	05.12
Oil products	32	<1	<1	<1	10.11	<1	05.12	<1	12.05
Ammonia nitrogen	32	<1	<1	2	01.08	1	01.02	<1	02.06
Copper compounds	32	4	4	8	01.08	8	11.07	7	01.08
Manganese compounds	32	3	<1	36	01.08	15	12.05	4	12.05
Volhov—Novaya Ladoga, 1.2 km below the city									
$BOD_5(O_2)$ (mg/l)	12	1.67	1.7	3	11.02	2.50	16.08	2.30	21.04
COD (mg/l)	12	58.9	63	101	01.09	93.0	16.08	71.0	20.10
Nitrite nitrogen	4	<1	<1	<1	11.02	<1	21.04	<1	16.08
Phenols	12	<1	<1	<1	09.12	<1	11.02	<1	16.08
Iron compounds	4	8	7	15	16.08	7	20.10	6	21.04
Copper compounds	12	5	4	14	22.11	10	01.09	9	16.08

(continued)

Table 11 (continued)

Main pollutants in river basins and sources of pollution	Number of samples analyzed	Average annual concentration in MPC		The largest concentrations of MAC in the year and their dates					
		Arithmetic	Median	First concentration	Date	Second concentration	Date	Third concentration	Date
Manganese compounds	12	4	3	9	16.08	9	11.02	9	20.07
Neman—Sovetsk, 1.5 km below the city									
$BOD_5(O_2)$ (mg/l)	12	2.58	2.6	3.0	12.07	2.90	14.06	2.9	18.01
COD (mg/l)	12	24.3	24.5	31.7	13.12	30.4	16.05	28.6	18.04
Iron compounds	12	1	<1	8	13.12	1	14.11	<1	14.03
Ammonia nitrogen	12	<1	<1	<1	18.01	<1	13.09	<1	15.02

the west it is bordered by the state border with Finland, in the north it is bordered by the Vuoksa River basin, in the east—the Neva River basin, in the south—the Gulf of Finland. The total area of the basin is 6200 km^2. Within the Leningrad region, there is 93.5% of the basin, the rest belongs to St. Petersburg (Fig. 1).

The hydrographic network is highly developed. The river network is represented mainly by small rivers and short channels connecting numerous lakes. The total number of rivers is 1744, and their total length is 2563 km. The predominant number of rivers (97%) are less than 10 km long. Only the Sister River is more than 50 km long. The density of the river network ranges from 0.87 km/km^2 (the Sister River) to 1.33 km/km^2 (the Roshchinka River). A characteristic feature of the rivers is the relatively large lakes percentage, which averages 5%. Almost all rivers flow out of lakes and, despite the relatively small length, have large catchment areas due to lakes located within them.

In total, 61 lakes with a total water surface area of 168.2 km^2 are included in the State Water Register, of which 39 lakes have an area of 1 km^2 or more, their total area is equal to 92% of the total area of the lakes in the region. Only 22 lakes have an area of less than 1 km^2. The largest lakes are the Krasnogvardeyskoye (10.6 km^2), Pionerskoye (13.8 km^2), Nakhimovskoye (14.3 km^2), and the Reservoir of Sestroretskiy Razliv (10.6 km^2). A brief description of the largest reservoirs is given in Table 12.

Statistical parameters of annual runoff for main hydrometric stations on the rivers of the basin of the northern coast of the Gulf of Finland are presented in Table 13.

3.3 The Neva River Basin Within St. Petersburg and the Leningrad Region

The Neva, a part of the system of watercourses and reservoirs of the Baltic Basin District, flows from the Ladoga Lake into the Neva Bay of the Gulf of Finland of the Baltic Sea. Taking into account the Ladoga Lake basin, but excluding the water bodies of the Onega Lake basin, the area of the Neva drainage basin is 281,000 km^2 with the river length of only 74 km. The Neva own basin area is 5180 km^2—just about 2% of the total basin area. The Neva is a part of the Volga-Baltic Waterway and the White Sea-Baltic Canal and is navigable throughout its entire length.

The drainage basin of the Neva is located on the territory of several entities of the North-West Federal District of the Russian Federation (from now on referred to as NWFD): St. Petersburg, Leningrad, Novgorod, Vologda Regions, the Republic of Karelia. A part of the catchment area is in Finland.

Maps of the drainage basins of the Neva River and its tributaries within Leningrad region are presented in Figs. 2 and 3.

Within the drainage basin of the Neva and Ladoga Lake, the most significant watercourses are rivers Volkhov, Svir, Vuoksa, Syas, Tikhvinka, Ojat, Pasha, Tosna and Izhora. Most rivers are calm since their slopes are not steep (up to 20–40 cm/km).

Fig. 1 A schematic map of the basin of the northern coast of the Gulf of Finland from the Russian-Finnish border to the northern border of the Neva River basin

Table 12 Some characteristics of the largest reservoirs of the basin of the northern coast of the Gulf of Finland

Name	Reservoir surface area (km^2)	Catchment area, (km^2)	Max depth (m)	Comments
Bolshoye Kirillovskoye	3.2	36.6	2	Source of the Perovka River
Nachimovskoye	14.3	85.5	22	Source of the Velikaya River
Bolshoye Simaginskoye (Krasavitsa)	2.6	97.5	19	Source of the Nizhnyaya River
Gladyshevskoye	6.0	294	24	Source of the Gladyshevka River
Reservoir of Sestroretskiy Razliv	10.6	566	2	It was built during the reign of Peter the Great below the confluence of the Sestra and Chernaya Rivers

All watercourses of the catchment basin of the Neva River and Lake Ladoga can be conditionally divided into watercourses (rivers, streams, channels, etc.) within the Leningrad Region and waterways (artificial and natural) of the own Neva basin.

On the territory of the Leningrad Region, there are about 340 rivers longer than 10 km. The largest of these are the Neva, Svir, with the tributaries Oyat and Pasha, Syas, Vuoksa and Volkhov.

Within the own basin of the Neva, there are tributaries of both the first and higher orders. 26 small and very small rivers flow into the Neva, the largest of them are Mga, Tosna, Izhora, Okhta and Slavyanka. Most of the streams are within the territory of the Kirovsky, Tosnensky, Vsevolozhsky and Gatchinsky districts of the Leningrad Region and St. Petersburg. The river network density in the basin varies from 0.7 to 1.6 km/km^2. Bog percentage of the territory (without the Lake Ladoga basin) is about 30%, lake percentage is insignificant, within 0.5%.

Table 14 presents the main statistical parameters of annual runoff for hydrometric posts in the Neva basin.

The Neva River basin has the most lake percentage among the other rivers basins within the Russian Plain. Lakes occupy about 14% of its area. The most significant reservoirs are the Ladoga and Onega Lakes, the largest in Europe and the European part of the country, as well as the Vuoksa and Otradnoye lakes with the surface area of more than 50 km^2.

The southern part of Lake Ladoga is situated in the Leningrad region. The total basin area of the lake is 258,600 km^2 (including the basins of Lakes Ilmen, Onega

Table 13 Statistical parameters of annual runoff for main hydrometric stations on the rivers of the Gulf of Finland basin

Post code	River/watercourse—station	Catchment area (km^2)	Average discharge (m^3/s)	Unit discharge l/s× (km^2)	Cv	Cs	Mean annual discharge (m^3/s)							
							Probability (%)							
							25	50	75	80	90	95	97	99
72763	Seleznevka River—Poselok Kutuzovo	143	2.56	17.9	0.32	0.64	3.04	2.47	1.96	1.86	1.58	1.38	1.28	1.28
72002	Seleznevka River—Poselok Luzhajka	486	4.23	8.70	0.32	0.67	5.03	4.07	3.24	3.06	2.61	2.28	2.11	2.11
72004	Petrovka River—Poselok Druzhnoselie	78.6	0.741	9.40	0.35	0.59	0.898	0.715	0.556	0.521	0.434	0.37	0.34	0.34
72005	Pankan-Oya watercourse—Poselok Druzhnoselie	15.3	0.151	9.90	0.33	0.48	0.183	0.147	0.115	0.107	0.09	0.076	0.070	0.070
72006	Rajya-Oya watercourse—Poselok Druzhnoselie	17.1	0.134	7.80	0.38	1.44	0.160	0.125	0.137	0.099	0.093	0.081	0.072	0.060
72007	Perovka River—Poselok Goncharovo	257	2.59	10.1	0.29	0.46	3.07	2.53	2.05	1.94	1.66	1.45	1.35	1.35
72008	Gorokhovka River—Poselok Tokarevo	700	7.72	11.0	0.23	0.38	8.87	7.6	6.45	6.19	5.51	4.99	4.72	4.72
72013	Nizhnyaya (Yulya-Joki) River—Poselok Iljichevo	82.1	0.928	11.3	0.17	0.14	1.03	0.924	0.821	0.796	0.733	0.681	0.65	0.65
72016	Sestra River—Beloostrov Station	390	4.48	11.5	0.25	0.29	5.2	4.42	3.7	3.53	3.1	2.76	2.59	2.59
72018	Chernaya River—Dibuny River post	88.0	0.99	11.3	0.22	0.3	1.13	0.979	0.839	0.806	0.722	0.656	0.62	0.62

Fig. 2 A schematic map of the Neva River basin within St. Petersburg and the Leningrad region

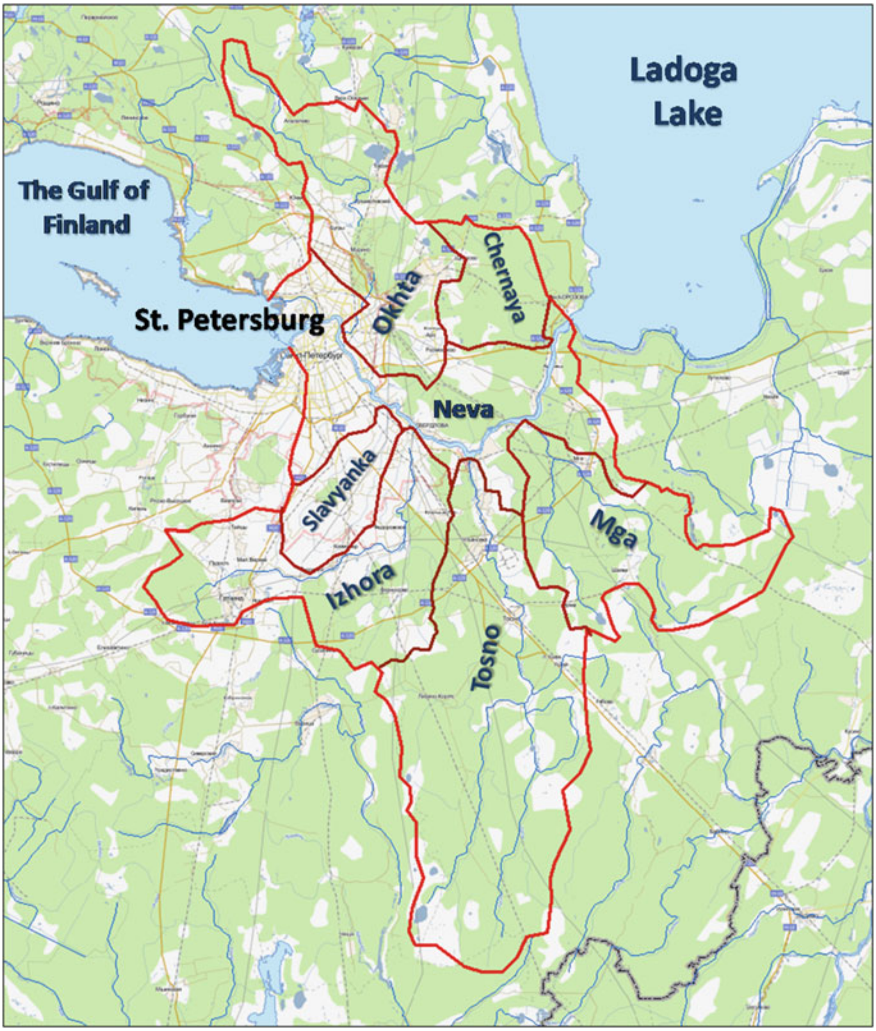

Fig. 3 A schematic map of the basins of the main tributaries of the Neva River

and Saimaa). The water surface area is 18,329 km^2, including 457 km^2 the area of the islands. The volume of water in the lake is 847.8 km^3. The average depth of the lake is 48.3 m, the maximum depth—230 m. Water retention time is 12 years. The Neva River flows from the lake, and several thousand watercourses flow into it. The largest rivers flowing into Lake Ladoga are Svir, Volkhov and Syas. The total area of these rivers basins is 90% of the area of Ladoga's basin. The drainage basin of the lake is distinguished with its high lakes percentage, most lakes (more than 1000) are concentrated on the Karelian Isthmus.

Table 14 Basic statistical parameters of annual runoff for hydrometric stations in the Neva basin within St. Petersburg and the Leningrad Region

No.	Post code	River-station	$\bar{Q}$ (m^3/c)	Cs/Cv	Cv	Mean annual discharge (m^3/s)								
						Probability (%)								
						50	60	70	75	80	90	95	97	99
1	72039	Mga River—Derevnja Gory	5.60	2	0.31	5.41	4.99	4.56	4.34	4.11	3.51	3.08	2.81	2.35
2	72043	Tosna River—Tosno Station	7.46	1.5	0.33	7.22	7.54	6.84	6.47	6.07	5.1	4.35	3.92	3.16
3	72055	Okhta River—Derevnja Novoje Devjatkino	3.79	1.5	0.26	3.72	3.47	3.21	3.07	2.92	2.55	2.27	2.09	1.78
4	72064	Avloga River—Derevnja Matoksa	0.93	1.5	0.26	0.91	0.85	0.79	0.76	0.72	0.63	0.56	0.52	0.45
5	72068	Vuoksa River—X GES Nizhnij B'ef	551	0.5	0.18	550	524	492	482	465	422	388	366	326
6	72076	Dymovka River—Poselok Zaytsevo	2.32	2.5	0.31	2.23	2.06	1.88	1.8	1.7	1.47	1.3	1.2	1.03
7	72082	Volch'ya River—Derevnja Varshko	4.01	2.5	0.18	3.96	3.79	3.61	3.51	3.41	3.15	2.95	2.83	2.6
8	72083	V'yun Кшмук—Poselok Zaporozhskoje	5.17	2	0.26	5.04	4.72	4.37	4.19	4.01	3.52	3.17	2.94	2.55
9	72090	Yanis-Joki River—Poselok Hyamekoski	39.6	0.2	0.27	39.5	36.8	33.8	32.3	30.5	26	22.4	20.2	16.3
10	72096	Uksun-Joki River—Derevnja Uuksu	14.5	2	0.23	14.2	13.4	12.6	12.1	11.7	10.4	9.52	7.94	7.92
11	72097	Tulema-Joki River—Derevnja Gilkozha	10.6	2	0.29	10.3	9.55	7.79	7.39	7.99	6.92	6.15	5.65	4.82
12	72098	Tulema-Joki River—Salmi Town	22.6	2.5	0.27	22	20.5	19.1	17.3	17.5	15.5	13.9	13	11.4

(continued)

Table 14 (continued)

No.	Post code	River-station	$\bar{Q}$ (m^3/c)	Cs/Cv	Cv	Mean annual discharge (m^3/s)								
						Probability (%)								
						50	60	70	75	80	90	95	97	99
13	72101	Lajmozh River—Selo Kolatselya	7.26	3	0.29	6.98	6.5	6.02	5.76	5.5	4.85	4.37	4.08	3.62
14	72102	EHnya-Joki River—DerevnjaRyajmyalya	5.96	2	0.24	5.84	5.51	5.15	4.96	4.76	4.25	3.87	3.63	3.2
15	72104	Vidlitsa River—Selo Bolshie Gory	11.7	1.5	0.27	11.5	10.7	9.91	9.48	9.02	7.87	6.97	6.43	5.47
16	72106	Novzema River —Selo Vidlitsa	3.98	3.5	0.23	3.86	3.65	3.44	3.33	3.21	2.92	2.7	2.57	2.35
17	72108	Olonka River—Derevnja Torosozero	12.0	0.5	0.29	11.9	11	10.1	9.54	7.98	7.54	6.4	5.72	4.51
18	72109	Olonka River—Selo Verkhovje	14.8	0.5	0.25	14.8	13.8	12.7	12.2	11.6	10.1	7.82	7.06	6.7
19	72110	Olonka River—Olonec City	27.0	1.5	0.23	27.6	26	24.3	23.4	22.4	19.9	17	16.8	14.7
20	72113	Megrega River—Derevnja Kuytezha	5.16	1.5	0.25	5.07	4.75	4.42	4.24	4.05	3.57	3.19	2.97	2.56
21	72114	Megrega River—Derevnja Sudalitse, Olonec City	12.3	1.5	0.25	12.1	11.3	10.5	10.1	9.63	7.48	7.58	7.04	6.07
22	72115	Inema River—Derevnja Inema	4.85	2.5	0.23	4.74	4.46	4.19	4.04	3.88	3.49	3.2	3.02	2.7

(continued)

Table 14 (continued)

No.	Post code	River-station	$\bar{Q}$ (m^3/c)	Cs/Cv	Cv	Mean annual discharge (m^3/s)								
						Probability (%)								
						50	60	70	75	80	90	95	97	99
23	72116	Tuksa River—Selo Tuksa, Derevnja Verkhnjaa Ladva	1.68	1.5	0.31	1.64	1.51	1.37	1.3	1.23	1.04	0.9	0.81	0.66
24	72121	Svir' River—XII GES Nizhnij B'ef	589	4	0.18	578	553	529	516	502	467	441	426	397
25	72129	Ivina River—Ladva Town	10.2	1.5	0.28	9.98	9.28	7.56	7.17	7.75	6.72	5.92	5.44	4.58
26	72135	Vazhinka River—Derevnja Grishino	24.2	1.5	0.26	23.7	22.1	20.5	19.6	17.7	16.3	14.5	13.4	11.4
27	72136	Vazhinka River—320 m below mouth of Chelmy River, Derevnja Kurpovo	29.7	1.3	0.17	29.5	27.2	26.9	26.1	25.3	23.3	21.6	20.6	17.7
28	72138	Muzhala River—Derevnja Grishino	4.44	2	0.3	4.31	4	3.67	3.5	3.33	2.86	2.53	2.32	1.96
29	72142	Yandeba River—Yandeba Station	3.12	1.5	0.28	3.06	2.84	2.62	2.5	2.37	2.05	1.8	1.65	1.39
30	72144	Oyat' River—Derevnja Mininskaya	7.16	2	0.25	7	6.57	6.11	5.87	5.63	4.98	4.5	4.2	3.67
31	72145	Oyat' River—Derevnja Timofeevskaya	17.6	1.5	0.27	17.2	17	15.7	15	14.3	12.4	11	10.1	7.59
32	72148	Oyat' River—Derevnja Akulova Gora	52.1	2	0.23	51.1	47.2	45.1	43.5	41.8	37.4	34.1	32	27.3

(continued)

Table 14 (continued)

No.	Post code	River-station	$\bar{Q}$ (m^3/c)	Cs/Cv	Cv	Mean annual discharge (m^3/s)								
						Probability (%)								
						50	60	70	75	80	90	95	97	99
33	72151	Nizhnjaa Kurba River—Derevnja Shondovichi	1.62	1.5	0.28	1.58	1.47	1.36	1.29	1.23	1.06	0.93	0.86	0.72
34	72152	Shoksha River—Derevnja Timofeevskaya	7.82	1	0.38	7.61	6.85	6.06	5.64	5.19	4.07	3.25	2.77	2
35	72154	Pasha River—Derevnja Porech'e	13.8	1.5	0.23	13.6	12.8	11.9	11.5	11	9.79	7.84	7.26	7.21
36	72155	Pasha River—ниже Derevnja Dubrovo	45.2	2	0.23	44.4	42	39.4	37	36.6	32.8	30	27.2	25.1
37	72156	Pasha River—Selo Chasovenskoye	62.3	2.5	0.25	60.7	56.9	53.1	51	47.9	43.5	39.5	37.1	32.8
38	72158	Yavosma River—Derevnja Ushakovo	7.48	1.5	0.25	7.35	6.88	6.39	6.13	5.85	5.14	4.59	4.26	3.67
39	72159	Tutoka River—Higher Derevnja Opoka	3.46	1.5	0.23	3.42	3.22	3.02	2.91	2.79	2.49	2.25	2.11	1.85
40	72160	Retesha River—Derevnja Nikulskoye	2.42	1.5	0.3	2.37	2.19	2.01	1.91	1.8	1.54	1.34	1.22	1.01
41	72161	Kapsha River—Derevnja Eremina Gora	16.6	2	0.26	16.2	15.1	14.1	13.5	12.9	11.4	10.2	9.52	7.28

(continued)

Table 14 (continued)

No.	Post code	River-station	$\bar{Q}$ (m^3/c)	Cs/Cv	Cv	Mean annual discharge (m^3/s)								
						Probability (%)								
						50	60	70	75	80	90	95	97	99
43	72169	Syas' River—Derevnja Yachnovo	52.4	1.5	0.25	51.5	47.2	44.8	43	41	36.1	32.2	29.9	25.7
44	72172	Volozhba River—Derevnja Pareevo	7.33	1.5	0.22	7.24	6.84	6.42	6.2	5.95	5.33	4.84	4.55	4.01
45	72173	Volozhba River—Derevnja Volozhba	12.0	1.5	0.25	11.8	11.1	10.3	9.92	9.48	7.37	7.5	6.98	6.04
46	72177	Lininka River—Derevnja Mosozevo	0.76	2	0.2	0.74	0.71	0.67	0.65	0.63	0.57	0.53	0.5	0.45
47	72179	Pjardomlja River—Derevnja Kondratovo	1.67	1.5	0.23	1.64	1.55	1.45	1.4	1.34	1.2	1.08	1.01	0.89
48	72188	Tikhvinka River—Derevnja Gorelukha	20.1	1.5	0.24	19.8	17.6	17.3	16.6	15.9	14	12.6	11.7	10.2
49	72192	Dymka River—Derevnja Domachevo	1.19	1.5	0.28	1.17	1.09	1	0.96	0.91	0.79	0.69	0.64	0.54
50	72195	Rybezhka River—Derevnja Rybezhka	2.23	2.5	0.25	2.17	2.04	1.91	1.84	1.77	1.58	1.44	1.35	1.21
51	72213	Volkhov River—VI GES Nizhnij B'ef	569	2	0.25	557	523	486	467	448	397	359	335	293
52	72233	Sharia River—Derevnja Gremjachevo	2.76	1	0.32	2.71	2.49	2.26	2.13	1.99	1.66	1.4	1.24	0.98

(continued)

Table 14 (continued)

No.	Post code	River-station	$\bar{Q}$ (m^3/c)	Cs/Cv	Cv	Mean annual discharge (m^3/s)								
						Probability (%)								
						50	60	70	75	80	90	95	97	99
53	72239	Pchevzha River—Derevnja Belaja	13.3	2.5	0.29	12.9	11.9	11	10.5	9.99	7.71	7.77	7.2	6.23
54	72246	Tigoda River—Ljuban' Station	4.01	1	0.3	3.95	3.65	3.33	3.16	2.97	2.51	2.15	1.93	1.55
55	72533	Saria River—Derevnja Dusjevo	1.06	2	0.36	1.02	0.93	0.83	0.79	0.74	0.61	0.53	0.47	0.38
56	72537	Nazia River—Nazia Station	1.45	2	0.32	1.4	1.28	1.17	1.11	1.05	0.89	0.78	0.71	0.59
57	72733	Slavjanka River—Derevnja Tjarlevo	0.68	3.5	0.24	0.66	0.62	0.59	0.57	0.55	0.5	0.46	0.44	0.4
58	72746	Morje River—cordon	4.15	2	0.23	4.08	3.85	3.61	3.48	3.36	3.01	2.75	2.59	2.3
59	72818	Neva River—Derevnja Novosaratovka	2500	3	0.16	2470	2370	2270	2220	2160	2020	1910	1840	1720

Only the very southern part of Lake Onega is on the territory of the Leningrad Region and adjoins the Podporozhsky District. The drainage basin of the lake is 51,500 km^2 and is almost entirely outside the Leningrad region. The lake water surface area with the islands is approximately 10,000 km^2, without islands—9700 km^2. The volume of the water mass is 295 km^3. The average depth of the lake is 31 m, and the maximum depth is 120 m. About 50 rivers and more than 1000 small watercourses flow into Onega. The Svir River flows out of the lake. The lake is an essential link in the Volga-Baltic and White Sea-Baltic waterways. The water level in the lake is regulated by the reservoir of Verkhne-Svirskaya hydroelectric power station (the area of the reservoir water surface is approximately 116 km^2).

3.4 The Basin of the Luga River and the Gulf of Finland Basin from the Northern Border of the Luga River Basin to the Southern Border of the Neva River Basin

The basin of the Luga River and the rivers of the Gulf of Finland basin (from the northern border of the Luga River basin to the southern border of the Neva River basin) has an area of about 16,800 km^2. It is located in the northwest of European Russia on the territory of four constituent entities of the Russian Federation—St. Petersburg, the Leningrad, Novgorod and Pskov regions. From the west the basin borders with the Narva River basin and from the east—with the Neva River basin. Rivers in the north of the basin flow into the Gulf of Finland (Fig. 4). The abundance of very small rivers is a distinguishing feature of the hydrographic network.

In total in the basin area there are 138 rivers longer than 10 km and 4764 shorter than 10 km. Abundance of very small rivers is a distinguish feature of the hydrographic network. Thus, streams shorter than 10 km make up 97% of the total number of rivers. The largest rivers are Luga (353 km) and Oredezh (192 km). Table 15 presents water resources of the main rivers of the basin in years of different water yield.

The rivers of the region are lowland rivers, characterized by mixed feeding with a predominance of snow. In an annual water level hydrograph, a spring flood, summer and winter low water and autumn floods are clearly distinguished.

The total number of reservoirs in the basin of the Luga River exceeds 1500; 99% of them have a surface area less than 1 km^2. Only six water reservoirs have a surface area more than 10 km^2, and one—more than 50 km^2 (see Table 16). Lakes percentage of the entire basin of the Luga River is 2.0%.

According to the State Water Register, where the largest and most significant reservoirs are included, there are 49 lakes on the territory of the whole water-resources region, of which 13 lakes are less than 1 km^2 and only five lakes are more than 10 km^2. Lakes are located through the territory of the region quite unevenly.

The total number of reservoirs in the Gulf of Finland basin (from the northern border of the Luga River basin to the southern border of the Neva River basin)

Fig. 4 A schematic map of the Luga River basin and the rivers of the Gulf of Finland basin (from the northern border of the Luga River basin to the southern border of the Neva River basin)

exceeds 750. Lakes percentage is insignificant and varies from 0.4 to 1.2%. The largest reservoir in this area is the Duderhofskoye Lake on the Duderhofka River in the Krasnoselsky District. Its area is 0.586 km^2.

3.5 The Narva River Basin

The Narva River basin covers an area of 56,200 km^2 and is located in the northwest of European Russia on the territory of two constituent entities of the Russian Federation—the Leningrad and Pskov regions, as well as in Estonia, Latvia and Belarus (Fig. 5). 63.5% of the basin area is located on the territory of Russia.

In the center of the basin, there is the Chudsko-Pskovskoye Lake, the fourth largest freshwater reservoir in Europe with water surface area of 3555 km^2. The Velikaya River (430 km long) flows into the lake from the south, its basin area is 25,200 km^2,

Table 15 Water resources of the main rivers of the basin in years of different water yield

Post code	River—Station	Basin area (km^2)	Average discharge (mm^3/s)	Unit discharge ($l/(s \times km^2)$)	Cv	Cs/Cv	Mean annual discharge (m^3/s)				
							Probability (%)				
							25	50	75	95	99
72564	Luga River—Derevnja Voronino	864	5.77	6.7	0.39	0.21	7.28	5.69	4.13	2.19	1.20
72566	Luga River—Luga City	2330	16.1	6.9	0.34	0.25	19.7	15.8	12.2	7.50	4.90
72569	Luga River—Tolmachevo Station	6350	44.7	7.0	0.30	0.14	53.6	44.5	35.4	23.3	16.0
72574	Luga River—Selo Kinoshi	12,500	94.3	7.5	0.28	0.11	112	93.8	75.5	50.7	35.7
72577	Luga River—Kingisepp City	12,800	102	8.0	0.31	0.3	122	100	79.5	53.2	37.8
72589	Oredezh River—Derevnja Morovino	3060	21.9	7.2	0.30	−0.03	26.3	21.9	17.5	11.2	6.73
72603	Yashhera River—Derevnja Dolgovka	581	4.69	8.1	0.34	0.12	5.78	4.66	3.54	2.07	1.27
72605	Lemovzha River—Derevnja Khotnezha	948	7.42	7.8	0.33	0.48	8.97	7.22	5.66	3.78	2.72

(continued)

Table 15 (continued)

Post code	River—Station	Basin area (km^2)	Average discharge (mm^3/s)	Unit discharge ($l/(s \times km^2)$)	Cv	Cs/Cv	Mean annual discharge (m^3/s)				
							Probability (%)				
							25	50	75	95	99
72609	Saba River—Derevnja Rajkovo	1280	9.93	7.8	0.33	0.31	12.1	9.75	7.58	4.86	3.32
72610	Vruda River—Derevnja Izvoz	544	6.15	11.3	0.30	0.39	7.32	6.02	4.84	3.36	2.50
72614	Dolgaya River—Derevnja Zagorie	777	6.66	8.6	0.34	0.10	8.18	6.63	5.05	2.99	1.85
72615	Samro River—Derevnja Usadishhe	129	0.906	7.0	0.32	0.21	1.10	0.896	0.702	0.449	0.304
72617	Hkrevitsa River—Selo Ivanovskoje	316	4.23	13.4	0.26	0.12	4.96	4.21	3.46	2.45	1.82
72546	Strelka River—Derevnja Oliki	94	1.72	18.3	0.25	0.23	2.00	1.70	1.42	1.05	0.819

(continued)

Table 15 (continued)

Post code	River—Station	Basin area (km²)	Average discharge (mm³/s)	Unit discharge (l/(s×km²))	Cv	Cs/Cv	Mean annual discharge (m³/s)				
							Probability (%)				
							25	50	75	95	99
72552	Kovashi River—Derevnja Lendovshhina	505	4.04	8.0	0.34	0.28	4.95	3.98	3.07	1.92	1.28
72559	Sista River—Derevnja Srednee Rajkovo	573	6.80	11.9	0.26	0.10	7.98	6.78	5.58	3.96	2.95

Table 16 Total number of lakes and reservoirs in the basin of the Luga River and their surface water areas

Reservoirs water surface intervals (km^2)	Number of reservoirs within intervals	Total area of reservoirs (km^2)	Ratio of the total reservoirs number (%)	Ratio of the total reservoirs area (%)	Number of lakes (reservoirs) with current and past stationary hydrological observations
Less 1.0	1547	40.8	99	15	1
1.0–10	20	49.6	1	19	6
10.1–50	5	117.4	0	44	5
50.1–100	1	59.6	0	22	–
Total	1573	267.4	100	100	12

what is 45% of the total Narva River basin. From the northern part of the lake, the Narva River (77 km long) flows out and continues to the Gulf of Finland of the Baltic Sea. In 20 km from the mouth of the river the Narva hydro-facility is constructed, which forms the Narva reservoir with an area of 191 km^2 and volume of 365 mln m^3, into which the Plyussa River flows from the south.

Within the RF, about 65% of the total runoff of the Narva River is formed, the rest is formed in the territory of Estonia. Most of the water resources of the basin belong to the Velikaya River (61%).

The Narva River has the second largest runoff among the rivers flowing into the Gulf of Finland. Streamflow of the river is regulated by the Pskovsko-Chudskoye Lake in the upper reach, and in the lower one—by the Narva reservoir. The water level in the lower reach (up to the city of Narva) is influenced by the Gulf of Finland. Highest levels are usually observed in August–September, lowest—in March-May. The height of surges at the mouth of the river is on average 0.2–0.4 m. In the upper reach, the highest water level is observed during the spring floods, in April–May, the lowest—in December–January. The rate of spring rise exceeds, on average, six times the decline rate.

The main tributaries are rivers Vtroya, Struga, Bolshaya Cheremukha, Borovnya, Mustayigi, Plusa, Kulgu, Tirvaye, Rosson. There are 39 tributaries shorter than 10 km, their total length is 113 km.

A characteristic hydrographic feature of the Narva River basin is a large number of lakes (about 4500). Most of them are relatively small, with the water surface area less than 1 km^2. Lakes are unevenly distributed within the basin, form numerous groups in certain river basins and at watersheds.

Lake Chudsko-Pskovskoye is the fourth largest freshwater reservoir in Europe and the largest European transboundary basin, as it is located on the border between Russia and Estonia. The total area of the lake is 3555 km^2, of which 1985 km^2 belongs to Russia and 1570 km^2 to Estonia. The reservoir is divided into three main parts:

Fig. 5 A schematic map of the Narva River basin

Lake Chudskoye (Peipsi), 2611 km^2, Lake Pskovskoye—708 km^2 and connecting them Lake Teploye—236 km^2.

Table 17 presents parameters of various probability annual runoff of the main rivers within Narva basin.

4 Water Resources and Hydrological Regime of Rivers in the Russian Part of the Baltic Sea Basin Under the Climate Change

Global warming of the modern climate is obvious and confirmed by observational data on the increase in the surface mean air and ocean temperature, a decrease in the

Table 17 Water resources of the main rivers within Narva basin in the years of various water yield

Post code	River—Station	Catchment area (km^2)	Average discharge (m^3/s)	Unit discharge ($l/(s\times km^2)$)	Annual runoff (km^3)	Cv	Cs/Cv	Mean annual discharge (m^3/s)						
								Probability (%)						
								1	5	25	50	75	95	99
41001	Narva River—Derevnja Vasknarva	47,800	330	6.90	10.4	0.27	1.5	554	483	404	389	325	218	174
41009	Narva River—Narva City	56,000	389	6.95	12.3	0.24	1.5	608	547	473	458	392	268	213
72623	Plyussa River—Selo Plyussa	1440	10.1	7.01	0.32	0.28	1.0	16.7	14.8	12.5	12.0	10.1	6.45	4.89
72625	Plyussa River—Derevnja Brod	5090	39.7	7.80	1.25	0.27	1.0	63.5	57.0	49	47.3	39.9	25.8	19.6
72627	Plyussa River—Slancy City	6340	50.8	8.00	1.60	0.27	1.0	77.7	68.7	57.7	55.5	46.1	28.8	21.4
72654	Velikaya River—Opochka City	3500	30.3	8.66	0.96	0.26	2.5	52	44.2	34.9	29.4	24.7	19.1	15.9
72660	Velikaya River—Derevnja Guytovo	13,400	97.6	7.28	3.08	0.31	2.5	185	153	115	95.3	76.0	52.7	39.1

(continued)

Table 17 (continued)

Post code	River—Station	Catchment area (km^2)	Average discharge (m^3/s)	Unit discharge ($l/(s\times km^2)$)	Annual runoff (km^3)	Cv	Cs/Cv	Mean annual discharge (m^3/s)						
								Probability (%)						
								1	5	25	50	75	95	99
72661	Velikaya River—Derevnja Pyatnovo	20,000	139	6.95	4.38	0.31	2.5	250	213	174	165	135	86.8	68.0
72682	Sorotj River—Derevnja Osinkino	3170	23.6	7.44	0.74	0.34	2.0	42.7	37.2	30.5	29.1	23.5	13.5	9.52
72727	Pskova River—Derevnja Chernyakovitsy	914	8.83	9.66	0.28	0.28	1.0	14.7	13.1	11.2	10.7	8.99	5.69	4.26

area of snow cover and sea ice, and the global mean sea level rise. Climatic changes over the territory of the Russian Federation are documented in the annual reports of Roshydromet (see the issue of 2016 [20]), which are available in the Roshydromet website. The territory of the Russian Federation seems to be more vulnerable to the current climate change in comparison to the Northern Hemisphere and the Globe as a whole.

The beginning of significant climate warming over the territory of the Russian Federation can be considered the late 1970s–early 1980s. According to the calculations presented in [20], the linear trend in the growth of surface mean annual air temperature Over the RF is 0.43 °C a decade, 1976–2012, which is more than 2.5 times higher than the rate of global warming at 0.17 °C a decade).

An increase in precipitation over the RF is less obvious than in air temperature due to due to more complex mechanisms for their formation. It is important to note that in regions with the lowest water availability, there is also a decrease in precipitation. This circumstance may have a negative impact on economic activity in these regions in the future.

An increase in surface temperature and a change in the moisture regime leads to changes in runoff in the territory of the Russian Federation. Since 1981, there has been a stable increase in water resources throughout the entire Russian Federation, as well as an increase in the inter-annual variability of water resources.

At the same time, along with the increase in inter-annual variability of water resources, for many rivers statistically significant positive trends in runoff during the winter and summer-autumn low water periods have been revealed [21]. The «synchronous» increase in the low-level runoff (especially in winter) and the trend rate, observed during the past decades throughout vast territories, have no analogues over the entire period of instrumental observations.

As for the Baltic Sea region, climate change here is similar to the change over the territory of the Russian Federation. Change of the mean annual air temperature averaged over 4 meteorological stations located in the Baltic Sea basin (Vyborg, St. Petersburg, Pskov and Kaliningrad) for the period 1948–2015 is presented in Fig. 6.

As can be seen from the graph, there is a stable trend for an increase in the surface air temperature in the research basin over the last decades. If we compare the mean annual temperature for 1981–2015—the period of strongly marked climatic changes, with the previous period of 1948–1980, then the change will be just over 1 °C.

According to the comprehensive studies carried out by the SHI specialists for the entire territory of the Russian Federation [21], the following changes in renewable water resources occur in the basin of the Baltic Sea and in the adjacent areas:

1. Water resources significantly change over time. Annual runoff has increased for most rivers in the European territory of Russia (ETR), including the Baltic Sea basin. The most increase (by 10–20% or more) is revealed for the Narva and Western Dvina rivers.
2. For the rivers of the Baltic Sea basin, the spring runoff has decreased by 10–30% in recent decades.

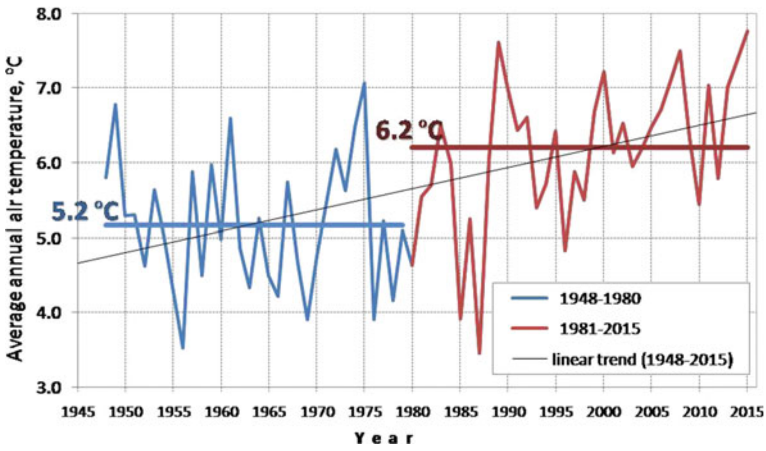

Fig. 6 Long-term dynamics of the average annual air temperature in the Baltic Sea basin

3. A decreased role of a spring flood in the formation of annual river runoff, a reduction in the maximum and an increase in the minimum water discharge are the main features of the change in the intra-annual distribution of water flow within a large part of the ETR. The Eastern European type water regime, typical for the rivers of the region and characterized with one annual runoff maximum, is transformed into a regime, characterized with a multiple peaks hydrograph during maximum runoff period. Previously, such changes in the water regime did not occur due to the dominant role of the spring flood in annual runoff formation [6, 22–24].
4. A statistically significant trend in the flood beginning and in the peak discharge occurrence toward earlier dates, but in the ending of floods—toward later dates,—has been revealed for the upper reaches of large and middle river basins, the runoff of which forms within the ETR. The flood duration has increased by approximately 10–20 days, depending on the area of a river basin and its geographical location [22, 25].
5. Increase in winter runoff is typical for the nearly entire country. The winter runoff in the basins of the western ETR rivers has increased by 50–120%. It has been established that an increase in winter temperature has led to a decrease in the depth of freezing of the soil and an increase in its drainage properties, an increase in the number and duration of winter thaws, during which snowmelt and water loss from the snow cover occur, causing replenish of groundwater and surface runoff formation. As a result, rivers winter runoff increases, the snow cover water content decreases by the beginning of spring, what creates conditions for the decrease in the spring flood runoff.
6. An important feature of the current changes is a sharp increase in the variability of winter river runoff comparing to the preceding multi-year period: it is extremely high in some years and very low in others. This process is most clearly seen in

the central and western parts of the ETR. In the Baltic Sea basin, this process is the most common for the Velikaya river.

7. Based on the analysis of changes in maximum runoff regime, driven with climate impact, it was found that for the ETR river basins, where the spring flood has decreased, the maximum water discharge has also decreased significantly [26–28]. Reduction of the maximum runoff by 20–40% is typical for the majority of rivers in the south-western and western parts of the ETR, where the maximum discharges are formed during the spring flood period.
8. Water availability at the basins of the North-West of Russia, where the Baltic basin is located, remains quite high—up to 20 thousand m^3/person.

5 Probable Changes in Water Resources for the Near Future

Recent assessments of possible changes in river runoff in Russia in the 21st century were based on the results of Atmosphere-Ocean General Circulation Models (AOGCM), which participated in the CMIP3 [29] and CMIP5 [30] comparison programs and were used in the 4th and 5thIPCC assessment reports [31, 32], are given in [21, 33–40].

In accordance with [35, 39], in the coming decades, there is no reason to expect any significant changes in the water resources of the main rivers of the country as a result of climate warming. Most probably an insignificant (within 5%) increase in annual runoff, which is within its natural variability.

Estimates of annual runoff changes under climate warming, carried out for the mid-21st century from the ensemble results of AOGCM [37], have shown that in the northern part of the East European Plain the water resources will remain practically unchanged.

SHI has also performed an analysis of runoff estimation results, obtained from 35 hydrodynamic models of the CMIP5 project applied to the territory of Russia [39, 41]. The analysis has proved that 24 models give realistic results of annual runoff. Verification criterion was the correspondence between modeled and actual annual runoff depths for the largest rivers of the country for 1981–2000. This allowed assessing possible future changes in water resources of the country in relation to the estimates for the base period.

Calculations were made for the forecast periods of 2021–2040 and 2041–2060 years in relation to the period of 1981–2000, which was chosen as the base one. Calculations were made both for the moderately aggressive scenario RCP4.5, and for the «hard» scenario RCP8.5. An approach based on ensemble averaging was used. The results were averaged over 20-year periods and compared with the corresponding values for the period 1981–2000. The obtained results made it possible to distinguish the following main features in the distribution of predicted changes in river runoff across the territory of the Russian Federation, including the Baltic Sea basin.

In most of the country, we should expect an increase in annual runoff, the most significant in the east and northeast. The only exception is the basins of the rivers of the North Caucasus, as well as the southern part of the European territory of the country, including the entire Don river basin. The maximum increase is expected for the rivers of the Far East of the country and in the basins of Yana, Indigirka, Kolyma and Kamchatka. The increase in the annual runoff in the north of the Asian part of the Russian Federation will occur more intensively than in its southern parts. By the middle of the century, changes in the annual runoff for both scenarios will only increase. However, their main spatial features will remain the same: a further decrease in annual runoff of the Don River is expected in the lower reaches of the Volga and Ural rivers. Its increase in the northeast and east of Russia will be more pronounced.

In this case, the simulated values of the changes up to 2030, obtained for the two scenarios considered (RCP4.5 and RCP8.5), almost do not differ both in magnitude and in direction. It should be noted that in most cases the values of the resulting changes in annual runoff depths for the future do not exceed the intermodel variability, calculated for the ensemble models. This fact indicates that the expected changes in annual runoff are, in most cases, insignificant and do not exceed the calculation errors.

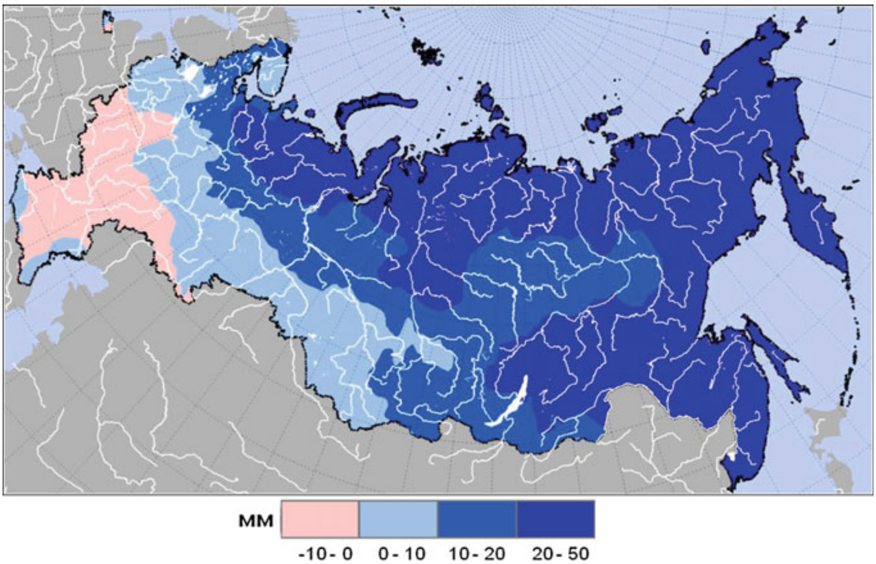

Fig. 7 Ensemble of 24 models (CMIP-5). Scenario RCP4.5. Changes in annual runoff depths across Russia during the period 2041–2060 to the period 1981–2000

Figure 7 shows estimates of changes in annual runoff depths across Russia in the middle of the 21st century in relation to 1981–2000, obtained from ensemble data from 24 models for the RCP4.5 scenario.

As for the Baltic Sea basin, according to the results obtained, in the coming decades, there is no reason to expect any significant changes in annual runoff of major rivers in this territory as a result of climate change. Here, minor changes in annual runoff are most probably, within its natural variability.

According to the calculations, insignificant future changes in the runoff will occur in the Neva river basin (its water resources make up more than 50% of the water resources of the Baltic Sea basin) (Fig. 8). Moreover, if under the RCP4.5 scenario a slight gradual increase in water resources is projected, then under the RCP8.5 scenario the changes are more clear: practically no changes to the projection of the nearest perspective and a more significant increase, compared to the RCP4.5 scenario, for the middle of the century.

It should be noted that the further increase in winter temperatures, predicted by most climatic models, allows us to assume with a high degree of certainty that the increased winter runoff of rivers, observed from the late 1970s to the early 1980s, will continue in the coming decades. At the same time, the relative share of spring runoff in the annual runoff will decrease.

6 Priority Research Areas

On 19–21 November 2013, the VII All-Russian Hydrological Congress was held in St. Petersburg. It was organized by Roshydromet in cooperation with interested organizations and federal executive authorities in accordance with the decree of the Government of the Russian Federation No. 1047-p of June 21, 2013.

Since 1924, when the first All-Russian Hydrological Congress was held, the hydrological congresses have been the platform for the discussion on the current state of hydrological science and practice, and setting priorities for their development in order to address the challenges, faced by the country.

In the Russian Federation in the recent years, a number of important federal legal acts have been adopted that determine the priority role of water resources in ensuring sustainable social and economic development of the country. They formulated the main tasks for solving water resource problems: guaranteed supply of the population and sectors of the economy with water of the required quality, protecting people and objects of the economy from dangerous hydrological phenomena, ensuring sustainable operation of water infrastructure facilities, restoring aquatic ecosystems and recreational potential of water bodies.

Meeting the set tasks requires significant investments and involves a number of risks, including those caused by the uncertainty of future climate change and the spatio-temporal distribution of water resources.

The VII Hydrological Congress made a conclusion: in the Russian Federation, hydrological regime and state of water bodies will continue changing under the

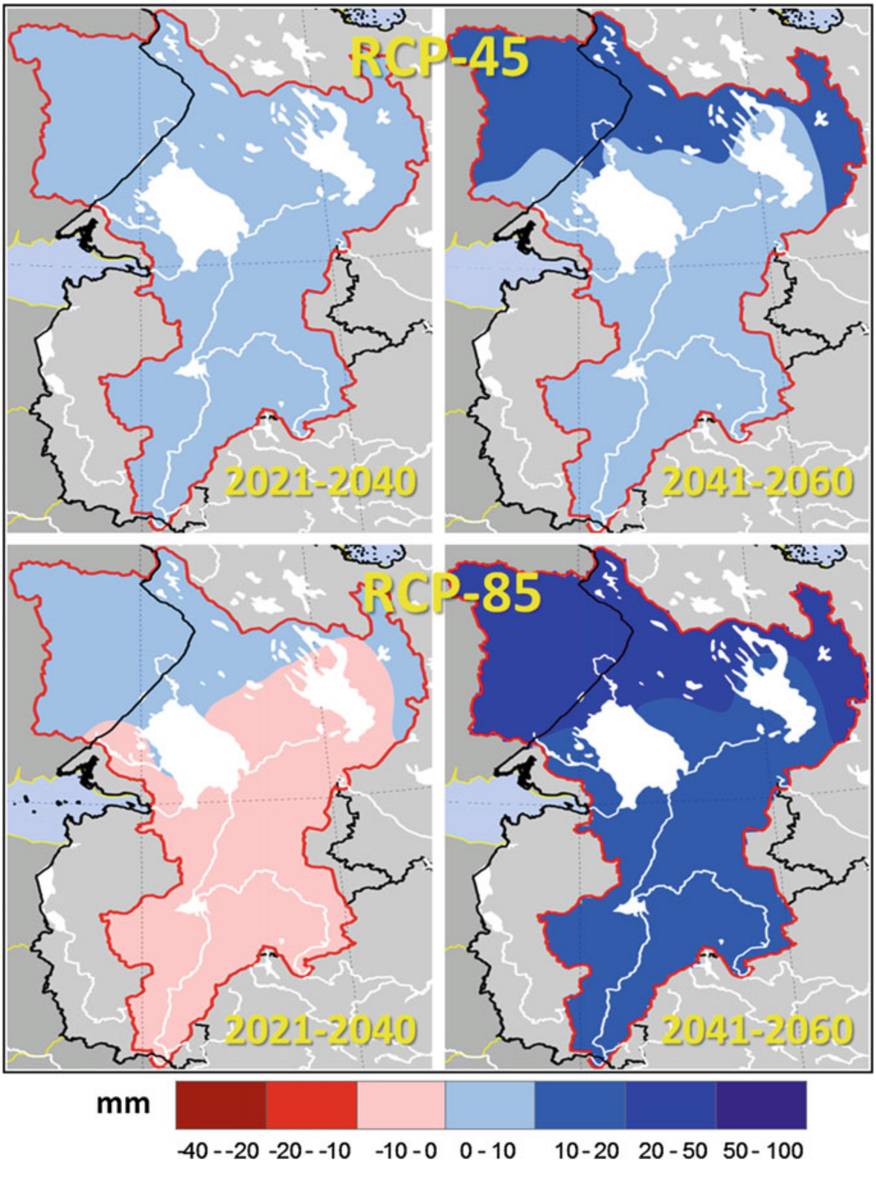

Fig. 8 Changes in annual runoff depths (mm) for the periods of 2021–2040 and 2041–2060 to the period 1980–2000 across the basin of the Neva River. An ensemble of 24 models (CMIP-5)

influence of global and regional changes in the climate system and anthropogenic factors [42].

The analysis of studies on the range of problems of research on the country's water resources leads to the following conclusions regarding the prospects for their solution:

1. There is an urgent need to prepare territorial generalizations on the characteristics of the hydrological regime of the country's rivers due to significant climatic and anthropogenic changes in the water runoff and its intra-annual distribution. The current stage of the country's development stipulates the fulfillment of this work consistently, for the largest river basins, the entities of the Russian Federation and the Federal Districts, taking into account the results of implementing modern Federal targeted programs. The result of these studies may be the preparation of a modern edition of the monograph «Surface Water Resources».
2. To improve the methods of hydrological calculations and forecasts under changing the climate and economic activities, it is necessary to expand research in the field of genetic hydrology—the science of causes and mechanisms of changes in surface water runoff and its intra-annual distribution. This task inevitably involves the wider use of meteorological and hydro-geological information for hydrological research, as well as data from the water balance stations network, which needs to be modernized and expanded, and the program of observation—updated.
3. A promising and relevant topic of hydrological research in the coming years is the development of technologies for estimating specific water discharge for transboundary and border rivers of Russia under deficit or lack of hydrological monitoring data.
4. It seems important to conduct periodic analysis of correspondence between water runoff and withdrawal for economic needs, especially in years of different water availability. Assessments of «water stress» are necessary to obtain up-to-date information on anthropogenic pressure on water resources in regions of the Russian Federation.
5. It is necessary to intensify research in the field of river flow theory, in which, along with the theory of formation and variation of water runoff, scientific concepts should be developed on its other components (sediment, chemicals, living matter (plankton), heat flow). Without taking into account the joint changes in all components of river runoff, it is impossible to make progress in the theory of dangerous hydrological phenomena, in understanding mechanisms, driving quality formation.
6. Special attention should be paid to development of scenario forecasts of water resources future state, taking into account the impact of a number of climatic and anthropogenic factors and providing, based on them, recommendations for the most rational, environmentally sound water use and implementation of adaptation measures. Scientific research in this area should focus on development of global and regional AOGCMs and hydrological cycle models.

7 Conclusions

The Russian part of the Baltic Sea basin is a very complex hydrological object in terms of its geographical location, distribution of water resources, human impact and also due to specific features of the regional socio-economic development. This chapter is devoted to the assessment of renewable water resources, their current and possible changes, carried out mainly at the State Hydrological Institute. Starting with the publication of the monograph «Water Resources and Water Balance of the Soviet Union» (1967), in which the comprehensive assessment of the water resources and water balance of the Baltic Sea basin was carried out for the first time, and ending with generalized and systematized materials presented in the Schemes as well as the studies of probable changes in water resources in the near future.

In the chapter, the priority research areas, announced at the last VII All-Russian Hydrological Congress, were considered. The Congress is a platform for discussing the most challenging problems of hydrological science and practice. It develops recommendations for consolidation of the country's scientific, technical and production potential for solving problems in the field of hydrology and water management complex, interaction between scientific communities at the national and international levels. These priority directions were formulated according to the problems of the national scale water resources, and are relevant for such complex and large basins as the Russian part of the Baltic Sea basin.

The chapter uses GIS of water bodies (basins) in the Russian part of the Baltic Sea basin, created at the State Hydrological Institute as a part of development of the Schemes for the integrated use and protection of water bodies. During the preparation of this chapter, GIS were especially partially translated into English.

It is necessary to say separately about the predictive assessments of possible changes of river water resources in the future. The estimations and description of water resources, presented in this chapter, are results of collective efforts of the SHI' experts, but the materials on forecasting estimations are one of the areas of scientific research of the authors. Initially completed studies for the entire territory of the Russian Federation, allow us to make conclusions for the investigated basin. The authors wish to note that this approach is not a standard and it should be considered as one of the possible alternative methods for assessing future changes of water resources.

8 Recommendations

The materials presented in this chapter are intended for wide use by hydrologists from research and educational institutions, primarily from the countries of the Baltic region. The authors tried chronologically, as far as the permissible volume of the chapter allows, to tell about the history of analysis and quantitative assessments of water resources (renewable) and water balance of the basin investigated, carried out by specialists firstly in the Soviet Union and then in the Russian Federation. Along with the historical data, the most generalized and systematized data on the water resources of the Russian part of the Baltic Sea basin, presented in the Schemes, are given. Schemes will be described in more detail in the next chapter. Problems of water resources and their regulation have been among the most important world scientific and technical problems. The authors hope that the information, prepared by them and presented in this and in the following chapter, will promote development of cooperation between scientists and other stakeholders from the Baltic region in the field of water resources and their regulation.

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Schemes of Integrated Use and Protection of Water Bodies in the Russian Part of the Baltic Sea Basin as a Basis for Water Resources Management

Mikhail V. Georgievsky, Vladimir V. Kostko and Maria A. Mamaeva

Abstract The chapter deals with the legal and methodological support for the use of water resources of the Russian Federation in the frame of development and implementation of the Schemes of integrated use and protection of water bodies (Schemes), including development standards for the permissible impact on water bodies (PIWBs), in accordance with the Water Code of Russia. The Chapter describes the regulatory and legal provision of Schemes (Water Code and Water Strategy of the Russian Federation); basin management principle, applied in Russia in the field of use and protection of water bodies; content and structure of Schemes. Schemes and PIW are listed, which were developed and approved for basins of rivers flowing into the Baltic Sea from the territory of Russia.

Keywords Schemes of integrated use and protection of water bodies · Standards of permissible impact on water bodies · Water strategy of Russia · Baltic Sea Basin · Water resources management

1 Introduction

Schemes of integrated use and protection of water bodies (Schemes), according to the idea of those who proposed to introduce them as a norm in the Water Code, had to replace the schemes for the integrated use and protection of water resources, previously developed in the Soviet Union and later in Russia.

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They were developed in the 1970s and corresponded to the principles of the planned economy of the Soviet Union, as they represented development plans for river basins over a twenty-year period. At the same time, they had to serve as pre-project materials for the development of riverside territories for implementing national economic, environmental and flood protection activities. Development of these schemes corresponded to the general paradigm of scientific and technological progress, which existed in the USSR in the 1970–80s. As applied to the water management complex of the country, the schemes, according to the beliefs of that time, met the tasks of scientific and technological progress.

Development of Schemes for the integrated use and protection of water resources was carried out by numerous staff of Water Management Institutions (more than 60 Institutions). These Schemes, like all other planning documents at that time, had to be approved at the government level, which meant coordinating them practically with all departments.

None of these Schemes was approved during the entire development period. Much of the information has been destroyed over time, and the materials have not been claimed since the collapse of the USSR [1, 2].

The Schemes for the territory of the Russian Federation had been developed since the issue of the RF government decree of December 30, 2006, No. 883 «On the procedure for developing, approving and implementing Schemes of the integrated use and protection of water bodies, and introducing changes to these schemes».

The Water Strategy of the Russian Federation for the period until 2020 [3] indicates that the Schemes are the main instrument for ensuring the integrated use of water bodies, and their development is one of the priority areas for improving public administration.

The purpose of this chapter is to familiarize the reader, first of all, not speaking Russian, with the history of development, regulatory and methodological support, content and structure of the Schemes, including PIWBs, on the example of the Russian territory of the Baltic Sea basin.

All Schemes and PIWBs listed in this Chapter are available for free download (though only in Russian) and can be used for further more detailed study.

2 The Water Code and the Water Strategy of the Russian Federation as the Legal Framework for the Schemes

Over the past 15 years, in the Russian Federation the efforts of the state to address priority problems in the field of hydrology and water management complex have significantly increased. A number of important federal legal acts and federal programs were adopted that determine the priority role of water resources in ensuring the sustainable socio-economic development of the country. They formulate the main tasks for solving water resources problems: guaranteed to provide the population and sectors of the economy with water of the required quality, protecting people and objects of the economy from dangerous hydrological phenomena, ensuring sustainable operation of water infrastructure facilities, restoring aquatic ecosystems and recreational potential of water bodies.

These legal acts and federal programs include:

- Water Code of the Russian Federation (2006) [4];
- Water Strategy of the Russian Federation for the period up to 2020 (2009);
- Climate doctrine of the Russian Federation (2009) [5];
- The strategy of activities in the field of hydrometeorology and related fields for the period up to 2030 (taking into account aspects of climate change) (2010) [6];
- Federal target program «Development of the water management complex of the Russian Federation in 2012–2020» (2012) [7].

The most significant and important documents, considering water resources management, are the Water Code and the Water Strategy of the Russian Federation.

The Water Code of the Russian Federation is a basic normative legal act that regulates, in conjunction with civil law, water and property relations, associated with circulation of water bodies and is the basic foundation of regulation relations in water use in Russia. The Water Code of the RF came into effect on January 1, 2007. Since then, the 1995 Water Code of the Russian Federation was declared invalid, as well as recognized legislative acts of the USSR that contained norms regulating water relations.

This Code defines norms of regulation relations during use and protection of water bodies and such concepts as water area, water management, water body, water regime, water fund, water disposal, water user and others.

The Water Code of the Russian Federation is based on the following basic principles:

- importance of water bodies as the basis for human life and activities;
- priority of water bodies protection over their use;
- conservation of specially protected water bodies, use of which is restricted or prohibited by federal laws;
- target use of water bodies;
- priority of using water bodies for drinking and domestic water supply over other purposes, etc.

The Water Code of the Russian Federation consists of 7 chapters and 69 articles. The Water Code establishes property rights and other rights to water object, conditions, terms and content of water use agreements, objectives and types of water use, duties and rights of water users, fundamentals of water bodies protection, types of liability for violation of water legislation and other provisions directly related to water bodies use.

The Water Code of the Russian Federation has established a close link between five articles, aimed at creating Schemes of integrated use and protection of water bodies:

- Article 33, considering the Schemes to be the basis for implementing water management and water protection measures for water bodies, located within river basins;
- Article 32, according to which hydrographic and water management zoning of the RF territory should be carried out to create Schemes, and that the Schemes shall be established for hydrographic units;
- Article 30, which reads that the data of water bodies monitoring should be included in the State Water Register;
- Article 31, according to which the information basis of the Schemes is the State Water Register;
- Article 35, defining the procedure for the development of water quality targets for water bodies and standards for the permissible impact on them, which are an integral part of the Schemes.

The Water Strategy of the Russian Federation for the period until 2020, adopted in 2009, is a strategic planning document that defines the main activities for the development of the water management complex in Russia. The strategy is designed to provide water resources for the implementation of the Concept for the long-term socio-economic development of the Russian Federation until 2020 (https://policy.asiapacificenergy.org/node/869).

The Strategy defines the main activities for the development of the water management complex in Russia in order to ensure sustainable water use, water bodies protection, protection from negative water impact, as well as activities to form and implement Russia's competitive advantages in the water resources area. It also establishes basic principles of state policy in the field of use and protection of water bodies; considers making and implementing management decisions for aquatic ecosystems conservation that provide the maximum socio-economic benefits and create conditions for effective interaction between participants of water relations.

Responsible for the implementation of the Strategy are the following Ministries of Russia: the Ministry of Natural Resources, the Ministry of Economic Development, the Ministry of Regional Development, the Ministry of Agriculture, the Ministry of Transport, the Ministry of Energy and the Ministry of Industry and Trade with the participation of other interested federal executive bodies (http://government.ru/en/ministries/).

Despite the fact that at the time of the adoption of the Strategy the Russian Federation was one of the most well provided with water resources states, its water sector faced a number of problems that adversely affected the pace of its socio-economic development. Among the problems of the water management complex of Russia are: irrational use of water resources, the negative impact of human economic activities on them and current risks of negative water impact on population and economic entities, insufficient scientific and technical and human resourcing of the water sector. Besides, state monitoring of water bodies is outdated and the system of public management of water bodies use and protection requires further development.

For solving key problems, the following directions for the Strategy implementation have been identified:

- guaranteed provision of population and sectors of the economy with water resources;
- protection and restoration of water bodies and ensuring protection from the negative impact of water;
- improvement of public management;
- development of the system of water bodies state monitoring;
- maintenance of innovative development of scientific and technical and technological base;
- development of human resources in water management complex.

Priority directions of improving public management, within the framework of the Water Strategy, is the implementation of the following mechanisms envisaged by the Water Code of the Russian Federation:

- development of Schemes of integrated use and protection of water bodies (Schemes);
- development of standards for the permissible impact on water bodies, taking into account regional characteristics and individual characteristics of water bodies (PIW).

3 Schemes of Integrated Use and Protection of Water Bodies (Schemes)

As follows from the Water Code, Schemes include systematized materials on the status of water bodies and their use and are the basis for implementing activities on water management and protection of water bodies located within river basins.

Schemes are developed to:

- determine the permissible anthropogenic load on water bodies;
- identify water demand in the future;
- ensure the protection of water bodies;
- determine the main activities for preventing negative impacts of water.

Schemes for each river basin are developed and approved, after consideration by Basin Councils, by the federal executive body authorized by the Government of the Russian Federation.

Schemes are mandatory for public authorities, local governments.

The Government of the Russian Federation establishes the procedure for developing, approving and implementing Schemes, introducing changes to these Schemes.

In accordance with the Decree of the Government of the Russian Federation «On the procedure for developing, approving and implementing schemes for the integrated use and protection of water bodies, introducing changes to these schemes»

[8], Schemes are developed by the Federal Water Resources Agency according to the Rules approved by this Decree, «Methodological Guidelines on the development of schemes for the integrated use and protection of water bodies» (Methodological Guidelines) [9] and taking into account the recommendations of the Basin Councils. Schemes are approved by the Federal Water Resources Agency if there is a positive conclusion of the state ecological expertise.

Schemes are developed for a period of at least 10 years and include quantitative and qualitative indicators of the water resources status and water use parameters for a river basin, sub-basins, water management areas and territories of the constituent entities of the Russian Federation.

The following Ministries of the Russian Federation are involved in the development of Schemes: the Ministries of Economic Development, Health, Construction, Housing and Utilities, Agriculture. In the process are also involved the Federal Services for Hydrometeorology and Environmental Monitoring, for Supervision of Natural Resources, other interested Federal agencies of executive authority and bodies of state power of subjects of the RF.

The development of Schemes takes into account the long-, medium- and short-term economic and social development forecasts for sectors of the economy, by regions; and, for transboundary water bodies—the provisions of international treaties of the Russian Federation in the field of joint use and protection of transboundary water bodies.

Schemes establish:

- target water quality indicators in water bodies, characterizing the composition and concentration of chemicals, microorganisms and other water quality indicators in water bodies, which are planned to be achieved after the completion of the water protection and water management measures provided by Schemes. Target indicators of water quality are developed by the Federal Agency for Water Resources with the participation of the Federal Agency for Fisheries, the Federal Service for Hydrometeorology and Environmental Monitoring and the Federal Service for Supervision of Natural Resources. During this process, natural features of each river basin or its part and the conditions of the intended use of water bodies or their parts, located within a relevant river basin, are taking into account;
- a list of water management and protection measures for water bodies, aimed at preservation and restoration of them, ensuring the sustainable functioning of water management systems within a river basin and achievement of water quality targets for water bodies. The list is developed by the Federal Water Resources Agency with the participation of interested Federal Executive authorities and public authorities of the relevant subjects of the Russian Federation;
- water management balances for river basins, sub-basins and water-resource regions under various water yield, calculated by the Federal Water Resources Agency in accordance with the methodology [10], approved by the Ministry of Natural Resources and Ecology of the Russian Federation;

– water abstraction (withdrawal) limits (limit volumes) from a water body and wastewater discharge limits (limit volumes) corresponding to the quality standards, determined in accordance with water management balances for river basins, sub-basins and water-resource regions under various water yield. Also, are taken into consideration permissible impacts (permissible total impact from all sources on a water body or its part), which are set [11, 12] according to the established procedure and approved by the Federal Water Resources Agency;
– quotas for water abstraction (withdrawal) from a water body and for wastewater discharge. They correspond to the quality standards, assigned for each subject of the RF and approved by the Federal Water Resources Agency as part of water abstraction (withdrawal) limits (limit volumes) from a water body and wastewater discharge limits (limit volumes) within river basins, sub-basins and water-resource regions;
– the main targets for reducing the negative impact of floods and other negative water impacts characterizing the reduction of human health and environmental damage, financial losses including violations of human living conditions from negative impacts of water. Besides, activities aimed at achieving these targets are listed, including measures for preventing floods and reducing the risk of natural disaster situations in specific river basins, ensuring the safe operation of water management systems within river basins, and protecting from water negative impacts in certain areas and facilities. The indicated targets and measures are developed by the Federal Water Resources Agency with the participation of interested Federal Executive bodies and public authorities of the relevant subjects of the RF;
– estimated funding necessary for the implementation of Schemes and calculated on the basis of funding required for the development of water management balances and the implementation of water management activities and water bodies protection measures, as well as activities aimed at reducing the negative impact of water.

Schemes are implemented by state authorities and local self-governments through planning and implementation of water management activities and water bodies protection measures aimed at meeting the current and future water demand, the systematic reduction of human impact on water bodies, ensuring rational use and protection of them, as well as prevention of negative impact of water.

The scheme of regulatory and methodological support of Schemes is shown in Fig. 1.

4 Norms of Permissible Impact on Water Bodies (PIWBs) and Water Quality Targets for Water Bodies

In accordance with the Water Code, PIWBs are developed to maintain surface and ground water at the status that meets the requirements of legislation [11, 12].

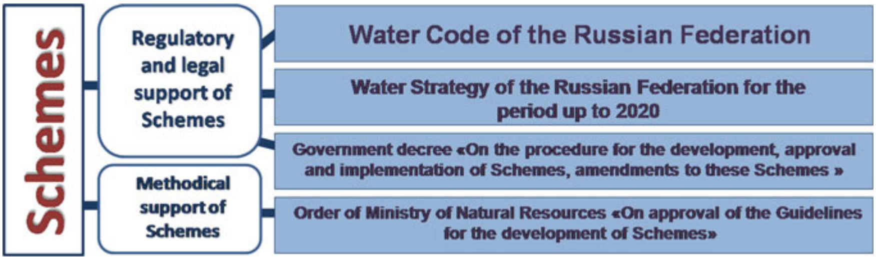

Fig. 1 Diagram of regulatory and methodological support of schemes

PIWBs are developed on the basis of the maximum permissible concentrations of chemicals, radioactive substances, microorganisms and other water quality indicators.

The amount of substances and microorganisms contained in wastewater discharges into water bodies, including drainage water, should not exceed the established standards for the permissible impact on water bodies.

PIWBs are intended to establish safe contaminants levels, as well as other indicators characterizing the impact on water bodies, taking into account the natural and climatic features of water bodies in the region and man-made environment that has developed as a result of economic activities.

PIWBs are determined based on the purpose of the water body. The purpose of the water body or its site (or priority use of the water body) is determined by the current legislation. The main territorial unit when developing standards for the permissible impact on water bodies is a water-resource region. Norms of permissible impact on water bodies approved in accordance with the established procedure are used to solve issues related, in particular, to the development of Schemes, water management balances, and planning of water management and water protection measures.

PIWBs are established taking into account the water body and its ecological system status on the basis of water quality standards for the water body and are developed for the following types of impacts:

- input of chemical and suspended substances;
- input of radioactive substances;
- input of microorganisms;
- input of heat;
- water discharge;
- water abstraction (withdrawal);
- use of water spaces for construction and placement of berths, stationary and (or) floating platforms, artificial islands and other structures;
- changes in the water regime when using water bodies for exploration and mining.

PIWBs are developed for water-resource regions that are or may be subjected to significant loads over the next 5 years as a result of economic and other activities on the relevant basin, including the water space of a water body.

The list of standardized types of impacts on water bodies is specified for a particular water body and/or water-resource regions taking into account the current status of the water body, the characteristics of the current impact on it and the long-term development plans for the territory.

PIWBs are established for extreme water conditions at which the standardized type of impact most strongly affects the water body.

PIWBs are established for at least 15 years, based on the status of each specific water body identified during the development of PIW. The adjustment of PIW is carried out no more than once every 5 years based on the results of state control and supervision over the use and protection of water bodies.

Water quality targets for water bodies in each river basin or its part are developed by Federal Executive Authorities, authorized by the Government of the Russian Federation, taking into account natural features of the river basin as well as the conditions for the targeted use of water bodies located within the river basin [8].

5 Basin Management Principle for Use and Protection of Water Bodies

Features of the scope of public administration in the field of water use and protection are determined by the particular nature of waters as an environment object. A distinctive feature of public administration in this area is the principle of basin management of water use and protection.

A Basin District is the main unit of management in the field of use and protection of water bodies in the Russian Federation. It consists of river basins and associated ground water bodies and seas. Basin Districts in Russia appeared in 2006 due to the adoption of the new Water Code. In accordance with Article 28 of the Water Code, twenty Basin Districts are established in the Russian Federation:

1. **Baltic Basin District**;
2. Barents-White Sea Basin District;
3. Dvina-Pechora Basin District;
4. Dnieper Basin District;
5. Don Basin District;
6. Kuban Basin District;
7. West-Caspian Basin District;
8. Upper Volga Basin District;
9. Oka Basin District;
10. Kama Basin District;
11. Lower Volga Basin District;
12. Ural Basin District;
13. Upper Ob Basin District;
14. Irtysh Basin District;
15. Lower Ob Basin District;

16. Angara-Baikal Basin District;
17. Yenisei Basin District;
18. Lena Basin District;
19. Anadyr-Colyma Basin District;
20. Amur Basin District;
21. Crimea Basin District (new).

The basin districts are divided into water-resource regions. A water-resource region, according to the Water Code of Russia, is a part of a river basin, which characteristics allow setting limits for the abstraction (withdrawal) of water resources from the water body and other parameters for the water body use (water use). In Russia, each water-resource region has its own 12-digit code containing 9 digits and 3 dividing points. The first two digits encode the basin district, the third and fourth define the basin code, the sixth and seventh are optional sub-basin designation, the latter code the water-resource regions itself. **The Baltic Basin District** consists of the following water-resource regions:

01.01.00.001	The Neman River
01.01.00.002	The Pregolya River
01.01.00.003	Rivers of the Baltic Sea basin in Kaliningrad region without the Neman and Pregolya Rivers
01.03.00.001	The Velikaya River from the source to the Guytovo gauging station
01.03.00.002	The Velikaya River from the Guytovo gauging station to the mouth
01.03.00.003	The basin of Lake Chudsko-Pskovskoye without the Velikaya River
01.03.00.004	The Narva River
01.03.00.005	The Luga River from the source to the Tolmachevo gauging station
01.03.00.006	The Luga River from the Tolmachevo gauging station to the mouth
01.03.00.007	Rivers of Gulf of Finland basin from the northern border of the Luga basin to the southern border of the Neva basin
01.04.01.001	The Shuya River
01.04.01.002	The Suna River
01.04.01.003	Lake Vodlozero basin
01.04.01.004	The Vodla River
01.04.01.005	The Vytegra River
01.04.01.006	Lake Onega Basin without the Shuya, Suna, Vodla and Vytegra Rivers
01.04.01.007	The Svir River from the source to the Nizhnesvirsky hydroelectric complex
01.04.01.008	The Svir River from the Nizhnesvirsky hydroelectric complex to the mouth
01.04.02.001	The Shlina River from the Nizhnesvirsky hydroelectric complex to the mouth
01.04.02.002	The Msta River without the Shlina River from the source to the Vyshnevolotsky hydroelectric complex
01.04.02.003	The Lovat and Pola Rivers
01.04.02.004	The Shelon River
01.04.02.005	Lake Ilmen basin without the Msta, Lovat, Pola, and Shelon Rivers

01.04.02.006	The Volkhov River
01.04.03.001	The Syas River
01.04.03.002	Lake Ladoga basin without the Volkhov, Syas and Svir Rivers
01.04.03.003	The Neva River from the source to the Novosaratovka gauging station
01.04.03.004	The Neva River from the Novosaratovka gauging station to the mouth
01.04.03.005	Rivers and Lakes of the Gulf of Finland basin from the Russian-Finnish border to the northern border of the Neva River basin
01.05.00.001	Rivers of Karelia within the Baltic Sea basin at the Russian-Finnish border, including Lake Leksozero.

Basin Councils are created within the Basin Districts, which include representatives of Federal Executive bodies, public authorities of the entities of the Russian Federation, local authorities as well as representatives of water users, public associations and indigenous communities of Siberia, the North and the Far East of Russia.

The Basin Council is a body of collective decision-making in the field of use and protection of natural resources in the Basin District. In accordance with Article 29 of the Water Code of the Russian Federation, Basin Councils are established to ensure the rational use and protection of water bodies. Basin Councils get organizational and technical support from the territorial agencies of the Federal Water Resources Agency—**the Basin Water Administrations (BWAs)**. Basin Councils are formed by a decision of the Federal Water Resources Agency for 5 years. Currently, there are 20 Basin Councils.

The main task of the Basin Councils is the development of recommendations for use and protection of water bodies within the boundaries of the Basin District. Recommendations of the Basin Councils are sent to the relevant Federal Executive bodies, executive authorities of the entities of the Russian Federation and local self-government bodies, which exercise powers in the field of use and protection of water bodies. Recommendations are taken into account when developing Schemes.

BWAs are territorial bodies of the Federal Water Resources Agency of the inter-regional level. BWAs perform the functions of providing public services and manage a federal property in the field of water resources in the regions of Russia. The powers of BWAs include:

- water protection activities: development and implementation of Schemes; establishment of boundaries of water and coastal protection zones for water bodies, seas or their particular parts; protection of them, prevention their pollution, contamination and depletion of water; implementation of measures to eliminate the consequences of these events. For water users, standards for permissible discharges of substances (except for radioactive ones) and microorganisms into water bodies are set;
- implementation of measures to prevent negative impacts of water and eliminate its effects on water bodies;
- possession, use and direction of Federal property and water bodies that are in Federal ownership including granting water bodies, parts of water bodies, seas or

their particular parts for use; the issue of a permit for the creation of an artificial land plot on water bodies;
- integrated water resources management—state monitoring of water bodies, hydrographic and water management zoning, installation of reservoir operation schemes, an organization of territorial redistribution of surface runoff, replenishment of water resources of ground water bodies;
- conducting state accounting and research of water bodies—the State Water Register, development of automated analytical systems for processing information on water resources of the Russian Federation;
- implementation of functions of the state customer, placing orders and conclusion of state contracts and other civil law contracts;
- coordination and control of the activities of Federal State Budgetary Institutions and Federal State Unitary Enterprises subordinate to the Federal Water Resources Agency;
- interaction with public authorities of foreign states and international organizations;
- interaction with the population;
- organization of congresses, conferences, seminars, exhibitions and other events;
- powers directly related to the functioning of the Administration (administrative, economic, financial, personnel issues) as well as to work with documents and archival data.

At present, there are 14 BWAs in Russia: Amur, Upper Volga, Upper Ob, Dvina-Pechora, Don, Yenisei, West Caspian, Kama, Kuban, Lena, Moscow-Oka, Neva-Ladoga, Lower Volga and Lower Ob.

The territorial Body of the Federal Water Resources Agency over the territory of the city of St. Petersburg and the Leningrad, Kaliningrad, Novgorod, Pskov regions and the Republic of Karelia is **the Neva-Ladoga Basin Water Administration (Neva-Ladoga BWA)**. It performs the functions of rendering state services and managing a federal property in the field of water resources within the basins of the water bodies of the Baltic and White Seas and the basins of the rivers discharging into them (Neva, Narva, Zapadnaya Dvina, Pregolya, Neman, etc.). The Basin Council of the Baltic Basin District operates under the Neva-Ladoga BWA.

6 Schemes Content

The general structure of Schemes is shown in Fig. 2. A scheme consists of six volumes (books) and appendices.

By now, eight Schemes of integrated use and protection of water bodies in the Baltic Basin District have been approved:

- **Scheme of the Volkhov River basin**;
- **Scheme of the Luga River and the rivers of the Gulf of Finland basin (from the northern border of the Luga River basin to the southern border of the Neva River basin)**;

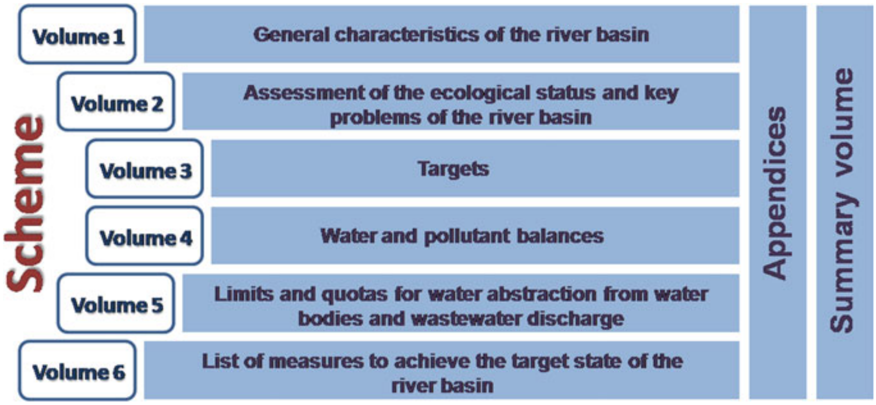

Fig. 2 Schemes content

– **Scheme of the Narva River basin**;
– **Scheme of the Neva River basin**;
– Scheme of the Neman River basin and the rivers of the Baltic Sea basin (Russian part in Kaliningrad region);
– **Scheme of water bodies of Karelia in the Baltic Sea basin (Russian part of the basins)**;
– **Scheme of rivers and lakes of the Gulf of Finland basin (from the Russian-Finnish border to the northern border of the Neva River basin)**;
– Scheme of the Zapadnaya Dvina River basin.

As mentioned in Chapter «Water resources of the Russian rivers of the Baltic Sea basin and their possible changes under global warming», six of the eight above Schemes (in bold) were carried out by specialists of SHI.

Figure 3 shows the location of all eight water-resource regions for which Schemes have been developed.

Schemes are available for download (in Russian) from the website of the Neva-Ladoga Basin Water Administration of the Federal Water Resources Agency (www.nord-west-water.ru/activities/ndv/).

Below is a description of the structure of each Volume.

Volume 1. General characteristics of the river basin.
According to Methodological Guidelines Volume 1 should contain the following sections:

1. Brief geographical description of the river basin.
2. Socio-economic characteristics of the river basin.
3. Characteristics of the hydrological and hydrogeological study of the river basin.
4. Hydrological units and water-resources regions belong to the river basin.
5. Water objects of the river basin. A list and main parameters.
6. Hydrological characteristics of the river basin.

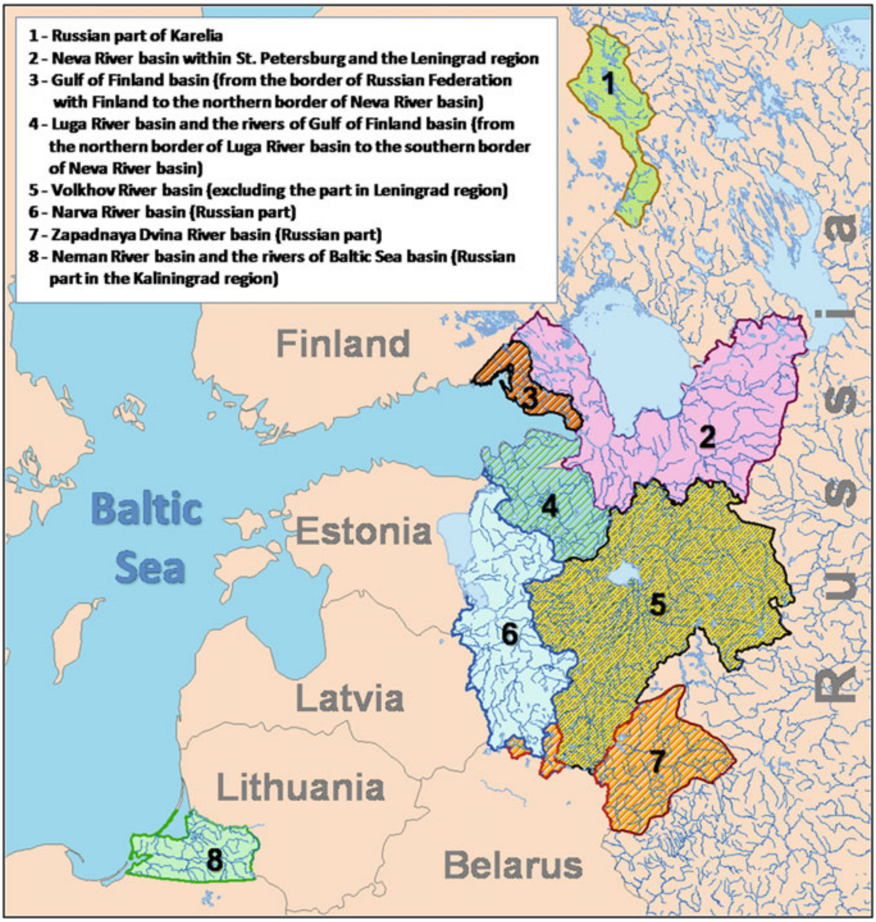

Fig. 3 Map of the locations of parts of the Baltic Sea basin, for which schemes have been developed

7. Hydrogeological characteristics of the river basin.
8. Characteristics of economic development of the water object and the existing management infrastructure.
9. Characteristics of the use of water bodies.
10. A list of water bodies of the river basin and their parts where protection measures are carried out by state authorities of the subjects of the Russian Federation (for each subject of the Russian Federation with an indication of the authorized executive body of the subject of the Russian Federation);
11. A list of water bodies of the river basin where the implementation of measures to prevent negative impacts of water and eliminate its consequences is carried out by the state authorities of the subjects of the Russian Federation (for each

subject of the Russian Federation with indication of the authorized executive body of the subject of the Russian Federation).

12. A list of water bodies of the river basin where the implementation of measures to prevent negative impacts of water and eliminate its consequences is entrusted to the territorial bodies of the Federal Water Resources Agency;
13. A list of water bodies of the river basin the implementation of measures in respect of which is entrusted to municipal authorities, individuals and legal entities (for each subject of the Russian Federation with the indication of the authorized body of municipal authority, individuals and legal entities).

Volume 2. Environmental assessment and key problems of the river basin.

1. Distribution of water bodies of the river basin by categories (natural, substantially modified, artificial).
2. Assessment of the ecological status of water bodies in the river basin (distribution of water bodies by ecological class).
3. Assessment of the ecological status of ground water bodies in the river basin.
4. Assessment of the scale of economic development of the river basin.
5. Assessment of water resources supply to the population and economy of the river.
6. Assessment of the negative impact of water on the population and economic infrastructure of the river basin.
7. Integrated assessment of the ecological state of the river basin.
8. Key problems of the river basin.

Volume 3. Target indicators.

1. General characteristics of the target state of the river basin after the completion of the Scheme activities.
2. Characteristics of the target state of individual water bodies.
3. Target indicators of water quality for water bodies of the river basin.
4. Key targets for reducing the negative effects of floods and other negative impacts of water.
5. Target indicators of the ecological state of water bodies in the river basin.
6. Target indicators of development of the system of state monitoring of water bodies in the river basin.
7. Target indicators of water supply of the population and the economy of the river basin.
8. Target indicators of the development of water infrastructure of the river basin.
9. Financial, economic and socio-economic targets.

Volume 4. Water management balances and balances of pollutants.
In accordance with Methodological Guidelines Volume 4 “Water management balances and balances of pollutants” should contain the following balances:

1. Water-resources balances for water-related years (for the entire river basin, sub-basins, water-resources regions and individual water bodies).

2. Water-resources balances for low-water and high-water groups of years (for the entire river basin, sub-basins, water-resources regions and individual water bodies).
3. Balances of pollutants in water bodies of the river basin for different water content conditions and levels of socio-economic development of the river basin.

Volume 5. Limits and quotas for water withdrawal from water bodies and wastewater discharge.
In accordance with Methodological Guidelines Volume 5 should consist of the following limits and quotes:

– limits for water resources abstractions from water bodies in the river basin for each water-resources region (water bodies, sub-basins and the entire river basin);
– quotas of the subjects of the Russian Federation for water resources withdrawal from water bodies of the river basin for each water-resources region (water bodies, sub-basins and the entire river basin);
– limits of wastewater discharge, corresponding to the quality standards, to the water bodies of the river basin for each water-resources region (water bodies, sub-basins and the entire river basin);
– quotas of the subjects of the Russian Federation for wastewater discharge corresponding to the quality standards to water bodies of the river basin for each water-resources region (water bodies, sub-basins and the entire river basin).

Volume 6. A list of activities to achieve the target state of the river basin.
In accordance with Methodological Guidelines Volume 6 should contain the following activities:

1. Fundamental activities.
2. Institutional activities.
3. Measures to improve operational management.
4. Structural measures (construction and reconstruction of buildings and facilities).
5. Summary of required financial costs.
6. Calendar schedule for the implementation and financing of activities.
7. General assessment of the potential impacts of the Scheme's activities on the environment.

Paragraph 22.4 of Methodological Guidelines provides a list of 9 activities that can be considered as fundamental:

(1) identification and classification of water bodies by type and state;
(2) improvement of water resources assessment and use;
(3) development of a scientific and methodological base of water use and protection management including development of economic mechanisms to promote effective water use;
(4) restoration and development of the observation network for the state of water bodies and water management systems;
(5) development of simulation mathematical models;
(6) identification of territories subject to flooding, their classification and mapping;

(7) development and support of basin geoinformation systems;
(8) educational programs;
(9) ensuring coordination of the Scheme's activities.

The following types of activities can be considered as institutional in accordance with paragraph 22.5 of Methodological Guidelines:

(1) activities aimed at compliance with the established limits and quotas for water abstraction (withdrawal) from water bodies and wastewater discharge;
(2) development of a normative-technical base of water management complex functioning and water use regulation (including revision (improvement) of technical documents in the field of construction; development of rules of water resources use of reservoirs and water management systems; rules of technical operation and improvement of reservoirs, etc.);
(3) development of rules, programs, action plans in cases of extremely low water availability and extremely high water availability (including hydrological forecasts, regulation of water distribution procedures and use of reserve water sources, an increase of reliability and efficiency of water supply systems, identification of alternative or additional sources of water supply sources, etc.);
(4) regulation of use (reservation) of territories potentially affected by flooding;
(5) regulation of land use in water protection zones of water bodies (including their development and improvement) and in catchments to prevent pollution and depletion of water bodies;
(6) regulation of the use of shores and the beds of water bodies;
(7) preparations of justifications of payment rates for the water facilities use stimulating the effective and sustainable use of water bodies;
(8) regulation of the volume and procedure of control and supervision activities aimed at the protection of water bodies from pollution and depletion, as well as ensuring the safety of water infrastructure;
(9) development of insurance systems for risks associated with the negative impact of water.

7 Approved Norms of Permissible Impact on Water Bodies in the Baltic Sea Basin

In the previous section, are listed eight developed and approved Schemes of integrated use and protection of water bodies in the Baltic Basin District which are currently being used for water management and protection activities.

Similar to the Schemes, were developed the following Norms of permissible impact on water bodies (PIWBs) including water quality targets for water bodies within the Russian part of the Baltic Sea basin:

– Norms of permissible impact on the Volkhov River basin;

- Norms of permissible impact for the Luga River basin and the rivers of the Gulf of Finland basin (from the northern border of the Luga River basin to the southern border of the Neva River basin);
- Norms of permissible impact on water bodies for the Narva River basin (Russian part of the basin);
- Norms of permissible impact on the Neva River basin;
- Norms of permissible impact for the Neman River basin and rivers of the Baltic Sea basin (Russian part in Kaliningrad region);
- Norms of permissible impact for the Neva River basin including the Svir River, the rivers of the Onega and Ladoga Lakes basins;
- Norms of permissible impact for the rivers and lakes of the Gulf of Finland basin from the Russian-Finnish border to the northern border of the Neva river basin;
- Norms of permissible impact for the rivers basins of the Baltic Sea basin in Karelia;
- Norms of permissible impact on water bodies of the Zapadnaya Dvina River basin.

All PIWBs are freely available on the website of the Federal Water Resources Agency (http://voda.mnr.gov.ru/activities/list.php?part=35).

8 Conclusions

Schemes of integrated use and protection of water bodies have both their supporters and critics. Opponents usually point out the following shortcomings in development of Schemes:

- the absence of a number of approved regulatory and methodological documents necessary for the development of Schemes (such as «Methods of assessment of the ecological status of water bodies», «Guidelines for the justification and development of flood control measures», «Guidelines for the definition of the water regime during the use of water bodies for exploration and mining», etc.);
- the absence in the State Water Register all the complete information required for the development of Schemes [13], first of all, raw data from hydrological and hydrochemical gauging stations;
- approach to the development of Schemes, presented in the Methodological Guidelines, includes some archaic views on development programs design, which are typical for planned but not for market economy. Since the economy of modern Russia is an unstable market economy, it is impossible to design development programs for decades. It makes sense to consider only the medium-term and, to some extent, long-term development of an area, as well as short-term plans developed based on the priorities, the implementation of which is determined primarily by the financial capabilities of each fiscal year;
- elaboration of Schemes requires the state medium and long-term forecasts of socio-economic development of industries and sectors of the economy, which are often absent for some regions.

Nevertheless, despite all the criticism during the Schemes development, all of them have been successfully developed and approved. Currently, they are the basis for the implementation of water management and protection measures for water bodies in river basins [4] in the Russian Federation for the following period of 30–40 years, with the intermediate calculation time in 5–10 years.

9 Recommendations

In this chapter, the authors attempted to generalize and systematize information on the Schemes for integrated use and protection of water bodies, including standards for the permissible impact on water bodies.

Summarizing presented materials, it is necessary to specially note that the Schemes for integrated use and protection of water bodies:

- are **the basis** for the implementation **of water management actions and measures to protect water bodies** in river basins;
- **include the latest systematized materials** on the status of water bodies and their use;
- are **instruments (information and intellectual supporting tools) for making management decisions** on river basins (achieving water quality targets for water bodies and reducing the negative consequences of floods and other negative water impacts);
- within the **next 15–20 years** will remain **the only approved documents** recommended by the Government of the Russian Federation.

The implementation of the Schemes' activities will contribute to a balanced socio-economic development of the Russian regions. Measures to reduce human impact on water bodies will allow achieving high ecological standards of life of the population, preserving the health of citizens, improving the state of aquatic ecosystems in river basins. The implementation of measures aimed at rationalization and integrated use of water resources will make it possible to reduce the water consumption of the economy, guarantee drinking and household water supply for the population and create reliable conditions for the development of industry, energy, water transport and agriculture through effective use of water resources of Russian rivers.

The materials presented in this Chapter are to help specialists, working in hydrology and related sciences (ecology, water management, social geography, etc.), get familiar with the history of Schemes development, their legal support, content, advantages and disadvantages (in the opinion of the authors and their colleagues); a case study of the Russian part of the Baltic Sea basin – a very complex hydrological object.

Since now practically all the Schemes for the Russian Federation are developed, approved and freely available in Russian, the authors recommend all the interested specialists to familiarize with some Schemes, taking advantages of modern automatic translation systems and using the information and content of the Schemes presented in this Chapter.

Acknowledgements The authors are grateful to all specialists of the State Hydrological Institute and other scientific organizations who took a direct part in the development of Schemes mentioned in this Chapter.

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Implementation of Water Policy for Estonian Water Resources

Estonian Fluvial Water Bodies and Inundation Directive

Elve Lode, H. Tõnisson, Marko Vainu, G. Kapanen, R. Rivis and M. Muru

Abstract Report, according to the EU Floods Directive (2007/60/EC) with insurance purposes was completed in Estonia, 2016. The output of this work fulfilled the Directive targets to produce the flood maps of inland water bodies, with return periods of 2, 5, 10, 25, 50, 100, 200, 500 and 1000 years. The flood maps were created in *ArcMap10.2.2* and *ArcHydro* environments, based on data of absolute maximum water levels (WLs) of Estonian state hydrological network. Created 834 flood maps based on data of 152 gauging stations: flood maps of 37 fluvial water systems and 8 standing water bodies. The flood heights with corresponding return periods were obtained from probability analysis of WLs data. Obtained results illustrate that the higher risk for the floods is expected at intersections of branching streams in Low-Estonia and upland margins of High Estonia. Before completion of the report, the existing flood maps covered only a small fraction of Estonia, i.e., territory of 17 cities only. Developed by us the flood map creation tool, is simple, allows modelling and visualising both the flood heights and corresponding overflows of watercourses over the whole country. However, the outcome depends on the availability of hydrological data and the quality of digital elevation models.

Keywords Stream development · Floods · Numerical prediction · Flood maps

1 Introduction

A ***flood*** could be interpreted as the temporary overflow of water that submerges usually dry land and that natural floods occur in rivers when the flow rate exceeds the capacity of the river channel, particularly at bends or meanders in the waterway

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(e.g., [1]). This would apply for areas without tide, i.e., costal sea shores where there are flood and low tide regularly.

In EU Floods Directive floods are defined as "…natural phenomena which cannot be prevented" [2]. Whereas some human activities, such as increasing human settlements and economic assets in floodplains, reduction of the natural water retention by land use, and climate change contribute to an increase in the likelihood and adverse impacts of flood events. According to European Environment Agency (EEA) the floods can be distinguished: (a) by the source of floods, e.g., rivers and lakes, urban storm water and combined sewage overflow, or seawater, (b) by the mechanism of floods, e.g., natural exceedance, defence or infrastructural failure, or blockage and (c) by other flood characteristics, e.g., flash floods, snowmelt floods, or debris flows [3].

However, hydrologically, there are three distinguished phases of the annual water regime in the streams: seasonal floods, flash floods, and seasonal low-flows [4]. Seasonal floods could be defined as seasonally repeated phenomena with a relatively long increase of water amount in the stream channel, causing the water level (WL) to rise and overflow low-flow stream channel heights and the floods on the floodplains. The flash floods, in that case, are characterized by relatively short-term and non-periodic WL rise, resulting from rapid thawing of snow or glaciers and abundant rains. Significant floods may occur if one flash flood follows another. Snowmelt usually causes spring floods in the streams of flat terrain and summer floods in mountainous regions. Usually, both types of floods have multi-peak hydrographs. But, flash-floods of rain water are considered to be more unpredictable, and in the case of heavy rain showers or cloudbursts also more dangerous in comparison with seasonal floods [4].

According to EEA report [3], almost 1500 floods have been reported in Europe since 1980. More than 750 floods had occurred since 2000. The number of very severe flood events increased throughout 1980–2010, but with large inter-annual variability. This increase has been attributed to improved reporting of flood events and land-use changes and increased heavy precipitation in Europe. "Global warming is projected to intensify the hydrological cycle and increase the occurrence and frequency of flood events in large part of Europe" [3]. However, in regions with projected reduced snow accumulation during winter, the risk of early spring flooding could decrease. Whereas, as it was reported, prediction of quantitative changes in flood frequency and magnitude remains highly uncertain [3].

River floods, caused by prolonged or heavy precipitation and/or snowmelt are common natural disasters in present Europe, and—along with storms—are the most important natural hazard in terms of economic damage. Resulted in damaged infrastructure, property and agricultural land, and loss of health and life of people, and loss of environment and cultural heritage [3]. According to the NatCatSERVICE database (Natural catastrophe know-how for risk management and research) floods in Europe have caused direct economic losses of more than 150 billion EUR (based on 2013 values) since 1980. That is "almost one-third of the damage caused by all natural hazards. Less than a quarter of these damages were insured" [3].

Despite "general agreement that Europe-wide or at least transnational-scale flood hazard maps have the potential for many applications, including climate change studies, only a few products exist" [3]. Difficulties remain to compile large consistent datasets. So far, the EU Floods Directive has improved this situation only to a limited extent [3].

However, the purpose of the EU Floods Directive is:

(I) to establish a framework for the assessment and management of flood risks in the EU,
(II) to include the flood risks into the river basin management plans in order to achieve good ecological and chemical status of water bodies in the basins, and
(III) to contribute to the mitigation of the flood effects in water body basin [2].

It means that according to the EU Floods Directive the following activities should be performed in all EU countries:

(a) flood risk assessment,
(b) production of flood hazard and flood risk maps,
(c) compilation of flood risk management plans, and
(d) to make all flood risk plans public, implement them, report the results and improve the plans [2].

Assessment and management of Estonian flood risks started in 2007 [5] and the current Estonian Water Act is focused on *significant flooding risk areas* [6, 7]. Hereby, the determination of significant flood risk areas is based on the assessment of four priority sections:

(1) damage to human health and property;
(2) erosion or denudation of a riverbeds or coasts;
(3) destruction of natural or cultivated plant communities caused by coverage with alluvial materials transported during floods;
(4) impediment to the use of ownership, cut-off of access routes or significant deterioration in access conditions [8].

However, the strategy of integrated flood risk management should compromise flood protection of different structural assets, e.g., dikes, levees, upstream retention areas, etc., together with non-structural property protection, land use planning and insurance arrangement (EU Solvency II Directive [9, 10]). Therefore, a project of "Creation of flood maps of Estonian inland water bodies" (later: Flood Map Project) was initiated by the Estonian Insurance Association in 2016. Institute of Ecology (School of Natural Sciences and Health, Tallinn University) has implemented it, and output of this work fulfilled the EU Floods Directive targets with insurance purposes to assess the flood risks of floodplains of inland water bodies and to visualise the flood extents on corresponding digital maps. Flood maps were created for the nine high water level (WL) scenarios, with return periods of 2, 5, 10, 25, 50, 100, 200, 500 and 1000 years.

2 Materials

2.1 Development of Estonian Fluvial Watercourses

According to Arold [11] the oldest inland watercourses of Estonia are located in its southern part. These were formed there after the retreat of the Baltic Ice Lake about 12,600 years ago (Fig. 1). Development of deep river valleys in south Estonia took place very quickly during the retreat of the Peipsi Ice Lake, and the deepening of the valleys continued until the beginning of the Holocene. At the end of the Ice Age, the great lakes in the south largely dried up, and valleys of the watercourses were deepened. Together with the following uneven land uplift, intensive lake sediment accumulation began in the valleys with simultaneous terrestrial paludification processes. This kind of development has continued until the present day, and accumulated peat thicknesses of that region may reach down to 10 m depth in lower courses of several streams.

Development of fluvial watercourses of north-eastern and western Estonia took place together with the recession of the sea a few thousand years later. This is particularly evident in the flat surface of the west Estonian Kasari and Pärnu River valleys. In the north, the fluvial watercourses began to develop in two stages: in the first stage, the glacier stream deltas were formed in the bays of the north-eastern coastal cliff and the second stage started with the land rising from the sea in the west-north part of Estonia and continues to this day. Therefor, in the north the cliff, along with the waterfalls, divides the river valleys into two distinct parts: valleys on the Baltic Sea retreat terraces, north from the cliff foot toward the sea, and flat floodplains from the top of cliff edge toward the main land. Others, the north Estonian river valleys, are constantly deepening into the crust surface due to erosion with simultaneous land uplift [12].

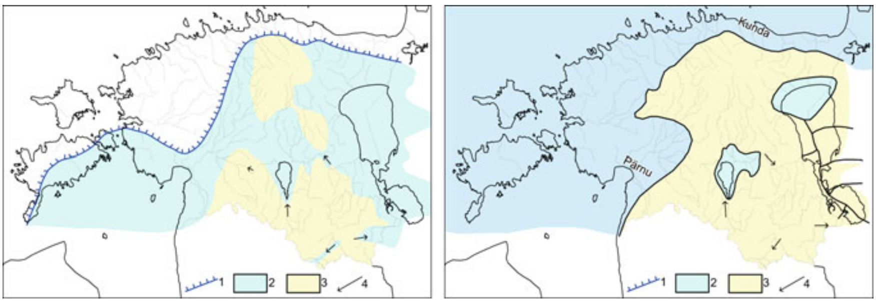

Fig. 1 Proportions of inundated and dry areas of Estonian territory during the Pandivere Ice stage about 12,050 years ago (the left image) and during transgression of the Baltic Ice Lake about 10,800 years ago (the right image), where: 1—margin of the glacier, 2—inundated land, 3—dry land, 4—flow direction of canalised surface water bodies (authors of the figure origin: A. Miidel, T. Hang, E. Tavast, in: [12]). The background image on the schemes: a network of Estonian main rivers at present [data of Estonian Nature Information System (EELIS)]

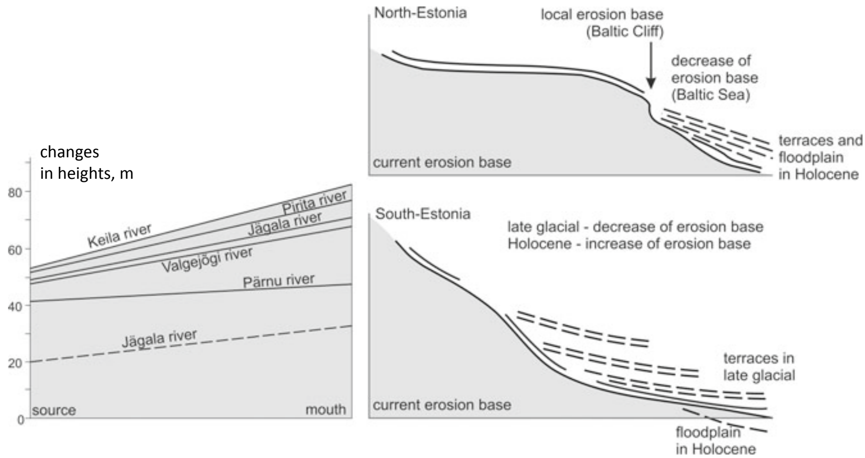

Fig. 2 Height changes of longitudinal profiles of rivers falling into the Baltic Sea in the north-west and west coasts of Estonia during the Baltic Ice Lake retreat until today (continuous lines on the left scheme) in comparison with land uplift of Jägala River on the north during the Ancylus Lake formation until today. Schemes on the right: erosion trends of northern and southern river valleys. Authors of the figure origin: A. Miidel, G. Eberhards, T. Hang, E. Tavast, in: [13]

Reconstruction of the shoreline development of the Baltic Ice Lake since 10,200 years ago shows that due to the land uplift the lower courses of the north-western rivers have risen 20–30 m more than their upper courses (Fig. 2). At the same time, land uplift led to the development of flat and wet floodplains in the middle courses of the same rivers [12].

Adding to these conditions, development of the river valleys directed towards the western coast, i.e., to the coasts of Gulf of Riga and Väinameri Sea has been influenced by the southwest-northeast Pärnu–Kunda oriented tectonic fracture zone [14]. Therefore the right tributaries of the River Pärnu are deepening their valleys, as the flow of the left tributaries is impeded because they flow against the land uplift [12].

2.2 *Basic Background Information*

Changes in climatic conditions

In meteorological terms, Estonia is located on the west-east climate gradient [15]. The present winter warming in Estonia is characterised by lowered air pressure and increased cyclonic activity [16, 17]. During the second half of the 20th century, mean annual air temperature in Estonia increased by 1.0–1.7 °C and precipitation by around 10% [18]. During the period of 1989–2011 increase of winter air temperature was 1.7 °C, while warming of the coldest month was 2.4 °C in comparison with 1964–1988 [19]. Precipitation during 1989–2011 cold season increased by 10%, mainly due to a shift from light rains towards heavier 60–90 mm rains. During the warm season, they decreased by 5%, but the unevenness of precipitated amounts increased, sometimes to values of up to 240 mm per month [19].

During 1951–2015, the duration of permanent snow cover over the whole Estonia decreased, on average, by 1–4 days for every ten years [20].

Hydrotopography

According to Arold [11] the continental ice sheet, glacial meltwaters and sea waters were the most influential factors of development of Estonian topography; at the present distinguishable in two different parts, also named as Low and High Estonia with a corresponding hydrographic network (Fig. 3).

According to Estonian Nature Information System (EELIS), there are 2675 coded fluvial water bodies in Estonia with a total length of about 21,000 km. More than half of those, i.e., 54% are ditches and channels. The 67% of natural watercourses are categorized as very small fluvial water bodies with prevailing length less than 10 km. Only 1.4% of the rivers belong to the medium 100–500 km length class (Table 1). Thereby, the length of the longest Võhandu River is 191 km, and the longest man-made Hirve main ditch is 37.9 km; it is a heavily modified fluvial water body (i.e., Uru brook).

According to Raudsaar et al. [23], inland water bodies cover 5.7% of Estonian area, whereas without considering the trans-border Peipsi Lake, the coverage is only 1.6% (i.e., 71.4×10^3 ha).

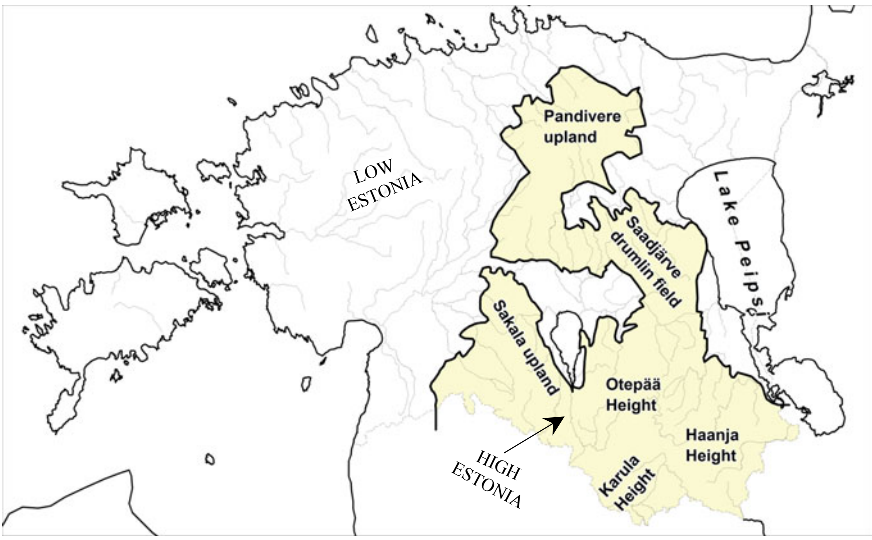

Fig. 3 Two distinguishable parts of present-day Estonian topography: (1) the Low Estonia with absolute height up to 60 m a.s.l. and (2) the High Estonia, consisting of several uplands and heights, with maximum height up to 317 m a.s.l. Low Estonia is a flat and comparably warm area, and it was flooded when the continental land receded. The map is created after Arold [11]

Table 1 Distribution of Estonian fluvial water bodies classified according to Vendrov et al. [21] and Bogoslovskiy et al. [22], where N—the number of water bodies

Distinguished class		Type of the water body			
Name	Length of the watercourse (km)	River, brook		Ditch, channel	
		N	%	N	%
Very small	<10	825	66.5	1360	95
Small	10–25	285	23.0	72	5
	25–100	113	9.1	3	<0.5
Medium	100–500	17	1.4		
Large	>500				
Total		1240	100	1435	100

By the catchment size (F, km^2) there are 13 river systems with the basin area more than 1000 km^2 in Estonia, whereas the largest Emajõgi River basin is 9740 km^2, i.e., 22% of Estonian territory [12]. In this way there are only 5 rivers having medium size basins (i.e., classified as $2000 < F < 50{,}000$ km^2 in: [4]). Hydro-topographically the largest is the Narva River—Lake Peipsi basin, expanding on 56,225 km^2 of Estonian-Russian cross-border area, from which only 30.5% is in Estonian territory [24].

Without the Peipsi Lake, there are 2546 coded standing water bodies in EELIS database, from which 60% are natural lakes with total water surface area of about 47,500 ha, rest are the inland man created water reservoirs with a total surface area of about 15,750 ha. The number of EELIS coded dams is 952, regulating the water flow on 421 fluvial water bodies of Estonia.

Density of watercourses

The mean density of Estonian fluvial watercourses is 0.72 km/km^2 [11]. According to Kõiv [25], the lowest densities (i.e., < 0.2 km/km^2) are found on the Pandivere upland, north-east of Estonia, and on the coasts of the Estonian islands in the west. In the north densities are about twice as high as in south-east of Estonia (i.e., 0.8–1.2 km/km^2 and 0.4–0.6 km/km^2, respectively), and it differs significantly across the main hydrographical districts of Estonia (later called: hydrological basin (HyB)), i.e., 0.79 and 0.78 km/km^2 on the Gulf of Riga and Gulf of Finland HyB, respectively, 0.69 km/km^2 on the Narva River—Lake Peipsi HyB and 0.44 km/km^2 for HyB of Estonian Baltic Sea islands [25] (Fig. 4).

Water regime

On the long-term temporal scale (i.e., 60–70 years) there is a cyclic variability of discharges of Estonian watercourses; the longest cycle is about 30 years, followed by the 6-year and 3.5-year fluctuations [12]. Wet or water-rich periods have been recorded between 1900–1910, 1948–1962 and 1977–1991 [12].

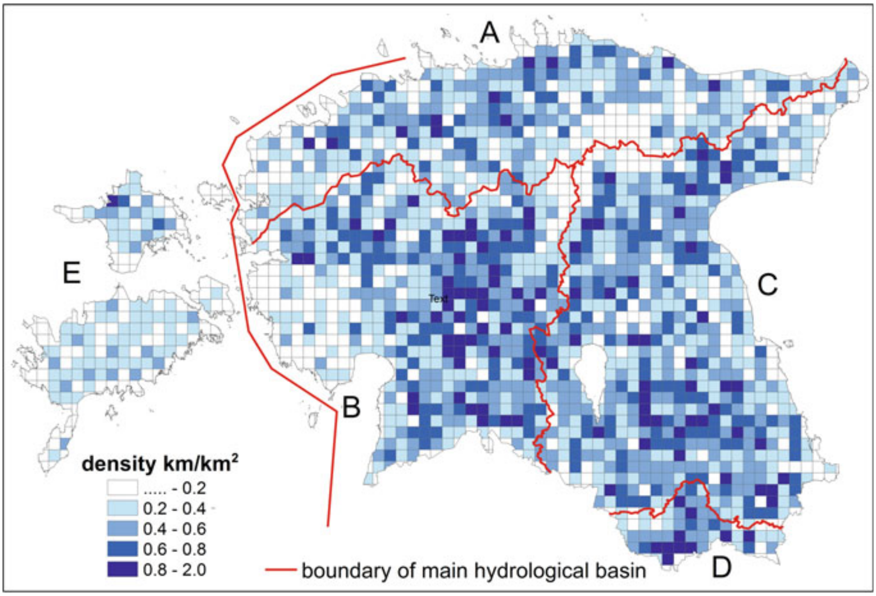

Fig. 4 Density distribution of fluvial watercourses (km/km^2) together with water divides of main hydrological basins (HyBs), where: A—the Gulf of Finland, B—the Gulf of Riga, C—the Narva River–Lake Peipsi, D—the Koiva River, and E—the Baltic Sea islands HyB. The map of the density distribution is based on data of Estonian Nature Information System (EELIS)

The regional factors such as karst, paludification, land use, and its changes are reflected in annual runoff regime of Estonian fluvial water bodies. Rivers, greatly regulated by the lakes (e.g., the Narva and Emajõgi River) or considerably fed by groundwater (e.g., streams at the foot of the north-eastern Pandivere Upland), have a relatively even distributed annual discharge pattern [12].

According to Järvet [26], there are four water regime periods with corresponding WLs in Estonian rivers: spring and autumn high WL periods, and winter and summer low WL periods. The most noticeable are the spring high water periods and the low water periods at the end of the summer. The autumn high water periods depend on abundance of autumn rainfalls and low evaporation rates.

The long-term annual WL fluctuation of Estonian rivers is within range of 2–4 m; in Low Estonian Pärnu River it could reach 5.5 m during extreme floods. However, during the spring seasons, the Narva River in the north forms the highest discharges in Estonia (i.e., 2000 m^3/s for the season by the annual mean of 399 m^3/s) [12, 25].

Runoff

In Estonia, annual runoff is about 12 km^3 at the mean amount of precipitation of 667 mm and discharges of 260 mm. For the 20th century, variation of precipitation dependent runoff coefficient is estimated to be 0.34–0.43 [12]. Almost the same amount of water (i.e., 12.6 km^3 per year [25], flows into the Gulf of Finland from the Narva River, formed on the Narva River–Lake Peipsi large basin.

On average, 43% of the annual runoff is formed during the spring season, 14%, 24% and 19% during summer, autumn and winter season, respectively. The spring maximum flows, i.e., 40–90% of the annual runoff, are formed at the end of April [25].

The seasonal variability of the flows is relatively small in the Emajõgi and Narva River, regulated by the Lake Võrtsjärv and Lake Peipsi, respectively. Therefore, the largest drainage modules of those rivers reach only 30–50 l/s km^2, while on many other rivers (e.g., the Pärnu, Pedja, Kasari River) it raises to 250–300 l/s km^2. During the floods, the velocity of Estonian rivers is about 0.5–1.0 m/s and sometimes it reaches 2–4 m/s in lower courses of the northern rivers [25].

Floods

On annual scale important indicators of floods are the time of its occurrence and its duration; since during floods the WLs, flow velocity and erosion in the riverbeds are high and overflows to the floodplains are extensive. In Estonian case, the spring floods are typical for many of Low Estonian rivers (e.g., the Navesti, Halliste River), where floods are promoted by the flat relief, low topographical heights and lack of the flow-through lakes [25].

In the cases of particularly high WLs, facilities such as dams, levees, bridges, roads, buildings and also river valleys could be damaged. Usually, extensive overflows are formed by the rivers with shallow valleys in central and west of Estonia. The major flood areas in Estonia are the lower courses of the Halliste River (known as the Riisa floods) and the Kasari River in the west coast of Estonia, the upper course of the Emajõgi River (i.e., outlet of the Lake Võrtsjärv) in central Estonia, and shallow coasts of the Lake Peipsi and the Lake Võrtsjärv (Fig. 5).

It has been estimated that the Riisa flood area at the maximum WL stand in 1928 was 175 km^2 and overflow of the Emajõgi River might reach nearly 100 km^2 [12]. Smaller floods can occur during the ice-fall in the spring due to ice blockages in the rivers. Also, large floods of the upper course of the Emajõgi River (flat and heavily meandering wetland area, where river lacks a clearly defined floodplain) can be formed because of an unusually large amount of water falling into the river from its northern Pedja River tributary. During such floods, the Emajõgi River changes the flow direction backward, and overflow area spans several kilometres without definite borders [27]. Such a unique event takes place usually in May, but sometimes also in winter. The backward flow current is low, 7 cm/s, and flooded area at that time is called as the Emajõgi Streamlake (i.e., Järvejõgi) [12].

Monitoring

Hydrology Department of KAUR is responsible for both, collection of hydrological observation data and compiling of Hydrological Year Books.

Historically, the WLs of Estonian watercourses have been recorded in 152 hydrological gauging stations (HGSs). At present only 58 HGSs are in operation [28] (Fig. 5). During the Flood Map Project there were available daily WL data of 46 HGSs for the period longer than 50 years, 38 HGSs for the period between 25 and

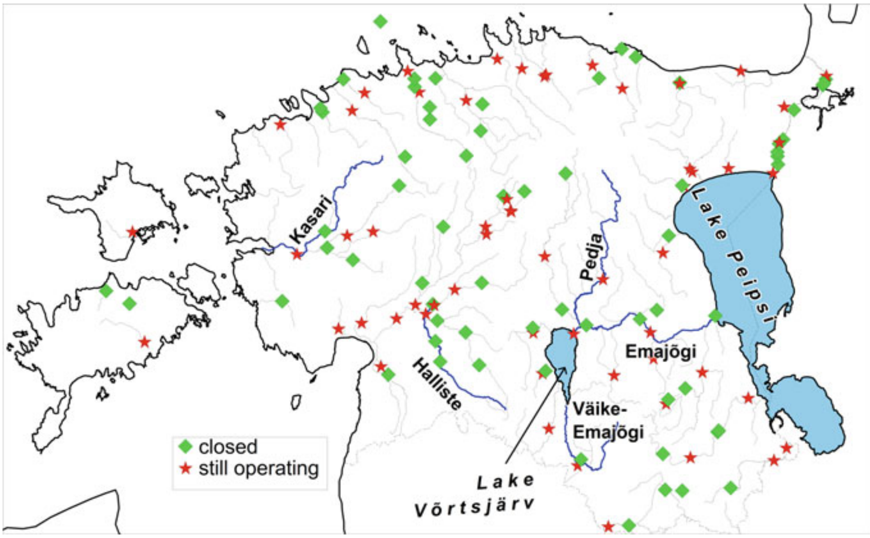

Fig. 5 Water bodies with the high flood risks in Estonia (blue coloured on the map): the lower courses of the Halliste and Kasari River, the upper course of the Emajõgi River together with its northern tributary, the Pedja River, and shallow coasts of the Lake Peipsi and the Lake Võrtsjärv together with the Väike Emajõgi River. Red and green symbols on the map mark the surface water gauging stations (HGSs) (data from Hydrology Department of Republic of Estonian Environment Agency (KAUR))

50 years, 45 HGSs for the period between 10 and 25 years, and 23 HGSs for the period between 4 and 10 years (Table 2).

As a routine, in Hydrological Year Books monthly mean WLs of watercourses are published for all hydrological gauging stations. Together with monthly mean WLs the highest and the lowest WL of the month are published correspondingly. The highest and lowest WLs for the month are selected among all daily instantaneous and digitally-recorded values of the respective month and they could be named as absolute extreme values, e.g., monthly absolute maximum (abs.max.WL).

Table 2 Classified operation periods of hydrological gauging stations (HGSs) of Estonia, where: a—number of years, n—number of stations

HGS operation length, years	All stations		Operating HGSs in 2014		Closed HGSs	
	n	%	n	%	n	%
≥50	46	30.3	33	21.7	14	9.2
25 ≤ a < 50	38	25.0	11	7.2	27	17.8
10 ≤ a < 25	45	29.6	4	2.6	41	27.0
4 ≤ a < 10	23	15.1	13	8.6	9	5.9
Total	152	100.0	61	40.1	91	59.9

3 Methods

3.1 Boundary Conditions of the Flood Map Project

An agreed boundary conditions of the Flood Map Project were:

(1) flood maps of Estonian rivers will follow widely used visualisation approach, where the river floods of corresponding WL return periods are visualised on terrain elevation maps (Fig. 6). together with corresponding numerical values in absolute heights (i.e., m a.s.l.); and
(2) the flood maps will be created for the fluvial water bodies with state observation data of corresponding HGSs (including historical data) where the highest water levels (i.e., abs.max.WL) could be obtained; i.e., no any comprehensive data range prolongation or modelling of missing data by analogue river should be applied.

The overall scheme of execution of the project work is presented in Fig. 7.

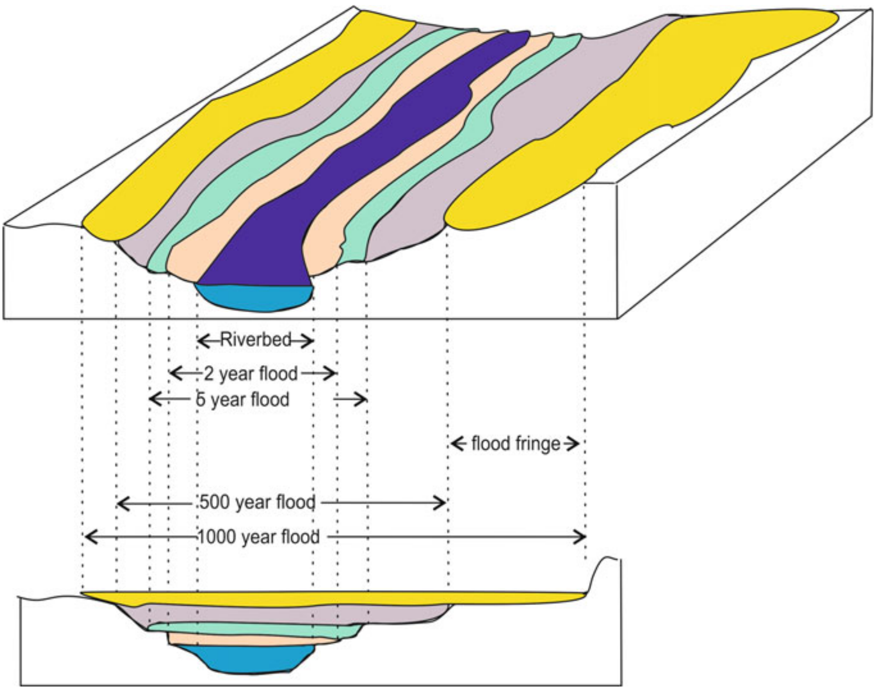

Fig. 6 A conceptual approach to visualizing floods on elevation maps, where differences between neighbouring flood heights of corresponding return periods (i.e., 2, 5 … 1000 years) forms corresponding flood fringe on the river valley

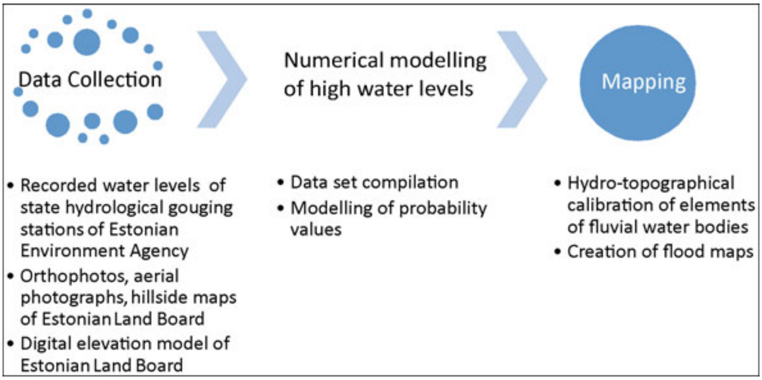

Fig. 7 Flowchart of the Flood Map Project [29]

3.2 Composing of Data Sets

For the Flood Map Project 152 data sets of abs.max.WLs, based on diurnal recordings, were collected together with corresponding occurrence dates. After the critical control of obtained data ranges, (e.g., the length and continuity of observation periods, regional representativeness, and location changes of HGS) the 110 data sets were subjected to analysis and modelling of flood heights with corresponding return periods.

In spite of the first level critical control, non-equality of obtained abs.max.WLs by an event occurring time in data sets remained; because of changes in observation programs and facilities both within the same station and within different stations over the whole monitoring network. So, the newer abs.max.WLs of automated HGSs are chosen from hourly records, but the older data (mainly data before the 2010 year), from three hour or 24-hour records. Such inconsistencies were typical for the long-term observation data, and it was taken into account in critical control of obtained results from data probability analysis.

3.3 Numerical Modelling of High Water Levels

Data sets, suitable for numerical modelling, were divided into three groups:

(1) series with long data ranges by the length of 50 years and longer, i.e., $N \geq 50$;
(2) series with short data ranges, i.e., $25 \leq N < 50$; and
(3) series with very short data ranges, i.e., $5 \leq N < 25$,

where N is observation years with corresponding abs.max.WLs.

Probability P curves of annual abs.max.WLs were composed according to formula (1) [30]:

$$P = \frac{m - 0.3}{n + 0.4} \times 100\%, \quad (1)$$

where, m—is the rank of each individual member of the data range in descending order, n—is the length of the used data range.

For creation of flood maps with return periods of 2, 5, 10, 25, 50, 100, 200, 500 and 1000 years, the WL values of probabilities of $P = 50.0$, 20.0, 10.0, 4.0, 2.0, 1.0, 0.5, 0.2, 0.1% needed to calculate correspondingly. Since probability curves compiled from recorded annual abs.max.WLs usually were limited with P value < 1.0%, i.e., observations were limited within 100 years, theoretical curves with the highest fit ($r^2 \geq 0.9$) to empirical curves were used for modelling of abs.max.WLs with P value > 1.0%. Both, the choice of the theoretical curve and the test of goodness fit of 12 theoretical curves were performed in *JMP Pro 12.1* environment by the *Fit Y by X* module.

In the case of short and very short data sets, however, attempts for prolongation of data ranges were made. Although, there was list of river analogues, earlier used for calculation of different river discharge parameters with missing or short data ranges [31], the usage of them for abs.max.WLs failed. The reason was that probability curves of prolonged data sets showed too high similarity with the used analogue, mainly because of too low correlation r value with analogue (i.e., $r \leq 0.7$). An alternative to prolongation of data values was to use short and very short empirical data sets as they were. Being aware, that in that case predicted high WLs with P value > 1.0% includes a high risk for lowered abs.max.WLs of corresponding probability values. However, those values helped to make certain corrections on the delineation of flood fingers on the flood maps, and obtained probability results were furnished with simple quality indicators, i.e., *high*, *low* or *very low* quality.

There were interruptions of continuity of daily observations during the war periods, sometimes also later periods, in several HGSs. Thus, in the case of interruptions during non-spring high water periods, values of recorded spring floods were used as annual abs.max.WLs. Otherwise, data fulfilling of that particular short interruption period were performed via analogues and via time series graph studies of the same HGS data. In those cases, modelled high WLs also were furnished with lower rank quality indicator.

The *JMP Pro 12.1* modelling results of high WLs for the P value >1.0% were performed to the critical control by using a simple empirical approach, where values were determined from

$$F_a = \frac{100(2n - 1)}{2y}, \quad (2)$$

where F_a—is the probability occurrence (%), n—is the rank of each event, y—is the total number of events [32].

Results of numerical modelling of high WLs with the return periods of 2, 5, 10, 25, 50, 100, 200, 500, and 1000 years, based on 110 data sets, were transformed into the table format with corresponding HGS name and its location coordinates (Fig. 8) and they were forwarded for creation of the flood maps [29].

Return period, year	Predicted value, m a.s.l.
1000	5.16
500	5.16
200	5.15
100	5.14
50	5.13
25	5.10
10	5.01
5	4.89
2	4.69

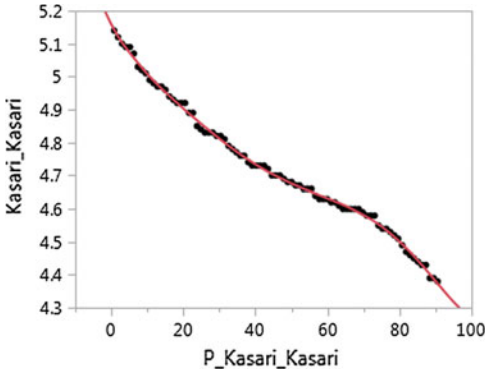

Fig. 8 Table format of modelled high WLs in absolute heights (m a.s.l.) within corresponding return periods (years). On the graph: empirical WL data (dots on the graph) of the Kasari_Kasari HGS in the mouth of the Kasari River together with Six Degree Polynomial Fit of corresponding theoretical curve (red line on the graph) by the correlation coefficient $r^2 = 0.998$. Used software: *JMP Pro 12.1*

3.4 Hydro-Topographical Calibration of Elements of Fluvial Water Bodies

Vector polylines of fluvial watercourses, were downloaded from Estonian National Topographic Database (ETD). The positions of all polylines, marking the fluvial watercourses on the map, were initially inspected.

Already when the first river polylines were checked, it was found that the spatial "runs" of the river polylines need significant correction. In the course of the correction, polylines of the side-branches and oxbows of the main watercourses were removed, and exact positions of the trajectories of river polylines were corrected according to orthophotos and aerial photos from different years, also hillside maps and high-resolution topography maps were used. The triple or fourfold polylines, representing the wider riverbeds were changed to one, and digitised riverbeds on reservoir areas were removed respectively (Fig. 9). As a result, the river lengths presented in EDT of most rivers decreased by 10–20%.

Spatially corrected river polylines needed also Z coordinate correction for downstream directed flood modelling from the source toward the mouth of the river.

In parallel, more than 500 dams of ETD were inspected. Based on visual inspection of orthophotos and aerial photos, and elevation data from LiDAR survey the dams were classified in three types:

Type 1—the dam is partially or completely destroyed, there is no noticeable reservoir formed behind the dam;
Type 2—the dam is preserved to a significant degree, but it is very low, there is a noticeable reservoir, formed behind the dam; and
Type 3—concrete dam (often it is high), there is an extensive reservoir, formed behind the dam.

Fig. 9 Example of corrected vector polylines on reservoir area (light blue on the map), ponded on north Estonian Jägala River. Yellow line—polylines downloaded from Estonian National Topographic Database (ETD). Background orthophoto: Estonian Land Board

Around and along corrected river polylines digital elevation models (DEMs) with the pixel size of 5 × 5 m was created in *ArcMap10.2.2* environment. The width of the DEMs was determined according to the expected maximum spatial extent of the floods on the river valley. Created DEM models were used for geo-coordination (i.e., omitting of X, Y and Z coordinates) of each point of the river polyline with the 5 m distance sequences along the river polyline. As a rule, the elevation values (i.e., Z coordinates) along the river bed needed correction (i.e., filling the pits, cutting the peaks) to enable a continuous downstream flow in modelling procedure. These elevation deviations were mostly caused by the trees fell into the river, bridges and culverts.

As a next step, actual widths of particular riverbeds along the river polyline were "burned" into the DEM, i.e., 5–50 m buffers were created for each polyline. The narrowest 5 m buffers were created for the small watercourses, while larger rivers needed up to 50 m wide buffers. There is a simple explanation of why those buffers needed. LiDAR data always tend to include some false information obtained from the LiDAR scanning across the water bodies. Therefore, buffer modelling procedure needed to remove incorrect elevation data (e.g., caused by false reflections) from riverbeds.

3.5 Floods Modelling on Digital Elevation Maps

The WL heights of nine flood scenarios were calculated with 5-metre steps along each river polyline (Fig. 10). Upstream floods were performed as linearly decreasing WLs

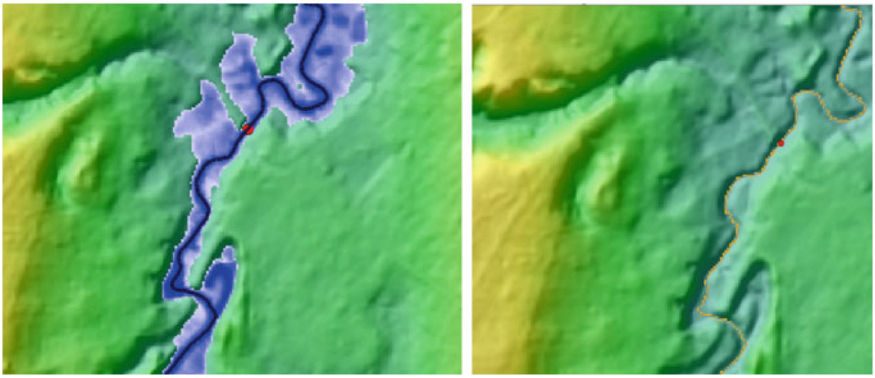

Fig. 10 Example of the river overflows (the left image) modelled for each 5 m pixel size along the polyline in the river bed (the right image). The red dot on the map—location of hydrological gouging station

from HGS toward the source of the watercourse and on downstream, it was presumed that the relative WL heights of the floods down to the river mouth remain the same as they were modelled for the corresponding HGS on the upstream. This kind of downstream modelling might look slightly artificial, but as most of the monitoring stations are not too far from river mouths, deviation from the real WL heights is minimal. If there were two or more HGSs in one river, then the WL heights (i.e., the Z values) along the polyline were obtained from linearly connected WLs between neighbouring HGSs. In this way a smoothed and downstream directed WLs along the whole river polyline was achieved.

Special consideration was given to flood height modelling along the riverbeds with the dams. In the case where there were low dams (i.e., Type 2) on upstream from the HGS, the flood WLs were connected to the height of the dams. In the case of more prominent dams (i.e., Type 3) and large reservoirs a zero flood level height was attributed to the river upstream from the dam until the end of the reservoir.

The floods from the sea considered as primary in the lower courses of the rivers, falling directly into the sea. Therefore, the flood heights along a river towards the river mouth were modelled only until they reached the particular sea flood height or, if necessary, gradually reduced to sea flood height. A similar approach was used also in the case of rivers falling into the lakes, or smaller tributaries joined a major watercourse.

ArcHydro tools were used to model the flood overflows outside the riverbeds. Therefore the river polylines were rasterized for nine flood scenarios by assigning pixel values with modelled flood heights along the watercourse. Using the flood rasters and correspondingly corrected DEMs, spatial extensions and heights of the floods with return periods of 2, 5, 10, 25, 50, 100, 200, 500 and 1000 years were produced for all used rivers.

Obtained results of the flood overflows were verified by comparison with available time series of (historical) satellite images and orthophotos. In many cases, available

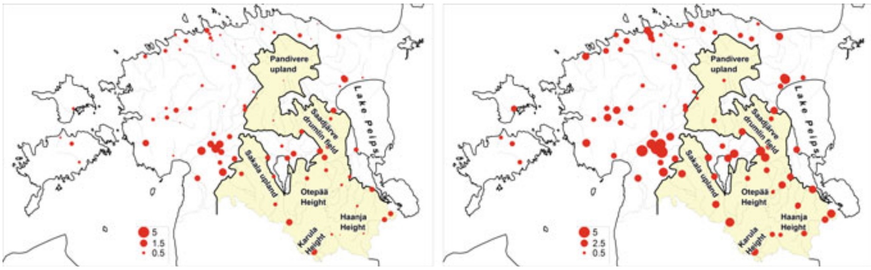

Fig. 11 Symbol maps of numerically modelled 2 years (on the left) and 1000 year (on the right) scaled flood heights (size of the circle in m) above topographical heights (m a.s.l.) of each HGS location

DEMs also needed corrections since the DEMs created from LiDAR data, missed the surface height under the smaller bridges or collector pipe bottom heights. Therefore, modelled floods could "flow" over the roads or railway dams or whatever obstacles. In the correction stage, these obstacles were also "burned" into the flood DEMs. Any overflow was not "allowed to enter" into the neighbouring catchment.

4 Results

To the end of the project, 834 flood map layers were created; from which 666 layers belong to the 37 fluvial water systems. The river mouth regions of four watercourses needed additional floods modelling, finally visualised on 72 map layers, and floods on eight standing water bodies were presented on 96 map layers.

Generalised results of numerical modelling of 2 years and 1000 year-flood heights on the HGS locations illustrate that flood areas with higher risks, based up to 2014 recorded abs.max.WLs, are located on intersections of branching streams in Low-Estonia, i.e., the fluvial systems of Pärnu River and Kasari River, and at High Estonia upland margins (Fig. 11).

As examples of realisations of numerical modelling of the flood heights on the flood maps are presented in Fig. 12 and generalised flood maps with insurance purposes over whole Estonia in Fig. 13.

5 Discussion

From the insurance point of view, there are rather few settlements or buildings (except old water mills) along the river valleys on the floodplains. Several buildings located on the frequent and large overflow areas, e.g., Soomaa region on the Halliste River, the mire area and flood meadow on the Emajõgi River, already has been adapted

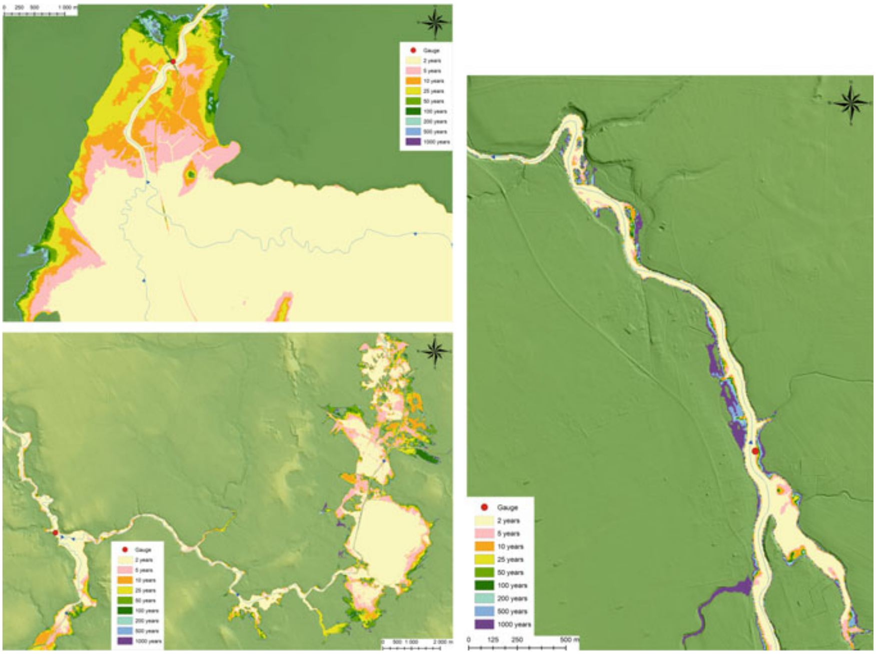

Fig. 12 Flood maps of Low Estonia Halliste River, and the Väike Emajõgi River at the upland margins of High Estonia (upper and lower map on the left) in comparison with the north Estonian Purtse River (the left map). See also the Fig. 5

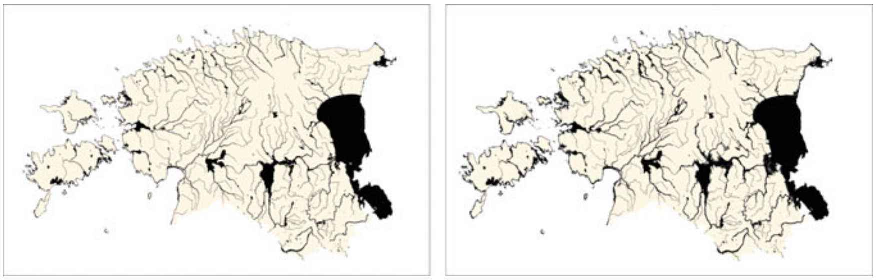

Fig. 13 Generalised flood maps of 2 years (on the left) and 1000 year (on the right) return period in Estonia (black polygons and lines on the maps). Maps compiled by Ü. Reimets

to such circumstances. However, there are also some striking examples. The most warning example is the new residential area located on the western meadow of the north Estonian Pirita River, where the buildings located on the river floodplain. Part of this floodplain having the floods with a return period of 10 years, but most of the settlement is located on the area with the flood return period of 25 years. The entire settlement should be flooded at least once after 200 years. Hereby, from the flood maps, it is seen, that older buildings of the same settlement are located exactly on the border of the maximum floods, i.e., outside of the flood risk area.

Despite predicted extensive overflows on the Pirita River, those floods might not be so extensive in the near future. Since the Pirita River is a part of the drinking water supply of Estonian capital, Tallinn city, it can be assumed that the growing population of Tallinn and associated higher water consumption may reduce both the amount of water flowing in the river as well as floods.

On many river valleys, especially on small river valleys, it is possible to see that the low, sometimes with ditched meadows around the riverbeds are flooded extensively. It may be surprising that such small rivers having enough water to form such floods. However, our field experiences show that such situations are quite possible during very short period in the spring when the rapid snow melt in the surroundings could cause a large overflow of still frozen, narrow and straightened riverbed. Hereby it is important to stress that such floods may occur in any part of visualised by us flood polygons, and also, that the modelled flood polygons may not be flooded entirely in the same year, i.e., during the same return period flood event overflows can occur in different parts of the polygon in different years.

Extensive floods are also seen in the valleys of the small rivers which flow through the former peat extraction fields or drained mire areas. Topographically those areas are only a few tens of centimetres higher than the river valleys. Depreciation of drainage systems of such area may lead to a restart of paludification processes, i.e., it might be called as reclamation of the flood buffering capacity on the landscape together with corresponding changes in overflows along the riverbed.

In the deep valleys of the northern Estonian rivers, even the largest overflows on the maps differed by only a few pixels along the riverbed (see the Purtse River in Fig. 12). Therefore it could be concluded that the floods of northern rivers of Estonia had a minimal impact on the surrounding areas outside the river valleys. However, whatever modification or disturbances on the river valleys could cause flood risk increment also of those rivers.

6 Conclusions

As a result of the work, it is the first time when the flood maps are covering the almost entire area of floodplains of Estonian rivers, i.e., almost 90% of the flood areas are mapped. We can confirm that the best software was used and input of flood maps modelling based on almost all valuable information that can be found in Estonia.

In numerical modelling of flood water levels and especially the water levels with return periods of 500 and 1000 years, it carefully observed that those values would stay within realistic limits, because of used different exponential curves in analyses. However, in needed generalizations during the mapping procedure, it always followed the principle to generalize the flood polygons toward a larger extension, rather than smaller; for example, by correction, the riverbed extension in the DEM model the wider riverbed polygons were used. At the same time, every effort was made to prevent the overflow expansion across the water divide between neighbouring catchments.

However, it should be stressed, that no any climate scenarios, riverbed erosion or accumulation of sediments in the riverbeds or on the floodplains were applied. Moreover, the present climate scenarios are valid for no longer than 100 years, which is ten times shorter in comparison of used flood return periods up to 1000 years. Also, there is no any information related to the development of different erosion processes in Estonian riverbeds ahead of 1000 years.

7 Recommendations

Our firm requirement to insurance companies is that produced by us flood maps should be updated from time to time. Preferably, the upgrade should be done after 5 or 10 years. The major changes that may occur during such a period are primarily human activities; e.g., removing or creation of dams, changes in the morphology of the riverbeds and their locations in the landscape, creation of new polders, road dams, and other constructions. Also, changes in water consumptions can significantly change the floods and overflow in the landscape.

One of the prerequisites for high quality upgrading is access to the newest LiDAR data. It should be hoped that the cross-border basins of the Narva River and the Piusa River will be covered with available higher quality LiDAR data and DEM models soon. Also, higher upgrade results could be gained from data obtained from automatic hydrological gauging stations, intensified monitoring of water consumptions, and newer GIS modules for the flood modelling on the river valleys. The climate change scenarios could also be adapted into the flood modelling.

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Joint Methodology for the Identification and Assessment of Groundwater Dependent Terrestrial Ecosystems in Estonia and Latvia

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Abstract Dynamic interactions between ground- and surface water are widely known, but the role of groundwater in terrestrial and aquatic ecosystems is often poorly understood and documented due to the spatiotemporal complexity. Many countries have not yet completed the assessment of groundwater dependent ecosystems (GDEs). GDEs are valuable ecosystems that depend on groundwater input and

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can not be considered and assessed separately. Changes in the quantity and chemical composition of groundwater recharge may result in significant and permanent damage on GDE flora and fauna. Aquifers are dynamic systems which are not subject to administrative boundaries and borders, therefore should be managed in close cooperation between neighbouring countries. According to the European Union's Water Framework Directive 2000/60/EC, a groundwater body is considered to be in "poor status" if environmentally negative pressure on groundwater causes significant damage to related GDEs. The identification of GDEs in Estonia is currently underway. A theoretical approach on how to identify, assess, and monitor the groundwater dependent terrestrial ecosystems (GDTEs) has been developed. Similar climatic and hydrogeological conditions allow to adapt the methodology to Latvia and develop it jointly further. The first step in this joint methodology is to (i) find indicators and (ii) define criteria for (i) the evaluation of quantitative and qualitative effects of groundwater bodies on GDTEs and (ii) assessment of ecosystems. Subsequently, the quantitative and qualitative effects on GDTEs using assessment schemes must be identified. In this chapter, we are presenting a methodology for GDTE identification and assessment which could be used in similar situation in other countries.

Keywords Water Framework Directive · Groundwater management · Terrestrial ecosystems · Spring fens

1 Introduction

Groundwater dependent terrestrial ecosystems (GDTEs) are valuable ecosystems which quality and existence rely on groundwater supply. Any changes in quality and quantity of groundwater feeding the GDTE often result in significant and permanent damage of water dependent flora and fauna [1, 2]. GDTEs are directly or indirectly protected by the number of European Union directives (Birds, Habitats, Groundwater, Floods) and international agreements such as the Ramsar Convention on Wetlands. Many GDTEs are included in Natura 2000 network of protected sites. These ecosystems are typical of high value as they provide habitat for endangered species, support high biodiversity, and provide valuable ecosystems services. The assessment of GDTE should be a part of groundwater management. Still, the role of groundwater interactions with terrestrial ecosystems is poorly understood due to the complexity of the processes occurring both above and under the ground [1, 3].

Water Framework Directive 2000/60/EC [4, 5] is a legally binding legislative act in the European Union which came into force in 2000. Water Framework Directive (WFD) aims to protect and improve all European water resources, including groundwater. Environmental objectives for groundwater are set in Article 4 with the main goal to achieve good groundwater chemical and quantitative status. Definitions of these two terms are given in Annex V of WFD [4, 5]. Environmental objectives are applied to "groundwater bodies" (GWBs)—management and reporting units set by each Member State. The general criteria for GWB delineation under WFD are well described by Sánchez et al. [6].

Good groundwater status eliminates any potential damage to groundwater dependent terrestrial ecosystems (GDTEs) caused by human-induced pressures on GWB feeding the ecosystems. The status of GWB is determined through six classification tests, from which one assesses whether GDTE has been significantly damaged by poor quality or insufficient quantity of water received from GWB [7]. So the quantitative and qualitative effects of GWS on GDTEs must be identified. Quantitative effect means that anthropogenic pressure has caused a decrease in groundwater level below a critical limit to sustain the related GDTEs in their natural state. Qualitative effect means that anthropogenic influence has affected the groundwater body in a way that its chemical composition causes the deterioration of the ecological value of the GDTE. If significant damage to GDTE is caused through the transmission of pollution by groundwater or by groundwater abstraction that reduces the natural baseflow discharges, then a whole GWB is in poor status, and restorative measures should be applied [8].

According to Groundwater Directive 2006/118/EC [9], Member States shall derive and set threshold values (TVs) for GWBs failing to achieve good status resulting from significant damage to GDTE. TVs are groundwater quality standards representing pollutant concentrations, which must not be exceeded to achieve good chemical status for a GWB [10].

The accomplishment of GDTE classification test remains one of the key challenges for hydrogeologists and ecologists working on the implementation of the WFD's requirements. Technical Report No. 6 [11] prepared by Groundwater working group of the European Union's common implementation strategy (CIS) of WFD explains the role of GDTEs in WFD and suggests overall technical solutions for the assessment of interactions between GWBs and GDTEs. Still, it leaves broad flexibility for the Member States to develop their approaches according to their specific needs. Results of a questionnaire (responded by two non- and 19 Member States) clearly outlines the remaining gaps and difficulties in this matter. Only a few countries reported a clear criterion for identification of GDTEs, whereas "expert judgement" was reported as a key criterion in all countries. Consequently, the assessment of significant damage to GDTE is the mostly subjective opinion of the evaluator. Therefore, the exchange of best practices and compilation of outcomes from the cooperation between ecologists and hydrogeologists at European level in up to date guidelines are highly recommended [12].

Eamus et al. [13] identify four important knowledge gaps in the sustainable management of GDEs, both terrestrial and aquatic. First, the identification of such ecosystems in the landscape. Second, the estimation of the amount of water used by GDTE. Third, the assessment of main threats or pressures. Moreover, fourth, the identification of likely responses of the ecosystems to over-extraction of groundwater. Lack of ecological and hydrological monitoring data is the main obstacle to adequately assess whether significant damage to GDTE has occurred [7]. The determination of impact and response to GDTEs and effective pollution management is not possible due to often missing monitoring data on land use practices and fertilizer use [3]. Hinsby et al. [10] recommend derivation of more strict TVs (as close as possible to natural background levels) to protect GDTEs. However, it requires a more detailed understanding of GDTE functioning than generally available. Only carefully designed and holistic national monitoring programmes may provide the missing long-term data in the future [1].

Whiteman et al. [7] point out that many GDTEs are in areas which are currently classified as "unproductive strata" which do not meet the criteria for "aquifer" according to WFD and may be eliminated from GWBs. Following that, identification and assessment of GDTEs outside GWB are not carried out. Sánchez et al. [6] highlight that any groundwater flow influencing the ecological or chemical quality of dependent ecosystem should be regarded as an aquifer. Even more, catchment areas of GDTEs identified as being at risk should be delineated as separate GWBs. This will allow to implement appropriate measures for the protection of these ecosystems rather general measures across large GWB [14].

2 Country Profiles

Estonia and Latvia are two northernmost Baltic states (Fig. 1). Two countries share 343 km of common borders and have a long common history. Currently, both countries are full members of the Council of the Baltic Sea States, NATO, OECD, and the European Union. Since the beginning of 1990-ies, both countries have declared itself to be the restoration of the sovereign nation that had existed from 1918 to 1940. Estonia and Latvia have parliamentary democracies and are closely cooperating on defence, environmental protection, and other fields. As both countries are also connected hydrologically and have geological similarities (Fig. 2) it reasonable to deal also with groundwater related issues together.

2.1 Republic of Estonia

The Republic of Estonia, the northernmost of the three Baltic States, is located in the North-East of Europe, on the coast of the Baltic Sea, which surrounds Estonia from north and west (Fig. 1a). The territory of Estonia is 45,339 km^2, of which around 4.8% is standing water bodies. In total Estonia has over 110,000 standing water bodies, of which natural lakes are one of the smallest group (1562), exceeded by mostly very small ponds (51,780) and bog pools (45,309) [15, 16]. The largest natural lakes are Lake Peipsi (3555 km^2) shared with Russia and Lake Võrtsjärv (270 km^2) in central Estonia. There are over 7000 rivers, brooks, and canals in Estonia. 90% of the rivers are short, up to 10 km. The longest river is Võhandu (191 km). Estonian landscape is characterised by mires—20.9% of the territory is paludified. The most paludified is south-western part of the country, but the most abundant distribution of mires is

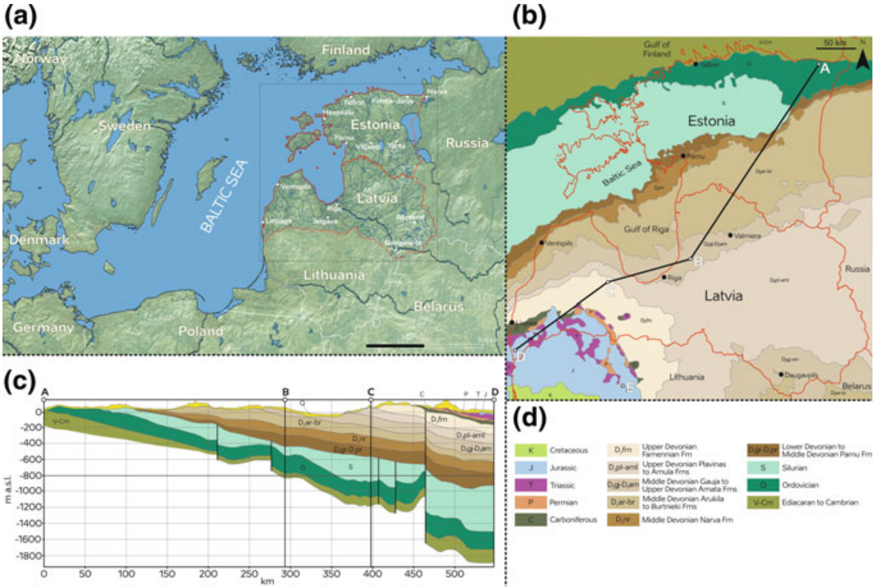

Fig. 1 **a** Location, main cities, rivers, and lakes of Estonia and Latvia. (Map source: Natural Earth and Estonian Topographic Database). **b** Geological map and **c** geological cross-section of the study region without Quaternary cover (labelled line denotes the location of the cross-section; thick vertical lines denote major fault structures). **d** Legend of the geological map and cross-section

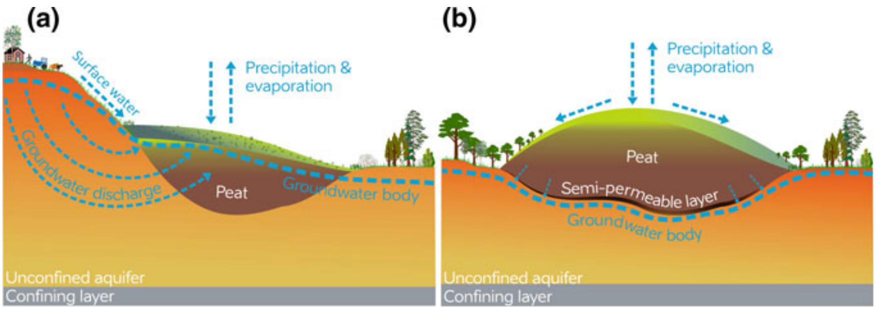

Fig. 2 Conceptual models for two main types of terrestrial ecosystem dependence on groundwater in Estonia and Latvia: **a** the ecosystem is fed by the groundwater body, **b** the ecosystem is supported by the groundwater body

in the valleys of south-eastern Estonia [17]. The largest mires are Puhatu (468 km^2) and Lihula-Lavassare (383 km^2). Estonia has 2355 islands. The biggest ones are Saaremaa (2673 km^2) and Hiiumaa (989 km^2).

Climatically Estonia belongs to the mixed-forest subregion of the Atlantic continental region of the temperate zone. The climate is wet, with cool summers and moderately mild winters. Mean annual temperature is 4.7 °C; in February −6.6 °C, in July +16.3 °C, mean annual precipitation is 500–700 mm. [18]

Geologically Estonia is located within the boundaries of the southern slope of the Fennoscandian Shield, the lowest part of which is formed by crystalline basement rocks, covered by Ediacaran sandstones and clays and Palaeozoic rocks 200–780 m in thickness (Fig. 1b, c). Cambrian rocks in North Estonia are represented by sand-, silt- and claystone, Ordovician and Silurian rocks in Northern and Central Estonia are carbonate rocks (limestones, dolostones, domerites, and marls) and Devonian rocks in South Estonia mainly sand- and siltstones. The Quaternary deposits are of uneven distribution—in North Estonia usually less than 5 m or absent, on Haanja and Otepää heights often more than 100 m. The development of modern landscapes began after the retreat of the continental ice sheet, glacial meltwaters and the sea. The Earth's crust that was released from the weight of the ice cover started to rise, especially rapidly in North-West Estonia (currently being near Tallinn about 2 mm/year). Estonia is a generally flat country, where uplands and plateau-like areas alternate with lowlands, depressions, and large valley-like forms. The average height above sea level is approximately 50 m, ~ 40% of Estonia's territory is at an absolute height of 50–100 m. [19] The highest point in Estonia (and in the Baltic States), the Suur Munamägi Hill (318 m), is in the Haanja Heights in south-eastern Estonia.

Hydrogeologically Estonia is a typical artesian basin with 5 main groundwater aquifers: Devonian (D) in Southern Estonia and Silur-Ordovician (S–O), Ordovician-Cambrian (O–C) and Cambrian-Vendian (C–V) in Central and Northern Estonia. The uppermost aquifer is the Quaternary that feeds the deeper aquifers. Available resource of groundwater is 1.5 million m^3 per day [20, 21]. The abstraction of groundwater is approximately 45 million m^3 per year. In rural settlements and most of the towns, groundwater is the main source of water supply. Only in Tallinn and Narva surface water gives a considerable share of consumption. For management reasons, 39 bodies of groundwater have been distinguished based on their levels. Out of 39 groundwater bodies, 8 is in worse than good condition, mostly because of the elevated level of nitrates or hazardous substances. In North-East Estonia (the area of oil-shale mines) the serious problem is the sulfate contamination. A permit for the special use of water is required if groundwater is abstracted in a volume of more than 5 m^3 per day. The individual residents with a personal well are not included in the abstraction calculations, as their abstraction is below the threshold [21].

2.2 Republic of Latvia

The Republic of Latvia is located in the North-East of Europe, it is part of the Baltic States, standing in between the rest of the Baltic State countries—Estonia in North and Lithuania in South (Fig. 1a). Latvia is bordering with the Baltic Sea, including the Gulf of Riga. The area of the territory of Latvia is 64 573 km^2, of which around 47.7% are forests, 36% are agricultural lands, and 3.8% inland waters. Mires cover about 10% of the territory of Latvia. However, small mires with thin peat layers are not included; therefore, this number could be larger [22].

There are more than 12,5 thousand rivers, brooks and canals in Latvia with a total length of 100 thousand km, but the total length of solely rivers is 37.5 thousand km, however, only 777 rivers are longer than 10 km and 17 rivers longer than 100 km [23–26]. The longest river in the territory of Latvia is Gauja (452 km). However, the longest river is Daugava with a total length of 1005 km of which 352 km are in Latvia. The catchment areas of Latvian rivers are small, and only 213 rivers have catchment area larger than 100 km^2 [23]. The total area of rivers in Latvia is 358 km^2. The rivers in Latvia are relatively young—they formed after the last ice age and are not more than 15.7 thousand years.

According to the Central Statistical Bureau of Latvia, there are 2256 lakes in Latvia that are larger than 1 ha and 133 lakes larger than 1 km^2, with a total area of 1000 km^2 and covers 1.5% of the territory of Latvia [23]. The largest lakes in Latvia are Lake Lubāns (80.7 km^2) and Rāznas Lake (57.6 km^2). There are around 800 reservoirs with an area larger than 1 ha with a total area of 225 km^2, that is around 0.3% of the territory of Latvia. The largest reservoirs are made for hydropower stations and are located on the river Daugava, namely, Rīgas, Ķeguma, and Pļaviņu hydropower station reservoirs [23].

Latvia has a temperate continental climate with that is driven by its location in North-West part of Eurasia continent and the presence of the Atlantic Ocean. Changes in local climate are determined by terrain and the presence of the Baltic Sea or the Gulf of Riga. During the last decades (1981–2010) mean annual temperature in Latvia is 6.4 °C; in February −3.6 °C, but in July +17.4 °C. Annual precipitation varies from 580 mm in lowlands to 760–870 mm in uplands [27].

The territory of Latvia is in the central part of the Baltic Artesian Basin where the thickness of the sedimentary cover varies from 500 m in the northern part to more than 2000 m in the southwestern part of Latvia [28] (Fig. 1b, c).

Traditionally groundwater in Latvia is delineated into three zones, which are separated by regional aquitards [29, 30]. The Ediacaran-Cambrian aquifer complex lies on top of the crystalline basement an is composed of sandstones, siltstones, and clays [28]. The thickness f the complex varies from 50 to 150 m. The dominant water type is Na–Cl, sometimes Ca–Na–Cl type with average mineralization is about 100 mg/l [31]. The Ordovician-Silurian sedimentary sequence is composed of deep marine facies—marls and clays with occasional limestone and dolostone beds, and it forms a regional aquiclude separation Ediacaran-Cambrian aquifers [28]. The thickness of aquiclude varies from 80 m in the southeast to up to 800 m in the west [32]. Lower Devonian Gargzdu formation to middle Devonian Parnu formation forms the lower to middle Devonian aquifer system of the passive (brackish) water exchange zone within [30]. Predominantly, it is composed of sandstones, with siltstones, marls, and clays reaching a thickness of 200 m in the western part of the aquifer. This zone is dominated by brackish water with high SO_4 and Cl concentrations along the high Na, Ca, and Mg values [31].

Narva formation is an important regional aquitard. Its thickness varies from 100 m in eastern Latvia to 200 m in western Latvia [32]. Sediments of middle and upper

Devonian to Quaternary age form an active water exchange zone. A substantial part of this zone is formed by the sequence of clastic sediments that are stratigraphically relevant to Arukila, Burtnieki, Gauja, and Amata formations. This sequence has a rhythmical structure where sandstones predominate at the base of each formation and fine-grained siltstones and clays dominate at the upper part. Above this terrigenous sequence of middle-upper Devonian, a pie of interlayered dolostones, clay dolomites, dolomitic marls, limestones, marls, clays, silts, sandstones, and occasional gypsum of the upper Devonian Frasnian and Famennian stages reside. The complex is present in large part of Latvia, missing only on its northern edges and the southeast. It gains importance at the southwestern edge of Latvia, where its thickness is approaching 300 m [28]. The whole region is covered by Quaternary, mostly glacial and marine sediments, which discordantly lie atop of the Middle Devonian-Jurassic sequence. From a hydrogeological point of view, it is important in upland areas, where patches of glacial till loams (aquitards) and glaciofluvial sand and gravel (aquifers) sequences can exceed 200 m [29].

Quaternary groundwater quality can be divided into four large groups (Ca–Mg–HCO_3 type waters with low nitrate and ammonium concentrations, two groups with diffuse agricultural contamination with nitrates and contamination, Ca–HCO_3 water type in sandy deposits). Highest nitrates concentrations are typically found in groundwater that are in the areas considered to be most protected from pollution (having a high proportion of clays). This can be explained by the fact that intensive agricultural activity occurs in the most fertile soils which are located atop of clayey sediments [33, 34].

2.3 Groundwater Monitoring in Estonia and Latvia

In general, Estonian and Latvian groundwater monitoring programmes are quite similar, but there are some differences in observable water quality indicators (Table 1). The main difference is that in Estonia until now, phosphorus and nitrogen are not measured in the groundwater. This is also problematic from the GDE point of view because in surface water monitoring, those are one of the main parameters for deciding the ecological status of the habitat.

2.3.1 Groundwater Monitoring in Estonia

In Estonia regular observations of groundwater started in 1946 and development of hydrogeological observation network began in 1960.

The density of the groundwater monitoring network depends most directly on the level of human impact on both groundwater quantity and quality (e.g., water abstraction, intensity, and nature of the industrial activity) in different regions. Monitoring of quantitative status of delineated groundwater bodies performed in 247 monitoring

Table 1 The aggregated list of observable water quality indicators of GWBs in Estonia (EE) and Latvia (LV)

Parameters	LV	EE	Parameters	LV	EE
Traditional measurements			*Nitrogen compounds and their ionic forms*		
Temperature	Yes	Yes	NH_4^+, mg/l	Yes	Yes
Conductivity 20 °C, μS/cm	Yes	Yes	NO_2^-, mg/l	Yes	Yes
pH index	Yes	Yes	NO_3^-, mg/l	Yes	Yes
Eh, mV	Yes	Yes	$N_{tot.}$, mg/l	Yes	No
Fe_{tot}., mg/l	Yes	Yes	TOC, mg C/l	Yes	No
O_2 dissolved, mg/l	Yes	Yes	DOC, mg C/l	Yes	No
Key ions			UV absorption, cm^{-1}	Yes	No
Na^+, mg/l	Yes	Yes	Permanganate index, mg/l	Yes	Yes
K^+, mg/l	Yes	Yes	*Heavy metals*		
Ca^{2+}, mg/l	Yes	Yes	Cd, μg/l	Yes	Yes
Mg^{2+}, mg/l	Yes	Yes	Pb, μg/l	Yes	Yes
Cl^-, mg/l	Yes	Yes	Ni, μg/l	Yes	No
SO_4^{2-}, mg/l	Yes	Yes	Hg, μg/l	Yes	Yes
HCO_3^-, mg/l	Yes	Yes	As, μg/l	Yes	Yes
Mn, μg/l	Yes	No	*Chemical pollutants*		
$P_{tot.}$, mg P/l	Yes	No	Trichlorethylene, μg/l	Yes	Yes
PO_4^{3-}, mg/l	Yes	Yes	Tetrachloroethylene, μg/l	Yes	Yes
Total hardness, mmol/l	Yes	Yes	Trichloromethane, μg/l	Yes	Yes
			1,2-dichloroethane, μg/l	Yes	Yes
			BTEX, μg/l	Yes	Yes
			Pesticides	Yes	Yes

wells by manual water level measurements with the frequency once per month. Similarly, to the sequence of meteorological measurements, the sequence of automatic recordings of 163 monitoring wells is 8 times per day, i.e., after every three hours during the day. The network of groundwater monitoring wells is denser for monitoring of the water levels of Ordovician Ida-Viru and Ordovician Ida-Viru oil-shale basin groundwater bodies, where the quantitative pressure on a groundwater water body is the highest due to oil shale mining.

Monitoring network of water quality established in a way that obtained data would allow a reliable evaluation of the chemical status of every delineated groundwater body. If the groundwater body or group of groundwater bodies with similar hydrogeological conditions are at least in good quality status, then the monitoring of groundwater bodies are optimised by decreasing the number of monitoring wells. However, attention is turned to the monitoring of groundwater bodies in nitrate-sensitive areas with the high monitoring sequence, i.e., at least 8 times during 24 h period in wells in

53 locations as well as with the less-frequent monitoring in the wells in 72 locations, which differ in terms of monitoring frequencies.

To minimise errors caused by less-frequent samplings and measurements, the minimal monitoring frequencies are settled in "Requirements for river basin water monitoring programmes" (Regulation No 25 of the Minister of the Environment) and is valid since April 2011. In the case, when monitored data range has high variance, then the monitoring frequency in the relevant monitoring well is increased to a level which allows to determine the status class of groundwater body with great reliability. The high monitoring frequent is also established to the groundwater bodies that are at risk because of the bad ecological status of corresponding surface water bodies.

2.3.2 Groundwater Monitoring in Latvia

Regular surveys of groundwater quality in Latvia have been conducted since 1959. The groundwater quality monitoring network was set up between 1970 and 1980, initially to assess the groundwater water quality and changes in confined aquifers, as these aquifers began to be used intensively for centralized extraction and supply of drinking water during this period not only in urban areas but also in rural areas. From 2004, the groundwater monitoring network also includes springs. This is an important improvement in the monitoring network, as springs with high water flow mostly represent water quality in much larger catchment areas than wells and are an important indicator of diffuse pollution.

Groundwater status within the monitoring network is observed in 311 wells at 61 stations and 30 springs. Of these, quality (chemical composition) observations are provided at 53 stations in 218 wells and 30 springs, while in quantitative (water levels) observations at 60 stations in 305 wells.

The frequency of monitoring observations during the six-year cycle of monitoring of river basin districts includes a detailed breakdown of monitoring stations by groundwater bodies and types of monitoring. Monitoring points that are monitored each year and observable parameters for groundwater quality can vary according to the annual monitoring plans developed. The frequency of groundwater monitoring is variable: the frequency of quantitative observations—two times a day (automatic level measurements) up to four times a year, and the frequency of groundwater chemical observations is four times a year, up to once a year (over a six-year period, it changes from one time in six years to one time each year).

The frequency of monitoring observations and its determination in the following years may change, taking into account the new monitoring data obtained, experience gained, developed scientific projects in connection with the implementation of the WFD, and new requirements of EU and Republic of Latvia regulatory enactments. This will be assessed by developing a monitoring plan for each specific year.

3 Results and Discussion

3.1 *Identification of Terrestrial Ecosystems Depending on Groundwater in Estonia and Latvia*

Only terrestrial ecosystems that are directly depending on GWB are considered as part of the GDTE classification test under WFD. Thus the first step is to identify whether certain terrestrial ecosystems theoretically can be groundwater dependent [11]. However, the reliance of a terrestrial ecosystem on GWB can be complex. For example, fens receive a continuous supply of groundwater [1] and strongly depend on the certain quantity and quality of groundwater input throughout a year (Fig. 2a). Bogs receive only precipitation, but groundwater pressure prevents natural drainage [1]. Therefore, bogs are sensitive to changing groundwater quantity rather than quality (Fig. 2b).

Identification of GDTEs in the landscape is rather a difficult task considering the needs for research in multidisciplinary teams, time, and funding resources. Early assessment of GDTE dependency degree on GWB is a vital step as well to carry out their appropriate management. It may require a decade of monitoring before drought occurs and groundwater dependency is expressed, and the threshold response of an ecosystem could be identified and described [13].

It is suggested by the European Commission [11] that Member States shall use available knowledge base from national assessments for EU Habitats Directive. Most of the Member States (nineteen) reported that they rely on Natura 2000 designations when identifying GDTEs and about half of the respondents (ten) used additional wetland designations to those declared under Natura 2000. Seven countries identified the Annex I habitats typologies when selecting GDTEs for further assessment [12]. In England and Wales, professional knowledge and research information were used to determine which wetland plant communities are critically dependent on groundwater [35].

Identification of GDTEs in Estonia and Latvia is based on a two-step approach. First, habitat types listed in Annex I in the EU Habitats Directive [36] were selected. Second, additional criteria were applied to select GDTEs for assessment—such as area, occurrence within GDTEs complexes, and presence of certain species occurring solely in groundwater-dependent habitat types. The agreed habitat types and used additional selection criteria considered when selecting GDTEs in Estonia and Latvia are reported in Table 2.

In Estonia and Latvia, the habitat data come from different inventories, and the interpretation of national habitat identification is slightly different in both countries. Considering the identification and interpretation differences, area, and distribution of the selected groundwater-dependent habitat types, also the criteria for GDTE identification slightly differ (Table 2). Presence of some protected species occurring solely in groundwater-dependent habitat types is used as additional criteria (sites important for these species are considered GDTEs also if smaller than the minimum

Table 2 Selected habitat types and additional criteria for selecting groundwater dependent terrestrial ecosystems in Estonia and Latvia [37]

Habitat types listed in Annex I of the EU Habitats Directive [36]	Additional criteria used (Latvia/Estonia)
Considered as GDTEs	
Humid dune slacks (2190)	Single polygon with 1 ha area or smaller if part of a habitat complex with the total area of at least 1 ha
Fennoscandian mineral-rich springs and spring fens (7160)	Single polygon with 1 ha area or smaller if part of a habitat complex with the total area of at least 1 ha
Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae* (7210*)	Single polygon with 10 ha/20 ha area or smaller if part of a habitat complex with the total area of at least 10 ha/20 ha. *Cladium mariscus* stands in lakes are excluded
Petrifying springs with tufa formation (*Cratoneurion*) (7220*)	Single polygon with 1 ha area or smaller if part of a habitat complex with the total area of at least 1 ha
Alkaline fens (7230)	Single polygon with 10 ha/20 ha area or smaller if part of a habitat complex with the total area of at least 10 ha/20 ha
Fennoscandian deciduous swamp forests (9080*)	Single polygon with 20 ha area or smaller if part of a habitat complex with the total area of at least 20 ha
Considered as GDTEs in exceptional cases	
Molina meadows on calcareous, peaty or clayey-silt-laden soils (6410)	Considered as GDTE if part of a GDTE habitat complex (e.g. 7210*, 7230) with the total area of at least 20 ha
Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels (6430)	Single polygon with 20 ha area or smaller if part of a habitat complex with the total area of at least 20 ha (only in Estonia where the habitat type, according to the national habitat interpretation, includes poor fens and poor paludified grasslands)
Active raised bogs (7110*) and Degraded raised bogs still capable of natural regeneration (7120), Transition mires and quaking bogs (7140)	Single polygon with 20 ha area or smaller if part of a habitat complex with the total area of at least 20 ha (only in NE Estonia in oil shale mining region and only quantitative dependence), not considered GDTE in the rest of Estonia and in Latvia
Bog woodlands (91D0*)	Transition mire and bog woodlands (only in NE Estonia in oil shale mining region and only quantitative dependence)—single polygon with 20 ha area or smaller if part of a habitat complex with the total area of at least 20 ha. Coniferous fen woodlands (included in 91D0*) (in both countries)—single polygon with 20 ha area or smaller if part of a habitat complex with the total area of at least 20 ha

area): eight species in Latvia and 30 in Estonia. The criteria are applied both inside and outside Natura 2000 network.

Though the criteria allow to use the existing habitat data with varying quality and exclude non-relevant habitat types, still the final decision in site selection must base on expert judgement. Such as a decision on what is a habitat complex is based on terrain, soil and forest data. From 2018 to 2020 the approach is being tested in transboundary Gauja/Koiva river basin in Estonia and Latvia under the project "Joint management of groundwater-dependent ecosystems in transboundary Gauja/Koiva river basin (GroundEco)" financed from Interreg Estonia-Latvia cross-border cooperation programme 2014–2020.

Conceptual models may include information on habitat type and understanding of linkages between GWB and GDTEs or degree of dependence on GWB. Still, considering the likely large number of GDTEs, conceptual models may never be developed for all sites. In case of missing data or conceptual models, information from neighbouring countries might be used, and the final decision can rely on expert judgement [38]. As reported, expert judgement plays a key role when determining GDTE dependence degree on GWB in other countries as well. However, only a few countries have clear assessment criteria or have carried out field studies to assess dependency [12]. In the case of Estonia, conceptual models for GWBs are under development, whereas Latvia has not started this task. Also, Lithuania has not carried out GDTE identification and assessment. Thus it is not possible to rely on their experience as well.

3.2 Assessment of Significant Damage to Groundwater Dependent Terrestrial Ecosystems from Groundwater Body

According to the European Commission [11], the expression "significant damage" is based upon the magnitude of the damage and the ecological or socio-economic significance of terrestrial ecosystem. If the required environmental supporting conditions for GDTE (both quantitative and qualitative) are in place, then the status of GWB is considered as good [7].

Groundwater body could have a negative quantitative and/or qualitative effect on the GDTE if:

- human influence (such as groundwater abstraction) has lowered groundwater level, so that does not provide enough water to sustain the GDTE in its natural state (quantitative effect) [2];
- human influence (such as fertilizer application) has affected the GWB in a way that it is chemical composition causes the deterioration of the ecosystem (qualitative effect).

If a GDTE occurs within Natura 2000 network, then the failure to meet its conservation targets can be assumed as significant damage, though for GDTEs outside Natura 2000 network the damage (depending on the ecosystem type and degree of damage) can be considered as equally important as in areas within Natura 2000 network. A GDTE which is crucial for tourism might be considered to have socio-economic significance. Thus changes in environmental supporting conditions may lead to its damage expressed as reduced number of visitors and income from tourism [3, 11].

3.3 Assessment Schemes for Quantitative Effect

After identification of GDTE in the landscape, the next step is to assess whether GWB could have a negative effect on the GDTE. Combination of water level measurements in groundwater monitoring wells in GDTEs and their surroundings are typically used indicators for quantitative changes. For example, seasonal dynamics of mire water levels compared to short- and long-term average levels will indicate already occurring negative effects in GDTE (Fig. 3, Step 1). Significant groundwater abstraction,

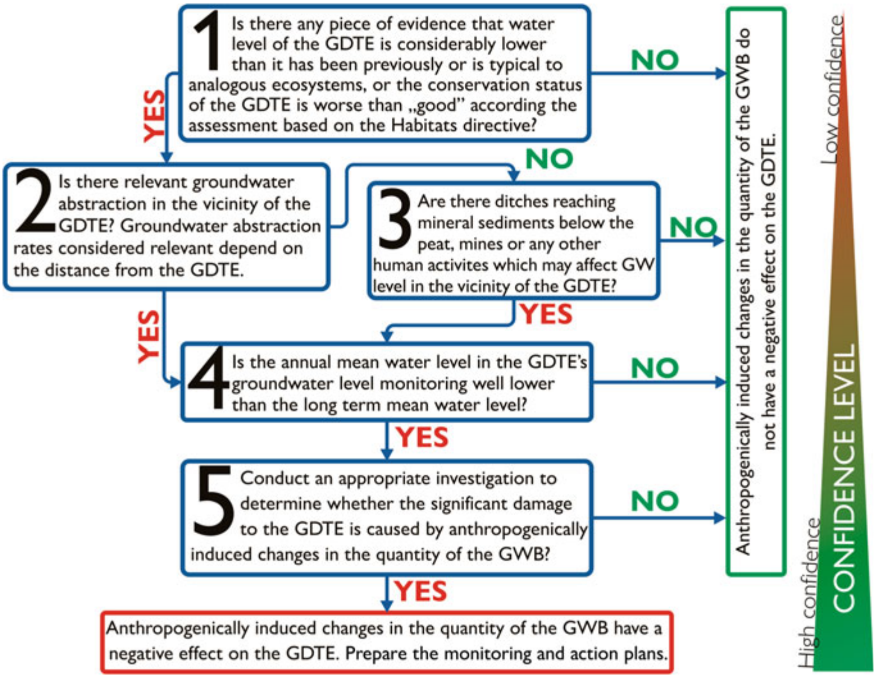

Fig. 3 Proposed scheme for assessment of significant damage to groundwater-dependent terrestrial ecosystem caused by quantitative pressures on GWB

dense abstraction well network or known human activities lowering the groundwater levels near GDTE can also result in a decrease of groundwater inflow to GDTE, thus deteriorating its condition (Fig. 3, Step 2–3). Groundwater level drop in the monitoring well of GWB feeding the mire or the change of spring discharge providing the base flow for spring fen will indicate the first negative tendencies (Fig. 3, Step 4). Still, appropriate measures may stop the negative influence, but timely actions may prevent potential damage to GDTE. Proposed assessment scheme (Fig. 3) requires often limited long-term monitoring data [3] or missing water level targets for different GDTE types [7]. Thus, the most common indicator is actual evidence of damage in GDTE (Fig. 3, Step 1) observed as an ecological response to groundwater depletion [2].

Some commonly used groundwater quantitative management approaches in GDTE management area are volumetric allocations, buffer/well exclusion zones, groundwater level triggers, and groundwater rate of decline triggers. Their advantages and disadvantages from a technical and implementation perspective are well described by [39]. It is proposed that simple as possible assumptions are used to initially analyse possible impacts on GDTEs by groundwater abstraction (Fig. 3, Step 2). More complex methods such as a combination of most appropriate tools or local-scale mathematical models should be used to conduct investigations when there is evidence for the possible threat to GDTE (Fig. 3, Step 5).

Proposed quantitative assessment scheme (Fig. 3) provides more concrete steps, then the initially proposed scheme by the European Commission [40]. At the same time, it leaves more flexibility by also considering indirect data (such as analysis of any evidence in Fig. 3, Step 1 and 3) and assigning the confidence levels. The reason for that is reporting deadlines set by WFD [4] and the high probability that many necessary data will remain missing as their gathering takes a long time.

Unfavourable status of GDTE is often caused by surface drainage. Due typically smaller area of the spring fens in comparison with minerotrophic fens, the area affected by the surface drainage is usually smaller in the spring fens, and the drainage caused water deficit might be more intensively mitigated by the constant inflow of groundwater. As highlighted by Kilroy et al. [14], the delineation of catchment areas for GDTEs is an essential step to carry out an appropriate assessment of quantitative pressures.

UKTAG [35] emphasizes that many GDTE could be damaged by a variety of pressures such as afforestation and land development which are not directly related to groundwater supply, and identification of main pressures requires detailed assessments. Thus, other potential causes must be ruled out at first. The negative quantitative effect from GWB is expected if there have not been any changes in the surrounding drainage network and other surface water bodies, but the water level in mire has dropped and discharge from the mire has decreased. It is important to consider also meteorological conditions which may have a considerable effect on the water regime in the mire. When the linkage degree between GDTEs and GWB is not well understood, then GWB can be classified as of good status but may remain at risk. These cases may be prioritised for further investigation [11].

3.4 Assessment Schemes for Qualitative Effect

The chemical status of GWB is determined based on established TVs by each Member State required by Groundwater Directive [9]. The criteria for establishment and application of TVs are set in guidance document [40], and it is based on the outputs of European Union research project "BRIDGE" [41]. Derivation of groundwater TVs for GDTEs is a complex task and requires a good knowledge of ecological needs and responses to various pollutants of each GDTE type. Also the information about influence area expressed as GDTE catchment area and domination pressures, as well as a good understanding of the main physical, chemical and biological processes occurring in the pathway from groundwater formation in GWB to groundwater inflow into GDTE is needed [1, 2, 10, 14].

Many EU Member States struggle with the derivation of TVs for GDTE and have set limits for nitrates mostly. In terms of phosphates, the derivation process is ongoing in the United Kingdom [42, 43]. GDTEs are often not considered when establishing national groundwater monitoring networks, and lack of long-term integrated monitoring programmes combining the needs for both groundwater and nature protection has lead to poor understanding of GWB and GDTE interactions [3]. Thus, Estonia and Latvia have not established TVs for GWBs considering GDTEs.

Similarly, to quantitative assessment scheme (Fig. 3) also proposed a qualitative or chemical assessment scheme (Fig. 4) is applied to terrestrial ecosystems identified as being groundwater dependent. Only if there is any evidence of GDTE not having a good status (Fig. 4, Step 1) the following analysis should be carried out. Considering the fact that groundwater TVs for GDTEs are missing in many countries [2] and their establishment is a long term process which includes the negotiation between various experts, managing authorities and decision-makers, the proposed second step (Fig. 4, Step 2) suggests usage of indirect data (such as fertilization amounts, location of polluted sites and land cover data). Such analysis will indicate if there are any significant human-induced chemical pressures, their type and will point out the relevant parameters to be monitored and analysed. After the national monitoring should provide necessary data for comparison with established TVs (Fig. 4, Step 5). Again there are certain proposed strategies on how to set GWB chemical status in case the groundwater monitoring results exceed the derive d TVs [40]. Still the chosen approach is a matter of each Member State.

Proposed qualitative assessment scheme (Fig. 4) slightly differs from the one proposed by European Commission [40] again providing more flexibility to conduct preliminary analysis using indirect data to identify if the damage to GDTE potentially could be a result of chemical pressures on GWB supporting the GDTE (Fig. 4, Step 2). In the case of missing knowledge, the GWB is considered to be still in good status but with low confidence, thus allowing to prioritise such cases for further investigations. Only then use of appropriate groundwater TVs, and consequently, derivation of them is suggested (Fig. 4, Step 4). The reason is the same as for quantitative assessment scheme (Fig. 3) that the Member States must report results in a certain timeline [4].

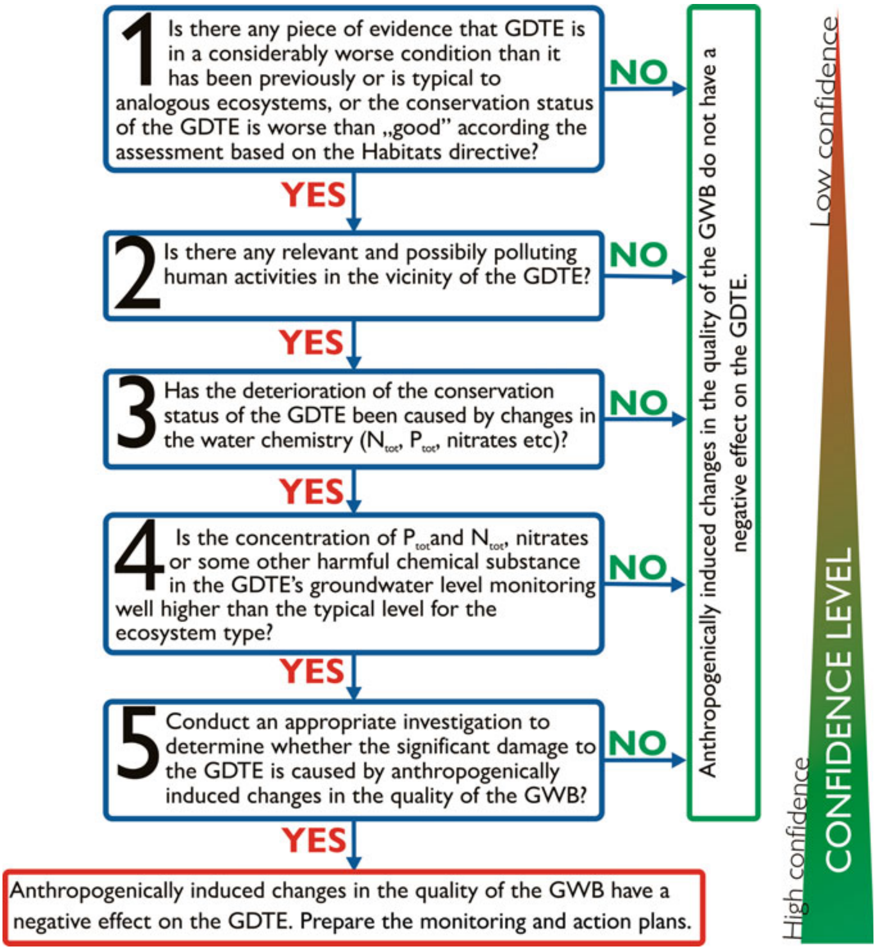

Fig. 4 Proposed scheme for assessment of significant damage to groundwater dependent terrestrial ecosystem caused by qualitative (chemical) pressures on GWB

3.5 Application of the Evaluation Schemes of Groundwater-Dependent Terrestrial Ecosystems in Estonia

In Estonia, the assessment schemes were tested on the 70 GDTEs, but none of them reached the end of the scheme. In some cases, groundwater abstraction was identified in the vicinity of GDTEs with worse than good status. However, because of the lack of water level monitoring wells in the GDTEs and adjacent groundwater level monitoring wells, the potential effect of lowered groundwater levels could not be detected. Still, most probably there are GDTEs in worse than good status because of too low groundwater level.

The qualitative effect could not be assessed at all because there are no habitat-specific thresholds of chemical substances in Estonia. Also, the chemical composition of the mire water has not been monitored. According to the existing knowledge at present, there are no GDTEs in Estonia whose status is worse than good because of groundwater water quality.

3.6 Monitoring Scheme for Groundwater-Dependent Terrestrial Ecosystems

Determination of GDTEs and assessing the effects of GWBs on the ecosystems is complicated because monitoring networks often have not been established to determine interactions between groundwater and surface water. Currently, in Estonia, the parameters monitored from surface water or terrestrial ecosystems are relevant only for these ecosystems. Parameters monitored from GWBs are relevant only for groundwater and monitoring points are located mostly in places that are not representative for GDTE.

Monitoring of the quantitative dependency of GDTEs (mires) should be based on observations of mire water level and their ecological status. The mire water level should be monitored in piezometers equipped with automatic loggers. Obtained data enables to analyse water level dynamics and to compare the data with meteorological data. Also, the water levels in deeper peat layers and the underlying Quaternary sediments are good indicators and should be monitored in piezometers equipped with the data loggers. If the water levels in the deeper peat layers or the mineral sediments are lower than the mire water level, then it is an indication that water is seeping into the underlying groundwater body.

The groundwater levels of GWB should be monitored, respectively. It should be preferably done in monitoring wells as close as possible to the particular mire. In addition to the establishment of the monitoring network, the ecological status of the mire ecosystem must be determined, based on the methodology developed for mire habitat types. If the drop in the mire water level has already been determined, the habitat status assessment has to follow up regularly, in order to determine the actual effect of water level drop on the status of the ecosystem. The number of mire water monitoring stations and their spatial placement depends on the specifics of the monitored mire including its area of extension, the spatial distribution of different habitat types, the location of negative pressure(s), etc. For a small and compact area, probably one station is sufficient. If negative pressure affects the mire through the GWB only from one direction, then the monitoring stations should be installed to the side of the mire that is closest to the pressure and the centre of the mire.

In the selection process of mires that have to be equipped with monitoring networks for observing the effects of GWBs, areas that have the highest ecological value, are located in protected areas and/or Natura 2000 areas and would presumably suffer most, have to be preferred.

In Estonia, at the present such areas are mires that potentially depend on the Ordovician Ida-Viru Oil-Shale Basin GWB (Muraka and Selisoo mire, Puhatu, and Sirtsi mire), Quaternary Vasavere GWB or Quaternary Männiku-Pelguranna GWB. A monitoring network has already been established in Muraka and Selisoo mire. Other groundwater-dependent mires are most likely not significantly affected by groundwater quantity. According to the current knowledge, there are no valuable or protected mires depending on other groundwater bodies that are threatened by groundwater level decrease caused by groundwater abstraction.

4 Conclusions

The Water Framework Directive aims to protect all water resources, including groundwater bodies. For groundwater, environmental objectives are set in Article 4, and the main goal is to achieve good groundwater status. Groundwater dependent ecosystems (GDEs) are valuable ecosystems that depend on groundwater input and cannot be considered and assessed separately. Any changes in the water quantity or quality often result in significant damage of dependent flora and fauna. Therefore, they cannot be assessed separately from the groundwater body (GWB). The presented methodology allows to tests the potential effect of GWBs on GDTEs as far as there are available data. Before the assessment, indicators, and criteria that reflect both the quantitative and qualitative effect of groundwater bodies on the GDTEs must be defined. The first step of the methodology is to find out the ecological status of the GDTE. If the ecosystem status is unfavourable, potential other causes have to be ruled out at first. After identification of groundwater dependency, the assessment of the quantitative and qualitative effects on GDEs using assessment schemes follows. It must be noted that it is not possible to develop a simplistic and universal evaluation scheme that gives a high-reliability answer without the acquisition of additional data. Developed schemes enable to pinpoint the GDEs for which the effect of groundwater body cannot be ruled out as the cause for the unfavourable status. Thorough studies must be performed to determine the actual effect of the groundwater body, the size of the effect, and suitable mitigation measures.

While the identification of vegetation dependent on groundwater remains a great challenge, the distribution of GDTE in the landscape is important for water management needs. The tools and techniques used for the identification of GDTE locations can be of various complexity. However, they all have rather large uncertainties or include subjective assumptions. The question remains whether to use automatic tools with limited possibilities and thus high uncertainty or rely on subjective desk studies and the decisions of evaluating experts? The combination of both might be the best option.

5 Recommendations

The main challenge in GDTE assessment is the lack of relevant data. During this study four main areas where identified where more effort and research is encouraged:

(i) Development of integrated monitoring networks. Most groundwater, surface water and nature protection monitoring networks have been designed long before GDTE protection was highlighted by European Union directives and researchers. As a result, the locations of monitoring sites do not cover the areas of interest and their results cannot be combined for GDTE assessment needs. Sustainable management of GDTEs can be achieved only by intensive cooperation between multidisciplinary research teams and all levels of managing authorities—decision or policy makers, national environmental protection agencies and municipalities.

(ii) More site-specific research. Integrated monitoring networks will provide the missing long-term data at country level or regional scale, still will not deliver site specific data necessary for quantitative and chemical assessment of each GDTEs type. To implement proposed GDTE assessment schemes it is essential to carry out two types of investigations: first, to gather relevant seasonal data for designation of TVs for most typical GDTE pollutants such as nitrogen and phosphorus compounds. Second, to carry out seasonal investigations to deliver groundwater level trigger values. Only then the main pressures on GDTEs (such as groundwater abstraction or land use occurring in the catchment areas) could be appropriately assessed and programmes of measures (such as restrictions of certain human activities) could be justified to stakeholders by data driven analysis.

(iii) Transboundary cooperation is encouraged to save time and money resources and combine existing knowledge base. As well groundwater cannot be divided by human drawn boundaries such as country borders, thus the human induced activities in one county can affect the status of GWB and GDTEs in another country. It is important to emphasize that such cooperation projects and joint research activities are most effective when delivering joint publications in Open Access sources. Currently only part of cooperation projects develops materials in English and many good experiences remain unpublished or are available in national languages only.

(iv) Stakeholder engagement. It is important to increase the overall awareness of groundwater and associated nature protection to achieve sustainable assessment of GDTEs in long term and to maintain safe drinking water for future generations. For this reason, it is recommended that citizen science should be a part of each cooperation and research project.

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Conclusions

Update, Conclusions, and Recommendations for "Water Resources Quality and Management in Baltic Sea Countries"

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Abstract This chapter sheds light on the book's main findings and recommendations of the chapters presented in the book. In addition, an update is made from the recent published results of research work on quality and management of water resources in Baltic Sea Countries. Additionally, a set of recommendations for future research work is pointed out to direct future research towards water resources in Baltic Sea Countries. Additionally, we added a special chapter to the conclusions section on "Estonian Wetlands and the Water Framework Directive" due to its uniqueness nature.

Keywords Water resources · Management · Contaminant · Groundwater · Constructed wetlands · Water bodies · Baltic Sea countries · Latvia · Germany · Russia · Estonia · Water quality

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1 Introduction

The main and only source of clean drinking water is groundwater in the Baltic countries—Estonia, Latvia and Lithuania. Under the Soviet rule, ecological problems in the Baltic States were not given sufficient attention. As a result, groundwater quality is decreasing due to constantly increasing surface pollution. The top, unconfined aquifer, especially in many urbanized areas, is unfit for use. In addition, pollutants are beginning to reach the lower, artesian aquifers, particularly organics. A monitoring system was developed to assess and forecast groundwater quality. Nonetheless, in order to protect groundwater, it is important, in addition to monitoring, to implement new rules, legislation and assurances.

This book presents the perspectives and results of high quality research on water resource management issues in the Baltic countries. The book discusses the latest results from several comprehensive studies and evaluations of occurrence, surface and underground water quality within the Baltic countries to assist decision-makers in preparing for sustainable development as well as maintaining public administration and data requirements. The book's goal, therefore, is to strengthen and discuss the management of water resources in these Baltic countries, with special attention to water quality. The book presents state-of-the-art information that can be used efficiently in the integrated management of water resources to solve a variety of problems.

The next section presents a brief summary of the important findings of some of the recent (updated) published studies on the quality and management of water resources in Baltic Sea countries, followed by the main findings of the book chapters in addition to the main recommendations for researchers and decision-makers. The update, conclusions, and recommendations presented in this chapter come from the data presented in this book.

2 Update

The following are the major update for the book project based on the main book theme:

- **Overview of the Water Bodies in the Baltic Sea Countries**. A separate Sustainable Development Goal (SDG) has been allocated to marine ecosystems among the 17 global goals established by the United Nations (UN), which is SDG No. 14 [42]. Because of its unique geographical, oceanographic, and climatic characteristics, the Baltic Sea habitats are highly susceptible to the environmental impacts of human activities at sea and in their catchment area [21]. The Baltic Sea Drainage Basin (BSDB) is a vast heterogeneous region. The drainage basin is occupied by 14 countries and covers an area of 1,739,000 km^2 (Belarus, Czech Republic, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, Russia, Slovakia, Sweden, and Ukraine) and home to about 84 million. There are

14 larger international river basins within the BSDB, with an approximate area of 1,050,000 km^2. These river basins have different sizes. Some of these basins sharing among several countries. Also, these river basins share witnessed environmental issues and how they are handled. But there is something they have in common. All of them are international and are based in the same geographical area, the Baltic Sea Area. However, increased industrialization and natural resource exploitation have resulted in the Baltic Sea Large Marine Ecosystem (BSLME) declining and decaying since the 1940s. Today, the Baltic Sea drainage basin is populated by more than 85 million people and their actions can affect and change the Baltic Sea climate for good or worse. The goal of the chapter is to develop a synthesis of the existing knowledge and add a new perspective on the water bodies in the Baltic Countries Sea using RS.

– **Overview of Water Resources, Quality, and Management in Baltic Sea Countries**. Surface water and groundwater resources differ widely among these countries due to the existence of various rivers, lakes, streams, dams, drains, reservoirs, and aquifers [26]. These water resources control the water quality condition and the ecological and aquatic processes of the Baltic Sea [35]. Moreover, in the past 10 years, several wastewater treatment plants, sewerage collection systems, and infrastructure projects have been constructed to handle a large amount of wastewater in the Baltic Sea region [31]. Due to the importance of the Baltic Sea resources, a number of studies have recently been conducted to cover the water status of the Baltic countries [4]. In addition, more studies have been performed to evaluate the ecosystem and water management within the Baltic region [13]. Although some Baltic countries have considerably succeeded in achieving the water-quality standards, various challenges still remain [20]. For this purpose, water and regulatory authorities attempt to raise consumer concerns and public awareness of water scarcity [7]. In this context, the current chapter gives an overview of water status and features for the Baltic Sea countries.
– **Environmental Quality of Groundwater in Contaminated Areas—Challenges in the Eastern Baltic Region**. The lack of water in the future will force society to find more sophisticated solutions for the treatment of polluted water to gain secondary and tertiary usable water. It also applies to the improvement of groundwater that comes from contaminated zones. Contamination of soil and groundwater is a legacy of modern society. All around the world, contaminated areas cause environmental problems: degraded fields, landfills, old and existing industrial and military installations are contributing to pollutants spread to the outer environment [22]. Assessment of contaminated and potentially contaminated sites in the Baltic Sea region began slightly in the 1980s, but mainly after the collapse of the Soviet Block in the 1990s. Today governments of the Baltic States have prepared the priority lists of problem zones; for example, the National Registry of Contaminated Areas in Latvia includes areas contaminated with various inorganic and organic pollutants. Sites are divided into three categories: the first: around 250 contaminated sites (exceeding the threshold values 10 or more times); the second: >2600 potentially polluted sites and the third deals with areas additionally monitored or already remediate [10]. Two categories of healing technologies

exist: insitu and ex situ. On-site (in situ) technologies treat soils and groundwater with biological, physical, chemical, physicochemical, thermal and stabilization methods [10, 11]. However, most dominant methods ex situ are simple excavation and pump-and-treat. Complex pollution recovery requires integrated solutions, which always are expensive and complicated from the technological aspects. The European Union (EU) Waste Management, Water Framework, and Groundwater Directives are incorporating the guidelines and rules on how to treat the problems and improve the situation. From these main legal instruments, each country in the EU derivate their legal instruments through specifying problems with contamination and providing details of monitoring, assessment, analyses and remediation. Monitoring of pollution hand in hand with the planning of treatment are crucial to find and implement strategies for improvement of groundwater quality. There are tens of thousands of areas in the Baltic Sea region that expect immediate corrective measures which differ in nature, cost, risk, and other factors.

– **Water Quality Assurance with Constructed Wetlands in Latvia**. The Administration of Latvian Environmental Protection Fund in a report in the year 2017 recommended choosing an individual treatment plant with electricity supported aeration and activated sludge for decentralized systems if storage or septic tanks are not appropriate solution [41]. Possible problems in wastewater flow or electricity supply interruption cases and limitations in pollutant concentrations in wastewater if the proposed biological treatment method is implemented are reasonably mentioned in this report. Regulations Regarding the Management and Registration of Decentralized Sewerage Systems by the Republic of Latvia Cabinet states the requirements for the decentralized sewerage systems situated in the territories of villages and towns [33]. Depending on the climate conditions as precipitation amount and the lowest air temperatures, spreading of wastewater over the filter layer is possible or freezing protection for the pipes has to be provided. Latvia is located in a humid climate zone with a long-term average annual precipitation of 667 mm [38] where precipitation exceeds evapotranspiration resulting in an average annual runoff of 245 mm. In Dobele meteorological station located in a middle part of Latvia, annual average air temperature in a period of 2014 to 2017 was observed 8.6 °C during vegetation period (April to September) and 7.7 °C during non-vegetation period (October to March) [39]. The air temperature was under the 0 °C on average 51 days in a period of 2014 to 2017. Regulation approves industrially manufactured wastewater treatment installations that discharge the treated wastewater into the environment and the total capacity whereof is below 5 m^3 per day, septic tanks and wastewater containers which collect untreated wastewater, septic tank sludge, feces, or sewerage system treatment waste [33]. The technology of the inlet part of the constructed wetland can differ noticeably and the design basically depends on the surface conditions of the object. Wastewater can be discharged into the wetland if the terrain conditions are convenient or it can be pumped with the pressure.
– **Phosphorus Fluxes in the Baltic Sea Region**. Phosphorus (P) is an essential major plant nutrient for all living organisms. To maintain the growth of healthy crops and receive optimum yields, a sufficient P level in the soil has to be maintained by

using organic and/or inorganic P fertilizers. Quantitative assessments and a better understanding of P flows within different systems (e.g. on regional or on a country scale) can be used for the implementation of more effective policy strategies to ensure a more sustainable, site-specific P management [12]. Studies are investigating P flows in different countries differ regarding data included (mainly due to their availability), specific methodologies, flow diagrams used, outcomes etc. Thus, it is very difficult to compare data obtained for different countries and from different researchers [24, 43]. In order to make comparisons between countries, and to develop EU wide political strategies and policies for protecting the environment from nutrient leaching and eutrophication, Eurostat/OECD have been working on establishing a common robust and feasible methodology for calculating P (and N) budgets. The EU member states, Norway and Switzerland have agreed to follow the land budget approach and have published their harmonized methodology in a handbook in 2013 [28]. As pointed out on the Eurostat web page on Agricultural Nutrient Balances Eurostat [18], the national P budgets compiled and presented by Eurostat/OECD are the outcome of a set of calculations provided by the countries. For instance, some countries use estimates of the livestock population based on data from the Livestock Surveys, or they have used other data sources like national registers on livestock Eurostat [18].

– **Regulatory Scenarios to Counteract High Phosphorus Inputs into the Baltic Sea**. In Europe and also in the Baltic Sea Region (BSR) different methods are employed to determine the soil P status and the plant available P fraction in the soil, which is the background for the P fertilizer recommendation [19]. The different extraction procedures make a direct comparison of data difficult as the different methods extract slightly different P fractions. Additionally, the threshold values for evaluating the soil P status proved to be not congruent in the different countries and recommended fertilizer rates can deviate highly [19]. In addition to the diverging assessment of the soil P status the recommended fertilizer rates for optimum P supply may deviate by up to 28% for grain crops and 37% for sugar beet [19]. A prerequisite for a sustainable P use in agriculture is a balanced P fertilization where inputs equal outputs. The concept of 100% utilization expresses that plants utilize transformation products from previous fertilizer applications despite a decrease in their solubility over time if P has been applied originally in easily plant-available form [36]. Following this approach, mobilization and immobilization processes are kept in a dynamic balance. In soils under humid conditions where the plant available P content is so high that additional P rates yield no increase in crop P content, the fertilization rate can be calculated solely via the P off-take by the harvest products [36]. A major problem of P in animal manure as well as in digestates or sewage sludge is the low dry mater content in combination with low P and nutrient concentration in the material. Therefore, transportation costs are high when compared to the value of nutrients [8]. Knudsen and Schnug [27] calculated the profitability of transport distances of different organic fertilizers in relation to their nutrient concentrations. With respect to the P concentration, the maximum economic transport distance for farmyard manure and sewage sludge is much lower than 100 km, which stress the problem of areas with concentrated livestock farming. Transport of dry materials, like thermo-chemically treated ash can be operated economically over much longer distances of about 500 km [8].

– **Challenges of Flood Risk Management at The German Coast**. Different strategies were developed in the Member States of the European Union to deal with climate change-related impacts and risks. Differences in the strategies can be explained by different cultures how to deal with risk. Moreover, they are also due to different historic experiences and developments which resulted in different flood protection strategies and dimensioning approaches [1]. In terms of flood risk, the respective areas are protected by the sea walls, allowing for anthropogenic activities and long-term investments. However, 100% safety through such technical protection systems does not exist. Therefore, according to the European Floods Risk Management Directive, these coastal areas are classified as high-risk areas. In case of failure of the protection systems, large areas will be flooded. Organizing the dimensioning of dikes consistently with the related flood risk management would require to consider different fields of action, e.g., according to the German flood risk management cycle, as introduced by the German Working Group on water issues of the Federal States and the Federal Government [29] or to the Dutch Multi-Layer-Safety approach (MLS) [30]. Both concepts consider preventive measures, including the technical flood protection, but also spatial adaptation measures reducing exposure and vulnerability to floods as well as emergency management while a flood happens. In addition to the MLS-concept, the flood risk management cycle from the LAWA [29] already considers recovery activities to reduce damage by quick and appropriate action after a flood event. Dealing with change also requires to take instationarity into account while dimensioning coastal protection structures and organizing adaptation processes. One possible option is the scenario approach which explicitly describes different development paths for the future. Subsequently, decisions can be taken based on the spectrum of plausible model projections. While climate change impacts have been quantified for diverse regions, the challenge remains how to deal with the underlying uncertainties, and how to agree on joint action with the regional decisions makers [2]. In addition to today's water management challenges, climate change is expected to aggravate efficient water management [9]. The current strategy of dimensioning dikes has resulted in generally high safety standards along the German North Sea coastline. Finally, it is a safety standard for the technical structure "sea wall" [3].
– **Water Resources of the Russian Part of the Baltic Sea Basin and Their Possible Changes Under Global Warming**. The Baltic Sea is the most substantial transboundary water body in Europe. It washes the shores of countries such as the Russian Federation, Estonia, Latvia, Lithuania, Germany, Finland, Sweden, Norway and Poland. More than 85 million people live in the basin, of which almost 15 million people live in a coastal zone of 10 km wide. The Russian part of the Baltic Sea basin is challenging subject of research concerning distribution and formation of water resources, as well as its geographical location. Serious changes in the main factors determining the fluctuations of water resources and their change in time and territory have occurred in Russia over the last thirty years. That is why, the need for a modern assessment of renewable water resources and an assessment

of their probable changes in the future for the territory of the Russian part of the Baltic Sea basin is an urgent task. The purpose of this chapter is to summarize the results of studies carried out in Russia, and first of all at the State Hydrological Institute (SHI). It is also aimed at presenting an objective assessment of surface water resources, taking into account their changes under the climate impact for the case of the Russian part of the Baltic Sea basin, including estimates for the territory of the USSR. The beginning of significant climate warming over the territory of the Russian Federation can be considered the late 1970s–early 1980s. According to the calculations presented in Report on climate peculiarities in the Russian Federation in 2016 [32], the linear trend in the growth of surface mean annual air temperature over the RF is 0.43 °C a decade, 1976–2012, which is more than 2.5 times higher than the rate of global warming at 0.17 °C a decade.

– **Schemes of Integrated Use and Protection of Water Bodies in the Russian part of the Baltic Sea Basin as a Basis for Water Resources Management**. Development of Schemes for the integrated use and protection of water resources was carried out by numerous staff of Water Management Institutions (more than 60 Institutions). These Schemes, like all other planning documents at that time, had to be approved at the government level, which meant coordinating them practically with all departments. None of these Schemes was approved during the entire development period. Much of the information has been destroyed over time, and the materials have not been claimed since the collapse of the USSR. The Schemes for the territory of the Russian Federation had been developed since the issue of the RF government decree of December 30, 2006, No. 883 «On the procedure for developing, approving and implementing Schemes of the integrated use and protection of water bodies, and introducing changes to these schemes». The Water Code of the Russian Federation has established a close link between five articles, aimed at creating Schemes of integrated use and protection of water bodies. In accordance with the Decree of the Government of the Russian Federation «On the procedure for developing, approving and implementing schemes for the integrated use and protection of water bodies, introducing changes to these schemes», Schemes are developed by the Federal Water Resources Agency according to the Rules approved by this Decree, «Methodological Guidelines on the development of schemes for the integrated use and protection of water bodies» (Methodological Guidelines) and taking into account the recommendations of the Basin Councils. Schemes are approved by the Federal Water Resources Agency if there is a positive conclusion of the state ecological expertise.
– **Estonian Fluvial Water Bodies and Inundation Directive**. Hydrologically, there are three distinguished phases of the annual water regime in the streams: seasonal floods, flash floods, and seasonal low-flows. Significant floods may occur if one flash flood follows another. Snowmelt usually causes spring floods in the streams of flat terrain and summer floods in mountainous regions. Usually, both types of floods have multi-peak hydrographs. But, flash-floods of rain water are considered to be more unpredictable, and in the case of heavy rain showers or cloudbursts also more dangerous in comparison with seasonal floods. "Global warming is projected to intensify the hydrological cycle and increase the occurrence and frequency of flood

events in large part of Europe" [15]. However, in regions with projected reduced snow accumulation during winter, the risk of early spring flooding could decrease. Whereas, as it was reported, prediction of quantitative changes in flood frequency and magnitude remains highly uncertain [15]. Despite "general agreement that Europe-wide or at least transnational-scale flood hazard maps have the potential for many applications, including climate change studies, only a few products exist" [15]. Difficulties remain to compile large consistent datasets. So far, the EU Floods Directive has improved this situation only to a limited extent [15]. Assessment and management of Estonian flood risks started in 2007 [5] and the current Estonian Water Act is focused on significant flooding risk areas [6]. Hereby, the determination of significant flood risk areas is based on the assessment of priority sections. However, the strategy of integrated flood risk management should compromise flood protection of different structural assets, e.g., dikes, levees, upstream retention areas, etc., together with non-structural property protection, land use planning and insurance arrangement (EU Solvency II Directive [37]. Therefore, a project of "Creation of flood maps of Estonian inland water bodies" (later: Flood Map Project) was initiated by the Estonian Insurance Association in 2016.

- **Joint Methodology for the Identification and Assessment of Groundwater Dependent Terrestrial Ecosystems in Estonia and Latvia**. Groundwater dependent terrestrial ecosystems (GDTEs) are valuable ecosystems which quality and existence rely on groundwater supply. Any changes in quality and quantity of groundwater feeding the GDTE often result in significant and permanent damage of water dependent flora and fauna [34]. Good groundwater status eliminates any potential damage to groundwater dependent terrestrial ecosystems (GDTEs) caused by human-induced pressures on GWB feeding the ecosystems. The exchange of best practices and compilation of outcomes from the cooperation between ecologists and hydrogeologists at European level in up to date guidelines are highly recommended [17]. Eamus et al. [14] identify four important knowledge gaps in the sustainable management of GDEs, both terrestrial and aquatic. In total Estonia has over 110 000 standing water bodies, of which natural lakes are one of the smallest group (1562), exceeded by mostly very small ponds (51,780) and bog pools (45,309) [40].
- **Estonian Wetlands and the Water Framework Directive**. The novelty of ensuring good status of groundwater was its linkage with the surface water via integrated water management of ground- and surface waters, thus being defined for the first time at the European level [16]. Whereby, for good groundwater management, only that portion of the overall groundwater recharge could be abstracted, what remains from the needs of connected ecosystems,—"whether they be surface water bodies or terrestrial systems such as wetlands" (EU Water Framework Directive (2019). In this way the remained amount of groundwater is defined as the "sustainable resource" and WFD limits the groundwater abstraction to that quantity (EU Water Framework Directive (2019). During subsequent years until 2015 occasional conflicts of interest appeared between the need to achieve a good ecological status of the water bodies stated in the WFD and other regulations, oriented towards

protection and restoration of wetlands. Based on existing knowledge about functional diversity of European wetlands, where biogeographical region, geomorphic setting, water source, and hydrological regime were considered, the "functional classification approach" was suggested as a "useful tool to assist with the implementation of the WFD and in particular identification of wetlands of significance". Lessons described and learned from reality until today show that there is still place for improvement of cooperation between water and nature conservation authorities via more case-oriented planning, and via respect to the climate change both in environmental management programs of WFD as well as Natura 2000 regulations [23].

3 Conclusions

Across the whole process of the current book plan, some conclusions drawn from this book are made by the editorial teams. Including methodological insights, the chapter derives key lessons from the areas in the book, in particular, the successful work on quality and management of water resources in Baltic Sea Countries. Such findings are necessary for the Baltic Sea Countries to increase sustainable water resources. These are discussed in the following order.

– **Overview of the Water Bodies in the Baltic Sea Countries**. The Baltic Sea is a shallow semi-enclosed sea with an area of 415,000 square kilometers and a maximum depth of 460 meters. A heterogeneous wide area is the Baltic Sea Drainage Basin (BSDB). The drainage basin is shared by 14 nations, covering an area of 1,739,000 km^2 and nearly 84 million inhabitants. There are 14 larger international river basins within the BSDB, with an approximate area of 1,050,000 km^2. These river basins vary in size, a number of countries sharing basins, environmental issues encountered and how they are treated. More than 200 rivers flow into the Baltic Sea, producing a catchment and drainage area of nearly 1,700,000 km^2 that is about four times larger than the sea itself. This catchment area is considered to be part of the Large Marine Ecosystem of the Baltic Sea (BSLME). As a result of global warming, potential sea-level rise would impact the world's coastal regions. Although it is not known how high the sea level rises, it will have significant and international consequences. So how could one judge if the land was going up or the water was going down? A solution could be to measure the rate of incidence over a broader area for a long time, in this case, throughout the Baltic Sea. Renewable energy is one of the ways to cope with the rapidly changing environment. Wind and wave turbines are becoming increasingly common, although it is vital to ensure that they harm the environment as little as possible. Nonetheless, the adoption of new resource management approaches and marine environmental protection programs alone will probably not yield the desired result if the citizens of the Baltic Sea countries, who are the end-users of the many services offered by the sea, do not change their minds towards more sustainable ways of living and consuming resources.

- This chapter aims at giving an essential overview of the water resources and conditions of the Baltic Sea countries. It is concluded that: Intensive anthropogenic and natural inputs have seriously threatened the ecological situation of the Baltic Sea countries. Recently, research studies evaluating the ecosystem and water management within the Baltic region have considerably increased due to the importance of the Baltic Sea resources. During 2011–2019, the total number of publications reported using the keywords "Water", "Baltic", and "Countries" was 186 and 243 according to the Scopus and Web of Science databases, respectively. The available surface water and groundwater resources vary broadly among the Baltic countries due to the existence of multiple rivers, lakes, streams, dams, drains, reservoirs, and aquifers. A series of international activities and European agreements have been established by the governmental authorities to secure the long-term protection of the environmental quality in the Baltic region. The developed Baltic countries such as Sweden, Germany, and Denmark have adequate water resource management systems; however, some countries such as Lithuania, Estonia, and Poland still have some water resource challenges.
- Constructed wetlands for wastewater treatment are not broadly used in Latvia however most pilot-scale wetlands show a good potential in water quality assurance. There are examples of in-stream practice of surface flow constructed wetlands for treatment of domestic wastewater and runoff from agricultural catchments as well as an example of subsurface flow constructed wetlands for the treatment of domestic wastewater and storm water in climate and management conditions of Latvia. The highest reduction level was detected for TN and TP by 99 and 98%, respectively, at Tervete constructed wetland which could be explained by higher nitrogen concentrations at the inlet and appropriate wetland parameters according to the treated wastewater. A regular monitoring and wider studies would lead us some way towards enhancing our understanding of site-specific factors influencing the treatment and nutrient retention efficiency of constructed wetlands.
- P budgets and flows in particular regions or countries are assessed and suitable strategies discussed to identify and improve the P use efficiency in these countries. These strategies will help to reduce P losses, close the P cycles and protect vulnerable waters, such as the Baltic Sea, from further eutrophication. The P budgets and flow analyses show that in most of the Baltic Sea Region (BSR) countries P inputs exceed outputs, and a high amount of P that entered the system is retained, especially within the soils of the agricultural production sector. The continuous accumulation of P in the soil results in excessive P surpluses and increases the risk of P losses and eutrophication in the long run. Various suitable measures to help to minimize these P losses are proposed, including more stringent recycling of wastewater P (communal sewage sludge and their ashes; struvite and related precipitation products from wastewater treatment), biodegradable solid wastes (biowaste compost) and incinerated slaughter residues. However, the commercial implementation depends on the overcoming of considerable obstacles which include the development and implementation of adequate technology, the adjustment of existing and

creation of new governmental regulations and promoting social acceptance of the necessary changes. Furthermore, the monitoring of P fluxes needs improvement in order to generate more consistent and comparable results. It is recommended that fluxes are modelled not only on a national but also on a regional scale in order to be able to account for the specific geographical condition of each country. Also, the P status of agricultural soils with its changes over time and some key soil characteristics need to be considered on a sub-national/regional scale to assess the actual risk of P loss via erosion/run-off/leaching from a particular area/region. Finally, P flow analyses should comprise several years to monitor long-term developments and trends in P flows.

– 10 years after the BSAP was ratified still no significant progress can be reported with respect to the nutrient discharge into the Baltic Sea region and the eutrophication level is still alarming. Therefore, the goal to have clean water in the Baltic Sea by 2021 has failed. Comparable to the climate targets it is obvious that substantial progress cannot be achieved if legal rules are missing. Without such rules, it is hardly possible to achieve the proposed goals. Therefore, in this chapter different possible options are discussed, by which the extent of eutrophication of the Baltic Sea can be reduced in future if the discussed options will be implemented in EU legislation. Each measure alone will help to reach the target but implementation of the whole set of measures will have a much higher potential to reach the goal to change the Baltic Sea from an endangered polluted environment into an ecological one with a high biological biodiversity and an even higher touristic value as today. Agriculture is the largest user of P and the most significant source for P losses by environmental dispersion (surplus enrichment in soils, erosion) and irreversible fixation (meat and bone meals and ashes). Consequently, it should be a prime task to develop and verify strategies, which avert or reduce these undesired side effects to an unavoidable minimum.
– Anthropogenic land use of low lying coastal areas requires efficient protection against the sea as well as efficient drainage management to cope with storm floods and inland excess water at the same time. While dimensioning of technical solutions, such as dikes and pumping stations, is usually based on statistical analyses of historical data, such data is not available for strategic planning processes of non-stationary environments. To provide planning criteria, a scenario-based approach is introduced to be used as a basis for strategic planning of future coastal drainage concepts along the German coast. Such an approach can support integrative coastal risk management. Another challenge is the traditional perception of the efficiency of such technical installation and accordingly planning which is focusing on physical protection and safety. In contrast to well-established safety based approaches in Germany, the EU-floods directive asks for concepts assisting the management of flood risks. The floods directive demands for combining protection against, prevention of and the management of water-related risks. Since in many cases current national and state rules still rely on the safety based approach, a new perception is, therefore, necessary, taking into account the remaining risks. People must be willing to deal with residual (flood) risk related risks.

– The Russian part of the Baltic Sea basin is a very complex hydrological object in terms of its geographical location, distribution of water resources, human impact and also due to specific features of the regional socio-economic development. The priority research areas, announced at the last VII All-Russian Hydrological Congress, were considered. The Congress is a platform for discussing the most challenging problems of hydrological science and practice. It develops recommendations for consolidation of the country's scientific, technical and production potential for solving problems in the field of hydrology and water management complex, interaction between scientific communities at the national and international levels. These priority directions were formulated according to the problems of the national scale water resources, and are relevant for such complex and large basins as the Russian part of the Baltic Sea basin. The chapter uses GIS of water bodies (basins) in the Russian part of the Baltic Sea basin, created at the State Hydrological Institute as a part of development of the Schemes for the integrated use and protection of water bodies. It is necessary to say separately about the predictive assessments of possible changes of river water resources in the future. The estimation and description of water resources, presented in this Chapter, are results of collective efforts of the SHI' experts, but the materials on forecasting estimation are one of the areas of scientific research of the authors. Initially completed studies for the entire territory of the Russian Federation, allow us to make conclusions for the investigated basin. The authors wish to note that this approach is not a standard and it should be considered as one of the possible alternative methods for assessing future changes of water resources.
– Schemes of integrated use and protection of water bodies have both their supporters and critics. Opponents usually point out the following shortcomings in development of Schemes. the absence of a number of approved regulatory and methodological documents necessary for the development of Schemes (such as «Methods of assessment of the ecological status of water bodies», «Guidelines for the justification and development of flood control measures», «Guidelines for the definition of the water regime during the use of water bodies for exploration and mining», etc.); the absence in the State Water Register all the complete information required for the development of Schemes, first of all, raw data from hydrological and hydrochemical gauging stations; elaboration of Schemes requires the state medium and long-term forecasts of socio-economic development of industries and sectors of the economy, which are often absent for some regions.
– As a result of the work, it is the first time when the flood maps are covering the almost entire area of floodplains of Estonian rivers, i.e., almost 90% of the flood areas are mapped. We can confirm that the best software was used and input of flood maps modeling based on almost all valuable information that can be found in Estonia. In numerical modeling of flood water levels and especially the water levels with return periods of 500 and 1000 years, it carefully observed that those values would stay within realistic limits, because of used different exponential curves in analyses. However, in needed generalizations during the mapping procedure, it always followed the principle to generalize the flood polygons toward a larger extension, rather than smaller; for example, by correction, the riverbed extension

in the DEM models the wider riverbed polygons were used. At the same time, every effort was made to prevent the overflow expansion across the water divide between neighboring catchments. However, it should be stressed, that not any climate scenarios, riverbed erosion or accumulation of sediments in the riverbeds or on the floodplains were applied. Moreover, present climate scenarios are valid for no longer than 100 years, which is ten times shorter in comparison of used flood return periods up to 1000 years. Also, there is no any information related to the development of different erosion processes in Estonian riverbeds ahead of 1000 years.

- The Water Framework Directive aims to protect all water resources, including groundwater bodies. For groundwater, environmental objectives are set in Chap. 11, and the main goal is to achieve good groundwater status. Groundwater dependent ecosystems (GDEs) are valuable ecosystems that depend on groundwater input and cannot be considered and assessed separately. Any changes in the water quantity or quality often result in significant damage of dependent flora and fauna. Therefore, they cannot be assessed separately from the groundwater body (GWB). The presented methodology allows to tests the potential effect of GWBs on GDTEs as far as there are available data. Before the assessment, indicators, and criteria that reflects both the quantitative and qualitative effect of groundwater bodies on the GDTEs must be defined. The first step of the methodology is to find out the ecological status of the GDTE. If the ecosystem status is unfavourable, potential other causes have to be ruled out at first. After identification of groundwater dependency, the assessment of the quantitative and qualitative effects on GDEs using assessment schemes follows. It must be noted that it is not possible to develop a simplistic and universal evaluation scheme that gives a high-reliability answer without the acquisition of additional data. Developed schemes enable to pinpoint the GDEs for which the effect of groundwater body cannot be ruled out as the cause for the unfavourable status. Thorough studies must be performed to determine the actual effect of the groundwater body, the size of the effect, and suitable mitigation measures. While the identification of vegetation dependent on groundwater remains a great challenge, the distribution of GDTE in the landscape is important for water management needs. The tools and techniques used for the identification of GDTE locations can be of various complexities. However, they all have rather large uncertainties or include subjective assumptions. The question remains whether to use automatic tools with limited possibilities and thus high uncertainty or rely on subjective desk studies and the decisions of evaluating experts? The combination of both might be the best option.
- As a result of the "Wetland Project" Estonian mires, floodplains, spring mires, and coastal wetland were associated with WFD important surface WBs for the first time. It is the first time when WFD important Estonian wetlands were defined, their extent calculated and ecological status assessed the pressure factors and the main water management measures described. Corresponding database structures were compiled, and map layers were visualized. The soil map based delineation together with corresponding basin modeling of WFD important wetlands, and especially peatlands associated with flowing WBs, turned to be highly complicated

and labour-intensive. Therefore, mainly Ramsar important wetlands were analyzed at first. However, it was the first time when the DEM based mire drainage basin delineation approach was integrated to the WB drainage basin delineation. Hereby it should be stressed that results gained from the "Wetland Project" are the first steps toward the functional classification of Estonian wetlands associated with WFD important surface WBs.

– Environmental contamination of Eastern Baltic is mainly of historical origin. Remediation is compulsory according to national legislation acts where concentrations exceed the prescribed risk based on numerical criteria or standards. Dump sites constitute a large part of contaminated sites and specific technologies as modified pump-and-treat systems of leachate, landfill mining, phytoremediation as well as preventive engineering structures construction have been tested and implemented. Complex contamination usually is remediated stage-by-stage using various technologies depending on the land use activities, social aspects, contamination level and economic feasibility.

4 Recommendations

Throughout the course of this book project, the editorial' teams noted some areas that could be explored to further improvement. Based on the authors' findings and conclusions, this section offers a set of recommendations providing suggestions for future researchers in exceeding the scope of this book. The following recommendations are mainly obtained from the chapters presented in this volume:

1. Successful spatial planning for the Baltic Sea in the future relies on the following: Sustainability. Spatial planning addresses economic prosperity, social well-being, and environmental targets at the same time and balance their respective needs. Pan-Baltic thinking. Considers the whole Baltic Sea ecosystem and the whole Baltic Sea as one planning space. Pan-Baltic topics that need to be addressed jointly include a healthy marine environment, a coherent pan-Baltic energy policy, safe, clean and efficient maritime transport, and sustainable fisheries and aquaculture.
2. Based on the literature survey, several recommendations should be considered: Small, remote, and rural communities should be supported by adequate infrastructure projects, minimum leakage systems, and wastewater collection structures. Advanced methods of wastewater treatment, with providing adequate training for staff, should be considered to meet the water quality standards regarding organics, nutrients, and anion and cation constituents. Stakeholders, decision-makers, and public and private ownership should engage under the water authorities of Baltic countries to maintain the "Water-Energy-Food nexus" strategy. Advanced water metering systems should be broadly implemented to sustain water reforms and tariffs. Promote the application of water safety projects, as well as maintenance and renewal of infrastructure. Conduct

risk assessment studies and incorporate guidance on materials used for small water supplies and utilities.

3. The functions of the constructed wetland should be adapted according to composition of the wastewater content and amount to improve water quality. The calculations of specific parameters of constructed wetland should be made following previous studies and governmental regulations. Building process should be considered to manage according to the design project and recommendations of an engineer.
4. Regarding the production of data to assess and monitor P fluxes, either within a country or in a supra-national region (e.g. the BSR) there is also a need for improvement. In line with, it is recommended that examination of fluxes is carried out not only on national but also on a regional scale in order to be able to account for the specific geographical layout and structure of the agricultural production sector of each country. In addition to regional fluxes, the P status of agricultural soils with its changes over time, as well as some key soil characteristics determining the P retention capacity of the soil, need to be considered on sub-national/regional scale in order to assess the actual risk of P loss via erosion/run-off/leaching from a particular area/region. Finally, P flow analyses should comprise several years, since the study of one single year only presents the actual state, while it does not allow to critically appreciate long-term developments and trends in P flows.
5. The chosen nutrient sources are exemplary as they are of the greatest concern today. Comparable regulations can be applied for other nutrient sources such as meat and bone meal or household wastes and composts. Whenever harmful substances such as organic contaminations, pathogens, or prions can be enclosed, recycling by thermo-chemical treatment is a viable option.
6. Some main challenges of coastal regions along the German North Sea were identified, which limit integrative strategic planning. Essential challenges are: A modern understanding of dealing with floods and coastal development requires an integrative risk-based approach. While good practice examples exist and the EU floods directive explicitly demands such approaches, they are not yet implemented along the German North Sea coast. The idea of equal safety for a heterogeneous area is no longer appropriate. Since dimensioning of dikes due to climate change assumptions directly affects the coastal drainage system, integrative planning and dimensioning of coastal protection and drainage system is essential but not yet common practice in North-West Germany. Taking decisions for an uncertain future requires explicit consideration of uncertainties, e.g., by applying scenario-based impact assessments to adopt coastal protection and drainage. Moving from a safety-based approach to risk management approach demands for activities in multiple fields of action such as prevention, spatial measures and emergency management. Since different actors are responsible for these topics, multiple actors also need to be mobilized and involved, including public organizations, aid organizations and citizens. Based on these challenges and the case studies collective action is recommended for the implementation of a risk-based management approach in coastal regions. Such action

is explicitly needed in North-West Germany but will generally assist adaptation in other coastal regions, as well.

7. The materials presented in this Chapter are intended for wide use by hydrologists from research and educational institutions, primarily from the countries of the Baltic region. The authors tried chronologically, as far as the permissible volume of the Chapter allows, to tell about the history of analysis and quantitative assessments of water resources (renewable) and water balance of the basin investigated, carried out by specialists firstly in the Soviet Union and then in the Russian Federation. Along with the historical data, the most generalized and systematized data on the water resources of the Russian part of the Baltic Sea basin, presented in the Schemes, are given. Schemes will be described in more detail in the next Chapter. Problems of water resources and their regulation have been among the most important world scientific and technical problems. The authors hope that the information prepared by them and presented in this and in the following Chapter will promote the development of cooperation between scientists and other stakeholders from the Baltic region in the field of water resources and their regulation.
8. Summarizing presented materials, it is necessary to specially note that the implementation of the schemes for integrated use and protection of water bodies will contribute to a balanced socio-economic development of the Russian regions. Measures to reduce human impact on water bodies will allow achieving high ecological standards of life of the population, preserving the health of citizens, improving the state of aquatic ecosystems in river basins. The implementation of measures aimed at rationalization and integrated use of water resources will make it possible to reduce the water consumption of the economy, guarantee drinking and household water supply for the population and create reliable conditions for the development of industry, energy, water transport and agriculture through effective use of water resources of Russian rivers.
9. Our firm requirement for insurance companies is that produced flood maps should be updated from time to time. Preferably, the upgrade should be done after 5 or 10 years. The major changes that may occur during such a period are primarily human activities; e.g., removing or creation of dams, changes in the morphology of the riverbeds and their locations in the landscape, creation of new polders, road dams, and other constructions. Also, changes in water consumption can significantly change the floods and overflow in the landscape. One of the prerequisites for high-quality upgrading is access to the newest LiDAR data. It should be hoped that the cross-border basins of the Narva River and the Piusa River will be covered with available higher quality LiDAR data and DEM models soon. Also, higher upgrade results could be gained from data obtained from automatic hydrological gauging stations, intensified monitoring of water consumption, and newer GIS modules for the flood modeling on the river valleys. The climate change scenarios could also be adapted into flood modeling.
10. The main challenge in GDTE assessment is the lack of relevant data. Four main areas are encouraged: Development of integrated monitoring networks.

Most groundwater, surface water, and nature protection monitoring networks have been designed long before GDTE protection was highlighted by European Union directives and researchers. As a result, the locations of monitoring sites do not cover the areas of interest and their results cannot be combined for GDTE assessment needs. Sustainable management of GDTEs can be achieved only by intensive cooperation between multidisciplinary research teams and all levels of managing authorities. More site-specific research. Integrated monitoring networks will provide the missing long-term data at the country level or regional scale, still will not deliver site-specific data necessary for quantitative and chemical assessment of each GDTEs type. To implement proposed GDTE assessment schemes, it is essential to carry out two types of investigations: first, to gather relevant seasonal data for the designation of TVs for most typical GDTE pollutants such as nitrogen and phosphorus compounds. Second, to carry out seasonal investigations to deliver groundwater levels trigger values. Only then the main pressures on GDTEs (such as groundwater abstraction or land use occurring in the catchment areas) could be appropriately assessed and programmes of measures (such as restrictions of certain human activities) could be justified to stakeholders by data-driven analysis. Transboundary cooperation is encouraged to save time and money resources and combine the existing knowledge base. It is important to emphasize that such cooperation projects and joint research activities are most effective when delivering joint publications in Open Access sources. Currently only part of cooperation projects develops materials in English and many good experiences remain unpublished or are available in national languages only. Stakeholder engagement. It is important to increase the overall awareness of groundwater and associated nature protection to achieve sustainable assessment of GDTEs in long term and to maintain safe drinking water for future generations. For this reason, it is recommended that citizen science should be a part of each cooperation and research project.

11. Our recommendation to the national structures managing water resources in Estonia, especially to those that are involved in the implementation of the Water Framework Directive (WFD) policy into everyday life, is to complete the integration of Estonian wetlands with the WFD. In practice, it means that the existing Estonian Nature Information System (EELIS) should be expanded toward WFD important wetland database. This should not be considered as an insignificant additional work in the WFD based reporting routine but should be seen as a part of the science-based management of water resources in Estonia. At present, Estonia is rich in both the water resources and wetlands, but in the light of results of the recent wetland inventories and some case studies, it is obvious that the area of wetlands in at least in *good* status is decreasing. Results of the "Wetland Project" indicate that assumption, that the status of a wetland, associated with the WB with at least a *good* status, is the same, seems not to be correct in all cases. The knowledge and experience gained from the functionally classified WFD important wetlands, together with the corresponding numerical values both for annual and long-term changes, should be seen as a basis for the management strategy of WBs both in the conditions of climate and

land management changes. However, one of the prerequisites for high-quality upgrading of the gained results is necessary to field inventories for the WFD purposes integrated with the newest information from remote sensing. It should be hoped that delineated drainage basin layers both for the wetlands and WBs, will soon be available from the EELIS database together with the quantity and quality values of all WFD important wetlands.

12 Chosen remediation techniques, as well as monitoring of dangerous objects, shall be performed after careful geological and hydrogeological analysis. Gentle and passive remediation techniques are preferable where such an opportunity is. Excavation and landfilling of contaminated soil in a hazardous landfill shall be the last option. The concept is to treat as much as possible solid and liquid matter in order to diminish the amount of hazardous masses. Careful historical data analysis, monitoring, collaboration among industry, authorities, and scientists (Triple helix approach) are keys for successful treatment approach decision making.

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Estonian Wetlands and the Water Framework Directive

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Abstract This chapter presents the delineation approach and results of status assessment of Estonian wetlands for implementation of the objectives of the Water Framework Directive (WFD). Determination of WFD important wetlands based on selection and visualisation of wetlands soils from Estonian electronic soil map (data of Estonian Land Board), and corresponding drainage basin delineation, both for wetlands and water bodies by using the *ArcMap10.2.2* software. There are 47 WFD important wetlands associated with the flowing water bodies covering more than 27,800 ha, and 19 wetlands associated with the standing water bodies covering 42,000 ha. The number of WFD important floodplain wetlands is 46 covering 15,000 ha, 24 spring mires on 390 ha and 107 coastal wetlands on 265 ha. Due to the heterogeneous landscape structure of Estonian wetlands inside the "zero" wetland contour line, the variability of both water quantity and quality of wetlands is relatively large. Therefore, without field studies of WFD important wetlands, it is

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impossible to perform a functional classification of the determined WFD important wetlands, i.e., their effect on nutrient retention or leaching, or effect on hydrological regime of connected with them water bodies.

Keywords Surface water body · Peatland · Floodplain wetland · Spring mire · Coastal wetland

1 Introduction

It had been almost twenty years since the EU WFD [1] was adapted for establishment of Community action in the field of water policy. The general objective of the WFD was the water management on the scale of the *river basin* in order to "…get polluted waters clean again, and ensure clean waters are kept clean." [2]. A good status of rivers, lakes, transitional and coastal waters, i.e., surface waters, had to be determined via a good chemical status and via a good ecological status, i.e., the good status of the biological community, the hydrology and the water quality [2]. Hereby, because of a big variability across the Community, the biological controls are specified "…as allowing only a slight departure from the biological community which would be expected in conditions of minimal anthropogenic impact." [2].

The novelty of ensuring good status of groundwater was its linkage with the surface water via integrated water management of ground- and surface waters, thus being defined for the first time at the European level [2]. Whereby, for good groundwater management, only that portion of the overall groundwater recharge could be abstracted, what remains from the needs of connected ecosystems,—"whether they be surface water bodies or terrestrial systems such as wetlands" [2]. In this way the remained amount of groundwater is defined as the "sustainable resource" and WFD limits the groundwater abstraction to that quantity [2].

However, units that ought to be used for reporting and assessing the compliance with WFD objectives are the "body of surface water" and the "body of groundwater" [3]. Hereby, the term "body of surface water" is defined as a discrete and significant part of lakes, reservoirs, rivers, and channels, i.e., part of standing and flowing surface water bodies, or as a part of transitional and coastal waters. Delineation of the surface water bodies also requires that each of those parts "must be capable of being assigned to a single ecological status class" [3].

The term "body of groundwater" is defined as a distinct volume of groundwater within an aquifer or aquifers. Whereas the determination of an "aquifer" requires two criteria to be considered: (a) significant groundwater flow (e.g., >10 m^3 per day as an average, or sufficient to serve the needs of 50 people), and (b) the volume of groundwater abstraction that could cause significant diminution of ecological quality of groundwater-dependent surface water body or terrestrial wetland ecosystem [3].

Many reports and articles have been published on the theme related to the integration of wetlands into the WFD since the adoption of the Directive in the year 2000. The reason for this could be for example, that the WFD "…does not provide any specific definition of what a wetland is, nor does it clearly state the extent to which wetlands should be used for the achievement of environmental objectives" [4]. And this was despite the fact, that in the WFD it was clearly stated that the purpose of the Directive is to "…establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which: (a) prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems." (WFD Article 1(a) [1]) [4].

Therefore the main line of the Guidance Document No 12, i.e., "Horizontal guidance on the role of wetlands in the water framework directive" [4] was to show that in addition to the application of the WFD environmental objectives for the protection and enhancement of ground- and surface waters, it is appropriate to use wetland protection and restoration with the purpose to fulfil the WFD objectives in a cost-effective and sustainable manner. Also, this document defines "wetland" as a "diverse, hydrologically complex ecosystem, which tends to be developed within a hydrological gradient going from terrestrial to mainly aquatic habitats" and as a "part of the hydrological continuum", which may comprise the parts of surface water bodies [4]. In this way it was defined that wetlands may significantly influence the status of surface water bodies both directly and indirectly, being linked with the water body through other hydrological pathways [4, 5].

Rather comprehensive hydrological classification of wetlands from their possible water transfer mechanisms point of view is presented by Maltby et al. [5]. Whereas, the presented mechanisms "…do not necessarily dictate the distribution of water within a wetland or the rate of movement, but rather define the hydrological interface with the surrounding environment." [5]. Based on existing knowledge about functional diversity of European wetlands, where biogeographical region, geomorphic setting, water source, and hydrological regime were considered, the "functional classification approach" was suggested as a "useful tool to assist with the implementation of the WFD and in particular identification of wetlands of significance" [5].

During subsequent years until 2015 occasional conflicts of interest appeared between the need to achieve a good ecological status of the water bodies stated in the WFD and other regulations, oriented towards protection and restoration of wetlands, e.g.,

- the international Ramsar Convention on Wetlands (i.e., the Ramsar Convention, [6]),
- the European Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (i.e., the Habitats Directive, HD, [7]),
- the Council Directive 2009/147/EC on the conservation of wild birds (i.e., Birds Directive, BD, [8]), besides with,
- the national and regional regulations, like as national Water and Environmental Conservation Acts, or Regional Authority's Resolutions [9].

Lessons described and learned from reality until today show that there is still place for improvement of cooperation between water and nature conservation authorities via more case-oriented planning, and via respect to the climate change both in environmental management programs of WFD as well as Natura 2000 regulations [9].

The aim of this chapter is to: (1) introduce the determination methods of Estonian WFD important wetlands and (2) present the results of WFD important wetlands, obtained by significant importance of peatlands, floodplains, spring mires and coastal wetlands to Estonian surface water bodies (WBs). Material used in this chapter is mainly derived from the project "Assessment of wetland status and setting of environmental objectives" (later named "Wetland Project", [10]).

2 Material

2.1 Contemporary Wetlands and Surface Water Bodies

Different type of wetlands in various management status covering about 25% of Estonian territory: 22% mires (incl. bogs, poor fens, fens), 1.8% floodplain wetlands (incl. mires and meadows), <1% coastal wetlands (incl. grasslands, reed beds, salt marshes) [11] (Fig. 1; Table 1).

One of the latest comprehensive assessments of ecological status and importance of Estonian wetlands carried out in 1997, where besides of evaluated flora and fauna, landscape development, self-regeneration capacity after the man-made disturbances and the hydrological value of wetlands were assessed [13]. Based on those inventoried 1560 Estonian wetlands [13], there are 400 mires, 65 floodplains and one of coastal grassland considered important in terms of flood and water regulation [11]. Other assessed functions of wetlands were their capability to maintain water quality and flood regulation, the importance for local haymaking, peat-cutting, and berry-picking. Altogether 97 wetlands were assessed to be of high importance from a hydrological point of view, 11 were special in terms of vegetation type and flora, 48 in localities of coastal grasslands, and 67 from a point of view of wetland development. In total about 400 localities had a certain special value, making up about 21% of all the wetlands included in the inventory [11].

Mires

As a result of several Estonian mire inventories carried out by 2013, it became clear that the area covered by mires, having at least *good* ecological status had decreased 2.8 times compared with the mire extension in 1950s [14], i.e., they are preserved on 250,000 ha, covering only 5% of Estonian territory [15]. At present it is estimated that about 3% of the previous mire area is used in peat extraction, about 27–33% of mires (mostly fens) have been drained for agriculture (e.g., cultivated grasslands,

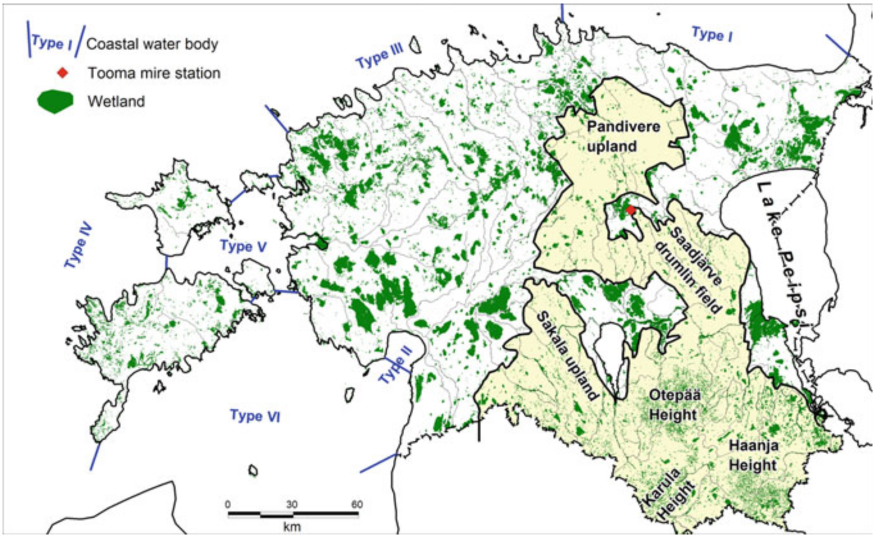

Fig. 1 Distribution of Estonian wetlands between two distinguishable parts of Estonian topography: (1) the Low Estonia with absolute height up to 60 m a.s.l. and (2) the High Estonia, consisting of several uplands and heights, with maximum height up to 317 m a.s.l. The databases used: Estonian Nature Information System (EELIS) and Estonian National Topographic Database (ETD). See also [12]

Table 1 Numerical values of the distribution of Estonian wetlands between two distinguishable parts of Estonian topography. The databases used: Estonian Nature Information System (EELIS) and Estonian National Topographic Database (ETD). See also [12]

Indicator	Area of distribution		
	Total area	High Estonia	Low Estonia
Land area (km^2)	45,339	15,170	30,169
Wetlands coverage (km^2)	3795	542	3253
Proportion of wetland (%)	8.4	3.6	10.8

pastures, and arable lands) and 33% for forestry. About 180,000 ha (i.e., 20%) of mires (mainly bogs) are protected [16].

Floodplain Wetlands

Floodplain wetlands occur on floodplains of surface WBs. Wetlands with the peat thickness >30 cm are called floodplain mires, in any other cases, they are floodplain meadows [17]. Floodplain wetlands occur mainly on the floodplains of the larger rivers, i.e., the Emajõgi River, the Kasari River, the Pärnu River, the Põltsamaa River, the Pedja River as well on the lakeshores (e.g., the Lake Peipsi) [15]. Mostly they are formed on deforested floodplains, and there are a small number of primary floodplain meadows in the west of Estonia.

There are about 3000 ha of floodplain wetlands identified up to 2013 [15]. Mainly they are occurring along slow-flowing rivers in eastern and south-eastern part of Estonia: five of them are larger than 100 ha, and largest, 248 ha Keeveskisoo wetland is located by the Soodla River in north Estonia. In the west, only 12 floodplain wetlands were identified with a total area of 219 ha, and there are no floodplain wetlands recorded in extensive areas of north-eastern, western and south-western part of Low Estonia and western islands [15].

Until the mid-twentieth century, most of the floodplain mires were used for hay making; when the mowing ended, these areas quickly began to overgrow with shrubs or afforested. In addition, many small Estonian rivers were straightened, and therefore, the hydrological regime of the floodplains changed significantly resulting in a large number of drained and overgrown or wooded floodplain wetlands [15].

Spring Mires

There are relatively few spring mires in Estonia, and they are unevenly distributed all over the country. About half of Estonian spring mires (i.e., 132 mires on 424 ha) are located in western part of the Saaremaa island, largest of them within the Viidumäe Nature Reserve, where they have also the highest floristic value among the Estonian spring-mires [15].

In the Estonian mainland, spring mires are more often found on the slopes of uplands, e.g., in the southern part of the Sakala Upland and in the western and southern parts of the Pandivere Upland. In the south, i.e., the Otepää Height, the distribution of spring mires is more even [15], and their distribution is limited in the western, central and northern part of Low Estonia.

Compared to other wetland types, spring mires are the smallest by the surface area. There are only two spring mires >50 ha in Estonia, both located on the western part of Hiiumaa and Saaremaa islands, three with the size between 20 and 50 ha, and eight between 10 and 20 ha. Other identified 252 spring mires are smaller than 10 ha, half of them even smaller than 1 ha [15].

Coastal Wetlands

Coastal wetlands, mainly meadows, are developed in the seawater impact areas on lightly saline coastal soils and by uneven land uplift conditions. They are unevenly distributed along the Baltic Sea coast of Estonia. Vegetation pattern of these wetlands is zonal, whereas the width of the zones depends on underlying soil and sediment distribution, geomorphology and micro-topography of the sites.

Typical factors for the development of coastal meadows are (1) seawater floods, shaping the coastal specific soil water regime; and (2) distribution of the coastal specific soils, with high but variable salinity content in the soil water, which promotes the development of halophytic vegetation [18]. Usually, coastal meadows form narrow stripes along the coastline, whereas only in some locations the width of the meadow strip exceeds 100 m. Also, not all plant communities occurring on the coastal meadows are classified as wetland vegetation and not all as grassland vegetation. Locations of coastal meadows correlate well with the distribution of the *Salic Fluvisols*.

Table 2 The number of WFD important surface water bodies (WBs) in Estonia [19]: HMWB—heavily modified water body, AWB—artificial water body

Estonian WFD important WBs	Number
Flowing WBs	
Natural	455
HMWB	142
AWB	42
Sum	639
Standing WBs	
Natural	86
HMWB	7
AWB	3
Sum	96
Coastal WBs	
Natural	15
HMWB	1
Sum	16

Water Bodies

According to the Regulation No. 44, approved by the Estonian Minister of the Environment in 2009 [19], the total number of surface WBs established in Estonia is 751, whereas 639 are different types of flowing and 96 standing WBs (Table 2). From all established flowing WBs about 19% (i.e., 121 WBs) belong to WBs with the *dark waters*, *rich in humic substances* (i.e., Type IA, IIA and IIIA in [19]), and only 10 lakes, i.e., 10% is the standing WBs with the *dark water* (i.e., Type IV in [19]).

3 Methods

Assessment of the WFD important wetlands started by selection and visualisation of wetland soils included in Estonian electronic soil map (Fig. 2).

The purpose of the soil differentiation was to:

(1) Identify the areal extent of the wetlands, incl. anthropogenically modified wetlands or their parts on the landscape, being so delineated with the "zero" contour line of the wetland soil extent, and
(2) Identify the areal extent of the wetland within the catchment of already defined WBs. Our general assumption was that in the case of the wetland areal extent $\geq$40% of the drainage basin of the surface WB, the water quantity and quality of the WB depends significantly on the wetland.

The used electronic soil map was digitised by the Estonian Land Board between 1997 and 2001 from the soil maps of the Soviet time collective farms, and the forest

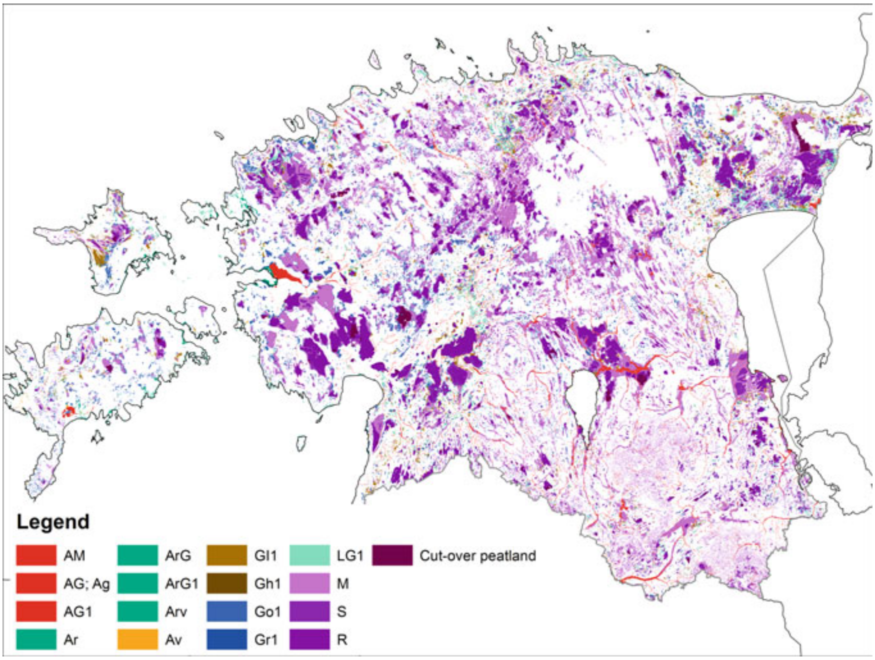

Fig. 2 Distribution of wetland soils used for the delineation of WFD important wetlands of Estonia (selection is made from the electronic soil map of Estonian Land Board). In the legend: AM—*Fluvic Histosols*, AG—*Gleyic Fluviosols*, Ag—*Endogleyic Fluvisols*, M—*Eutric Histosols*, AG1—*Histic Fluviosols*, Ar—*Hyposalic Fluvisols,* ArG—*Salic Fluvisols*, ArG1—*Salic Histic Fluvisols*, Arv—*Salic Subaquatic soil*, Av—*Subaquatic soil*, GI1—*Umbri-Histic Gleysols*, Gh1—*Gleyi-Histic Leptosols*, Go1—*Molli-Histic Gleysols*, Gr1—*Salic Gleic Fluvisols*, LG1—*Spodi-Histic Gleysols*, R—*Dystric Histosols*, S—*Eutric-Dystric Histosols*.

districts (for the most part on a scale of 1:10,000, some parts also on a scale of 1: 5000), and from the printed paper maps of 1954 and 1988 [20].

The used software during the "Wetland Project" was *ArcMap10.2.2*.

3.1 Identification of Wetland Extent

Course of the wetland "zero" contour line on the map was determined according to the fen, poor fen and bog peat polygons, merged together with other wetland soil polygons between them. The obtained extents of the "zero" polylines were verified by comparison with all available historical maps and published materials, time series of satellite images and orthophotos of corresponding wetlands.

During the delineation of "zero" contour lines, it was found that many wetland polygons associated with the flowing WBs articulated due to intensive management of wetland, or had partially or completely disappeared from the landscape. In the cases, if there were no perspectives to re-establish the original extent of the wetland for example via restoration, the course of the "zero" contours was corrected accordingly (Fig. 3).

On many occasions, wetland soil polygons alternated with a specifically oriented pattern of mineral soil polygons, e.g., ridge swale systems on the coastal plains [22]. In such cases, the polygons of the mineral soils remained within the "zero" contour line of the wetland [10].

As a rule, all wetland soil polygons with areal extent >10 ha were included within the "zero" contour line. Wetland polygons of less than 10 ha remained within the delimited wetland polygon only if they were already designated as environmentally significant wetlands, such as Natura 2000 sites for example.

The delineation of WFD important wetlands began with the largest and ecologically most important Estonian wetlands, e.g., Ramsar areas. Also, locations of surface WBs with *dark waters*, *rich in humic substances*, with different catchment sizes (i.e., Type IA, IIA and IIIA in [19]) influenced the choice of wetland to be delineated (Fig. 4).

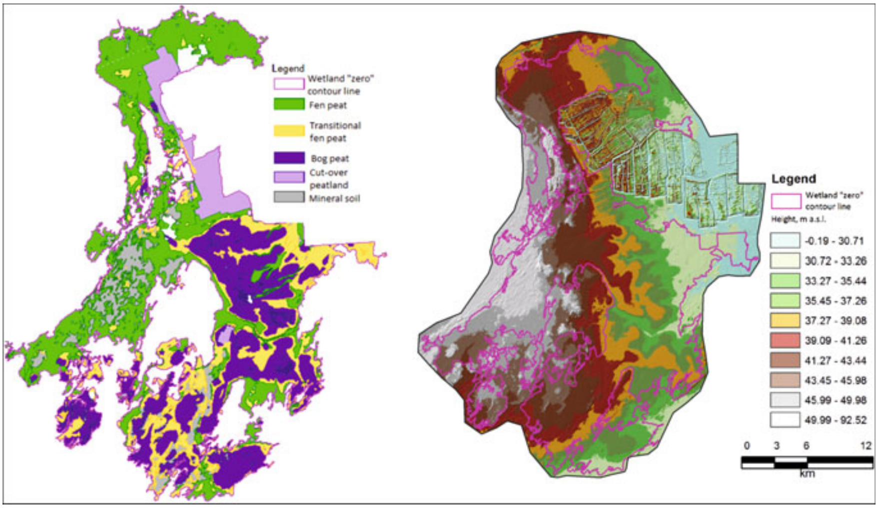

Fig. 3 An example of the soil distribution of Puhatu mire complex (north Estonia) within the delineated wetland "zero" contour line (the left image) together with its digital elevation model (the right image). The wetland "zero" contour line is re-delineated because of the oil shale mine (the upper right corner on the images), whereas the cut-over peatlands remained in the wetland area. The databases used: Estonian Land Board. The original maps were produced by Simmer [21]

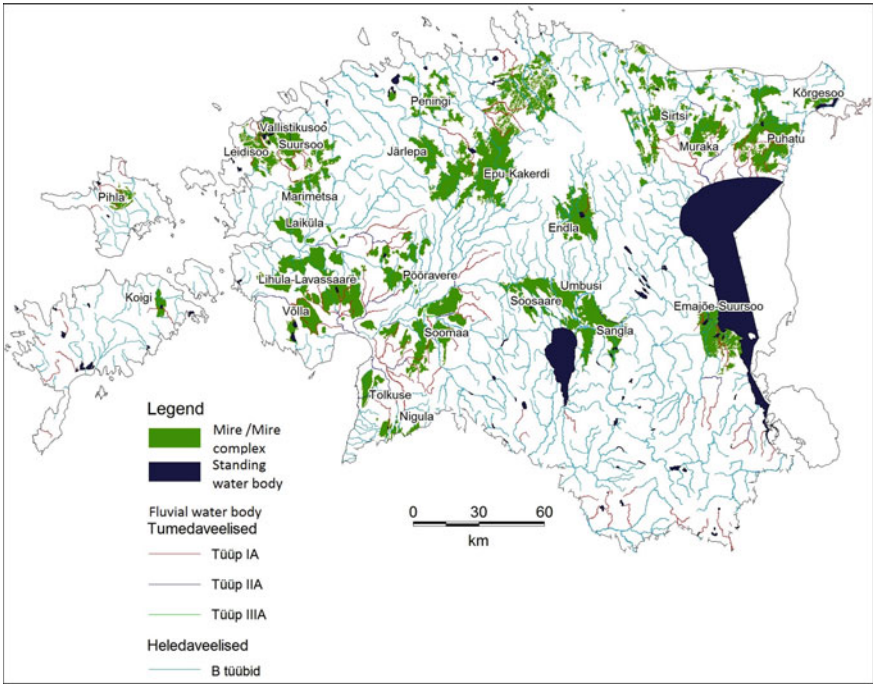

Fig. 4 The first choice of Estonian mires for determination of WFD important wetlands for fluvial WBs. The used databases: Estonian Nature Information System (EELIS), Estonian National Topographic Database (ETD), Estonian Land Board

3.2 *Identification of Water Body Important Wetlands*

The existence of digitalised drainage basins both of the wetland and the WB associated with that wetland are important for determining the share of wetland extent in the drainage basin of the corresponding WB.

Digital elevation models (DEMs) of Estonian Land Board with the pixel size of 5 × 5 m mainly, was used for delineation of the drainage basins of the WBs in *ArcMap10.2.2* environment. Obtained basin layers overlaid with corresponding wetland layers, and results were visualised in corresponding map layers (Fig. 5). Then the percentage of the wetland coverage of the drainage basin was calculated. Corresponding information about the environmental conditions, both of the WB and the wetland part was updated and saved in the WFD important wetland database.

During the "Wetland Project" the structure of a database for the WFD important wetlands was created, consisting of 55 and 34 indicators of WFD important wetlands for the flowing and standing WBs, respectively. The number of developed indicators was much lower for the floodplain wetlands (eight indicators), the coastal wetlands (13 indicators) and the groundwater-dependent spring mires (11 indicators) [10].

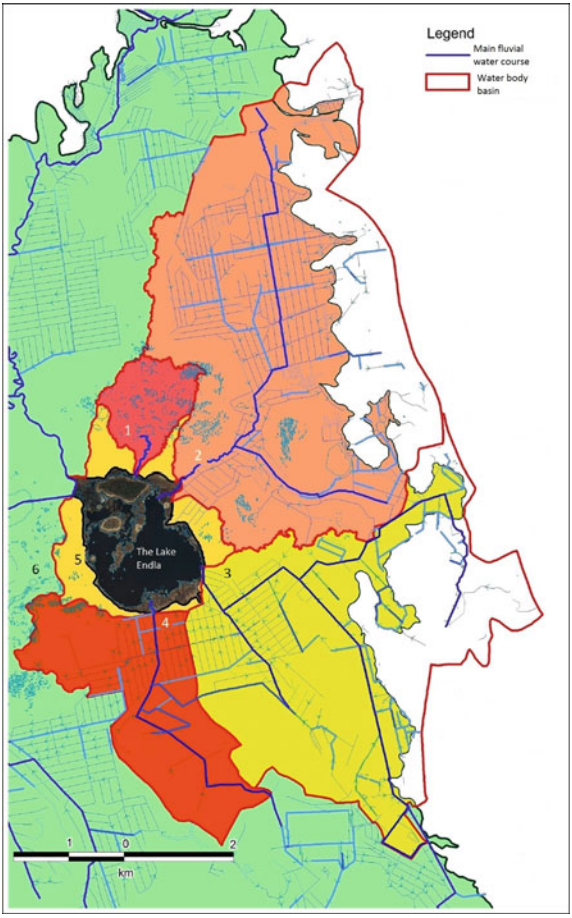

Fig. 5 Delineated drainage basins of the fluvial watercourses within the Lake Endla drainage basin (the coloured parts in the basins corresponding to the peatland polygons). The numbered drainage basins on the map: 1—the Linnussaare Brook; 2—the Mustjõgi River, 3 & 4—the main drainage ditches, named Koidu and Endla, respectively. The peatland coverage results are: drainage basins 1, 4 and 5 = 100%, drainage basin 2 and 3 = 80% & 75%, respectively. The 6th, light green area, is the part of the peatland not influencing the Lake Endla. The background drainage network on the map: Estonian National Topographic Database (ETD)

The assessment of ecological status (i.e., *good*, *poor*, *bad* status) of the part of the wetland belonging to the drainage basin of a certain WB, was made as a combination of (a) the soil-based historical extent of the wetland, (b) the land drainage (i.e., presence of flowing watercourses according to the Estonian National Topographic Database (ETD)), (c) contemporary land cover, examined from existing aerial and orthophotos, and (d) determined ecological status by different national wetland inventories (e.g., [12, 15, 23]).

Thus, the conditional levels of WFD important wetlands related for instance, to flowing and standing WBs are the following:

- *Good*—no visible marks of anthropogenic activity were discovered, e.g., no ditches, deepened or straightened natural water-courses, enlarged tree stands, agricultural fields, mining areas;
- *Poor*—there was a visibly distinctive increase of the tree stands on the area, but the typical micro-topography of the mire is preserved, some ditches were discovered on the border areas and very few ditches inside the mire area;
- *Bad*—the mire area was covered with a dense net of ditches, the increased tree stands were in compliance of the peatland's forest criteria, and there were active or terminated mining areas, including self-regenerating areas after intensive management [10].

3.3 Identification of Important Floodplain Wetlands

Determination of important floodplain wetlands was based on the extent of floodplain soils, e.g., *Endogleyic Fluvisols* (Ag), *Gleyic Fluviosols* (AG), *Histic Fluviosols* (AG1) and *Fluvic Histosols* (AM), in the river valleys or overflow areas of the standing WBs (see Fig. 2).

Another criterion for the selection of important floodplain wetlands was the representativeness of the wetland, e.g., the size of the floodplain extent, the importance of plant species, and the level of human impact. The narrow valleys of the water bodies, where wetland's soils "run" long along a natural and meandering riverbeds were also accepted. Ecological importance of delineated wetlands was taken from existing floodplain inventories (e.g., [24, 12]), environmental monitoring reports on vascular plant species and floodplain meadows (EELIS database) and management plans for floodplain meadows [25].

In addition, the hydro-morphological naturalness of the WB valleys was identified together with the land use in the surroundings of the wetland, e.g., agriculture, forestry, and vegetation conditions within the delineated wetland polygon, e.g., the intensity of the shrub growth, and part of non-meadow type of vegetation.

3.4 Identification of Important Spring Mires

Due to a comparably small surface area, data of the spring mires, and especially hydrological data has been incomplete quite a long time in Estonia. Unlike other wetlands, e.g., bogs, fens, they were mostly unmapped up to 2011. Some of them were studied in 1950–1960 with the aim to use the spring tufa sediments for the crop fields liming (e.g., [26, 27]). Systematic mapping was provided during the inventory of Estonian mires [15, 28] and during identification and status analysis of Estonian spring mires (e.g., [23]).

The first main criteria for determining WFD important spring mires were their area and ecological status: the larger the spring mire and the better its ecological status, the more significantly its influences the status of the surface WB. The spring mire area correlates, in most cases well with the amount of water feeding the spring mire, i.e., the extent of the groundwater catchment, and with the amount of groundwater discharging to the surface as springs or seepage areas.

The main criteria for assessing of ecological status of the spring mire were the stability of the groundwater discharge and the absence of human impact, primarily drainage, within the mire area and in its surroundings. In *very good* condition, there was no appreciable direct and indirect human impact on the mire area, and the existing vegetation reflected the existence of stable groundwater discharge in the area. In *good* condition, indirect effects of human activity were recorded, e.g., ditches, straightened spring brooks, etc., but the spring mire water level in the area was still high and the spring mire specific plant communities were preserved. The spring mire was considered to be in *poor* condition if the surrounding of the mire or mire itself was ditched and the springs discharged into the ditches, the mire water level and the proportion of the spring mire specific species in the plant cover were low.

3.5 Identification of Important Coastal Wetlands

The delineation of the coastal wetlands was based on the Av, Ar, ArG, and Gr soil types selected from the digital soil map (see Fig. 2). Because of rather expansive soil coverage of coastal wetlands, both vertically and horizontally from the coastline, the final wetland boundary was verified on the basis of the latest orthophotos.

Also, maps of the coastal grasslands of different projects (e.g., Natura 2000 habitat types, potential Natura 2000 habitat types, etc.) were used to verify the location of a determined coastal wetland. Since the coastal grasslands are determined by the species composition rather than the water and soil conditions, the soil map layers could not be used unambiguously.

Finally, identified wetlands were digitised from the orthophotos with a scale accuracy of 1:25,000–1:50,000. Very narrow (5–10 m wide) coastal wetlands were excluded from digitalization because of their low impact potential to the coastal water body. Coastal wetlands that were wider but smaller by the areal extent (i.e., <10 ha) were also not digitised. Wetland polygons located very close to each other or located within one narrow area (e.g., coasts of the smaller bays) merged into one area.

The coastline of the Estonian digital basic map was used to mark the seaward boundary of the coastal wetland. In the cases of extended reed coverage, the boundary of the wetlands was expanded towards the open sea. However, it must be emphasized that the delineated wetlands are certainly not very accurate at all locations, since land lift, the areal extent of floods and the frequency of overflows change the sea- and landward borders of coastal wetlands rather rapidly over time.

The WFD importance of coastal wetlands was determined at three levels, where:

1. *Very important*—wetland extent is relatively large and has a significant role in influencing the status of the coastal WB;
2. *Important*—wetland extent is relatively large, it has indented contour line and has an important local role affecting the status of the coastal WB;
3. *Insignificant*—wetland area is small, it has a long and narrow shape and does not affect the status of the coastal WB [10].

The ecological status of WFD important coastal wetlands was determined as follows:

1. G*ood*—wetlands with no nearby facilities or enterprises that could affect the aquatic/water environment;
2. *Poor*—wetlands with nearby facilities or enterprises affecting the aquatic/water environment, but the impact of those is not continuous and/or intensive;
3. *Bad*—wetlands with nearby facilities or enterprises affecting the aquatic/water environment, and the impact of those are continuous and/or intensive [10].

4 Results

4.1 Important Wetlands Associated with Flowing Water Bodies

The list of WFD important wetlands associated with flowing WBs consists of 37 mires with the total area of 1374 km^2 and 10 mire complexes [29] with the total area of 1967 km^2. By the hydrological function of those mires to the WB they were both as up- and downstream mires, and the middle course stream mires (Fig. 6).

Thus, the number of the WFD important mires associated with the flowing WBs because of their areal extent (i.e., >40% of the drainage basin area) was 19, subdivided between 43 drainage basins of the flowing WBs. Most of the WBs (i.e., 91%) associated with those mires have at least a *good* ecological status, and most of them are typified as WBs with *dark waters* and *rich of humic substances* (EELIS database). However, approximately 20% of those are typified as WBs with *clear waters* and a *low level of humic substances* (EELIS database). In addition, about 40% of those WBs are *heavily modified water bodies* without any type of ecological status determined (EELIS database).

Almost 50% of the mires, associated with flowing WBs have worse than *good* ecological status by both the bog and poor fen soil extent. By the fen soil extent more than 80% of estimated mire conditions had a worse than *good* status [10].

The main pressure for the bogs in *poor* conditions is formed by the edge ditches or the ditches crossing the bogs, and by the dredged and straightened bog watercourses. In such areas, there is an easily visible increase of the tree coverage and

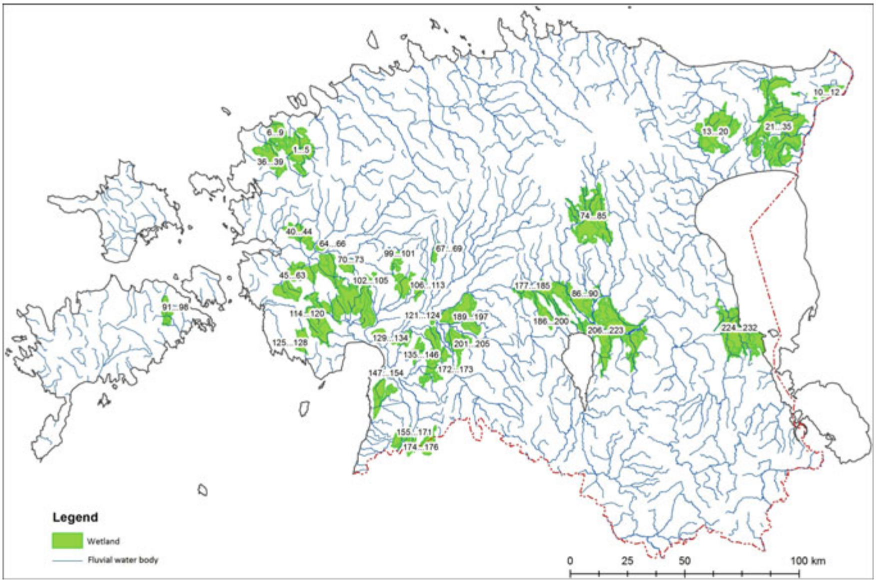

Fig. 6 Visualised results of WFD important mires associated with flowing water bodies in Estonia. The number marked on the wetland polygon indicates the ID number of the wetland or part of the wetland in the database of the "Wetland Project" [10]

some overgrowth of bog pools or lakes in the orthophotos. The main pressure factor for the bogs in *bad* conditions is the dense network of drainage ditches, which is accompanied by the high and dense tree stands. Also, peat extraction areas, both abandoned and active areas are an important pressure factor for the bogs.

The dense drainage network for forestry and arable land is the key pressure factor for the *bad* ecological status of fens. Often, the integrity of these areas has suffered from infrastructure and polder facilities.

Thus, the restoration of damaged peatlands is a key water management measure to improve the ecological status of WFD related mires associated with flowing WBs.

4.2 Important Wetlands Associated with Standing Water Bodies

The list of wetlands associated with standing WBs consists of 42 mires, 7 mire-complexes, and 19 quaking mires or reed beds with a total area of 42 km^2 (Fig. 7). The number of wetlands important for the standing WBs because of their areal extent (i.e. >30% of the drainage basin area) was 30, divided between the drainage basins of 20 standing WBs.

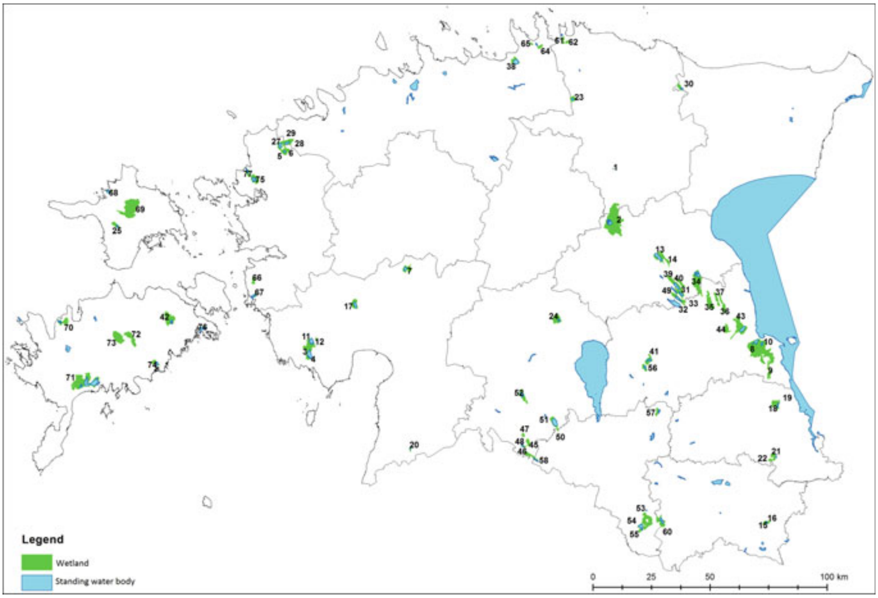

Fig. 7 Visualised results of WFD important wetlands associated with standing water bodies in Estonia. The number marked on the wetland polygon indicates the ID number of the wetland or part of the wetland in the database of the "Wetland Project" [10]

Forestry, agriculture, mining, and to some extent also human settlements and visibly notable increased tree stands within wetland areas are the key pressures for wetlands associated with standing WBs. So as, 82% of wetlands, related to the standing WBs have worse than *good* ecological status. Thus, the main water management measures can be the restoration of wetlands, which in most cases means closing the ditch drainages. However, the feasibility of sustainable management of organic soil in these areas also needs to be determined after gathering missing information from fieldwork or from existing databases that were not used in the "Wetland Project".

4.3 Important Floodplain Wetlands

There were 46 WFD important floodplain wetlands associated with flowing WBs with the total areal extent of about 15,000 ha. Two of them are associated with the standing WBs. Almost 80% of those wetlands have at least *good* ecological status and 85% associated with them WBs have *clear water* and a *low of humic substances* water type (Fig. 8).

In the river valleys, these wetlands form: (1) moderately wet meadows on the higher parts of the floodplains, and (2) wet meadows and floodplain wetlands on the lower parts of the floodplains. Since these wetlands have all functional importance to

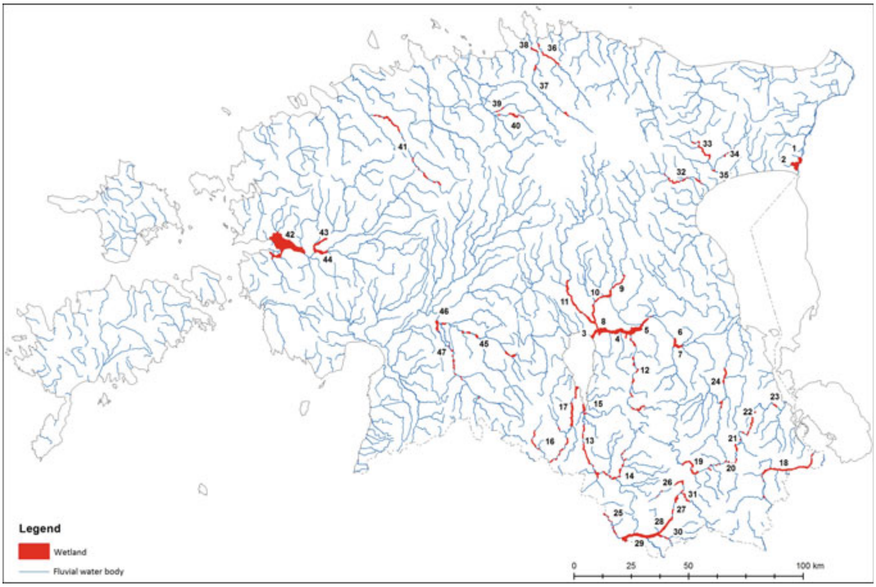

Fig. 8 Visualised results of WFD important floodplain wetlands associated with surface water bodies in Estonia. The number marked on the wetland polygon indicates the ID number of the wetland in the database of the "Wetland Project" [10]

the WFD water bodies, the key water management measure is to continue their maintenance. Both, moderately wet and wet floodplain meadows, were mostly mowed for hay in the nineteenth and twentieth centuries, and they are mostly unmanaged at present.

4.4 Important Spring Mires

As a result of the "Wetland Project", 24 WFD important spring mires or groups of spring mires were selected with the total areal extent of 390 ha (Fig. 9).

Both, the largest (Viidumäe, 90 ha) and the smallest (Odalätsi, 4 ha) selected spring mire is located on Saaremaa Island. Mainly, they are fed by groups of seepage springs; i.e., the groundwater discharges vary between 10 and 0.1 l/s as a mean (EELIS). Brooks formed in those areas influence both the status of the Pidula River and the Soela Strait (EELIS).

All WFD important spring mires, except one, are at least in *good* ecological status; 22 of those are functionally related to the flowing WBs, one to the standing WB and one to a coastal WB [10].

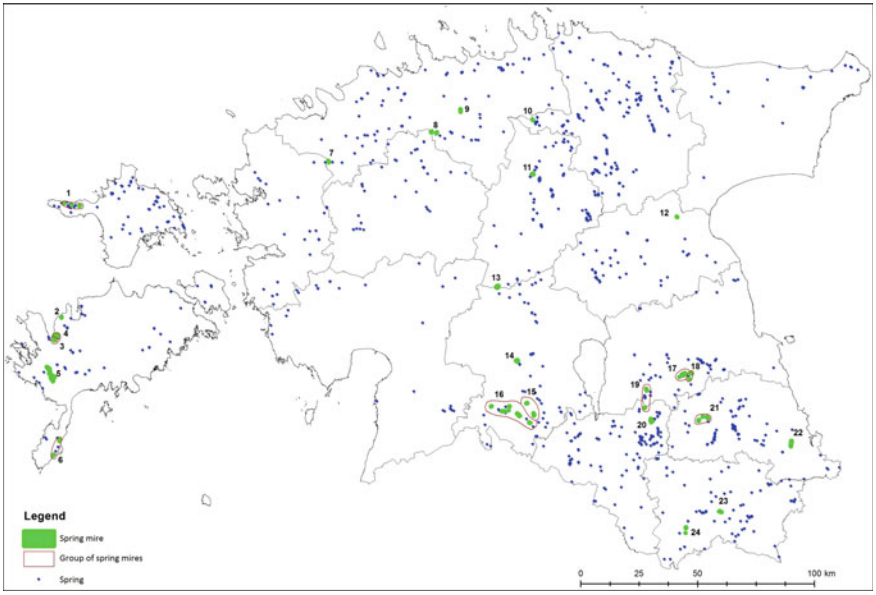

Fig. 9 Visualised results of WFD important spring mires associated with surface water bodies in Estonia. The number marked on the wetland polygon indicates the ID number of the wetland in the database of the "Wetland Project" [10]

4.5 Important Coastal Wetlands

There are 107 WFD important coastal wetlands with a total area of 265 km^2 in Estonia (Fig. 10). By their location they are associated with coastal WBs, which are classified into the:

Type II—i.e., oligohaline, semi-enclosed coastal water of the Gulf of Pärnu: 4.0–5.5 PSU;

Type IV—i.e., mesohaline, shallow, undulating coastal water of offshore coastal waters of the Western Islands: 6–7 PSU;

Type V—i.e., mesohaline, shallow, hidden from storm surge, and mixed coastal water of the Gulf of Väinameri: 3–6.5 PSU;

Type VI—i.e., mesohaline, shallow, hidden from storm surge, seasonally stratified coastal water of the Gulf of Liivi: 4–6 PSU (Fig. 1, [19]).

In this way, the water environments of the chosen coastal wetlands differ by salinity, by seawater depth and openness to the sea. Also, they are unevenly distributed along the Estonian coast, influenced by geological-geomorphological characteristics and types of the coasts. Wetlands associated with the coastal waters of the Gulf of Finland, for example, are in majority narrow by the shape and "running" parallel to the coastline. As a rule, they are small in area, but they are in *good* ecological status. The larger and rich by biodiversity wetlands are located on the western coast

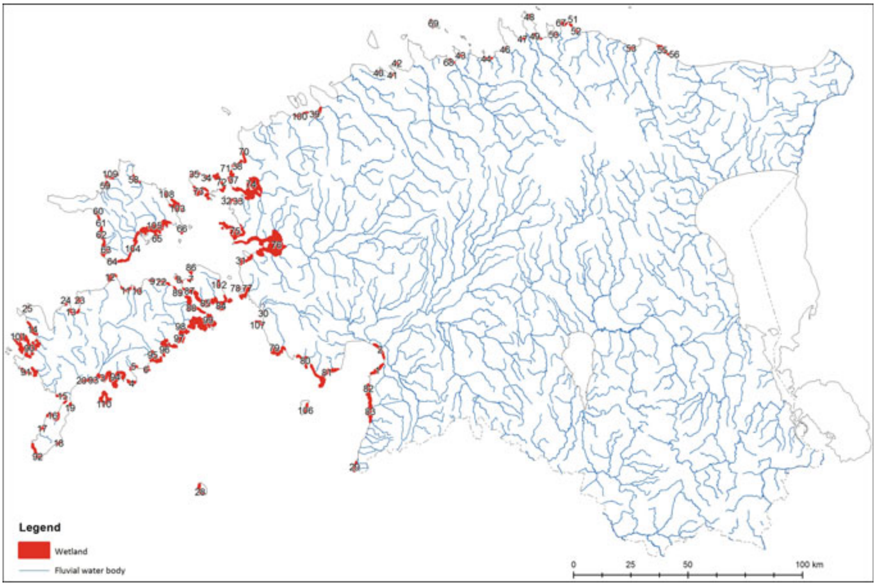

Fig. 10 Visualised results of WFD important coastal wetlands associated with coastal water bodies in Estonia. The number marked on the wetland polygon indicates the ID number of the wetland in the database of the "Wetland Project" [10]

of Estonian mainland and on the coast of the western islands. By the wetland type, the most important are coastal meadows and reed beds.

The main pressures for the coastal wetlands are eutrophication and increased climate-induced storminess. Coastal meadows tend to overgrow with reed and scrubs. Different facilities form the main point pressures for the coastal wetlands, and their main diffuse pressures are coming from agriculture, recreation, transport, direct and indirect residual pollution from wastewater.

5 Discussions

In this chapter, the methodology for determining of WFD important wetlands of Estonia is presented. Based on existing WFD surface WBs, the delineation and condition estimations of wetlands, is related to four main types of Estonian wetlands: (1) mires, including bogs, poor fens, and fens, (2) floodplain wetlands, (3) spring mires, and (4) coastal wetlands.

During the "Wetland Project," the structure of the database of WFD important wetlands was created together with relevant wetland indicators. In the databases, morphometrical characteristics of wetlands (e.g., areal extent in the drainage basin) are in many cases present only for a part of the whole wetland (e.g., drainage divide mires). However, both studying of the functional importance and defining the most suitable water management measures must be guided by the whole wetland extent with the corresponding data in the databases of WFD important wetlands.

Without the required fieldwork, it is not possible to carry out the hydrological—biological and hydro-chemical functional classification of the defined by us WFD important wetlands. We are still missing the necessary information of functional roles of the WFD important wetlands to the surface WBs. It is also unknown to what extent hydrological and chemical monitoring data, such as the long-term monitoring data of Tooma Mire Station (Fig. 1; see also, e.g., [29]), can be transferred to other important wetlands. There is no experience in Estonia for using wetlands analogue areas or analogous elements both for wetlands in natural or managed status.

Due to the heterogeneous landscape structure of the Estonian wetlands, i.e., occurring as separated polygons or multiple mire types within a "zero" wetland/mire contour line [30, 31], the variability of both water quantity and quality of our wetlands is relatively large. Therefore, without studies of WFD important wetlands, it is not possible to determine their effect on nutrient retention or leaching, or on the hydrological regime of WBs connected with them.

Also, it is unclear why many WFD defined surface WBs with a large share of wetlands in their drainage basins are typified as WBs having *clear water* with the *low level of humic* substances, compared to what would be expected due to the high percentage of the wetland coverage in their basins, i.e., *dark water* and *rich in humic* substances.

There are a number of wetland monitoring activities launched in Estonia, which largely fulfil the objectives of surveillance monitoring (WFD Annex V, 1.3.1). Application of operational (WFD Annex V, 1.3.2) and investigative monitoring (Annex V, 1.3.3) would be a prerequisite for the establishment of a permanent WFD important wetland monitoring system in Estonia.

The plant cover of natural wetlands is the most commonly monitored element of Estonian wetlands. However, the data are not site-specific, and data of water environment elements are either missing or incomplete. We know rather little both about the hydrological and ecological effects of wetlands under different management pressure, e.g., forested or cutover peatlands, drained meadows or spring mires.

6 Conclusions

As a result of the "Wetland Project" Estonian mires, floodplains, spring mires, and coastal wetland were associated with WFD important surface WBs for the first time. It is the first time when WFD important Estonian wetlands were defined, their extents calculated and ecological status assessed, the pressure factors and the main water management measures described. Corresponding database structures were compiled, and map layers were visualised.

The soil map based delineation together with corresponding basin modelling of WFD important wetlands, and especially peatlands associated with flowing WBs, turned to be highly complicated and labour-intensive. Therefore, mainly Ramsar important wetlands were analysed at first (Fig. 6). However, it was the first time when the DEM based mire drainage basin delineation approach (e.g., [29, 31]) was integrated to the WB drainage basin delineation.

Hereby it should be stressed that results gained from the "Wetland Project" are the first steps toward the functional classification of Estonian wetlands associated with WFD important surface WBs.

7 Recommendations

Our recommendation to the national structures managing water resources in Estonia, especially to those, that are involved in the implementation of Water Framework Directive (WFD) policy into the everyday life, is to complete the integration of Estonian wetlands with the WFD.

In practise, it means that the existing Estonian Nature Information System (EELIS) should be expanded toward WFD important wetland database. This should not be considered as an insignificant additional work in the WFD based reporting routine but should be seen as a part of the science-based management of water resources in Estonia.

At present, Estonia is rich in both the water resources and wetlands, but in the light of results of the recent wetland inventories and some case studies, it is obvious that the area of wetlands in at least in *good* status is decreasing. Results of the "Wetland Project" indicate, that assumption, that the status of a wetland, associated with the WB with at least a *good* status, is the same, seems not to be correct in all cases.

The knowledge and experience gained from the functionally classified WFD important wetlands, together with the corresponding numerical values both for annual and long-term changes, should be seen as a basis for the management strategy of WBs both in the conditions of climate and land management changes.

However, one of the prerequisites for high quality upgrading of the gained results is necessary field inventories for the WFD purposes integrated with the newest information from remote sensing. It should be hoped that delineated drainage basin layers both for the wetlands and WBs, will soon be available from the EELIS database together with quantity and quality values of all WFD important wetlands.

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