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Martina Zelenakova
Jitka Fialová
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Assessment and Protection of Water Resources in the Czech Republic

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Martina Zelenakova · Jitka Fialová ·
Abdelazim M. Negm
Editors

Assessment and Protection of Water Resources in the Czech Republic

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Editors
Martina Zelenakova
Technical University of Kosice
Kosice, Slovakia

Jitka Fialová
Mendel University in Brno
Brno, Czech Republic

Abdelazim M. Negm
Faculty of Engineering
Zagazig University
Zagazig, Egypt

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Preface

A wide range of topics strongly connected to the water assessment, protection and management in the Czech Republic is covered in this book in 18 chapters by 21 researchers, scientist and experts from different institutions, academic organization and research centres that are mainly interested in water resources aspects and related fields. The book is divided into five parts, namely Introducing the Book, Surface and Ground Water Bodies, Water in the Landscape, Hydro-management of Water Resources and Conclusions.

Two chapters are presented in Part I, the introduction. The introduction written by the editors with inputs from the authors of all chapters to introduce the different chapters to the audiences, and Chap. 2 titled "Past, Present and Future of the Laboratory of Water Management Research in Brno" was prepared by J. Pařílková, Z. Zachoval from Brno University of Technology, Faculty of Civil Engineering, Institute of Water Structures, focused on establishment, operation and foreseen of the Hydraulic Laboratory in Brno as an example where most of the universities have almost laboratories for water researches.

Part II consisted of six chapters dealing with the "Surface and Ground Water Bodies". Chapter 3 titled "Rivers in the Czech Republic" provides the basic information about rivers in the Czech Republic which is a small landlocked country located in central Europe between Poland, Germany, Austria and Slovakia. Being an inland country in Central Europe with rugged relief and located on the main European divide of three seas. The Czech Republic has no other source of water than precipitation. Of the 76,000 km of natural watercourses, 28.4% are altered.

Chapter 4 which is titled "The Role of Water in the Landscape" pays attention to the important aspects that in recent years, the Czech Republic has experienced extreme weather fluctuations leading to unexpected floods and long periods of drought. The current situation is a result of the long-term use of our landscape which is no longer able to retain and accumulate water, mainly due to technical alterations of watercourses, changes in land use and deforestation. Chapter 5 which is titled "Small Water Reservoirs, Ponds and Wetlands' Restoration at the Abandoned Pond Areas" addresses the small water reservoirs that are one of the basic elements of the agricultural landscape in the Central European space. They are one of the most valuable nature-loving elements of the cultural landscape. In the Czech Republic, they have a long historical tradition. On the other hand, Chap. 6 with the title "Small Bodies of Water Which Have Disappeared from the Czech Landscape and the Possibility of Restoring Them" deals with pond management that is a historical and landscape-forming phenomenon in the Czech lands. The ponds, whose traditional role is linked mainly with the economically lucrative fish farming, did, however, play a wider role within the historical landscape, where they fulfilled the requirements of society for water, they formed a potential supply of energy to power production facilities, or they were the part of the fortification of noble estates. The chapter describes the development and decline of pond management in the Czech Republic.

Chapter 7 which is titled "Protection of Water Resources" is oriented to water protection in the Czech Republic, in accordance with EU requirements, helping to improve the state of water resources, aquatic ecosystems, promote sustainable water use and mitigate the adverse effects of floods and droughts.

In Chap. 8 which is titled "Groundwater Flow Problems and Their Modelling", the author presents groundwater flow and methods how problems connected with it can be solved. It also presents groundwater flow modelling. Groundwater is an inseparable component of the hydrological cycle and water resource systems.

Part III consisted of four chapters dealing with "Water in the Landscape". Chapter 9 is titled "Hydrological Mine Reclamations in the Anthropogenically Affected Landscape of North Bohemia". It deals with the surface mining of brown coal that has long burdened the landscape of the northern part of the Czech Republic. The chapter presents the case study results obtained by numerical experiment. The area is disturbed by surface quarries, external spoil tips and related anthropogenic interventions in the territory and its vegetation. Most of these interventions resulted in the removal of vegetation and were connected with the distortion of the natural dynamics of surface water and groundwater.

While Chap. 10 with title "Modelling of the Water Retention Capacity of the Landscape" provides basic information about the procedure for calculation of spatial specification surface runoff which is based on a combination of specific functions of Geographic Information System and which is enabled by Runoff Curve Number method. The formulated LOREP model represents an application of a solution using a methodical approach for the identification and localization of areas with low flood storage capability.

Chapter 11 which is titled "Floodplain Forests—Key Forest Ecosystems for Maintaining and Sustainable Management of Water Resources in Alluvial Landscape" represents the floodplain forests as key forest ecosystems in lowland regions of the European temperate zone. Ecosystem services of floodplain forests are essential for maintaining and sustainable management of water resources.

On the other hand, Chap. 12 is titled "Agrotechnology as Key Factor in Effective Use of Water on Arable Land". It describes the necessity of water for food production. A demand for good-quality food puts pressure on agricultural production. Agriculture influences the amount of water available, and the quality of water is tightly connected with the intensity of farming and the use of crop protection agents and fertilizers.

The next five chapters from 13 to 17 come under the heading "Hydromanagement of Water Resources". Chapter 13 is titled "Management of Drinking Water Resources in the Region of South Moravia, Czech Republic". It presents and discusses the supplies of good-quality water for supply in the region of South Moravia. However, it is necessary to maintain these sources where appropriate, restore, monitor their quality and quantity and ensure their adequate protection from spoilage.

In Chap. 14 under the title "Ecosystem Services and Disservices of Watercourses and Water Areas", the authors discuss ecosystem services and disservices of the watercourse network in the Czech Republic. Ecosystem services and disservices are not systemised in detail yet. A complex system already developing on the international scene allowing for practical applicability of the approach is missing in the Czech Republic.

Chapter 15 with the title "Water Resources Management Planning in the Czech Republic" deals with the planning in the water sector that performed within the hydrological basins and is a systematic conceptual activity undertaken by the government. Its purpose is to determine and mutually harmonize public interests of water protection as a component of the environment, to reduce the adverse effects of floods and drought and to ensure sustainable use of water resources.

Chapter 16 is titled "Technical and Economic Evaluation of River Navigation". It is devoted to present a possible solution to water freight transport in the Czech Republic. One part discusses possibilities of evaluation of the economic efficiency of waterway projects by CBA method as well, while Chap. 17 with "Water Balance and Phase of Hydrocycle Dynamics" is about the climate dynamics in the Czech Republic that has been increasing during the past 20 years and even before it was already characterized by high variability. The number of weather extremes increases; there is a statistically significant increase in air temperature, but not of precipitation.

The last part consisted of one chapter. Chapter 18 is titled "Update, Conclusions, Recommendations for Assessment and Protection of Water Resources in the Czech Republic" and written by the editors. It closes the book by the main conclusions and recommendations of the volume, in addition to an update of some relevant findings which might be missed by the contributors to the volume.

Special thanks to the authors and the reviewers who made this high-quality volume a reality as a source of knowledge and latest findings in the field of water resources in the Czech Republic. Without the continuous effort of authors in writing and revising the different versions to satisfy the high-quality standards of Springer, it would not be possible to produce this volume and make it a fact.

Much appreciation and great thanks are also owed to the editors of the Earth and Environmental Sciences series at Springer for the constructive comments, advice and the critical reviews whenever since the submission of the book proposal. Great thanks and appreciation are extended to include all members of the Springer team who have worked long and hard to produce this volume and make it a reality for the researchers, graduate students and scientists around the world.

The book editors would be so pleased to receive comments, suggestions and feedbacks via their emails to improve future editions. The emails of the editors can be found inside the book at the footnote of their chapters.

Brno, Czech Republic — Jitka Fialová
Zagazig, Egypt — Abdelazim M. Negm
Kosice, Slovakia — Martina Zelenakova
January 2019

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Part I
Introducing the Book

Chapter 1
Introduction to the "Assessment and Protection of Water Resources in the Czech Republic"

J. Fialová, A. M. Negm and M. Zelenakova

1.1 Main Themes of the Book

The book started with two chapters as an introduction to the book. Chapter 2 presents the past, present and future of water management in a typical water resource laboratory in Czech Republic. The remaining chapters of the book are divided into three themes, namely surface and ground water bodies in six chapters from 3 to 8, water in the landscape covered in four chapters from 9 to 12, hydro-management of water resources covered in five chapters from 13 to 17. Then, it ends with conclusions and recommendation part in Chap. 18. The following section presents the main features of the chapters for each of the three themes.

J. Fialová
Department of Landscape Management, Faculty of Forestry and Wood Technology, Mendel University, Brno, Czech Republic
e-mail: jitka.fialova@mendelu.cz

A. M. Negm (✉)
Water and Water Structures Engineering Department, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm85@yahoo.com; amnegm@zu.edu.eg

M. Zelenakova
Department of Environmental Engineering, Faculty of Civil Engineering, Technical University, Košice, Slovakia
e-mail: martina.zelenakova@tuke.sk

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1.2 Surface and Ground Water Bodies (Six Chapters)

Chapter 3 focuses on rivers in Czech Republic. It provides basic information about hydrography, hydrological regime, biogeochemistry and biodiversity of the rivers in the Czech Republic.

In more detail, it represents three main rivers which drain the Czech Republic and flow into three separate sea basins. The chapter also refers possible environmental pressures which may deteriorate the natural character of the streams and rivers and focuses as well on some management and conservation measures.

It concludes that in spite of a significant improvement in water quality since 1990, significant pressures have emerged such as eutrophication, morphological alterations of the channels, disruption of sediment transport or fish migration that degrade aquatic ecosystem functions and restrict the structure of their biological communities. Therefore, future management of streams and rivers should consider the needs of water supply, wastewater dilution, hydropower generation or navigation on the one hand, and on the other hand good ecological status of watercourses supporting sustainable water balance of the landscape.

It recommends that employing purely technical solutions in water management, such as the construction of new dams, will not provide sufficient water for the Czech streams and rivers. Indeed, natural river beds with a rich structure of benthic sediments and frequent overbank flows can be used as an effective and relatively inexpensive means of solving numerous problems in water and landscape management.

Chapter 4 is about the role of water in the landscape. It attempts to describe functioning of the water in any catchment and the role of a small water cycle for maintaining the landscape capable of avoiding unexpected floods and long periods of drought.

In more detail, this chapter focuses on the description of the so-called small water cycle and a role of wetlands in landscape with emphasis on their direct role in regulating water and air temperature.

To solve the problems with water scarcity in the landscape, the chapter highlights a need to use a holistic approach which is based on the integration of all processes affecting water in the watershed. There are two main strategic goals for restoration of the complete water cycle: first the restoration of drainage patterns having natural hydro-morphology, and second the improvement of water-retention capacity across landscapes of Czech Republic.

Finally, it recommends the principles outlined in this chapter call for alternative approaches to land use and land management. Increased understanding of aquatic–terrestrial linkages would help provide the knowledge basis for difficult decisions about managing uplands, floodplains, wetlands, and river ecosystems in general. Moreover, engaging stakeholders and professionals from diverse disciplines in discussions about how to manage water on the landscape in a manner that is beneficial to all parties, including humans but also wildlife and ecosystems, is recommended.

Chapter 5 deals with restoration of small water reservoirs, ponds and wetlands at the abandoned pond areas. The chapter focuses on the restoration of small water reservoirs, ponds and wetlands at the areas of old, abandoned, surface water bodies, which were left mainly during the nineteenth century. Also, it presents a brief history of pond and small water reservoir development within the territory of the Czech Republic. It shows how the spatial analyses in the ArcGIS platform and different databases, including special national water management database, can be used for the detection of the abandoned areas, for the all analyses in the presented case studies, etc. The chapter includes a distribution of historical and abandoned ponds within the basic territorial units—districts—and the comment of the differences. Different tools and methods are used for the analysis of the abandoned ponds and newly built small water reservoirs, ponds and wetland areas: cluster analysis, mapping of landscape elements, critical points methods. The authors provide three case studies presenting the possible use of abandoned pond areas in the extensive agricultural landscape, urbanized landscape and intensive agricultural landscape. Also, this chapter ends with a set of conclusions and recommendations.

Chapter 6 is devoted to discussing small bodies of water which have disappeared from the Czech landscape and the possibility of restoring them. It describes the development and decline of pond management in the Czech Republic. It presents the results of spatial analysis using maps from the Second Military Mapping Survey. The majority of the area of former ponds is nowadays used as agricultural land. In these areas, we have carried out a detailed analysis relating to soil quality and the (lack of) potential for agricultural production. It is apparent that the current use of former pond areas is by no means optimal in all cases, and in a time when we face issues of hydrological extremes—flooding and drought, it is worth considering possible changes in the use of some of these sites within revitalization and flood-prevention measures.

Chapter 7 is about the protection of water resources. The chapter focuses on contamination and protection of water resources. The first part of this chapter presents the historical development of water resource protection in the Czech Republic and levels of water protection and also describes the financial compensation in protection zones. The second part of this chapter describes the protection of water resources in practice, in Vysočina and South Moravia regions.

It concludes that the protection of water resources is very important in the whole world. All the people need to realize that water is a basic natural resource, without which life would not exist. Nowadays, the Czech Republic, like many other countries, is struggling with the drought. The problem is not only the water quality but also the availability of drinking water and the availability of water for irrigation. In Europe, several types of resources are used to produce drinking water. The position of the Czech Republic in Europe is very special—belongs to the three European river catchments. For this reason, it is very important to protect the quality and quantity of surface and groundwater used in the Czech Republic, but also anthropogenic pollution of water spreading to neighbouring countries must be prevented. It needs it to treat water resources in accordance with the principles of sustainable development.

In relation to climate change and the effects of drought, we recommend specifying in more detail the protection of water resources for season droughts—i.e. to solve in more detail the protection of water resource efficiency.

The valid legislation needs to be elaborated, supplemented, updated and in practice adapted to a wide variety of natural and economic conditions. Protection zones like preventive protection are necessary, their importance we have to support with conducting education. However, there need legislation and political wish and support.

As far as legislation is concerned, it is primarily necessary to solve the problem with Decree No. 137/1999 Coll., which is ineffective; some of the provisions of this decree are inconsistent with valid Water Act. In this way, it is necessary for the Central Water Protection Authority to add activity and novelize or at least abolish that decree.

However, it would be advisable to devote more to the problem of financial compensation in protection zones; the development of a methodical approach could be beneficial. This issue needs to be elaborated. The failure to solve the current situation is not a starting point for farmers operating in the PZ, for water companies, it's not for improving the quality of drinking water.

The practical journey is clearly based on cooperation and understanding between water-farmers and farmers, as well as the involvement of researchers from universities who are independent experts.

Chapter 8 is about groundwater flow problems and their modelling. In this chapter, the main groundwater-related issues and possibilities of their modelling are discussed. Special attention is paid to the water supply problems and groundwater protection, to the groundwater issues in urban areas during no flood periods and at the flood events. The assessment of groundwater impact on the hydraulic and civil structures is mentioned too. Numerous examples of groundwater flow modelling and its results are presented as well. Additionally, the chapter focuses on the technically oriented problems affecting the groundwater flow characteristics. Typical problems in groundwater management are presented together with an overview and applications of groundwater flow models. One-, two- and three-dimensional models are briefly described. Related practical applications are listed and demonstrated in examples from technical practice. These are namely the influence of hydraulic and other structures on the groundwater regime, changes of the groundwater flow during floods and an impact of flood-protection measures.

Groundwater flow models significantly contribute to the sustainable management of groundwater resources, on optimization of groundwater withdrawal and assessment of negative impacts of phreatic surface drawdown due to groundwater exploitation. They are necessary for contaminant transport modelling in aquifers. The models are also a crucial part of soil stability calculations. In this chapter, the summary of the models and assumptions for their use are shown.

As geological and hydrogeological conditions are complex, it is crucial to deal with the uncertainties in the entering data. One of the tasks of modellers and interpreters is to estimate the error and uncertainty in the results achieved. Moreover, the groundwater management and seepage modelling is a multidisciplinary issue at which significant role is played by geologists and hydrogeologists, water managers and hydraulic and civil engineers.

In the chapter, it is recommended to define objectives and formulate the problem carefully. Relevant interpretation and explanation of results must be presented for final decisions and technical proposals. All these items need experienced staff with good knowledge about the necessary data for the solution and a clear vision about the results and their application.

1.3 Water in the Landscape

Chapter 9 is interested in hydrological mine reclamations in the anthropogenically affected landscape of North Bohemia. The chapter focuses on hydrological mine reclamations that are the most effective way of using the residual quarry after the end of coal mining. The chapter presents aspects and examples of hydrological mine reclamations in North Bohemia. It uses various methods to assess current conditions and also the future potential of the area considering hydrological mine reclamations. It concludes that hydrological reclamation represents an essential step towards the restoration of the aquatic regimen in an anthropogenically burdened landscape. It provides a recommendation connecting sustainable development and the different reclamation-related aspects including coal mining, residual pit, restoration, reclamation, hydrology, artificial lakes, water management, Northern Bohemia, Lusatian Lake District and sustainable development.

Chapter 10 focuses on the modelling of the water-retention capacity of the landscape. It chapter presents our approach to modelling of the water-retention capacity of the landscape. The proposed procedure for the calculation of spatial specification surface run-off is based on a combination of specific functions of geographic information system which is enabled by run-off curve number method. The formulated LOREP model represents an application of a solution using a methodical approach for the identification and localization of areas with low flood storage capability. This enables a comparison of the projected scenarios. The structured catalogue of non-technical measures in the landscape is a part of the model. The procedure of computation of territorial specific surface run-off is based on a combination of specific functions in GIS as fuzzy sets, hydrological equations of the run-off curve number method and spatially distributed unit hydro-graphs. Additionally, the chapter provides some recommendations to be considered when modelling a water-retention function

Chapter 11 "Floodplain Forests—Key Forest Ecosystems for Maintaining and Sustainable Management of Water Resources in Alluvial Landscape" deals with the ecosystem functions of floodplain forests related to water management in alluvial landscapes. Moreover, based on a critical review, the chapter focuses on the research and management practice of the water regime and its consequences for floodplain forests from European perspective. Also, the chapter presents the results of a case study from the Czech Republic related to the monetary evaluation of floodplain forest habitats under payment for ecosystem service concept. The chapter ends with a set of conclusions and recommendations to help decision-makers and stakeholders achieve sustainable development of floodplain forests.

Chapter 12 discusses the role of agrotechnology as a key factor in effective use of water on arable land. The chapter is focused on the assessment of water retention in the agricultural landscape. Partial issues are the soil and retention capacity of the soil, changes in precipitation distribution in the Czech Republic, problematic of transpiration, evaporation, water-use efficiency in crop production, agrotechnological measures and agrotechnological operations leading to water retention in landscape and soil and water conservation on sloping lands by agrophytotechnical measures. Also, it deals with issues of water retention in the agricultural landscape of the Czech Republic and in general terms with the conditions of Europe. The authors stressed that Central European agriculture and hence agriculture in the Czech Republic await a number of challenges related to water management in the landscape. In the context of ongoing climate change, with irregular alternation of intense rainfall, long droughts and rising demand for agricultural raw materials, it is necessary to apply ways to encourage effective water retention and its cost-effective use. Additionally, the chapter draws the attention that one of the tools for efficient water management can be various agrotechnological measures. Agrotechnology is one of the key factors in the effective use of water on arable land. Several recommendations are provided to be accounted for when considering the management procedures that lead to water retention in the landscape.

1.4 Hydro-Management of Water Resources

Chapter 13 is devoted to present the management issues of drinking water resources with a focus on the region of South Moravia, Czech Republic, as a case study. The chapter describes the main sources of drinking water in the region, water quality in individual areas and water systems for water distribution to the consumer.

The current supply of individual systems in the region is evaluated, both the quantity and the quality of the water supplied.

Strategies for further development of water supply, an extension of the water supply network, modernization of water treatment plants and interconnection of distribution systems are presented. Conclusions and recommendations on how to improve the use of water resources in sustainable development are provided at the end of the chapter.

Chapter 14 presents the ecosystem services and disservices of watercourses and water areas in Czech Republic. The chapter is focused on the theoretical framework and current state of implementation of ecosystem services and disservices in water management in the Czech Republic. Also, it presents basic ways of identifying ecosystem services of water resources. It also focuses on the less-used category of ecosystem disservices. This presents the current state of assessment and use of ecosystem services in the Czech Republic. Moreover, it reflects the practical experience of the authors with the development and support of the use and awareness of ecosystem services among experts and the general public. Additionally, the chapter provides a set of conclusions and recommendations for the future use of the stakeholders in Czech Republic.

Chapter 15 focuses on planning of water resource management in the Czech Republic. The chapter presents the watercourses and the river basin management system and the rights and obligations of owners, administrators and water managers. The introductory part is focused on an overview of current approaches to water management planning abroad. The chapter also describes the development and current form of water management planning documentation, including flood protection. Methodologically, the chapter is elaborated as a literary overview, especially of the legislative environment of water management planning. At the same time, it reflects the practical experience of the authors with the elaboration of the planning documentation and its implementation into practice. The performed evaluation indicated that although management, administration and planning in the water sector have been designed and implemented logically and effectively in the Czech Republic, it is still necessary to continue in a close link with other forms of the planning of landscape utilization and management. Based on the knowledge presented in the chapter, the authors offer some recommendation for further development of water management and planning in the Czech Republic.

Chapter 16 is about the technical and economic evaluation of river navigation. It focuses on the introduction of possible solutions to water freight transport in the Czech Republic. This chapter presents the transport trends in freight transport, the advantages and disadvantages of national water transport, the commodities suitable for water transport and the actual estimated demand for water transport. It uses CBA methods for the evaluation of economic efficiency of waterway projects with various new approaches to the creation of financial and economic cash flows, based on which the investment project can be decided. The description of the CBA approach is supplemented with the case study of the evaluation of special benefits connected with trafficly important water structures. It concludes that the new related benefits and losses, which can generate significant cash flow items for the calculation of economic efficiency indicators, were identified.

Chapter 17 focuses on the water balance and phase of hydro-cycle dynamics. The variability of the climate in the Czech Republic has been increasing in the recent decades, and the number of extreme weather events is on a rise. Exceptional drought in almost the entire country was observed in 2000, 2003, 2012, 2015, 2017 and 2018. Even though drought occurrence in the Czech climate is a random event, its frequency and intensity increase. In addition, it occurs in different seasons during the year. Drought is primarily caused by precipitation deficit, but a significant factor is also air temperature, which affects evaporation. Drought is, in fact, a consequence of water deficit in the landscape. A much better indicator of drought is, therefore, the water balance, calculated as the difference between precipitation amount and potential evapotranspiration, in a daily step. During years with exceptional drought, the deficit by the end of the vegetation period (30th September of that year) can be as high as 300 mm in the driest regions. The amount of usable water in the soil in such cases drops below 10%.

Precipitation is the only source of water in the Czech Republic. Its occurrence, however, is highly variable, and this variability is increasing—both temporal (distribution during the year) and spatial. The average annual precipitation ranges from 410 to 1705 mm. Slightly less than 40% of annual precipitation amount falls in the summer, often in the form of thunderstorms, and such water quickly runs off from the landscape, often causing soil erosion. The amount of water in the landscape is affected by the hydro-pedological characteristics of that particular soil. In order to retain a larger amount of water in the landscape, it is necessary to stop soil degradation and increase their infiltration and retention capacity. This is also associated with measures taken to reduce soil erosion because the plough layer has a significantly higher retention capacity than eroded soils, where the upper layer is not plough, but subplough layer. Increasing landscape variability would reduce run-off, because it would reduce airflow and thus reduce evapotranspiration.

Given the fact it has been proven that in the Czech Republic the average air temperature in the period between 1961 and 2010 was increasing and still increases, the evaporation also increases. It has also been statistically proven that the annual precipitation shows no significant increasing or decreasing trend and in recent years the annual averages were below-average. This means that drought in the Czech Republic is likely to occur more frequently and with also higher intensity.

1.5 Concluding Remarks

The book ends with the conclusions and recommendations in Chap. 18 where the editors present the most important aspects, conclusions and recommendations extracted from the book's chapters in addition to an update from other sources whenever it is relevant.

Acknowledgements We would like to thank all the authors for their invaluable inputs to prepare this chapter.

Chapter 2
Past, Present and Future of the Laboratory of Water Management Research in Brno

J. Pařílková and Z. Zachoval

Abstract One ancient wisdom says, 'He who does not know the past cannot create the future'. This is not only true for the peoples and countries, but also for every human activity and society. In the course of time, human society has often passed through booms and declines. However, the necessity for life was always the need for freshwater. Nowadays, when extremely dry months alternate with local torrential rainfall, water management is frequent, and construction of laboratories of water management was shown as a very wise act. The Faculty of Civil Engineering in Brno, Czech Republic, has its history reaching far back into the nineteenth century. Indisputably, the elaboration of the concept and the factual establishment of water laboratories is worldwide ground-breaking. Founder of the water laboratories in Brno is Prof. Ing. Antonín Smrček, Dr. h. c. To defend the first laboratories in the Austro-Hungarian Empire, he used both his literary talent and knowledge of Czech and German languages in speeches at international congresses on dams and navigation. Prof. Smrček was striving to contribute as effectively as possible to the development of his school and the Czech element in Moravia. Therefore, he became elected a deputy of the Moravian Land Diet (Parliament Assembly) and later also of the Vienna Reich Council where he collaborated, amongst others, with T. G. Masaryk. He stood up efficiently for the further extension of the Brno Technical College with mechanical, chemical, electrical, and cultural branches and carried through the chemical building on Žižkova Street. When appraising the life and work of Prof. Smrček is becoming more and more aware of the legacy of our ancestors. With humility and pride, we invite you to take a short trip through the past and present of the water research laboratories in Brno. Let us be grateful.

Keywords Laboratory of Water Management Research · Institute of Water Structures · Faculty of Civil Engineering · Brno university of Technology, Research

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J. Pařílková (✉) · Z. Zachoval
Laboratory of Water Management Research, Faculty of Civil Engineering, Institute of Water Structures, Brno University of Technology, Veveří 331/95, 602 00 Brno, Czech Republic
e-mail: parilkova.j@fce.vutbr.cz

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2.1 Past

In the present chapter, the authors attempted to acquaint the reader with the history of water management in Brno. Its theoretical foundations and organizational structure can also be found in laboratory research. Historical context is described as the establishment of the water laboratory and examples of major experimental research are presented.

2.1.1 A Brief History of Brno University of Technology with Links to the Pioneers of Water Management and Laboratory Research

In the context of historical events, the foundation of the Czech technical school was neither a sure thing nor simple [1–17]. In Europe, and therefore in Austro-Hungary as well, polytechnic schools were founded, but the Land Diet of the Margraviate of Moravia did not decide on the establishment of the Technical School in Brno until 1849. It laid down that the new institution would not have the character of a college and should be, and it was at the beginning, bilingual—Czech and German. The school commenced its activity on 14 January 1850 and kept making it better. Its significant professors included, e.g. Prof. Karel Kořistka, Prof. Florian Schindler and Prof. G. A. Marin. Act No. 92 of 4 May 1873 even promoted the school to a college of technical specialisation. Although the professional level of the school was on increase, its nationalist-conciliatory character soon disappeared. The school coped with a lack of support from the authorities, which was necessarily related to lack of financial resources. Also, the Germanisation pressures supported even by the school leaders became steadily stronger. In 1876, Czech was completely excluded from teaching. As a result, significant personalities of the school were leaving for other institutions, chiefly in Vienna, Prague, Cracow, Lyon or Salzburg. The number of students declined as well because Czech students were also leaving. The Imperial-Royal (I-R) Technical College in Brno became a German school, and the Slavonic population of the country was feeling ever more acutely that they needed their own college with the Czech teaching language. In the same period, the Olomouc University also underwent a deep crisis and ultimately ceased to exist. Many communities began to realise that a substantial gap had formed in the system of higher education and science in Moravia and they began to call for the renewal of the Moravian university, but now with its seat in Brno, in the capital of the land. It was not possible to dispute the eligibility of the Czech claim, but none of the Austrian governments wanted to antagonise German nationalists by this step. In the end, the government of Franz Anton Count Thun reached a Solomonic solution: although it did not give the university in Moravia to the Czechs, so the German nationalists did not have a cause for protests, but it submitted a proposal for the establishment of the Czech Technical College to the monarch for approval, whereby showing the goodwill of

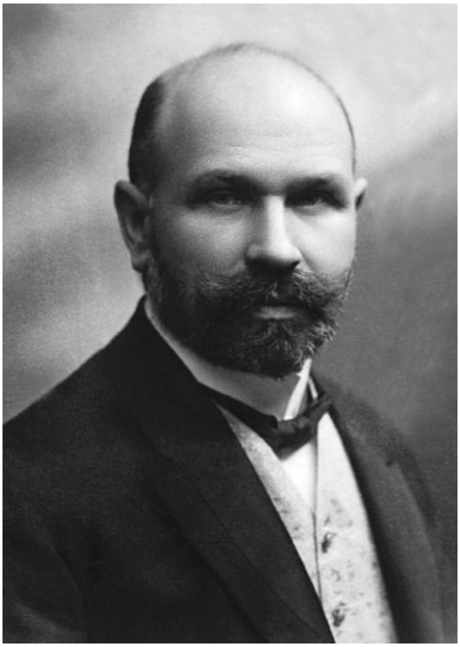


Fig. 2.1 Prof. Ing. Antonín Smrček, Dr.h

the Viennese court to the dissatisfied Czechs. The Austrian Emperor and King Franz Joseph signed the decree on the foundation of the Czech Technical College in Brno after a long hesitation on 19 September 1899. The school was established in Brno by a Supreme Decision of His Majesty Emperor and King Franz Joseph. At the same time, its first four professors were appointed, namely Karel Zahradník, Jan Sobotka, Jaroslav Jiljí Jahn and Hanuš Schweiger. Dr. Karel Zahradník, full professor of mathematics, became its first rector. On 1 November 1899, teaching in the field of civil engineering was commenced. Prof. Jan Sobotka was appointed the first dean of this field (Fig. 2.1).

At this time, Ing. Antonín Smrček satisfied the calls of friends and some of the Moravian Land and Reich deputies and on 22 April 1902, he submitted his application for a professorship (earlier he rejected the offer to apply for the professorship of water structures at the Vienna Technical College) to the Czech Technical College in Brno [2]. Because this professorship was paid by the Moravian Land, the affirmative proposal of the professor staff had to be first approved by the Moravian Land Diet. Subsequently, he was appointed a full professor at the Czech Technical College in Brno by a decree of the Ministry of Cult (Religious Affairs) and Education in Vienna, dated 31 October 1902. Although Prof. Smrček immediately commenced his pedagogical activity, he still had a large obligation to his former employer in the company Lanna in Prague, where he worked from August 1888. The company Lanna had a long tradition in the field of railway and mainly water structures (later it merged with the Hamburg company Vering, which provided particularly construction machinery) and was almost unrivalled in this field in the whole Austria. There, he had to conduct work commenced on the Rivers Vltava and Labe at the express order of the governor still one whole year before his successor was found and trained.

Prof. Smrček began to build the Institute of Hydraulic Engineering in provisional rooms, without aids, dedicating many of his own books and plans to begin with. He compiled lectures on foundation engineering, river regulation, water supply, structures of waterways, weirs and dams, and water power use from his theoretical knowledge and practical experience, which he steadily supplemented and corrected in the spirit of the world development of civil engineering. He required in practical exercises that the students had proved that they understood his lectures and knew how to apply the knowledge obtained. He considered scientific excursions to domestic as well as foreign constructions as an integral part of teaching (with his students he visited constructions in Germany, France, Italy, Poland, Yugoslavia, Belgium and The Netherlands [2]). The students thus were acquainted not only with various methods of construction work but also with the fact of how the construction had proved itself in practice.

Prof. Smrček, besides his work at the school, was steadily in contact with practice as a consultant and expert, participated in congresses, published profusely in journals and newspapers, wrote books, was a member of various commissions, and acquainted the public with technical progress and social needs at his lectures. Later, as a deputy, he pushed for adding other fields to the Czech Technical College (agricultural, electrical engineering, chemical, architecture, and general) and for the immediate commencement of construction of school buildings approved as early as 1905, even despite the opposition of the Brno Germans dominating the city hall. On 18 July 1907, at the Minister of Finances Korytowski, he put through the signing of the deed of ordering the construction of the Czech Technical College buildings in Brno. The new buildings on the plot called ‘At the Wonderful Vista’, behind the boundary of the then city where Veveří Street ended, were beautiful, practical and comfortable (Fig. 2.2). They are still pride of Brno University of Technology. The new building on Veveří Street was opened on 25 June 1911. Still, at the time when the construction was nearing its completion, the Brno professors asked the ruler that the school could bear his name. The emperor graciously consented, and the educational institution with a short tradition but with all the more ambitions could be called the ‘R-I Technical College of Franz Joseph’ from 1 May 1911 and it operated under this name until the breakdown of the monarchy in 1918.

However, even such a declaratively shown ruler’s favour did not help the Czech Technical College in Brno to exist as a full school capable of offering education in all technical fields. Before World War I, its students could study only:

I. Civil engineering;
II. A. Mechanical engineering, B. Electrical engineering;
III. Cultural engineering (water structures, amelioration); or
IV. Chemical engineering.

For the school year 1913–1914, Prof. Smrček was elected rector. It has been done after a strong intervention of the Minister of Public Works, Ing. V. Trnka, on the

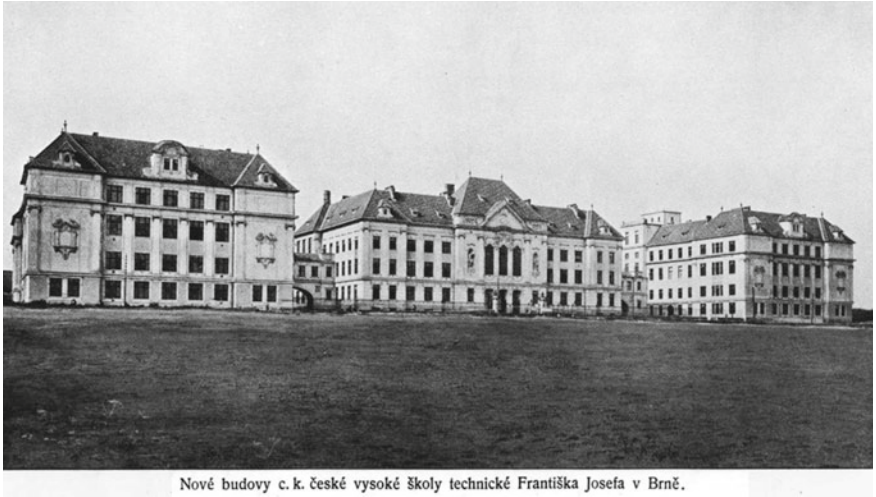


Fig. 2.2 New buildings of the I-R Czech Technical College of Franz Joseph in Brno

base a file entitled 'the rector averted a corruptive ordering of the construction of the chemical pavilion of the Czech Technical College to a German company'. During his rector's period, the construction of a chemical pavilion was commenced. At this time, Prof. Smrček also accomplished the approval of the construction of a water laboratory, for which he was striving since his professorship as early as 1903. He infallibly knew from his rich practical experience how difficult it was to dimension various objects of hydraulic constructions and design their shape correctly.

From the beginning, he conceived the laboratory for scientific work and for 'upbringing and lesson learning' of students. However, he long faced misunderstanding of his superior authorities. Some officials considered the laboratory as useless playing, but probably the main reason was the fact that neither the technical school in Vienna nor the German technical schools in Prague and in Brno had any such workplaces. But Prof. Smrček did not give up, and in the corridor of his institution, he sets up a provisional hydraulic flume 2.5-m long, 0.75-m wide and 0.15-m deep. He brought water from the water mains and collected it to a vessel at the end of the flume. There, he demonstrated to students, to a limited extent on small models, the effects of flowing water on the bottom, banks, and objects placed in the flume. However, he did not give up the ideas of his dreamt-up laboratory. He consulted the design of the laboratory with Prof. Engels from Dresden or with Prof. Rehbock from Karlsruhe and worked on preparations for its establishment. In 1906, he succeeded, on the basis of expertise on the unsuitability of an intended route of a ship canal far from towns and industrial conurbations, in obtaining money saved in the Ministry of Finances. As a Reich deputy in Vienna, holding this post in 1907–1912, and a member of an independent club of deputies, chaired by Prof. Masaryk, he turned to the Minister of Cult and Education, Count Stűrgkh, and on 15 February 1912, he reached approval under ref. no. 55997-II of at least minimum financial resources for the construction of the laboratory.

2.1.2 Historical Description of the Laboratory—Ground Plan, Pumping Circuits, Storage Tanks and Flumes

The rooms for the construction of a water management laboratory of the new technical college on Veveří Street were delineated in the basement of Building B. These were rooms of 19.58 m × 8.23 m and 9.02 m × 7.68 m, separated by a bearing wall 1.50-m thick. Their clear height was only 3.15 m [3–6]. In terms of space and practicality of use, the specification was not simple, and the necessary equipment was successfully placed into the rooms only in the twelfth proposed scenario—two flumes with glass walls and a river flume having a measuring space of 20.0 m × 3.5 m (Figs. 2.3, 2.4, 2.5, 2.6 and 2.7).

Both the rooms were connected with a 4-m-large clear opening in the bearing wall. The clear height was increased by deepening by 2.5 m, which enabled a two-floor arrangement. However, it was necessary to underpin the undermined foundations of the building, to relay distributions of heat, water, and electricity, etc. Only very little confined space was left for other operational rooms—a joinery workshop, a locksmith workshop, stores and an office.

Construction work began on 4 May 1914 and should have been finished by the end of that year. All plans, however, were interrupted by World War I. A number of professors (e.g. Ing. Karel Kostka) and students received call-up papers, the staff, and the workers carrying out the construction were dismissed by mobilisation. A military hospital was established in the rooms of the school building, originally for 700, later up to 1000 wounded. Material for the construction work was unavailable. Prof. Smrček was even denounced that despite the general order he continued in construction. Despite all obstacles, the work was successfully carried out, so the first experiments could be commenced early in 1917. He tested seepage of water through the soil of an embankment in a glass flume, naturally still without water circulation. The assembly of pumps, pipe systems and metal equipment of the laboratory was completed in 1919 (Fig. 2.8), and subsequently experiments with flowing water could be commenced.

2.1.3 Major Research Carried Out After the Laboratory Is Put into Operation (Earth-Fill Dams, Hydraulic Energy Dissipation, Weirs and Flood-Proofing Experiments)

The professional activity in the laboratory proceeded from the work of Prof. Smrček and was therefore very broad from the beginnings. In addition to water structures,

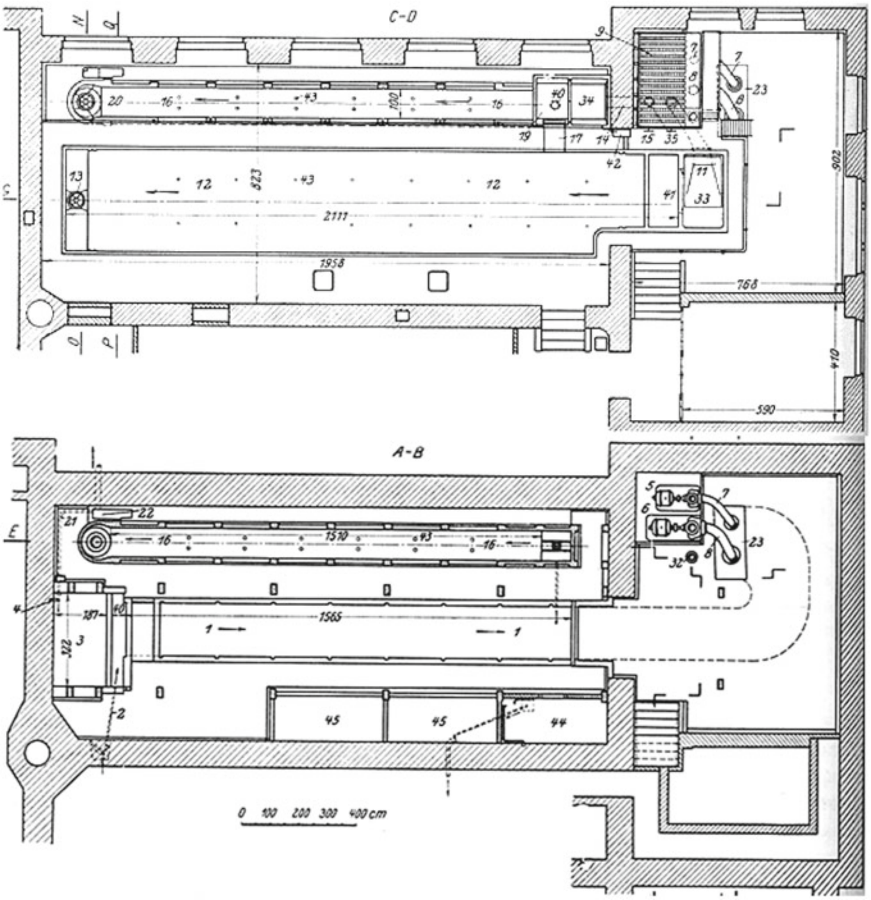


Fig. 2.3 General arrangement of the water laboratory [4]

Prof. Smrček participated in bridge constructions (reconstruction of Charles Bridge in Prague after flood in 1890, construction of a provisional railway bridge over the River Vltava in Prague—Trója), transport constructions (roads in Prague, Roztoky and Klecany), modifications of machinery (design of a steam circular saw for cutting sheet piles underwater) and other. Of a large number of water management works in the construction of which he took part, it is necessary to mention particularly the construction of a Labe-Vltava waterway. He prepared a project of canalisation of the Rivers Labe and Vltava all the way to Prague and significantly participated in carrying out the individual sluices and ports. As already given in the design activity, he continued with work also after his arrival in the college. He prepared a number of scenarios and details of the waterway Danube-Odra, designed a regulation of the River Danube in the Iron Gates, designed a waterway using the Rivers Vltava and Berounka through Pilsen to Regensburg on the Danube, prepared a design of

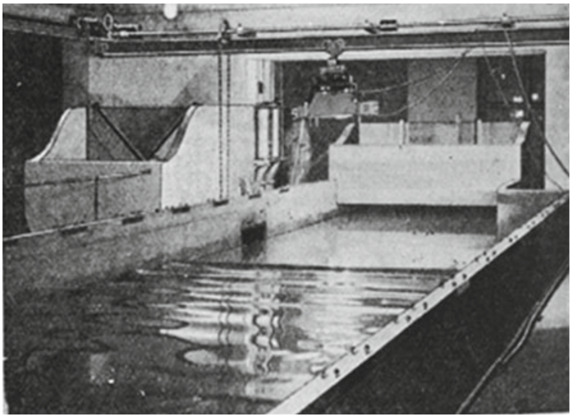


Fig. 2.4 River flume with a Poncelet measuring weir [4]

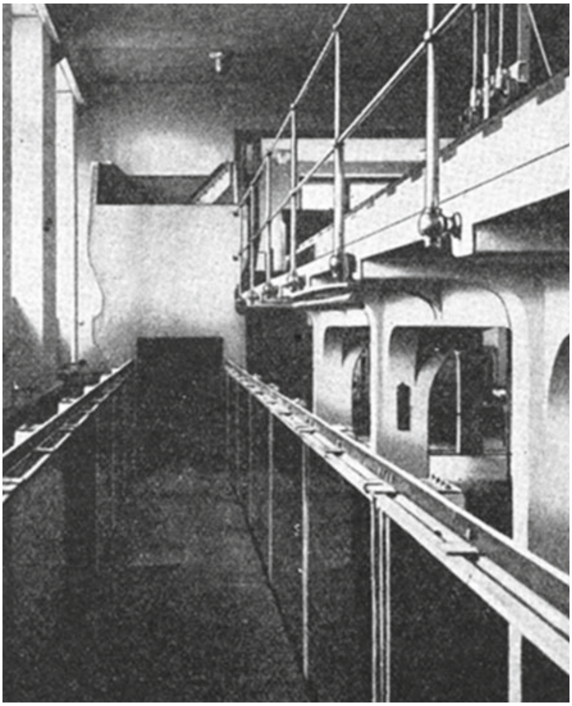


Fig. 2.5 View of a hydraulic flume with glass walls, concrete posts, and a track [4]

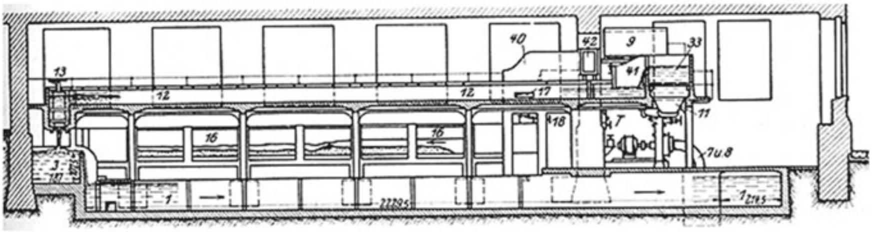


Fig. 2.6 Design of centrifugal pumps, pipes with regulating elements, a sand trap and a recirculation channel [4]

Fig. 2.7 View of a return channel partly covered with planking, a sand trap and a spillway are at the back to drain water into a storage tank, a part of a glass flume is on the right [4]

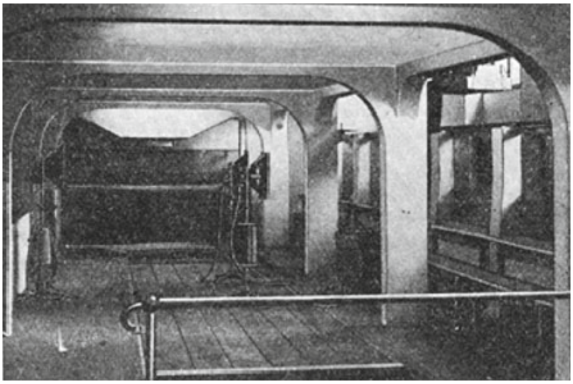
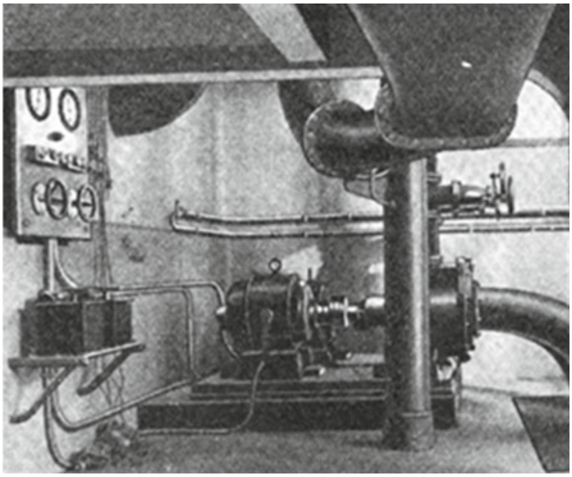
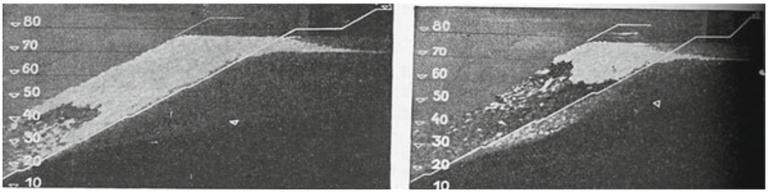
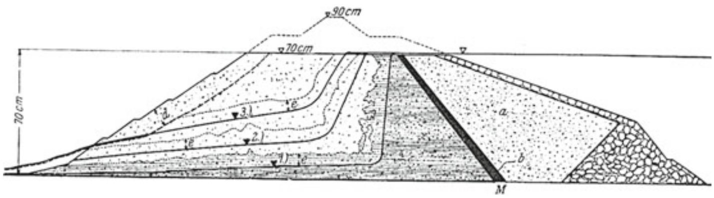


Fig. 2.8 A greater pump unit has a capacity of 150 l/s at 580 r.p.m., and develops 18.5 hp.; a smaller pump unit has a capacity of 100 /s at 720 r.p.m., and develops 13.0 hp. The inside diameters of the suction and discharge pipes are 300 mm and 250 mm, respectively [4]

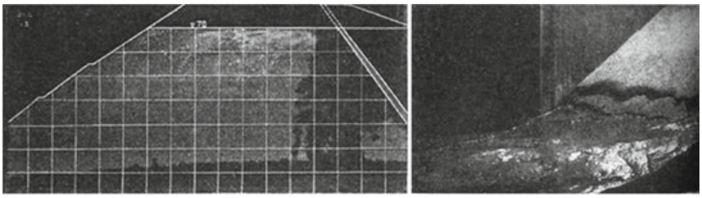




Water flowing through specific soil materials is recognisable by its dark colour. The effluent seepage area of the downstream slope begins to appear (left), under increased flow the seepage face of the slope becomes more extensive (right) – from a model of dam Štěchovice dam.



Model of a dam built of a coarse sand mixture – water flowing over the core wall M penetrates into the body of the embankment and saturates it up to the full lines 1, 2 and 3, above which the dotted lines indicate the corresponding limits of capillary moisture. When h reaches 0.86 cm and q = 1.15 l/s, seepage becomes serious, followed by rupturing the dam.

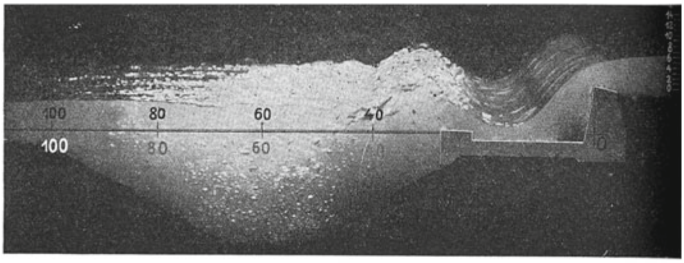


Model of a dam built of fine sand – water infiltration over the top of the core wall and the dam erodes slowly on the downstream side at the foot of the slope.

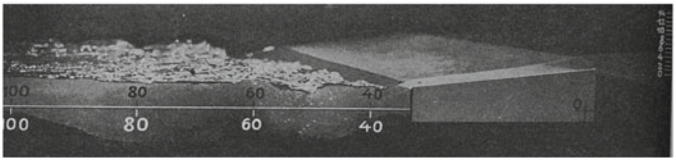
Fig. 2.9 Examples of accomplished experiments related to the matter of safety of earth-fill dams [4]

improvement of navigation conditions on the Danube from Bratislava to Genüye and many other water management plans.

Therefore, the experiments carried out in the laboratory were also focused on practical questions of hydraulic features. For example, the already mentioned tests of seepage monitored the issue of safety of earth-fill dams in conjunction with breach of the earth-fill dam of a reservoir on the River Bílá Desná in the Jizera Mountains on 8 September 1916. Other experiments were also focused similarly, carried out in a 1-m-wide glass hydraulic flume of the laboratory. These were, e.g. models of the embankment dam by Štěchovice (Fig. 2.9) or the reservoir dams on the River Váh by Ladce, where great attention was also placed on the composition of the earth material used.



The effect of water falling over a weir on the unprotected stream bed immediately below the apron [4].



Model of an old weir on the Vltava River – in the river bed a turbulent readjustment of sand particles is in progress [4].

Fig. 2.10 Examples of a study of water flowing over fixed weir constructions and dissipation of energy in the stream

Another important field which Prof. Smrček paid his attention to experimented with different types of weirs, mainly fixed ones, where he studied the effect of their shape on the formation of scour below them (Fig. 2.10). These experiments were the first of their kind and proceeded from cooperation with Prof. Rehbock.

Prof. Smrček gave lectures on the achieved results at navigation congresses, seminars organised for the expert and lay public and published them abundantly, whereby bringing about a great interest of professional circles not only in Europe but also in the USA and Japan. Popularity and recognition of the Brno 'Smrček's laboratory' had an essential effect on the dissemination of knowledge on hydrotechnical research and its significance. Very close colleagues of Prof. Smrček were Ing. Dr. techn. Karel Kostka, who under his guidance became a hydraulics expert and later a hydraulics professor at the Brno Technical College, where he worked until 1945, and Ing. František Okáč (Fig. 2.11), who completed work to build the water laboratory. At the Technical College in Brno and in the laboratory, other outstanding personalities in the field of hydraulics studied and practised, such as Ing. Goljevšček from Ljubljana, founder, and head of the water laboratory there. Ing. J. Klečka working in the USA in 1929 wrote to Prof. Smrček, on the occasion of his seventieth birthday, a greeting in which he stated how gladly and with pride the Czech engineers in America remembered him because his name and recommendation inspired respect and recognition of the Czech engineer and the Czech Technical College and opened the door in the international arena. In 1939, Prof. Ing. Dr. Karel Kostka recollected the lectures of Prof. Smrček [2], in which he combined theory with the projects on which he worked, interpreted water management structures built at home (Figs. 2.12 and 2.13) as well

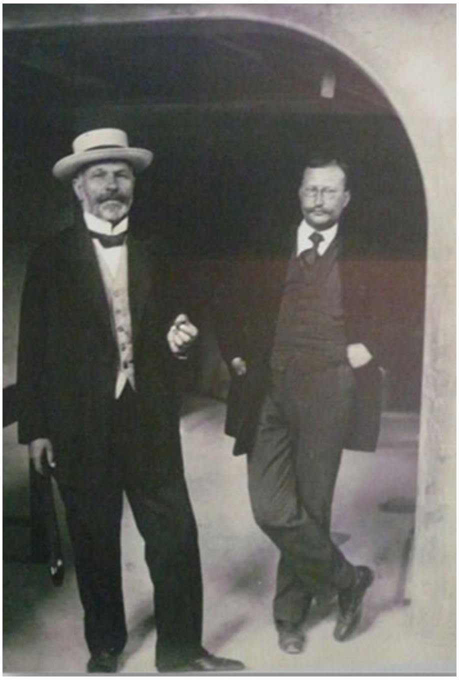


Fig. 2.11 Prof. Antonín Smrček and Ing. František Okáč in the laboratory on Veveří Street in Brno [9]

as abroad and drew attention to difficulties or mistakes which had accompanied them or had been made. 'Just from mistakes young engineers will learn most', he used to say, 'and it is a pity that they try to conceal them, because the same mistake can be made out of ignorance on another work.' [2]. Prof. Kostka worked with Prof. Smrček until 1932, when Prof. Smrček retired, and he states, '… I know that the laboratory was his love and pride. He could really be proud because his laboratory was amongst the first ones and ranked one of the best institutes of its kind. No wonder that it was a destination for professionals indeed from the whole globe, who found there not only many lessons, but also an example for the construction of their own laboratories.' [2].

In the period of World War II, the Czech universities and colleges were closed down and occupied by the SS units [1, 5, 6, 15]. The same fate also befell the Czech Technical College in Brno. Work in 'Smrček's laboratory', however, was not terminated.

After liberation in 1945, the school was renewed under the name The Technical College of Dr. Edvard Beneš in Brno, and the activity of the Institute of Hydraulic Engineering continued. In 1951, the Technical College in Brno was taken over by the Military Technical Academy, but with the exception of the Laboratory of Water Structures. On 24 July 1956, Brno University of Technology (BUT) was established,

Fig. 2.12 Prof. Antonín Smrček on the site of the Vranov dam—20. 8. 1927 (left) and on the site of the Kníničky dam–1940 (right) (Photographs from a family collection)

Fig. 2.13 Weir and the small hydroelectric power plant Štětí (a prototype, a physical model and a numerical model)

with three faculties: Faculty of Construction Engineering, Faculty of Architecture and Civil Engineering, and Faculty of Power Engineering. In 1960, both the construction faculties merged within BUT into the Faculty of Civil Engineering. The Faculty of Architecture as an independent faculty of BUT was then founded in 1976. From 1951 to 1992, the teaching of civil engineering took place in many buildings located all over the whole City of Brno, e.g. on Barvič, Veslařská, Gorký and Jaselská Streets and in Sady osvobození (now Koliště). In 1991, an agreement was signed between the rector of BUT and the rector of the Military Academy in Brno on the return of historical buildings on Veveří and Žižkova Streets back to BUT. In 1992, these premises were allocated to the Faculty of Civil Engineering, which thus returned to its original buildings, in which the history of BUT and of the Faculty of Civil Engineering began. The whole premises were given back in a very dilapidated condition and required extensive reconstruction and repairs. The Laboratory of Water Structures served until 1997 in the form of the original design, without significant construction modifications. In 1997–2000, within the construction modifications of the school buildings, it was reconstructed, but without its technical equipment, and in 2000, it was renamed to the Laboratory of Water Management Research (LWMR). In 2008, the pumping station was reconstructed. In 2017, 100 years have passed since the first experiment was carried out in ‘Smrček’s laboratory’ [16].

2.2 Present

The following chapter presents teaching and education at BUT and FCE at present. Attention is primarily focused on the developments and changes that took place in the water management research laboratory. Briefly is shown its research orientation, collaboration with practitioners, including the international aspects.

2.2.1 The Present of Brno University of Technology, Faculty of Civil Engineering and Institute of Water Structures

At the present time, BUT is formed by eight faculties which are the Faculty of Civil Engineering (FCE), the Faculty of Mechanical Engineering, the Faculty of Architecture, the Faculty of Electrical Engineering and Communication, the Faculty of Information Technology, the Faculty of Business and Management, the Faculty of Chemistry, and the Faculty of Fine Arts. In 2016, 21,235 students studied at BUT, of whom 6009 were women and 4456 foreigners [18].

The FCE is still the largest faculty of BUT with the highest number of students. It provides university education in the following study programmes:

- Bachelor (3- and 4-year, Bc. degree);
- Master (1.5- or 2-year, Ing. or Ing. arch. degrees); and
- Doctoral (3- and 4-year, Ph.D. degree); in the form of full-time or combined study.

In the academic year 2015–2016, 5465 students were enrolled in the bachelor and master study programmes. The number of students enrolled in doctoral study programmes was 445 as at 31 August 2016 [19]. The basic methods of teaching constitute lectures, seminars, studios, projects, exercises, consultations, traineeships, excursions and independent student work. Within international exchange programmes, a part of the study can be completed at some of the partner foreign universities. The BUT, of which the FCE is a part, obtained prestige ECTS Label and DS Label certificates of the European Commission for a period of 2013–2016 as the appreciation of the quality of the university institution. The ECTS Label certificate has been awarded to BUT as one of two Czech universities. It is an acknowledgment for the correct implementation of the credit system in all bachelor and master programmes in a link to the implementation of the Goals of the Bologna Process. The DS Label certificate has been awarded to BUT as an acknowledgment for the correct and free provision of diploma supplements to all graduates. The certificates attest that BUT meets the demanding criteria of the European Union in the area of university education. Both the certificates largely contribute to the extension of mobility and thus also to the internationalisation of the university.

At the FCE, there are 22 institutes now, 3 of which being specialised in water management issues, a library centre and a centre of AdMaS (Advanced Materials, Structures and Technologies), which is a modern centre of science and a comprehensive research institution in the area of construction, transport systems and the infrastructure of towns and municipalities, concentrating on the research, development and application of advanced construction materials, structures and technologies.

The LWMR is an organic part of the Institute of Water Structures (IWS), the professional specialisations of which [20] are hydromechanics, hydrotechnics and hydroelectricity. It studies objects of dams, weirs, sluices, intakes, hydroelectric power plants, stream beds, waterways, flood protection, pipe networks, valves, etc. Flow and interaction with objects is described using both mathematical (mainly numerical) models with simulation of flow of surface water and subsurface water in the pressure regime, or with free water surface as well, with transport of substances, and the effects on constructions and the environment, and physical models which dominated in the LWMR.

The specialisation of the LWMR dynamically follows the legacy of the works by Prof. Smrček in the area of physical modelling, but with respecting the current development of science and technology, with the use of tools of numerical modelling as well. It is particularly reflected in the following areas [20, 21]:

- Laboratory model research of weirs, dams, hydroelectric power plants (Fig. 2.13), navigation facilities, water courses, objects on sewerage networks, fixed and movable damming-up structures, inlets and outlets of hydraulic works, sediment regime in rivers and stability of stream beds, elements of hydraulic pressure circuits, etc.;
- Measurement of flow parameters (velocities, pressures, flow rates) on models and works; and
- Calibration of gauges of velocity and flow rate.

2.2.2 Teaching and Education (Kindergartens, Primary and Secondary Schools, Domestic and Foreign Universities, Universities of the Third Age, etc.)

The IWS provides teaching in bachelor, master and doctoral study programmes. In the academic year 2015–2016, 625 students were enrolled in the full-time form of bachelor study programme Civil Engineering. 47 students decided for the field of study Water Management and Water Structures (W) and were enrolled in the follow-up master study programme and 7 students in the doctoral study programme. One student was enrolled in the combined form of doctoral study.

The IWS, including the laboratory, organises educational courses within lifelong learning universities of third age and is also actively engaged in the pilot project BUT JUNIOR, in which BUT will prepare an interesting programme in the form of educational entertainment for elementary school pupils aged 12–16 at an appropriate faculty or in the university centre always on one Saturday in a month. Young scientists under the guidance of BUT pedagogues investigate in it the areas of architecture, construction, chemistry, electrotechnical engineering or intelligent technologies.

Fig. 2.14 Children from a kindergarten are watching the flow of water in laboratory flumes

The main activity of the LWMR, equally as in the time of Prof. Smrček's work, remains education of students of the field of study W during practical exercises. But, just as before, so today as well, the rooms of the laboratory are open to both the expert public and the lay public. Children from kindergartens go to play in the laboratory rooms (Fig. 2.14); various excursions, which are usually thematically specialised, are organised for students of elementary and secondary schools. The laboratory is used by students of other domestic and foreign colleges and universities, the professional specialisation of which is in some cases fairly far from the specialisation of the laboratory. For employees of enterprises from the area of water management, professional seminars or courses are organised, focused on increasing their expert qualification. Open Doors Days or the Nights of Scientists are very popular amongst the public when the laboratory is open practically to everyone.

2.2.3 The Present of the Laboratory of Water Management Research—Laboratories, Pumping Circuits, Instrumentation and Employees

'Smrček's laboratory' placed in Building B has preserved its building character until the present time. In all, it is divided into three laboratory rooms, administration and workshop facilities, and it also includes one auditorium for 26 students. Two-floor design of original laboratory spaces, two original non-tilting flumes with glass walls and a river flume are still fully functional. The original pumping station comprised two axial pumps with an input of 20 and 15 kW, respectively [2], and a cast iron pipe system. In conjunction with the addressed tasks, other pumps with lower inputs, in addition to the primary pumps, have been installed to the system over time. In conjunction with technology development and in relation to the growing demands for savings of electric power, the pumping station was innovated in 2008 [22]. The basic requirements were the possibility of regulating flow rates in the existing flumes with time in a range of tenths of a litre per second, including one output for placing

Fig. 2.15 Original pumping station (left) and pumping station innovated in 2008 (right)

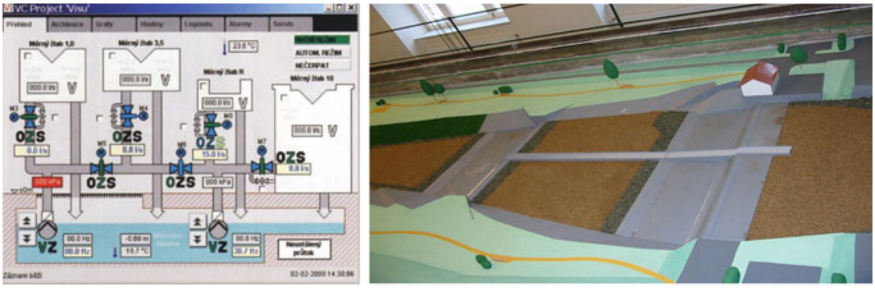


Fig. 2.16 Visualisation of an innovated hydraulic circuit (left), a model of the Hrabovský weir on the River Ostravice with a scenario of a solution of a fish ladder, at a length scale of 1:50 (right)

models in open space in the basement part of the laboratory, and the possibility of the current operation of two flumes.

The demanding requirements were solved by two identical pumps with an input of 2 kW × 9.5 kW, whereby achieving a substantial saving of electric power. The advantage of the innovated pumping system (Fig. 2.15) is the possibility of its automatic operation controlled through a touch screen (Fig. 2.16), or through any computer connected to the control unit of the pumps. For safety and operational reasons, it is possible to control the operation manually. The characteristic parameters of the hydraulic circuit are given in Table 2.1.

In 1943, a second laboratory room was built from the originally open atrium of Building B—a teaching laboratory that chiefly serves for teaching. It has a storage tank with a volume of about 35 m^3 of water. During and after its reconstruction in 1997–2000, it was gradually equipped with a pumping system with four submersible pumps ensuring the flow rate 160 l/s and less, a control system with a touch screen, two tilting flumes 1.0-m and 0.5-m wide, respectively, with glass walls, and one fixed flume 1.0-m wide with 1.5-m-high walls of organic glass with a connecting settling area of particles. The structure of the flumes is made of steel (Fig. 2.17).

Table 2.1 Characteristics of the hydraulic circuit [22]

Channel	Width (m)	Effective length* (m)	Max. flow rate (l/s)	Type of flume
Flume	3.5	18	160	Fixed, non-transparent walls, concrete construction
Flume	1.0	12	160	Fixed, glass walls, concrete construction
Flume	1.0	5	100	Fixed, glass walls, steel construction
Reserve	Max. 2.5	Max. 15	190	–

**Legend* The length to be used for carrying out research activities does not include the length for the primary settling of the inflowing current and the length of the drainage part of the flume

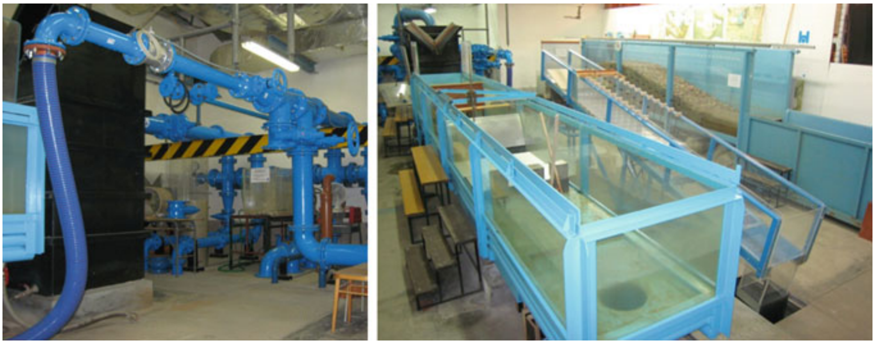


Fig. 2.17 Pumping system and flumes in the teaching laboratory

Other essential parts of the teaching laboratory are models serving for the practical teaching of students and demonstration models.

Since 2000, the LWMR has been extended by a third laboratory room in Building B, which is equipped with technology for aerodynamic modelling. It is possible to use one aerodynamic tunnel for the experiment, in which air velocities of up to 50 m/s can be used under conditions of self-model similarity, as well as an aerodynamic track with the measuring space 0.4 m × 0.4 m and the maximum achievable velocity 40 m/s. Also, a hydraulic circuit is placed there, with a range of flow rates of up to 120 l/s and a storage tank with a volume of 1.5 m^3, with water enriched with polyamide particles for the use of optical methods of velocity measurement (methods of laser and ultrasonic anemometry). Measurement is carried out in hydraulic flumes made of organic glass constructed for the current demands of research. The results obtained from measurement are used for the calibration and validation of numerical models (Fig. 2.18), or for the description of specific structures of flow.

With the advance of reconstruction work on the buildings returned to the Faculty of Civil Engineering, a new laboratory was built in Building F during the year 2003

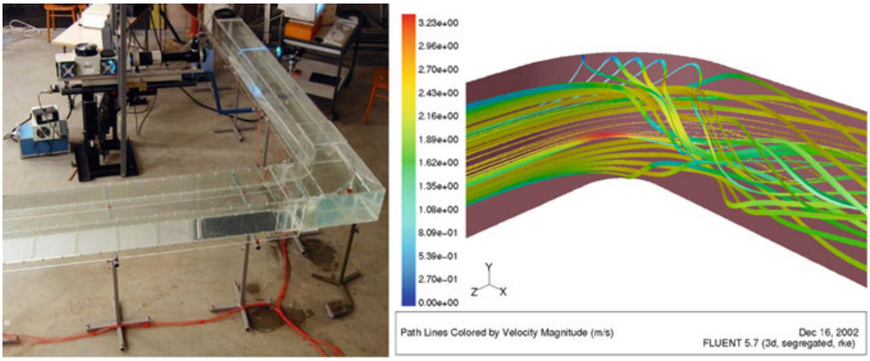


Fig. 2.18 Measurement of the structures of flow using laser technology for the validation of a numerical model

Fig. 2.19 Hydrotechnical laboratory in Building F of the premises of the Faculty of Civil Engineering (left: the original building, right: the new laboratory)

(Fig. 2.19), which has replaced the closed-down laboratory rooms below the Brno dam at Kníničky. Two tilting glass flumes of steel structure, one 0.4 m and the other 2.4-m wide, have been moved from the original rooms to Building F.

The laboratory in Building F has an independent hydraulic circuit fed from a tank of a volume of 80 m^3. Its total capacity 220 l/s is governed by four pumps, with the regulation and stability of flow rate being controlled by a single or double regulation (a frequency converter, a long overflow crest). The operation of the laboratory is controlled by a central computer (Fig. 2.20). All handling of the hydraulic system is carried out using servomotors.

By making the pumping system operational in the rooms of Building F, the possibility of constructing hydrotechnical models also in the outdoor areas close to the building has increased (Fig. 2.19).

In 2008, a laboratory in Building F was supplemented by an independent automated hydraulic circuit for groundwater flow research (Fig. 2.21). The range of utilisable flow rate is 3.3 l/s, the pressure head is up to 60 m and the storage capacity of water is 0.15 m^3.

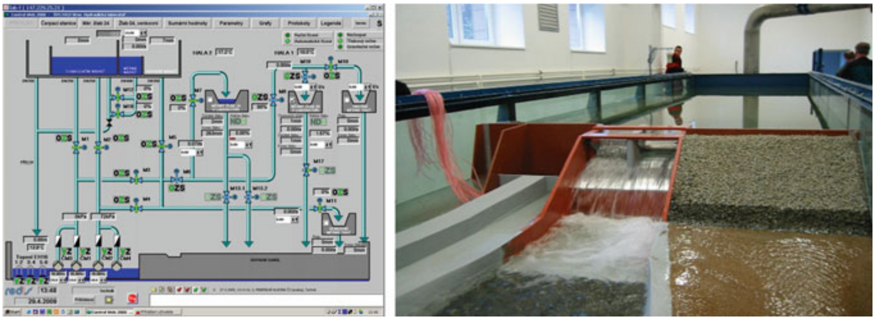


Fig. 2.20 Control of a hydraulic circuit, a model of the Znojmo dam and water reservoir

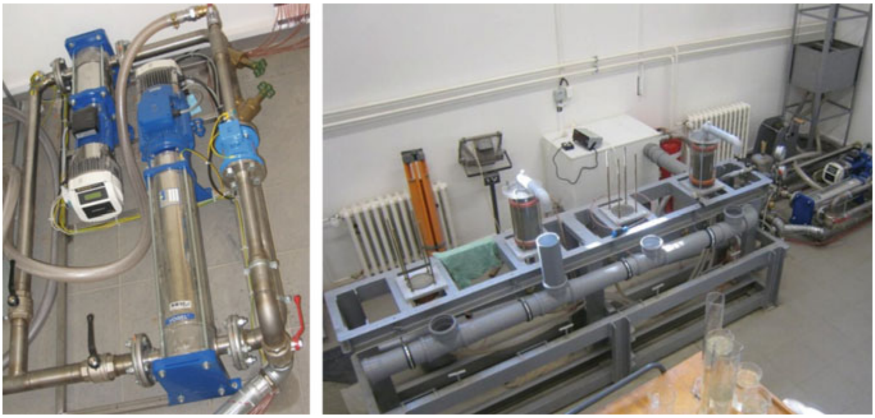


Fig. 2.21 Hydraulic circuit and a 'groundwater' station

In the LWMR, the following measuring and evaluating technology is currently used:

- Measurement of flow velocity: a current metre, pressure probes, constant temperature anemometry, thermistor probes, laser Doppler anemometry, ultrasonic or induction anemometers, ultrasonic velocity profiling, particle image velocimetry (PIV);
- Measurement of hydrodynamic pressure: multi-hole pressure probes, pressure sensors for pressures from units of millimetres to tens of metres of the water column, ultrasonic contactless or pressure contact probes for measuring flow depth;
- Measurement of forces and moments using sensors working with frequencies of the order of tens of hertz or using multicomponent scales for monitoring self-excited oscillations (applied particularly to aerodynamic tracks);
- Measurement of temperature fields using thermistors (Fig. 2.22); and
- Measurement of the electrical impedance (EIS) of a porous medium (Fig. 2.22).

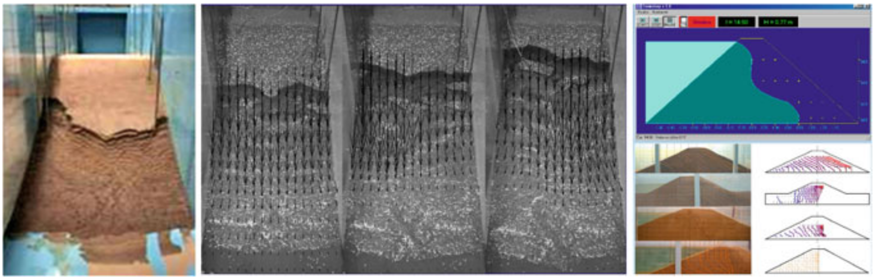


Fig. 2.22 Monitoring of the process of formation of a seepage face in laboratory conditions using the EIS method, the PIV method and the temperature field method

2.2.4 Science and Research (Experimental Research and Numerical Modelling, Including Student Work), Examples of Results and Implementations

In the area of science and research, the LWMR as a part of the IWS carries out basic and applied research. It assesses technical standards, articles, methodologies and calculation procedures. It provides advisory and consulting activity during design, administration and repairs of water management objects, carries out supervisions, risk analyses, professional translations, and expertises.

The researchers of the LWMR are specialising in precise measurements of flow characteristics, develop new gauges for them, measuring methods or procedures. They have received authorisation from the Czech Office for Standards, Metrology, and Testing, which authorises them to carry out official measurement of the flow of liquids, to check and calibrate velocity and flow rate gauges, to monitor flow and the behaviour of objects in field conditions. They are also concerned with investigation, verification, and correction of designs of objects using physical and numerical models. These activities are carried out through projects of basic and applied research, submitted to various agencies (e.g. Grant Agency of the Czech Republic (CR), Technology Agency of the CR), Ministries of the CR (e.g. the Ministry of Industry and Trade, the Ministry of Education, Youth and Sports, the Ministry of Agriculture, the Ministry of the Environment) and domestic as well as foreign programmes, or follow up or address current practical issues.

The results of the activities mentioned above are reflected in study supports, lecture notes or books and manuals intended not only for students but also for the public. They are presented in the form of articles in journals, papers at domestic and international conferences. An important part of the results includes certified methodologies, maps, software, prototypes and functional specimens, pilot plants and patents.

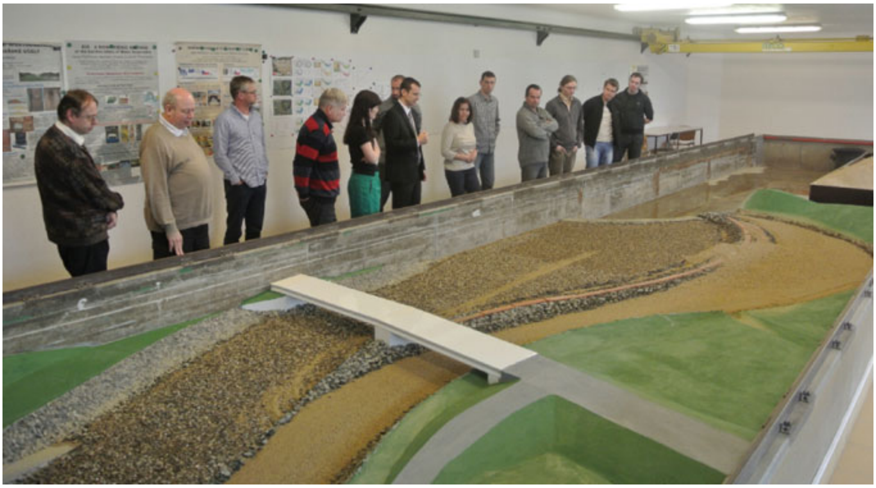


Fig. 2.23 Presentation of the process of sediment transport (a section of the River Opava, at a scale of 1:30) to the representatives of Povodí Odry, s.p. (a state-owned enterprise) and AQUATIS, a.s

2.2.5 Collaboration with Practitioners

The LWMR has the technological equipment, measuring and evaluating technology and staffing that can be ranked amongst the world leaders. Perhaps this is also the reason why state-owned enterprises, which particularly include river basin agencies, universities, state-owned organisations and domestic and foreign private companies, turn to it with the current issues addressed in practice (Figs. 2.22 and 2.23). Consulting, research and development activity and cooperation go far beyond the border of the Czech Republic, and so fulfil the legacy of Prof. Smrček (Fig. 2.24).

2.3 Future

Currently, young talented students and scientists are in the Czech Republic. Students of the BUT with their great ideas win at various international Olympiads and competitions. That is why, the university and its faculties have achieved significant international recognition.

Science and innovation have great growth potential in the Czech Republic, and the situation is improving overall. Nevertheless, it is possible to say that Czech universities lack money. It also needs to develop its legal stability and predictability. Students, young and emerging scientists need more access to the project's agenda. Requests for grants and reporting of results are currently too complex. The scientist is hardly looking for time to work without distraction and to concentrate deeply. And without intensive work, top scientific results will not come out. Although, given

Fig. 2.24 Installation of EIS probes into the earth-fill dam of the Karolinka water reservoir jointly with the representatives of the company GEO*test*, a.s

the European Structural and Cohesion Funds, Czech scientists often have the best equipment and good working conditions.

But more and more demands are being placed on pedagogical-scientific workers. They should have excellent knowledge, research, publishing, collaborating with industry, patenting, applying for grants, showing the results of grants to a number of different registers, acquiring new technological equipment and building new laboratories, travelling around the world, and internationalising their workplaces and research, all in very small teams and limited time. Bureaucracy has grown.

In the future, it is therefore desirable that the pedagogical-scientific worker did not waste time and only devoted himself to what he really knows and where is his highest added value. To maintain the potential of teaching, education, science and innovation and ensure its development in the field of water management as well.

2.4 Conclusion and Recommendations

Today, after more than 100 years since the first experiment was carried out in 'Smrček's laboratory' in Building B on Veveří Street, it is possible to keep admiring its functionality, practicality and aesthetics. In the course of time of its continuous operation, it has seen several changes that resulted from the 'ravages of time', the needs of research and teaching, new methods and gauges. The most essential changes leading to the current form of the LWMR can be considered its extension by other two laboratory rooms in Building B and the whole Building F. The replacement of laboratory equipment was carried out stepwise, particularly using its own resources, but often also with the help of those companies the employees or owners of which were former students of the field of study W. Great acknowledgement is due to them for it.

We can state with pride that a number of outstanding experts from the areas of hydrotechnics, hydromechanics, hydraulics and hydroelectricity were brought up or worked in the laboratory, being active at home and abroad. With regard to the significant development of technology in the last decades, it was necessary to increase the number of its staff also by experts from other professions (measuring technology, metrology, computer technology, etc.), without whom the operation of the laboratory would be impossible.

Judge for yourself the words of Prof. Smrček: ‘Science has not yet proceeded so far that the different, simultaneously acting effects of flowing water could be accurately expressed numerically. Therefore, wherever possible, we try to solve more complicated cases not only theoretically, but also practically, by direct observation and measurement in reality or by experiment. In such a way, we will obtain a new validation of the correctness of many old theories, valuable background information for the development of new theories and the certainty that the project will meet with success’. In the context of the current knowledge of science and technology, the words of Prof. Smrček can also be understood as a very far-sighted interconnection of current numerical modelling with physical modelling, and it is to be stated that they have been held true and will evidently hold true also far into the future.

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Part II
Surface and Ground Water Bodies

Chapter 3
Rivers in the Czech Republic

M. Rulík, L. Opatřilová, P. Jurajda, J. Špaček and V. Grulich

3.1 Introduction

Czech Republic is a small landlocked country located in Central Europe between Poland, Germany, Austria and Slovakia. The Czech landscape is exceedingly varied. *Bohemia* (*Czech*: *Čechy*), to the west, is drained by the Elbe (Czech: *Labe*) and Vltava Rivers, mostly surrounded by low mountains such as the Krkonoše range. The highest point in the country, Sněžka at 1603 m (5259 ft), is located here [1]. *Moravia* (Czech: Morava), the eastern part of the country, is also characterized by low rolling hills. This area is drained mainly by the Morava River, but it is also the headwaters of the Oder River (Czech: *Odra*) [1]. The main European watershed divide passes through the Czech Republic, splitting Czech Republic into three basic drainage areas: our rivers flow into three separate sea basins, i.e. the Black Sea (25.4% of land drainage; River Morava drainage basin), the Baltic Sea (9.4%; River Odra drainage basin) and the North Sea (65.2%; River Elbe drainage basin) (see Fig. 3.1).

M. Rulík (✉)
Department of Ecology and Environmental Sciences, Faculty of Science, Palacký University, Šlechtitelů 27, 771 46 Olomouc, Czech Republic
e-mail: martin.rulik@upol.cz

L. Opatřilová
Povodí Vltavy, State Enterprise, Praha, Czech Republic

P. Jurajda
Research Facility, Institute of Vertebrate Biology, Academy of Sciences CR, Brno, Czech Republic

J. Špaček
Povodí Labe, State Enterprise, Hradec Králové, Czech Republic

V. Grulich
Department of Botany and Zoology, Faculty of Science, Masaryk University, Brno, Czech Republic

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3.2 Biogeographic Setting

3.2.1 General Aspects

The Czech Republic is usually called the “Roof of Europe”—a watershed tripoint is located at Czech–Polish border on Mt. Klepý in Králický Sněžník Mountains. Czech rivers drain one ecoregion: Central European highlands and plains. Although most of our watercourses originate in the Czech territory, the Ohře, Dyje and Malše Rivers are significant watercourses having a larger portion of their headwaters outside the country’s borders. This results in specific hydrographic, hydrological and eco-hydrological properties of our watercourses, typical for the headwater regions. The basic hydrographic network is made up of nearly 100,000 km of watercourses with natural and modified channels.

3.2.2 Palaeo-geography

The territory of the Czech Republic is a unique area in the geological pattern of Europe. Bohemia and part of western Moravia and Silesia are a portion of the *Bohemian Massif*, one of the most significant and extensive fragments of the

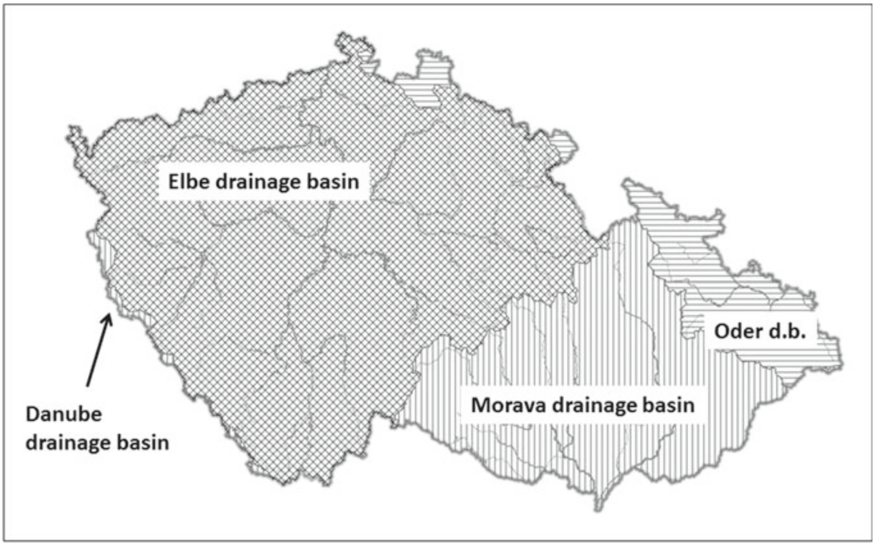

Fig. 3.1 Drainage basins of the Elbe, Morava and Oder Rivers before they leave the Czech territory. The narrow strip along the south-western border denotes some smaller tributaries of the Danube River (prepared by Marek Bednář)

Variscan orogen formed during the Devonian and the Carboniferous (over the interval c. 380–320 Ma). The eastern part of Moravia and Silesia belong to the *Western Carpathian orogen*, which is one of the subparts of the Alpine orogen—a vast mountain system of southern Europe [2].

3.3 Physiography, Climate and Land Use Patterns

3.3.1 Landform and Geology

Owing to its position in Central Europe, landscapes and landforms of the Czech Republic bear imprints of the intersection of major Eurasian geotectonic and bioclimatic domains. Here, the strongly denuded Proterozoic and Palaeozoic basement of the Variscan Bohemian Massif meets the young Cenozoic fold-and-thrust belt of the Western Carpathians. Sudetic Mountains with tundra-like landscapes and periglacial phenomena in watersheds contrast with vineyard-covered limestone hills in southern Moravia resembling the Mediterranean region. Due to complex geotectonic and geomorphological evolution, many landscapes in the Czech Republic can be classified as georegions of first-order importance. The area of Late Cretaceous transgression in the central and eastern Bohemia includes spectacular "rock cities" which are beyond doubt the most impressive in Europe and some of the largest on Earth. Some regions of the Czech Republic have received much scientific interest. For example, the loess sections of southern Moravia are among the most investigated and important natural archives of Late Quaternary climate change in Eurasia. Other examples are small young volcanoes in western Bohemia (especially Komorní hůrka/Kammerberg volcano) which were fascinating to J. W. Goethe at the beginning of the nineteenth century.

The Czech Republic is located in the contact zone of four important European geomorphological provinces—Bohemian Highlands, Central Polish Lowland, Western Carpathians and West-Pannonian Basin [3]. The Bohemian Highlands occupy 84% of the total area of the Czech Republic, and their origin is related to the Variscan orogeny at the end of the Palaeozoic era. Thereby, they represent both the largest and oldest geomorphological province of the Czech Republic containing the highest summit of the CR—Sněžka Mt (1603 m) as well as other high mountain ranges of the CR—Hrubý Jeseník Mts (Praděd Mt 1491 m), Králický Sněžník Mts (Králický Sněžník 1423 m) and Šumava Mts (Plechý Mt 1378 m). The altitude of the CR ranges from 115 m (Labe/Elbe River valley near Hřensko) up to 1602 m (Sněžka Mt in the Krkonoše Mts). The Western Carpathians (ca 9% of the CR total area) are partly composed of a system of rolling hills, highlands and uplands in the easternmost part of the republic country; and partly by a system of lowlands (the Carpathian Foredeep) in the mountain foothills. The West-Pannonian Basin occupies 6.5% of the total CR area. It represents lowland (exceptionally hilly) relief overreaching into the Czech territory from Austria and Slovakia in the form of Dolnomoravský úval and

Dyjskosvratecký úval basins. The Central Polish Lowland occupies only about 0.5% of the total state territory [4].

3.3.2 Climate

The Czech Republic has a temperate continental climate, with warm summers and cold, cloudy and snowy winters. The climate differs markedly among various regions, depending on the height above sea level. Heavy snowfall or even snowstorms are also possible on some days; the yearly average number of days with snow is less than 40 in the lowland regions and up to 120 in mountainous areas.

The location of the Czech Lands in Central Europe together with their relief and position in relation to the main pressure systems in the Atlantic-European area, influencing atmospheric circulations patterns, are the main factors determining the spatial and temporal climate variability. Temperature conditions largely reflect location and elevation above the sea level. The highest mean annual temperatures (more than 10 °C) are measured in lowlands and southern areas of the country and thus southern Moravia, Osoblažsko area and middle and lower portions of the Labe River belong to the warmest locations [5]. On the other hand, the lowest mean air temperatures are measured in mountainous regions, namely in the highest locations (less than 3 °C) of the Krušné hory Mts., Krkonoše Mts., Šumava Mts., Jizerské and Orlické hory Mts., Králický Sněžník Mts., Hrubý Jeseník Mts. and Moravskoslezské Beskydy Mts. Maximum precipitation is reached in summer at midyear with a long-term average of rainfall of 670 mm. Roughly 20% of precipitation comes in the form of snow. Generally, about 40% of precipitation falls in summer, 25% in spring, 20% in autumn and 15% in winter. Locations receiving the most rain are found in the highest elevations of the Bohemia and Moravian ranges where mean annual precipitation considerably exceeds 1200 mm (Krušné hory Mts., Šumava Mts., Jizerské hory Mts., Krkonoše Mts., Orlické hory Mts., Hrubý Jeseník Mts. and Moravskoslezské Beskydy Mts.) [5]. The lowest annual precipitation is measured in the Žatec Basin in the rainshadow of the Krušné hory Mts. Other locations with low precipitation throughout the year are southern and central Moravia (area of Moravian basins), the Polabí area and the Opava region. The Žatec region, Polabí Lowlands and southern Moravia are also characterized by the highest occurrence of dry periods as determined by precipitation deficit [5]. These discrepancies in precipitation are the main reason for the considerable differences in hydrographic characteristics of rivers and their catchments, in the regime of runoffs as well as great variability of runoff and ice phenomenon in various years.

3.3.3 Land Use Patterns

After 1989, new political and economic conditions led to changes in key land use characteristics. In this new era, sustainable utilization and landscape management emphasizing protection of landscapes for agricultural production were expected. Unfortunately, privatization of agriculture neither reduced the magnitude or intensity of land use nor did changes in land ownership enrich the biological diversity of the fields. This is the result of highly fragmented ownership patterns, among other reasons. Moreover, Czech agriculture typically has a high proportion of leased land (about 90%), which may affect farmers behaviour and their attitude towards the landscape. The rate of fragmentation of land ownership is especially important for grasslands, whereas arable lands are influenced mainly by soil conditions [6]. Landscape heterogeneity is another factor associated with providing ecosystem services, as well as enhancing cultural benefits to people. A study by Sklenička and Pixová [7] indicated that the reduction of landscape heterogeneity and changed towards a simpler land use pattern in Czech Republic has occurred over the last 150 years (1845–2000). In summary, after 1989, Czech agriculture turned to a more intensive use of fertile lands, coupled with the conversion of less fertile lands to permanent grasslands or forests. The difference in land use change at the national level between 2000 and 2010 is negligible [8].

According to the latest data, the area of arable agricultural land follows a downward trend. Grasslands, in contrast, increased in area by about 20,000 ha between 2000 and 2008 [9]. The main motivation for the development of grasslands is extending agricultural lands, agricultural land maintenance, soil conservation and water erosion prevention [8]. Agricultural land as a proportion of land area in Czech Republic fell gradually from 55.4% in 1995 to 54.6% in 2014. Arable land is represented at an above-average extent compared to other European countries. By the end of 2008, arable land covered 38% of Czech Republic [10]. Land use trends since 2000 show a slow decline in arable land area, which has been replaced by development or otherwise transformed areas (such as road infrastructure). This positive effect is clearly outweighed by the increase of artificial and developed areas, whose proportion and dynamics are key indicators of anthropogenic impacts on the landscape [10]. The area of arable land decreased mostly in the borderlands (by more than 50%). These regions of higher altitudes and cold climate are not as naturally suitable for agricultural production and therefore have been converted to grassland or forest. Grasslands increased in the area mainly on the northern and partly on the eastern borders of the country. The central area in the western part of the country—along with the central and southern area in the eastern part of the country—are the regions exhibiting the largest decrease in grasslands. These areas are agriculturally utilized by agriculture or have undergone development and urbanization [8].

Extreme fluctuations of precipitation, high temperatures, the increased duration of dry periods and the occurrence of droughts [11] are now characteristic climate conditions in the Czech Republic. Thus, our nation should focus on soil-protection measures in order to increase the water retention capacity of the landscape. Extensive water drainage affecting 25% of Czech land resources, introduced in the socialist era, is not only the cause of excessive water runoff but also significantly alters the chemical properties of soil and water [12]. Heavy machinery has caused soil compaction, and improper methods of soil management have depleted organic matter in arable soils by 50%. At present, the most serious risks include the gradual restriction of soil permeability, particularly from fragmentation by road infrastructure and fencing, and the continuing development of the landscape. The construction of highways and expressways, modification of railway corridors and new developments lead to fragmentation of the landscape and hinder its proper functioning [10].

3.3.4 Hydrography

Due to the particular climatic conditions of the Czech Republic, running water appears to be the dominant exogenous geomorphological force shaping the landscape regarding relief. The current state of drainage patterns reflects both the climatic and geological development of the area. Current drainage patterns were established at the end of the Tertiary period. During the Neogene, movements of the Earth's crust under the influence of the overturning of the Alpine–Carpathian systems took place in the Bohemian Massif, leading to changes in elevation and thus forming hydrographic networks. The rise of a mountain range on the edge of the Bohemian Massif leads to the unification of the drainage pattern into the Elbe River. However, the main integrating role in this process played out in the Vltava River. Its upstream sections, originally oriented to the south, turned near Vyšší Brod and then turned towards the South Bohemian basins. A breach of the Central Bohemian catchment divide caused by erosion led to a tributary of the Berounka River forming a new outflow from the South Bohemian basins. As a consequence, the Vltava River—formerly a tributary of the Berounka—became the larger of the two tributaries and therefore the major watercourse. During a later development, the Vltava River merged with the Elbe near the Mělník. Although the Vltava River is hydrographically more significant than the Elbe River, the watercourse downstream of the confluence has been historically called the Labe. In the quaternary, the development of the hydrographic network was accompanied not only by continuing tectonic movements but also by cyclic changes in climate. As a result of climate change, watercourse discharge, their longitudinal profile and the amount of material transported have changed. River terraces have been created in many places due to the unbalanced, active erosion–accumulation capacity of watercourses. Rivers experienced alternate periods of incision (depth erosion) and phases extending to the valley sides, accompanied by accumulation of river material and meandering (lateral erosion).

The basic hydrographic drainage pattern was formed by natural running waters and artificial waters such as drainage canals, raceways or water diversions. The distribution of drainage pattern density within the Czech Republic is variable. The average density of natural watercourses within the Czech Republic is 0.96 km.km^2; however, if only watersheds larger than 5 km^2 are included, then the density drops to around 0.47 km.km^2. The area of Středočeská tabule at the divide of the Ploučnice, Liběchovka and Pšovka Rivers, in addition to downstream sections of the Ohře and Vltava Rivers, exhibits the lowest density (less than 0.2 km^2). The highest density of watercourses (above 1.8 km.km^2) is found in mountainous headwater areas, mostly in the Moravskoslezské Beskydy, Vsetínské vrchy or Králický Sněžník and Hrubý Jeseník. Those areas are the headwaters of many important tributaries, for instance, Ostravice (Oder River basin), Vsetínská and Rožnovská Bečva (Morava River basin). The most common stream channel pattern is a dendritic drainage pattern.

From a hydromorphological point of view, two basic areas exist within Czech Republic. Watercourses of the Bohemian Massif are characterized by relatively minor transport of bed loads and stable channels, whose development is only noticeable from a long-term perspective (e.g. meandering parts of the rivers). Watercourses of the Western Carpathians are characterized by significant transport of bed loads even during normal discharge and having dynamic channel development (e.g. Bečva, Morávka, Olše and Ostravice rivers) [13]. The geological structure and morphology of the area determine the nature of the river valleys. In the mountainous regions, the deep canyon-shaped valleys are dominant with streams often having a torrent character. Lowland streams and rivers, flowing mostly through the area of hydrogeological basins, usually have flat valleys, often filled with relatively large quaternary fluvial sediments [14].

Based on hydromorphology, watercourses in the Czech Republic can be separated into nine unimpacted and two modified types [15]. The most frequent watercourse type throughout the Czech Republic is C4 (see Table 3.1) which is significantly less present in the Western Carpathians as compared to the Bohemian Highlands. Another of the frequently represented types of unimpacted streams—C2 occurs almost exclusively in the Bohemian Highlands. Some 15.5% of the total length of studied watercourses is located in the Western Carpathians. Here, the most frequent types are C1 which is represented mostly by large lowland rivers, and the A1 type, while type A2 are considerably more represented in the Bohemian Highlands. Compared to the Bohemian Highlands, there is a proportionally higher representation of modified channels in the Western Carpathians. On the other hand, a specific watercourse type representing streams of the planation surfaces on flat summits of the Czech mountains (Krušné hory, Šumava, Novohradské hory, Slavkovský les, Českomoravská vrchovina) is absent in the Western Carpathians. Due to the location of Czech Republic on the main European catchment divide, sinuous to meandering watercourses in the middle altitude with considerable valley slope are the dominant type in both geomorphologic units [15].

3.3.5 Hydrological Regime

Being an inland country of Central Europe and located on the main divide of three seas with rugged orographic relief, the Czech Republic has no other source of water besides rain (some exceptions are small streams flowing into the country at border-

Table 3.1 The most frequent watercourse types in Czech Republic (after [15])

River type	Description	Frequency of occurrence in Czech Republic (%)		
		Czech Republic	Bohemian Highlands	Western Carpathians
A1	Headwaters in the middle to higher altitudes	7.1	6.7	9.2
A2	Headwater streams in the highest mountain areas	8.2	9.0	4.2
C1	Lowland sinuous to meandering watercourses with the slope of the valleys up to 0.5%	10.1	8.5	18.8
C2	Sinuous to meandering watercourses in the middle altitude with the slope of the valleys up to 0.5%	10.2	11.9	0.9
C4	Sinuous to meandering watercourse in a middle altitude with the slope of the valleys 0.5–1.8%	19.1	21.6	5.5

lands). Annually, long-term average precipitation reaches ca 54 billion m^3 of water or 685 mm (= 685 L m^{-2} $year^{-1}$) while runoff from the Czech Republic is 28.8% of the precipitation (ca 15.6 billion m^3 water) in an average year. The runoff also supplies groundwater sources (in average 1.4 billion m^3 $year^{-1}$). These balances are long-term averages and may differ among years as well as among individual catchments. For instance, annual water runoff from the Czech Republic ranges from 8 to 19 billion m^3 [16].

Particularly in lower altitudes, a significant portion of the total runoff is represented by spring snowmelt—ca 45–50%. With increasing altitude, this spring snowmelt becomes less important while a portion of summer runoff becomes more dominant in the total runoff. Average specific total runoff reaches the highest values in the summits of the bordering mountains (ca 30–40 l s^{-1} km^{-2}), while in the lowest altitudes, namely in the driest areas of South Moravia, this form of runoff sharply decreases below 1 l s^{-1} km^{-2}. The average long-term river runoff in the Czech Republic is ca 480 m^3 s^{-1}. Our largest rivers reach about 308 m^3 s^{-1} in the Elbe (state border with Germany), 150 m^3 s^{-1} at the Vltava at the confluence with Elbe, 38 $m^3 s^{-1}$ at the Ohře confluence with the Elbe, 120 $m^3 s^{-1}$ at the Morava confluence with Danube, 44 $m^3 s^{-1}$ in the Dyje and 49 $m^3 s^{-1}$ in the Odra [17].

Due to the largely effluent character of Czech watercourses, groundwater runoff is a significant part of the total runoff—approximately 43% on average. However, because a dominant portion of surface runoff in the total runoff is concentrated into the brief periods of spring snowmelt, floods and generally during higher discharge, we can claim that groundwater runoff significantly exceeds this value of 43% for much of the year. Natural runoff conditions are to a minor extent affected by weirs, whereas large reservoirs, water diversions between river catchments and intensive use of surface and groundwater represent a much larger impact [14].

Catchments of the Oder, Elbe and portions of the Danube define the approximate borders of Central Europe. The most typical feature of Central European rivers is a low specific runoff in the lowlands—the lowest specific runoff reaching values of 2–4 $l\,s^{-1}\,km^{-2}$ with annual precipitation of 500–600 ml. Much higher specific runoff occurs in the border mountains of the Bohemian Massif (Sudety, Krušné hory), where discharge exceeds 20–25 $l\,s^{-1}\,km^{-2}$. In Central Europe, the annual balance of water circulation is conspicuously influenced by evaporation from summer precipitation and water storage within soils, replenished by snowmelt. This water can infiltrate into the soil, thereby lowering surface runoff and supporting growth and nutrition of vegetation until June. The accumulation of soil moisture and groundwater reserves limits the spring runoff below 50% of the annual runoff; rather, a value of 40% is typical for a large proportion of Czech Republic [18].

3.4 Major Rivers

Four major rivers and their multiple tributaries drain the Czech Republic. The Vltava River and Labe River drain most of the Bohemian part, while the Moravian and Silesian regions are drained by both the Morava and Odra Rivers, respectively.

The Elbe catchment forms a closed basin in the Czech Highlands, with a total area of almost 50,000 km^2. The main headwater areas of the Bohemian Elbe catchment are situated in the border mountain ranges of the Šumava, Krušné (Ore) Mountains, Jizera, Krkonoše (Giant), and Orlické Mountains, in addition to the Bohemian–Moravian Highlands. The river containing the most water, and therefore the main source of the Elbe catchment is the Vltava River. The Morava River catchment drains water to the Danube and eventually to the Black Sea. The main headwater areas are mountains in the north-eastern part of the catchment area—Jeseníky, Beskydy and the White Carpathians. A large part of the catchment area, especially in South Moravia, has a lowland character. However, the watercourses in the headwater areas of the Jeseníky Mountains and the Beskydy Mountains change rapidly in discharge during snowmelt or significant precipitation. The Odra is the smallest of the main river catchments in the Czech Republic, with its main course supplied primarily by the Opava, Odra, Ostravice and Olše tributaries, all of which flow together in a fan-shaped pattern into the Ostrava agglomeration. This pattern of the river network together with the mountainous character of the tributaries increases the risk of flood events.

3.4.1 Labe (Elbe)

With a length of 1094 km, the eighth-order River Elbe (*Czech*: *Labe*) is the third longest river in central Europe (after the Danube and Rhine). It drains more than half the area of Czech Republic and more than 25% of Germany. The Elbe is often seen as a river still possessing a natural river bed with active floodplains; for example, there are no impoundments on a 622-km stretch from Ustí nad Labem to Geesthacht. Indeed, its banks are still subject to fluvial dynamics, and the largest contiguous floodplain forest of central Europe has been preserved along with its course. Most of the river from Pardubice to Hamburg is used for navigation, and the river has 24 impoundments within its first 350 km. The phytoplankton biomass coming from these impoundments, further supported by significant nutrient loads downstream, affects the water quality along most of the river [19]. There are 25 million people living within the 148,242 km^2 Elbe catchment, 75% of which live in Germany and 25% in Czech Republic. All major urban centres in the catchment are on the Elbe or a large tributary, including Prague, Leipzig, Berlin and Hamburg.

After leaving the source pool in the Krkonoše (Giant's) Mountains, the river enters the Bohemian Cretaceous basin where the Elbe redirects its flow from the south-east to the north-west. Near Mělník, the Elbe merges with the Vltava (Moldau) River, which exceeds the Elbe in length, in catchment size and discharge. Downstream, the river valley cuts into volcanic bedrock at the Střekov castle near Ústí nad Labem, where the river is impounded by the last weir in the Czech segment [19]. This section is followed by a scenic river canyon called the Elbe Sandstones ("Labské pískovce" in Czech). The dominant feature and also the connecting element is the huge Elbe River Canyon, meandering through sandstones between Děčín and Pirna in Saxony [20] (see Fig. 3.2).

The runoff rate in the Elbe catchment averages 5.5 L km^2 s^{-1}. With a runoff rate of 5.9 L km^2 s^{-1}, the Czech part of the catchment contributes nearly all the total average. Discharge of the Elbe averages 293.0 m^3 s^{-1} at the gauge station Ústí nad Labem. The total length of the river is 1094 km, of which 387 km runs between its source and the Czech–German border. The largest tributary of the Elbe, the Vltava (Moldau) River, has a length of 430 km. The flow regime of the Elbe is of the rain–snow type. Hence, floods mainly occur in winter, but may also occur in summer, as exemplified by the extreme flood of August 2002 [19]. The largest tributaries of the river in the Czech Republic are the Vltava (mean discharge 154 m^3 s^{-1}) and Ohře (38 m^3/s) rivers. Due to impoundments in the Czech section, the river downstream lacks sufficient sediment load and is incised in several reaches. Although most of the Bohemian river section has been largely altered, the Elbe River still harbours snails and fairy shrimp (Anostraca) typical for floodplains, while the diversity of riverine species is significantly reduced there due to water pollution and weirs.

Fig. 3.2 View of the Elbe River between Dolní Žleb and Hřensko (Photograph by Martin Rulík)

In the Czech part of the catchment, the Elbe and its tributaries contain 19 reservoirs with a volume >0.3 million m^3 totalling 167 million m^3. The reservoirs are mainly used to for flood retention and for supplementing discharge at low water levels. The Elbe itself is impounded by 24 weirs that are mostly smaller, except at the reservoirs Labská and Les Království. Thus, the Elbe has been transformed into a chain of impoundments with few remaining free-flowing reaches. Impoundments allow navigation by ships between the uppermost harbour near Pardubice and Ustí nad Labem. Today, however, due to the limitation of a minimum depth for navigation, inland cargo transport by barges has considerably decreased since 1990.

3.4.2 Morava River

The 354-km-long Morava River is a Central European lowland river that originates in the Králický Sněžník Mountains at 1275 m asl in the north-western corner of Moravia, near the border between Czech Republic and Poland. In the downstream section, the river forms the border between Czech Republic and Slovakia (see Fig. 3.3) and between Austria and Slovakia [21, 22]. The Morava enters the Danube near Bratislava at Devín. The Dyje River (Thaya in German) is by far the largest tributary of the Morava with a length of 305 km. The Morava is a lowland river with an average slope of 1.8‰ that enters the Upper Danube. Plains cover 51% of the basin, highlands 35% and mountains 7%. The upper valley belongs to the Western

Carpathians and is predominantly montane pasture. The underlying geology mainly consists of crystalline bedrock (Bohemian Massif) and flysch. The lower Morava traverses the Neogene sedimentary Vienna Basin. Fluvisols predominate along alluvial sections of the Morava. The average annual discharge at the mouth is 100 m^3 s^{-1}. Flow peaks in early spring (March/April) and can last for weeks to months.

Due to highly developed industry and agriculture in the Czech sections, rivers of the basin serve as recipients of both urban and industrial wastewater effluents. Today, >80% of the human population is connected to wastewater treatment plants, and therefore water quality in the Morava River has improved in recent decades.

The Morava river floodplains belong to the most diverse ecosystems within Europe. "With an estimated 12,000 animal and plant species, it ranks 2nd after the Danube Delta" [21]. For instance, Hohausová and Jurajda [23] identified 22 fish species from the upper river, and *Gobio obtusirostris*, *Barbatula barbatula* and *Carassius carassius* were the most common species. Beran [24] found 43 species of aquatic Mollusca (28 gastropods, 15 bivalves) in the Litovelské Pomoraví Reserve, near Olomouc, including endangered species such as *Anisus vorticulus* and *Sphaerium rivicola*. Hašler et al. [25] recorded 542 phytoplankton species along the Morava and Dyje Rivers. In the lower Morava, both cold- and warm-water-adapted species co-occur because of the bimodal flooding regime from the Morava and Danube Rivers.

Downstream of the city of Litovel, the river has been regulated from the 1930s to 1960s, while along the lower Morava, 17 meanders have been cut off, the length of

Fig. 3.3 Morava river near Lanžhot—here the river forms the border between the Czech Republic and Slovakia (Photograph by Martin Rulík)

the mainstem has been shortened by 11 km (14% of this section), and the slope has increased from 0.15 to 0.19‰. Lateral embankments have led to an 80% reduction of the inundation area. Similarly, the Dyje River was channelized during the 1970s and the natural flood regime was disrupted due to upstream flow regulation [21]. Only the central section of the Morava River near Olomouc has maintained its natural character for considerable portions. The Litovelské Pomoraví Landscape Reserve, which covers an area of 9600 ha (57% forests, 36% periodically wet fields, 7% permanent wet fields) [26], belongs to our important floodplain areas protected by the Ramsar Convention (see Fig. 3.4). Also, extensive floodplains along the lower Morava are also protected by the Ramsar Convention.

3.4.3 Odra (Oder)

The Oder (Czech*: Odra*) is the sixth largest river flowing into to the Baltic Sea, with an annual discharge volume of 17.3 km^3. Being 854 km long, the Oder is the second longest river in Poland (after the Vistula). Only 6% of the catchment area lies in the Czech Republic, and 5% lies in Germany. Headwater streams lie in the Oderské Vrchy Hills near the settlement of Město Libavá. The Oder first flows south-east, then follows a valley heading north-east, called the Moravian Gate, that allows passage between the Sudety Mountains in the west and the Beskid Mountains in the east. The river then passes the city of Ostrava, an industrial centre based on coal

Fig. 3.4 In the Litovelské Pomoraví landscape area, the Morava River forms a unique anastomosing system consisting of old arms, oxbows and alluvial pools (Photograph by Martin Rulík)

Fig. 3.5 Oder River crossing the Czech–Polish border (Photograph by Martin Rulík)

mining and steel industry, and shortly afterwards crosses the Czech–Polish border (see Fig. 3.5) [19]. The upper river flowing through the Moravian Gate uses a tectonic fault that allows it to cross the geologically ancient mountain ridges bordering the Bohemian–Moravian basin to the north.

The relief of the Oder River was largely formed during the Quaternary when the river's terraced system originated. The Poodří Region is an area of precious natural resources that have been created by fluvial processes and also by humans who began manipulating the landscape in the Middle Ages. Since medieval times, several fish pond systems form a characteristic feature of the local landscape, which is nowadays appreciated for numerous wetland ecosystems preserved, thanks to conservation of meandering streams having a natural flood regime. The Poodří landscape was altered when floodplain forests were reduced and replaced by meadows. Unstable banks and ongoing fluvial processes led to the faster retreat of banks and formation of the meander belts. Currently, the Poodří landscape is protected and has also been included on the Ramsar Convention of Wetlands list [27].

Like other large European rivers, the Oder has been substantially modified by damming, regulation and other river engineering projects. Because the lower Oder forms the border between Poland and Germany, intensive development was limited so that some typical features of large rivers have been preserved. On the other hand, the Oder suffers along most of its length from significant inputs of wastewater and diffuse inputs of organic contaminants, nutrients and heavy metals. The lower Oder and Warta are still free-flowing and are potential sites for the re-introduction of migratory fishes such as salmon and sturgeon. However, such efforts conflict with planned river training projects to improve navigation on the Oder during periods of low flow.

3.5 Biogeochemistry (Sediment Loads, Nutrients and Pollution) of Rivers

The quality of surface waters is influenced mainly by point-source discharges (effluents from cities, municipalities, industrial factories and units of concentrated livestock production). Discharged organic pollution in terms of BOD decreased by 96.2% and CODCr by 90.8%, respectively, between 1990 and 2016, while suspended solids decreased by 95.1% (but see [28]). At the same time, effluents of many dangerous toxic pollutants also significantly decreased. A considerable decrease in the discharge of macronutrients (nitrogen and phosphorus) is due to the improved technology of wastewater treatment, namely the biological removal of nitrogen and biological or chemical removal of phosphorus. Ammonia nitrogen has practically disappeared, and most remaining nitrogen is present as nitrate, but total concentration of the mineral nitrogen dropped to only about half of the maximum level. Nitrate, however, is transported downstream to the sea with no loss [29]. Diffuse sources of pollution (agriculture, air pollution) also significantly affect the quality of surface and groundwaters. The diffuse-source pollutants originating mostly from agriculture—such as nitrogen and pesticides—represent the dominant water pollution source at some locations [30]. Since 2010, there has been a gradual increase in the use of fertilizers applied per hectare of arable land. This amount was around 6700 kg ha^{-1} during 2015–2016 while total consumption of the net nutrients supplied by mineral fertilizers amounted to 492.2 thousand tons [30]. This increasing trend in fertilizer application is the result of changes in the composition of crops (decrease in perennial forage crops and increase in subsidized crops—mostly corn and rape).

As one of the necessary measures to decrease diffuse pollution from agricultural sources (mainly nitrates), there exist designated “vulnerable areas” where specific rules for agricultural practices are prescribed. Currently, these vulnerable areas cover 41.9% of the total area of Czech Republic area and 50.2% of the total agricultural land within the Czech Republic.

3.6 Aquatic Biodiversity

3.6.1 Aquatic Macrophytes

Aquatic macrophytes are very dynamic and sensitive components of running waters in Czech Republic. Several basic factors drive the diversity of macrophytes. Among others, these factors include stream order, elevation and anthropogenic impact. Stream order primarily influences light limitation: in small streams shaded by riparian vegetation, the occurrence of most species is limited except for bryophytes which are generally present there. If upstream river sections are a sufficient source of diaspores, flooding or technical regulations may not have serious impacts on macrophyte diversity.

Macrophyte communities in Czech rivers usually have 1–2 conspicuous dominant taxa. This phenomenon led previous scientists to describe distinct communities although ecological differences between them were often insignificant. Stream and rivers with rich macrophyte vegetation are very rare today: we can distinguish up to 8–10 integrated plant associations at a single location. It is possible that monodominant communities existing today are secondary, impoverished fragments of species-rich vegetation that existed previously. Currently, lowland rivers that are naturally eutrophic are affected by technical alterations of their channels as well as by anthropogenic eutrophication. Excessive addition of nutrients leads to an increase in turbidity, which in turn limits the growth of submerged plants. The Elbe River section between Kolín and Mělník cities seems to be the most diverse Czech lowland river regarding macrophytes. Altogether 15 macrophyte species including *Nuphar lutea* and *Nymphaea candida*, or the less common species *Potamogeton nodosus* were recorded here in one-kilometre stretch. The occurrence of *Butomus umbellatus* with fluitant forms is characteristic for small lowland rivers, while *Ceratophyllum demersum* and *Potamogeton pectinatus* (also known as *Stuckenia pectinata*) which can tolerate epiphytic algae are dominant in turbid, polluted waters. Currently, it appears that these species are spreading to higher altitudes.

Middle reaches of rivers in foothills have degraded macrophyte vegetation in many instances, due to the occurrence of reservoirs. Most streams and rivers host monodominant growths which can, however, differ in composition from each other because of limited species migration between catchments. Streams with the dominant growth of *Batrachium fluitans* or *B. penicillatum* frequently occur. *Myriophyllum spicatum*, an aquatic moss *Fontinalis antipyretica* and a red algae *Lemanea fluviatilis* are also among the common and characteristic species occurring in these rivers and streams. The Ohře River between Cheb and Sokolov is the most species-rich river section of this type, with up to 15 species recorded. The very rare *Potamogeton perfoliatusi* occurs here, while fluitant forms of *Sagittaria sagittifolia* and *Schoenoplectus lacustris* are usually common. The latter species occurs only in these middle river sections in foothills. *Callitriche hamulata* is the dominant species usually found in smaller streams.

Mesotrophic conditions and cold water characterize streams and rivers in higher altitudes. Due to shade, aquatic macrophytes occur here in low diversity and sparse density. The unusually taxa-rich Vltava River above Lipno reservoir is the only exception, with one kilometre of river hosting up to 12 macrophyte species. Typical indicators of these cold and relatively undisturbed flowing waters include *Potamogeton alpinus*, *Myriophyllum alterniflorum* and the moss *Fontinalis squamosa*, whereas the occurrence of a subatlantic species *Potamogeton polygonifolius* is typical for small streams in Aš promontory.

Running waters in the Carpathian part of Czech Republic are rather unique. These streams and rivers host low macrophyte species diversity often represented only by mosses. The main reason for the limited macrophyte diversity here is considerable seasonal fluctuations in river discharge. In this region, the occurence and diversity of aquatic macrophytes are usually negatively correlated with the magnitude of gravel–sand loads.

3.6.2 Aquatic Invertebrates

There are more than 3500 species of invertebrates in the Czech Republic with an aquatic life cycle, mostly represented by insects. Research on aquatic invertebrates has a long tradition in the Czech Republic. Since the 1960s, these organisms have been used as water quality bioindicators. Aquatic invertebrates have also been one of the main components of the saprobic system and its classification, used in the Czech Republic and elsewhere [31]. At present, aquatic invertebrates are the main group for assessing the environmental status of rivers by the European Union (EU) Water Framework Directive (2000/60/EC) [32]. In particular, the Ephemeroptera, Plecoptera and Trichoptera (known as EPT) have long been used as bioindicators. These groups occur in virtually all types of running water. For example, *Baetis rhodani* is one of the most abundant Ephemeroptera species in Czech running waters [33].

The structure of aquatic invertebrate communities varies naturally, especially with regard to the magnitude of streamflow and altitude. The local composition of invertebrate assemblages is determined by the physical, chemical and biological conditions that gradually change along the river course, as well as by anthropogenic alterations like wastewater discharge and hydraulic engineering measures. Upstream sections of brooks and rivers are inhabited mostly by the EPT groups mentioned above, followed by *Gammarus fossarum*. Lower reaches of the rivers are dominated by Diptera, Mollusca and Oligochaeta, while the Chironomidae family dominates virtually all types of running waters. With regard to total species diversity, the highest species richness typically occurs in naturally preserved metarhithral and epipotamal river reaches.

The current status of aquatic invertebrate communities is primarily impaired by anthropogenic influences. Rivers and brooks in the Czech Republic are largely technically modified. Impairment is mainly caused by the straightening of stream channels, construction of weirs and alteration of riverbanks and river bottoms. These activities alter the natural flow regime and subsequently change the structure of invertebrate communities. A typical example is the River Elbe: at river km 370 km in the Czech territory there are 62 weirs exceeding 1 m in height, 25 locks and 2 dam reservoirs. These are the primary reasons for tens of kilometres long stretches of the river having lost its character of running water. These construction works are also detrimental barriers for fish and other organisms.

Other significant negative impacts are caused by eutrophication and acidification. Eutrophication due to excess phosphorus and nitrogen from wastewater and agriculture have already caused massive declines in Ephemeroptera, Plecoptera and Trichoptera species diversity, corresponding to an increase of Oligochaeta, Chironomidae and Hirudinida abundance. Acidification in the past primarily affected stream communities in mountainous regions via low pH and heavy metal leaching. Currently, many small watercourses in mountain areas have recovered to their pre-acidification status. Dominant species in acidified streams are *Diura bicaudata*, *Plectrocnemia conspersa* and *Siphlonurus lacustris*. However, the invertebrate community is still generally impaired. Aquatic invertebrate communities are also currently impacted by excessive pesticides used in agricultural production as well as by a growing number of micropollutants such as drugs, hormones and endocrine disruptors.

All these anthropogenic pressures and pollutants negatively affect sensitive species of aquatic organisms, with over 500 aquatic invertebrates in the Czech Republic on the Red list of threatened species [34]. One of the most endangered organisms is the freshwater pearl mussel *Margaritifera margaritifera*, which is currently documented at only 20 localities [35]. Additional threatened species include other molluscs—*Unio crassus*, *Sphaerium rivicola*, Odonata—*Ophiogomphus cecilia*, Ephemeroptera—*Ephoron virgo*, *Brachycercus harrisellus*, *Choroterpes picteti*, *Rhithrogena germanica*, and Plecoptera—*Agnetina elegantula*, *Isoptena serricornis*. For these species to persist, it is also necessary to preserve the natural meandering channel and the formation of gravel and sand banks.

Metarhithral and epipotamal zones are the most threatened parts of our rivers, caused by technical modifications and chemical pollution. Various large-scale ameliorations, morphological degradation of streams and rivers and their pollution also affect adjacent wetlands and alluvial, perennial or periodic pools. In these habitats, several taxa have already disappeared including the molluscs *Anisus vorticulus*, *A. septemgyratus*, *Gyraulus rossmaleri*, *Sphaerium nucleus*, *Valvata macrostoma*, large Branchiopod crustacean species, and the large Oligochaeta species *Criodrillus lacuum*.

The disturbance of the original communities allows for more rapid propagation of non-native species. At present, there are more than 30 non-native and invasive aquatic species in the Czech Republic. The most prominent is an American crayfish *Orconectec limosus*, which displaces native crayfish species and spreads Crayfish plague—*Aphanomyces astaci*. The freshwater clam *Corbiculla fluminea*, forming large populations in the Elbe downstream, also has a negative impact on our native molluscs. *Dikerogammarus villosus* is a predator directly eliminating the native amphipod and isopod crustacean species and additionally puts predation pressure on other aquatic invertebrates. Recently, crustaceans *Jaera istri*, *Corophium* *curvispinum* and *C. robustum* have spread in Czech rivers, while the mollusc *Potamopyrgus antipodarum* spreads mostly in small, lowland brooks. In Czech Republic, non-native species of aquatic invertebrates have occurred since the mid-nineteenth century. Originally they were introduced via ornamental trade. Later, when the Danube and Rhine River basins were interconnected, there was a spontaneous spread of non-native species accelerated by shipping. In the Czech Republic, non-native species are currently spreading in the Elbe spontaneously, partly due to shipping. In the other parts of the territory, the main causes of their spread are handling of fish stocks and deliberate release into nature (e.g. freshwater turtles of genus *Pseudemys*).

3.6.3 Fish Biodiversity

Our historical knowledge of fishes in the Czech Republic is quite complete. As long ago as 1856, A. Heinrich published a review of the fishes of the River Morava (Danube Basin), followed closely by Jeitteles [36, 37]. Not long after, A. Frič published "An overview of the fishes of Bohemia" (Elbe basin) [38]. Since then several exhaustive books have considerably widened our knowledge of Czech fishes (e.g. [39–41]). Despite its rather small area (78,864 km^2) and landlocked position in the centre of the European continent, Czech river systems flow into three separate sea basins, i.e. the Black Sea (25.4% of land drainage; River Morava drainage basin), the Baltic Sea (9.4%; River Odra drainage basin) and the North Sea (65.2%; River Elbe drainage basin). Consequently, the native fish fauna shows a high species diversity. This is especially true of the River Morava, a main tributary of the River Danube. The Danube itself has the highest fish species richness in Europe at ca. 130 species (including non-native species), representing ca. 5% of the continental fish fauna [19].

The current list of native Czech fish fauna consists of 59 species, of which four are lampreys. Of these, four migratory fish (beluga *Huso huso*, Atlantic sturgeon *Acipenser sturio*, Allis shad *Alosa alosa* and flounder *Platichthys flesus*) and two migratory lampreys (sea lamprey *Petromyzon marinus* and European river lamprey *Lampetra fluviatilis*) are now considered extirpated (though most of these species were historically rare). The formerly common Atlantic salmon (*Salmo salar*), which traditionally migrated up the Elbe to spawn in tributaries along its middle and upper stretches, was heavily impacted by large-scale river regulation at the turn of the twentieth century, with the construction of numerous weirs blocking their migration routes. Subsequent heavy pollution and overfishing resulted in the last migratory salmon from the Czech stretch of the Elbe being caught in 1948. Though it was too late to save the salmon population, fisheries managers quickly set about rescuing the last remaining Danubian salmon *Hucho hucho* and sterlet *Acipenser ruthenus* populations by repatriating specimens to other rivers and strengthening locally occurring populations through supportive stocking. Since the late 1990s, efforts have been made to re-establish a new migratory salmon population on the Elbe through restocking, with some success (Salmon 2000 project [42]). This has been aided to a large degree by the installation of fish passes at all major weirs formerly blocking migration routes.

By the Second World War, many large Czech rivers were degraded; however, conditions got worse over the second half of the twentieth century under socialism, with heavy industry and intensive agriculture resulting in water quality conditions below fish survival thresholds. Furthermore, many rivers were channelized and disconnected from the floodplain, and regulation by weirs and large reservoirs transforming long river stretches from natural riffle-pool sequences to slow-flowing or standing water bodies. As a result, the country's formerly rich fish fauna became impoverished, with many native fish species on the brink of extinction or extirpation.

Political and economic changes following the "Velvet Revolution" of 1989, however, led to the collapse of several large industries (e.g. sugar refineries, paper mills) that used outdated technology negatively affecting water quality. Simultaneously, financial resources available to the agricultural sector were considerably reduced, which resulted in a decrease in the use of fertilizers and pesticides, while many old wastewater treatment plants were modernized and new ones constructed. This quickly led to a dramatic improvement in the quality of Czech rivers, with subsequent changes in fish communities. In the River Morava, one of the largest rivers in the Czech Republic, fish species richness has increased continuously over the last 20 years, once again matching the status of 100 years prior [43]. Native Danubian species, such as the cactus roach *Rutilus virgo*, zobel *Abramis sapa*, blue bream *A. ballerus*, ziege *Pelecus cultratus*, yellow pope *Gymnocephalus schraetser*, zingel *Zinger zinger* and streber *Z. streber*, are now returning to our rivers in increasing numbers. Also, new Danubian species have spread from their original distribution ranges up to the Morava and are now commonly encountered, e.g. Danube ruffe *G. baloni*, Volga pikeperch *Sander volgensis* and tubenose goby *Proterorhinus semilunaris*. These changes have come about purely because of general improvements in water quality and the absence of the formerly regular seasonal fish poisoning episodes from agricultural pollution, with no changes in the overall geomorphology of most rivers. Further improvements will necessitate wide-scale river revitalization measures, including the longitudinal re-opening of river channels and re-connection of main channels to their floodplains and associated waterbodies.

Over the last 150 years, 34 non-native fish species have been registered in the Czech Republic. Others, especially earlier introductions, were not documented and appear to have disappeared relatively quickly. A number of authors have recently published overviews on non-native fish introductions into the Czech Republic (e.g. [41, 44]). Most of these species were deliberately introduced, either for aquaculture or to diversify the range of game fish for angling. Two species (stone moroko *Pseudorasbora parva* and black bullhead *Ameirus melas*) were accidentally introduced along with target species, two spread naturally up the Morava from the Danube (giebel *Carassius gibelio* and round goby *Neogobius melanostomus*), and one was introduced by an aquarist (three-spined stickleback *Gasterosteus aculeatus*). Of the 34 known non-native species, ten failed to acclimatize and disappeared soon after introduction. Six species (rainbow trout *Oncorhinchus mykiss*, grass carp *Ctenopharyngodon idella*, silver carp *Hypophthalmichthys molitrix*, bighead carp *Aristichthys nobilis*, maraene *Coregonus maraena* and peled *C. peled*) are maintained via artificial reproduction and stocking, or are grown commercially through pond aquaculture or in trout farms. Several species are presently reared under experimental conditions (sturgeons and paddle fish *Polyodon spathula*) or in enclosed fish farms (black carp *Mylopharyngodon piceus*, black buffalo *Ictiobus niger*, bigmouth buffalo *I. cyprinellus*, channel catfish *Ictalurus punctatus* and largemouth bass *M. salmoides*). Four species have successfully naturalized and form reproducing local populations in Czech waters and river systems (pumpkinseed *Lepomis gibbosus*, brown bullhead *A. nebulosus*, black bullhead and three-spined stickleback). Currently, only two species (giebel and stone moroko) have nationwide distribution, with locally invasive populations.

Just as elsewhere, local fish communities in Czech rivers are dependent upon hydromorphological, physical and environmental conditions that change with longitudinal gradients, with stretches along the longitudinal profile defined by the most typical fish species, i.e. the trout, grayling, barbel and bream zones [45]. Species richness typically increases from the species-poor, mountainous trout zone to the species-rich bream zone comprising the lowland floodplain stretches of larger streams and rivers. In the Czech Republic, the trout zone generally supports just one or two species, e.g. brown trout *Salmo trutta* or bullhead *Cottus gobio*. The grayling zone typically has populations of grayling *Thymallus thymallus*, minnow *Phoxinus phoxinus*, spirlin *Alburnoides bipunctatus* and brook lamprey *Lampetra planeri*. The barbell zone is generally species-rich and mainly inhabited by rheophilic species such as barbell *Barbus barbus*, chub *Squalius cephalus*, nase *Chondrostoma nasus*, vimba *Vimba vimba*, gudgeon *Gobio gobio* and stone loach *Barbatula barmatula*, though many others from the upper and lower zones may also occur. Finally, the Czech bream zone usually supports fish communities dominated by common bream *Abramis brama*, roach *Rutilus rutilus*, bleak *Alburnus alburnus*, ide *L. idus*, northern pike *Esox lucius*, zander *Sander lucioperca* and perch *Perca fluviatilis*, though many others may also be found.

Fisheries management and angling have long traditions in the Czech Republic, with the first salmon and trout hatchery station operating as early as the end of the nineteenth century. There is no commercial fishing in Czech rivers, and rivers are generally managed by angling clubs and associations. Angling is a very popular recreational activity in the Czech Republic; Czech and Moravian angling clubs presently have around 300,000 members, i.e. around 3% of the population. The most popular game fish species are common carp *Cyprinus carpio*, followed by predatory species such as pike, zander and wells *Silurus glanis*, with brown and rainbow trout the favourite species in trout fishing grounds. Of the 64 fish species (including non-native) commonly found in Czech rivers, 19 (30%) are supported through regular stocking by the angling clubs, with four more (22%) stocked locally.

With a few notable exceptions (e.g. the River Bilina), pollution is not the main limiting factor for fish populations in Czech rivers. Instead, there is an urgent need for improvements in the geomorphological status of many rivers, where channelization and regulation are presently holding back improvements in fish community structure and development. An absence of shallow gravel riffle stretches is limiting natural reproduction of rheophilous riverine species, while flood prevention dykes limit lateral connectivity between the main channels and their floodplains, thereby cutting-off phytophilic and phyto-lithophilic species from their natural spawning zones and nurseries. Likewise, high weirs limit longitudinal upstream movement of migratory species. Over recent years, low discharge levels have also had a detrimental impact on fish communities (with some smaller streams drying up completely). In some rivers, the return of the European otter *Lutra lutra* following its dramatic declines in the 1980s, and large overwintering flocks of cormorants may also be having an effect on local fish community structure. As a result of the above factors, 19 fish species presently require protection under National Czech legislation (395/1992 Sb.) [46], six being registered as "critically endangered" (zingel, streber, Kessler gudgeon *G. kessleri*, brook lamprey, Ukrainian lamprey *Eudontomyzon mariae* and Balkan golden loach *Sabanejewia balcanica*), three as "strongly endangered" (ziege, spirlin and *Cobitis* sp.) and ten as "endangered" (zobel, ide, yellow pope, common carp (wild form), burbot *Lota lota*, weather fish *Misgurnus fosilis*, virgo, minnow, bullhead and Siberian bullhead *C. poecilopus*). Nevertheless, the overall status of Czech fish populations is now better than at any time since the start of the twentieth century, with further improvements likely through the implementation of the EU Water Framework Directive [32].

3.7 Environmental Pressures on Biodiversity

3.7.1 Fragmentation

Anthropogenic impacts of various kinds have affected large portions of watersheds within the Czech Republic. Of the 76 thousand km of natural watercourses, 21.6 thousand km (28.4%) are impaired. River channels important for water management were altered by one-third of their total length, while nearly 40% of small streams in agricultural areas have been altered. According to the EU Water Framework Directive, 54% of all surface water bodies are classified as severely modified. During a process of the European legislation implementation, the quality of fish communities in Czech running waters was evaluated between 2006 and 2008: only 1.9% of the watercourses were in very good ecological status and 11% in good ecological status, whereas 47% of all running waters fell into the damaged and devastated status [47].

Technical alterations of watercourses consisted of channel stabilization and changes in course, slope or discharge profile of rivers. These alterations have mostly been aimed at flood protection in floodplains, protection from excessive runoff, improvement of water regime in surrounding parcels, modifications for water abstraction, energy production or engineering conditions for navigation. After large flood events in 1997 and 2002, there were many intensive discussions about the impacts of shortened watercourses on flooding. Comparison of past and present river channels revealed, for instance, that the Elber River was shortened by 12.3% of its original length spanning 1848–1992. Today, the Elbe is completely channelized from Mělník to Chvaletice. Since 1836, the Morava River has also been shortened due to regulation by 20% of its original length; active side channels of the Morava River decreased by 188 km of their original length of 743 km (i.e. 25% of the original length). In the Otava catchment, the most intensive shortening (nearly 40% in some reaches) occurred from the end of the nineteenth century until the middle of the twentieth century. Channel straightening leads to an increase in water velocity, thus increasing the magnitude of flooding [16].

At present, 6023 lateral barriers taller than 1 m are registered on Czech rivers. When considering the total length of the drainage system of 76 thousand km, every 12.7 km on average is obstructed by tall barriers. The number of migration barriers lower than 1 m is likely much more numerous. The most significant impairments of this type are in downstream sections of lowland rivers and in areas of intensive agricultural production. For instance, 37 impervious migration barriers occur along the length of the Morava River (283 km), while 27 km of the watercourse is affected by an impoundment (40% of the length). Moreover, more than 120 reservoirs have been built on Czech rivers [48].

3.7.2 Assessing Risk to Water Permanence in Streams

A categorization system has been proposed for risk of small Czech watercourses (I–IV. stream orders according to the Horton-Strahler) becoming dry. Three risk levels were described for individual catchments: low, moderate and high. Risk levels were defined based on individual and combined abiotic characteristics of the landscape including precipitation shortage, type of landscape cover, the proportion of geology containing clay, geomorphological parameters and proportion of standing waters [49].

The area with a low risk of desiccation represents 45.3% of the total area of the Czech Republic, 23.3% at moderate risk and 31.3% at high risk. This system of categorization could support decision-making processes, especially for water and agricultural management and nature conservation. The extent of risk is unambiguously related to the proportion of adverse landscape cover type, represented mostly by arable land. The proportion of arable land is related to climatic conditions and, in turn by altitude. Hence, it is not surprising that a low risk of desiccation occurs mostly above 500 m a.s.l. Landscape cover type also relates to the morphological status of streams and rivers—straightening and fortification of watercourses more frequently occur along with intensive agricultural use and urbanized areas [49].

3.8 Management and Conservation

3.8.1 *Economic Importance*

Currently, the main water uses include public water supply, communal services and business, agriculture, fisheries, industry, water transport, power engineering, recreation [16]. The largest water abstractions are for power generation, public water supply systems and industry [50]. Most abstractions are derived from surface water (77.8% of total discharge), with a smaller portion coming from groundwater (22.2%). A significant part of the abstracted water is intended for drinking water. In 2016, 585.4 million m^3 of drinking water was provided [50]. Untreated water is obtained in the Czech Republic from groundwater (about 45–55%) or surface water (about 45–55%). Large sources of drinking water include the Švihov water reservoir on the Želivka River and Káraný, which receives infiltrated water from the Jizera River. An important phenomenon in the Czech Republic was the past establishment of ponds. It is estimated there are approximately 25,000 ponds and small reservoirs in the Czech Republic, which are primarily important for aquaculture (mainly carp production) but at the same time fulfil a number of ecosystem services and help support the ecological stability of the landscape.

The Labe–Vltava waterway is at present the only suitable course for shipping and the only connection to the massive network of European waterways and seaports. Navigable conditions on the Elbe River from Střekov near Ústí nad Labem to Chvaletice are provided by a cascade of 21 locks. There are 18 chambers at 10 locks of the Vltava waterway.

Large hydroelectric power plants exist in the Czech Republic, mainly at reservoirs. In total there are ten large hydroelectric power plants (including pumping stations) here, most of which are situated on the Vltava River where they form the so-called Vltava cascade. Hydroelectric power plants account for less than 3% of total electricity production in the Czech Republic. The Hněvkovice reservoir on the Vltava River accumulates water required by the Temelín nuclear power plant.

3.8.2 *Conservation and Restoration*

The relationship between water management and society has historically undergone a number of changes. Significant interventions in the river network have been carried out since the eighteenth century on the territory of the Czech Republic. Since this period of industrialization, a number of river regulations, navigation canals, race canals for mills and flood protection measures were initiated [51]. With the rapid development of human settlements and industry, efforts have been made to exploit the energy and transportation potential of the watercourses and also protect against floods. Alterations of the watercourses and their alluvial floodplains have gradually encroached upon larger rivers in lowland areas with large populations of humans and industrial concentration. Extensive regulations were planned from the beginning of the nineteenth century on the Elbe, Moravia and Dyje Rivers. By the end of the Second World War, there was intensive socio-economic development and natural water resources were not sufficient to meet the needs of society. The watercourses and the surrounding river landscapes therefore gradually lost their natural character. The benefit to humans was primarily agricultural land, flood protection, navigation and electricity generation. The collectivization of agricultural land, the gradual industrialization of agriculture and along with the effort to use even less suitable land for crop cultivation have led to massive alterations of small watercourses, large-scale drainage and melioration of agricultural areas [51]. Drastic disturbance to the river network was accompanied by intensive mining and the development of heavy industry. A typical example is the North Bohemian river Bílina, whose river bottom disappeared due to surface brown coal mining; meanwhile, streamflow was drained into pipes in order to safely transfer water through the surface mines.

The legal regulation of nature protection in Czech Republic—in the modern sense of the phrase—dates back to the beginning of the twentieth century with the establishment of the independent Czechoslovak Republic (1918). In 1933, 30 protected areas were declared, and until 1938, a total of 142 nature reserves were established. The first protected landscape area (Bohemian Paradise) was established in 1956, and our first national park was established in 1963—Krkonoše National Park.

After 1990, ecosystem-based approaches to water management became commonplace. Restructuring, privatization and modernization of industry were implemented. At the same time, there was a significant decrease in the number of abstractions for agricultural irrigation. Livestock production was significantly reduced, and groundwater abstraction for agriculture decreased.

Territorial protection was enshrined in Act No. 114/1992 Coll. [52], on Nature and Landscape Protection and through the implementation of its decrees. In Czech Republic, there are two levels of this type of protection: large-scale protected areas and small-scale protected areas. Additionally, with the accession to the European Union, designation of the Natura 2000 network of protected areas has emerged, which was also enshrined in law.

Since 2002, the Water Act has been a legal instrument for qualified decision-making by water authorities. The purpose of this Act is to protect surface and groundwaters, to lay down conditions for the efficient use of water resources and to maintain and improve the quality of surface and groundwaters, to create conditions for reducing the adverse effects of floods and droughts and to ensure the safety of water works in accordance with European Community law. The Water Act also helps ensure the supply of drinking water to the public and protection of aquatic ecosystems, including adjacent terrestrial landscapes.

Unfinished sewer systems for smaller municipalities (under 2000 equivalent inhabitants) remain a problem for water quality in Czech Republic. Also, only a portion of wastewater treatment plants are equipped with a tertiary purification level, disallowing capture of all substances occurring in wastewater (e.g. residuals of medical products, especially hormonal). Fortunately, the proportion of people connected to the public sewage system is steadily increasing. In 2016, 84.7% of the Czech population was connected to the public sewer system. The clear majority (96.0%) of the sewerage system is administered by wastewater treatment plants (WWTPs). In 2000, 64.0% of the inhabitants were connected to sewers with WWTPs, whereas in 2016, 81.3% of the population were connected.

Protection of nature and landscape in the Czech Republic is under the responsibility of the Agency for Nature and Landscape Protection, a division of the Ministry of the Environment. This institution was entrusted by the Ministry of the Environment with the creation of a set of Natura 2000 protected areas under Directive 2009/147/EC on the conservation of wild birds and Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora [53]. Among the priority organisms in the aquatic environment are stone crayfish (*Austropotamobius torrentium*), freshwater pearl mussel (*Margaritifera margaritifera*), *Unio crassus*, lampreys, bivalves *Vertigo*, various species of dragonflies, croaks, newts and sensitive fish species.

Another administration responsible for water protection is the Czech Environmental Inspectorate, charged with overseeing compliance of legal standards regarding the environment. The organization also supervises compliance with binding decisions of administrative authorities regarding the environment. There is no simple solution for improving the poor hydromorphological state of numerous watercourses in the Czech Republic. Deliberations on the need for restoration of technically modified watercourses slowly gained momentum in Czech Republic after the Velvet Revolution in 1989, and in 1992 the Ministry of the Environment established a programme for restoration of river systems. The main reasons for the slow progress in improving the hydromorphological state of watercourses include difficulty obtaining land for restoration activities and complexities in the administrative-legal process.

3.8.3 Catchment and River Basin Planning

Water management planning has a long tradition in the Czech Republic. The first systematic overview of the possibilities of utilization of water resources was established in the years 1949–1953 under the State Water Management Plan of the Czechoslovak Republic. Unfortunately, the emphasis was mainly on supplying the water industry and the construction of large waterworks with hydroelectric power plants, in accordance with the interests of a centralized socialist economy. Subsequently, a Guideline Water Management Plan for the Czechoslovak Republic was prepared in the years from 1970 to 1975. This plan responded to increasing urbanization with an emphasis on the construction of water supply capacities and drinking water supply for new housing construction in cities and large municipalities.

A new impetus for water management planning was the preparation of a new Water Act amendment and the implementation of the EU Water Framework Directive after 2000. The new elements in these processes were public involvement and the approval of water management plans of the designated areas via self-government. The main water planning tool as defined in the Water Framework Directive is subbasin plans that include proposals for specific measures to progressively remove the most significant problems regarding water management. The plans for sub-basins were initiated and revised by local river basin managers in cooperation with relevant regional and national water authorities. Simultaneously, the first flood risk management plans that implement the requirements of Directive 2007/60/EC on Flood Risk Assessment and Management [54] were elaborated upon and approved in 2015. Plans for flood risk management are prepared by the Ministry of the Environment and the Ministry of Agriculture in cooperation with the relevant river basin managers and local authorities. Both water management and flood management plans are currently being processed for ten sub-basins: five in the Elbe, three in the Vltava and two in the Odra basin.

Other important strategic documents include the National Climate Change Strategy, the National Action Plan on the reduction of pesticide use, the water lines and sewage development plan, and provisions for connectivity among migratory fish pathways.

Among the significant water management problems in Czech Republic are excessive river flows, morphological changes and water shortages. An increasing amount of impervious, paved areas coupled with increasing frequency of torrential rains causes untreated wastewater to bypass sewage treatment and discharge directly into rivers.

Obstacles to improving the status of water bodies include insufficient constraints on farmland, which would otherwise restrict agricultural practices from adversely affecting water quantity and quality. Positive changes in agricultural practices have the potential to enhance water retention and reduce surface and diffuse pollution of water resources. The lack of implementation of restoration measures to improve the so-called good morphological state of watercourses is partly a consequence of poor cooperation among landowners and government agencies. Also problematic is the unclear use of "exemptions" in the implementation of measures to achieve good status of water bodies (under the Water Framework Directive).

3.8.4 The European Water Framework Directive

Implementation of the Water Framework Directive (WFD) in the Czech Republic is administered primarily by the Ministry of the Environment and the Ministry of Agriculture. In 2004, the Ministry of the Environment established the Working Group on the implementation of the WFD in agreement with the Ministry of Agriculture. The objective of the Working Group is to ensure coordinated cooperation between the ministries and institutions involved in the implementation of this Directive in Czech Republic, including international relations.

The Czech Republic is further involved in the work of the European Commission for the Common Implementation Strategy of the WFD and therefore sends representatives to individual working groups to ensure the transfer of information from the European to the national level. An important role in these activities is played by the T. G. Masaryk Water Research Institute, p.r.i. as a branch organization of the Ministry of the Environment.

As part of WFD implementation, Czech Republic has published methods for assessing the ecological status of water bodies in the Ecostat working group and has successfully calibrated procedures among the other EU Member States (in the so-called intercalibration effort) so that the results are mutually comparable. The Czech Republic also led one of the intercalibration groups—the East European Geographic Intercalibration Group (EC GIG)—in the second phase of the intercalibration process in 2008–2011.

3.9 Conclusions and Perspectives

Although there has been a significant improvement in water quality since 1990, particularly a decrease in saprobic pollution, other significant pressures have emerged such as eutrophication, morphological alterations of the channels, disruption of sediment transport or fish migration that degrade aquatic ecosystem functions and restrict the structure of their biological communities. Moreover, many streams and rivers in the Czech Republic have experienced extreme climate fluctuations leading to unexpected floods and long periods of drought in recent years. Regardless to what degree these extreme fluctuations are a consequence of ongoing climate change or the result of improper landscape management, flooding and drought are expected to adversely affect instream life as well as people. Therefore, future management of streams and rivers should consider the needs of water supply, wastewater dilution, hydropower generation or navigation on the one hand; and on the other hand good ecological status of watercourses supporting sustainable water balance of the landscape. Thus, while diffuse pollution from arable lands may be reduced by improved agricultural practices, hydromorphological alterations could also be considerably improved through stream restoration efforts (e.g. [55, 56]), re-opening and creation of side channels and by the construction of effective fish ladders at weirs [57–59].

There is still a gap between the findings of scientists and water management [60]. Coordination of activities among individual sectors is unsatisfactory, and standards are not clearly defined (e.g. among the watercourse administrators, fishing organizations and private owners). It is also clear that employing purely technical solutions in water management, such as construction of new dams, will not provide sufficient water for our streams and rivers [61]. Natural river beds with a rich structure of benthic sediments and frequent overbank flows can be used as an effective and relatively inexpensive means of solving numerous problems in water and landscape management [60, 61]. To avoid disturbances caused by extreme water fluctuations, we need to systematically change the way our landscapes are managed to support water retention.

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Chapter 4
The Role of Water in the Landscape

M. Rulík and S. M. White

Abstract In recent years, the Czech Republic has experienced extreme weather fluctuations leading to unexpected floods and long periods of drought. The current situation is a result of the long-term use of our landscape which is no longer able to retain and accumulate water, mainly due to technical alterations of watercourses, changes in land use and deforestation. Adaptation to climate change and prevention of further damage from extreme floods and droughts require an alternative approach to land use and land management. In the landscape, water performs multiple functions which are closely interconnected and dependent upon the functioning of the whole landscape. Thus, to properly manage water in the landscape, we need to embrace a holistic view—meaning protection and restoration of the whole landscape, not only fragments. Small water circulation should be promoted in the landscape; however, restoring the water cycle in the landscape is unattainable without revising agricultural practices and restoring alluvial processes, river ecosystems, and wetlands. There are two main strategic goals for restoration of the complete water cycle: first the restoration of drainage patterns having natural hydromorphology, and second the improvement of water retention capacity across landscapes of Czech Republic—water needs to infiltrate the soils at the same place where it falls as rain. This approach is based on the so-called new water paradigm and requires integration of all processes affecting water in the watershed, not only in the channels or reservoirs.

Keywords Water cycle · Landscape retention capacity · Catchment management · Wetlands · Evapotranspiration

M. Rulík (✉)
Department of Ecology and Environmental Sciences, Faculty of Science, Palacký University, Šlechtitelů 27, 771 46 Olomouc, Czech Republic
e-mail: martin.rulik@upol.cz

S. M. White
Department of Fishery Science, Columbia River Inter-Tribal Fish Commission, Portland, OR, USA

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4.1 Introduction

In recent years, the Czech Republic has experienced extreme weather fluctuations leading to unexpected floods and long periods of drought. Without a doubt, these extreme weather fluctuations are a manifestation of ongoing climate change. However, a commonly invoked reason for the occurrence of runoff extremes is decreased retention capacity and accumulation function of the landscape. The retention capacity of a landscape refers to the capacity for retaining water and in this way delaying rainfall runoff from the watershed [1, 2]. A typical characteristic of landscapes lacking retention capacity is decreased amount of available water. Indeed, current measurements indicate that the Czech landscape is suffering a water shortage. Gradual trends in the decline of the groundwater table [3] and decreasing discharge or even dessication of our streams and rivers [4] are the most conspicuous examples. Only a few years ago, the Czech Republic was a region where streams flowed with water year-round. Today, many small streams either become dry during the summer or experience flash flooding, with both extremes yielding catastrophic consequences for human infrastructure and ecosystems.

The current situation is a result of the long-term use of our landscape which is no longer able to retain and accumulate water due to regulation, straightening, truncating and deepening of watercourses, land use change, agricultural drainage and deforestation [5, 6]. The reduced retention capacity of a watershed is also a consequence of increasing soil compaction and long-lasting exploitation of the watershed, mostly the result of increasing development in floodplains. The combination of inundations, impedance and accumulation elements (forest ecosystems, natural watercourses and alluvial plains, meadows, wetland biotopes, etc.), form the 'retention potential' of the landscape (e.g. [7]). Elimination or alteration of these elements from the landscape results in rapid water runoff, erosion, the filling of watercourses with eroded soil containing high nutrient content, and also a significant drop in the supply of groundwater. Generally, research results confirm that Czech landscapes, which have been managed primarily for economic purposes for the last 60 years (but see [8]), have lost much of their natural capacity to alleviate the negative effects of weather extremes. Adaptation to climate change and prevention of further damage from extreme floods and droughts require an alternative approach to land use and land management [9]. From the hydrological point of view, '*small water circulation*' should be promoted in the landscape [2]. This involves water evaporation from the surface and its deposition in the form of rainfall occurring within one region of the landscape. In other words, water needs to infiltrate the soils at the same place where it falls as rain [5, 6, 10, 11].

4.2 Water and Water Resources

Water is a universal medium crucial for the sustainability of both ecological systems and human societies. More than 70% of the earth's surface is covered by water.

However, only 3% is fresh water available for human consumption. Fresh water is essential to all life and has played a central role in the development of human civilizations [12]. Nevertheless, 97% of the earth's freshwater resources is contained in groundwater and ice, and only 3% is contained in surface reservoirs—rivers, lakes, wetlands and streams (e.g. [13]). Fresh water is a renewable resource, yet the world's supply of groundwater is steadily decreasing, with depletion occurring most prominently in Asia, South America and North America. Water is an important resource providing for agricultural, industrial, household, recreational and environmental activities.

Water is continuously moving through the hydrological cycle. The amount of water on earth is finite; the natural water cycle controls the circulation and redistribution of that resource. Whether as runoff from the surface, flow in rivers, groundwater flow in aquifers, evaporation or transpiration, water is constantly being recycled. During this recycling process, there are changes in the quantity and quality of the water caused by natural and human intervention [14]. In nature, the hydrological cycle is well balanced, and fluctuations of environmental water stocks can be accommodated. However, when some parts of the system are altered, the resilience of the system may be jeopardized. This can happen when anthropogenic water consumption occurs without regard to the natural water cycle [15]. While this human intervention may have acute local effects, recent research also shows that large-scale hydraulic engineering produces global-scale impacts on the earth's water cycle by raising global sea levels [16]. Although the dominant natural input to any surface water system is precipitation within its watershed, the total quantity of water in that system at any given time is also dependent on many other factors. These factors include storage capacity in lakes, wetlands and artificial reservoirs, the permeability of the soil beneath these storage bodies, the runoff characteristics of the land in the watershed, and the timing of the precipitation and local evaporation rates. These factors also affect the proportion of water loss. Human activities can have a large and sometimes devastating impact on these factors. Humans directly alter the dynamics of the water cycle through dams constructed for water storage, through water withdrawals for industrial, agricultural or domestic purposes (e.g. [17, 18]) or by draining wetlands (e.g. [19]). Humans often increase runoff quantities and velocities by paving areas and channelizing streamflow [20]. The effect of global climate change on hydrological cycles is still uncertain, but higher temperatures will change some portion of snowfall into rainfall, the snowmelt season will be earlier and as a result the timing and volume of spring floods will change substantially [21].

Thus, the available water resources in a given area are a direct result of the water cycle, which in turn is influenced by climatic factors (e.g. wind, temperature, solar radiation) as well as anthropogenic activities. To plan sustainable use of water resources and develop both adaptive and preventive strategies regarding floods and droughts, we must understand how the water cycle works at both global and local scales. Current climate change and associated weather fluctuations, which are characterized by considerable variations, cause flash floods on the one hand, and water scarcity in the countryside and desiccation of streams on the other hand. Which preventative measures are necessary to initiate first is a question for water managers,

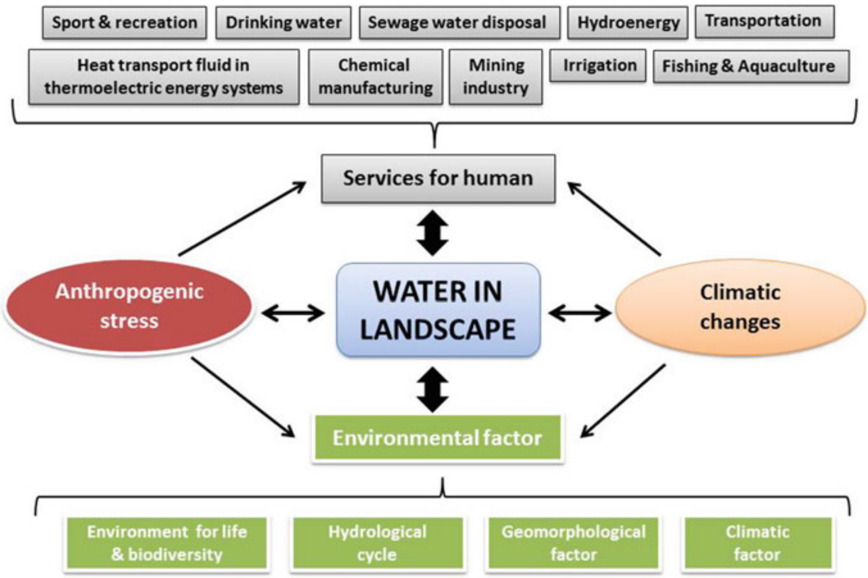

Fig. 4.1 Water provides services to the natural and human components of the landscape. Properly functioning water resources are closely interconnected with other factors; however, human activities and ongoing climatic can alter and sometimes disrupt these linkages (original)

farmers, and politicians. However, the key issue is to understand how water works in the landscape, what role it plays in the local climate or which ecosystem services water can provide. Opinions on this matter are quite different between water managers, engineers and ecologists—see Chap. 17 of this book.

4.3 Water in the Landscape

In the landscape, water performs multiple functions which are closely interconnected and dependent on the functioning of the whole landscape (Fig. 4.1). A landscape cannot function properly without water sources. Thus, to manage water in the landscape, we need a holistic view and we must protect and restore the whole landscape, not only some parts. Sustainable management of river catchments depends on a holistic view and being clear about the functions they perform [22]. Individual parts of the landscape—streams, forests, agricultural land, reservoirs and ponds are mutually interconnected and function as a whole. Moreover, all these parts play an important role in the small water cycle and may considerably affect the local climate.

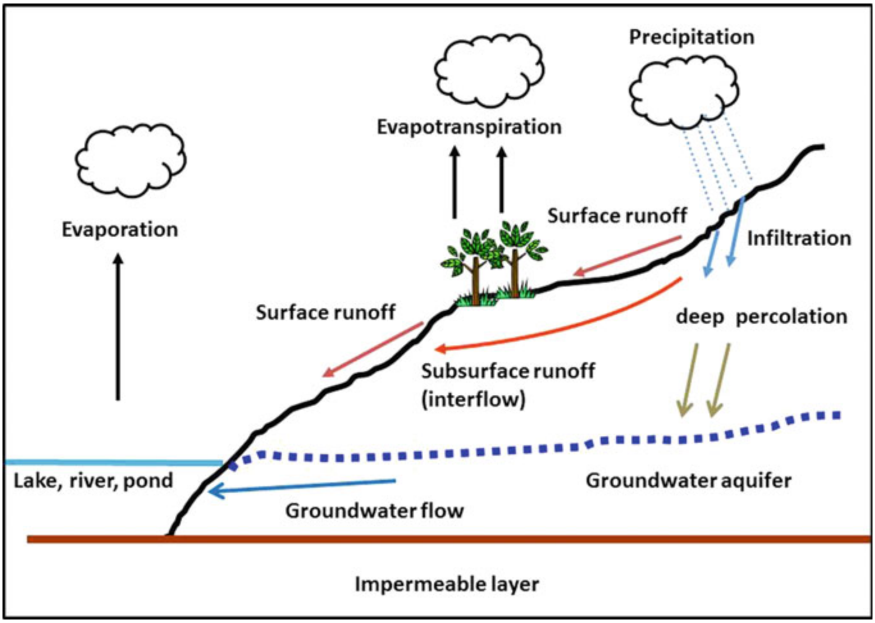

Fig. 4.2 "Small water cycle" in the catchment, typical for the healthy, water retention landscape in which most of the rainfall infiltrates, recharges the soil water and brings it up to full capacity, and moves down through the soil into groundwater where it becomes available for anthropogenic use or eventual flow into streams (modified after various authors)

4.3.1 Small Water Cycle

Solar radiation converts liquid water from the surface of the land and water into vapour through the process of *evaporation*. Humidity stored in vegetation is also released into the air through *evapotranspiration*. The water vapour in the atmosphere condenses into drops of water. From these, clouds are formed, and rain eventually returns in the form of *precipitation:* any form of solid or liquid water that falls from the atmosphere to the earth's surface (for example, rain, hail, sleet or snow). Precipitation that falls on land may return to the atmosphere through evapotranspiration, eventually, runoff into rivers and the ocean, or infiltrate into the groundwater system (Fig. 4.2). In temperate, moist climates, roughly one-third of the water runs off, one-third is evaporated back into the atmosphere, and one-third infiltrates into the ground. However, in drier climates, the proportion (but not necessarily the total) of the moisture that is returned to the atmosphere through evaporation is larger. In the Czech Republic, atmospheric precipitation is the primary source of natural water and accounts for about 670 mm annually in the long-term average or about 52.6 km^3 of the precipitation water $year^{-1}$ [23].

Evapotranspiration is the process that returns water to the atmosphere and therefore completes the hydrological cycle. Evapotranspiration can be divided into two subprocesses: evaporation and transpiration. Evaporation essentially occurs on the surfaces of open water, such as lakes, reservoirs, or puddles or from vegetation and ground surfaces. Transpiration involves the removal of water from the soil by plant roots, transport of the water through the plant into the leaf, and evaporation of the water from the leaf's stomata into the atmosphere.

In the Czech Republic, water naturally occurs mostly in the form of flowing water (rivers and streams), alluvial pools and wetlands in river floodplains, peat bogs in the mountain regions and groundwater. Moreover, in the Šumava mountains, there are five glacial lakes. Other surface waters are of anthropogenic origin: ponds, sandpits and flooded quarries or reservoirs. We have more than 160 reservoirs larger than 1 ha in the Czech Republic, while the current number of ponds and small water reservoirs larger than 0.5 ha is 7536. Their total area has decreased over time, and existing ponds now represent 73.6% of their total historical area [24]. The ponds allow accumulation of approximately 625 million m^3 of water; however, ponds are expected to fill in with sediment and therefore their estimated potential storage capacity is much lower. The extent of wetlands in the Czech Republic has also greatly decreased: in 1950, there were 1.3 million hectares of wetlands registered; however, in less than 50 years, this number decreased to less than one-third (350 thousand ha). Evaporation and evapotranspiration from these water habitats are of fundamental importance for the small water cycle in the landscape, and thus the local conditions of temperature and humidity. Evapotranspiration accounts for approximately 70% of precipitation in the Czech Republic.

Infiltration is defined as the passage of water through the surface of the soil, via pores or small openings, into the soil profile. Water infiltrating into the soil profile is a necessity for vegetative growth, contributes to underground water supplies that sustain baseflow of rivers and streams and decreases surface runoff, soil erosion and the movement of sediment and pollutants into surface water systems. Infiltration directly affects deep percolation, groundwater flow and surface runoff contributions to the hydrological balance in a watershed. Accounting for infiltration is fundamental to understanding and evaluating the hydrological cycle. For example, in the Czech Republic, the total area providing groundwater recharge is 15–20% [25]. In a healthy biotope, the topsoil layer functions as a balancing sponge that absorbs the rainwater—100-cm-thick surface layer of the 1 km^2 soil can retain on average 300 thousand m^3 water. However, the natural topsoil layer has disappeared due to erosion and unsuitable management from a large percentage of the planet's surface, and the landscape has largely lost the ability to absorb rainwater. From 1948 through the late 1980s, 270 thousand ha of meadows and pastures and 145 thousand hectares of field margins were ploughed in Czech Republic. Also, 120 thousand km of field pathways, 35 thousand of groves and hedgerows, and 30 thousand km of linear greenery were eliminated. More than a million hectares of fields were drained by pipe drainage [26].

Water retention capacity is an important soil property that governs soil functioning in ecosystems. Healthy soils efficiently regulate water storage in ecosystems and the landscape, as well as water availability for plants. This depends on many factors, of which soil texture, structure, organic matter content and quality, the functioning of soil fauna and microflora, pore size and distributions, soil depth, and properties of subsurface horizons are of the highest importance. For instance, on average, organic matter has been depleted by 50% in the arable soils in the Czech Republic [27]. However, to protect the soils and enhance crop production, agricultural (melioration) drainage has removed excess water from the soil surface or the soil profile of cropland by either gravity or artificial means. The two primary types of agricultural drainage improvements are *surface* and *subsurface systems*, used individually or in combination. In the Czech Republic, melioration drainage systems have been built on 1.1 million ha (11 thousand km^2) of land. When considering the total area of the Czech Republic (78,866 km^2), 1/7 of this area was drained by melioration. Agriculture land covers some 42,600 km^2 (i.e. 54% of the total ČR area)—more than ¼ of all agricultural land was meliorated. Given that outflow from the drainage melioration systems would be 0.5 l s^{-1} km^2 of underground water for six months per year, then the total runoff would be about 85.5 million m^3. This is a volume that, at a standard consumption of 125 L per person per day, could service 100,000 inhabitants for approximately 18 years [25].

Groundwater aquifers provide large and important reservoirs of water in the global water system. The volume of fresh water in the ground is about 20 times the volume accessible on the surface. Groundwater is therefore no small resource, and the fact that it is stored for years in aquifers highlights the enormity of the storage system. The groundwater system consists of areas of *recharge* (where water enters the groundwater system from the surface) and areas of *discharge* (where water leaves the groundwater system to the surface). In areas with surface water shortages, aquifers are increasingly becoming a principal source of fresh water. Although we have measurements of relative changes in storage for several the world's aquifers, the total amount of groundwater in storage is basically unknown; however, it is estimated at roughly 20% of the water stored in the Earth's oceans.

A large proportion of rainfall infiltrates seeps into the upper ground layers, but a proportion of this evaporates through plants or by capillary action or migrates to the surface and evaporates from the surface of the soil. There is still a large proportion, however, that reaches the water table. This water can then migrate slowly through the aquifer with some emerging as springs or seepage in low lying or steep areas and eventually reach the sea. However, there are many aquifers which are confined or so remote from the sea or watercourses that the water remains there for thousands of years. There are large bodies of water deep below deserts which are now being tapped as a source of water (e.g. [28]). In the Czech Republic, the usable capacity of groundwater is estimated to be at 1.44 billion m^3 $year^{-1}$ (i.e. 1.44 km^3 $year^{-1}$). The basic runoff (part of the total runoff from the area from groundwater) in the Czech Republic is on average about 4.0 l s^{-1} km^2 and accounts for about 36% of the total runoff from the area (but local runoff varies from <1.0 l s^{-1} km^2 up to >8 l s^{-1} km^2) [25].

Runoff is all water transported out of the watershed by streams and rivers. Some of this water may have had its origins as *overland* or *surface flow*, while much may have originally infiltrated and travelled through the soil mantle to streams as *subsurface runoff* or *interflow* (Fig. 4.2). Also, water that infiltrates into groundwater may later emerge far downstream through seeps and springs to add to streamflow. There are two possible situations in the landscape that govern runoff:

(a) Landscapes in which most of the rainfall infiltrates, recharging soil water, bringing it up to field capacity and transporting it down through the soil into groundwater where it becomes available for use or eventual flow into streams. Some of it may move down through the soil as interflow, also providing water to the stream, but both routes shown are subsurface and generally involve a longer transit time to the stream. Stored groundwater and even soil water are available to maintain streamflow during the sometimes-lengthy period between storms (*baseflow*);
(b) Landscapes where most of the rainfall does not infiltrate, but instead is forced to move across the surface as *overland flow;* moving rapidly, it can erode hillsides and quickly flow into streams, leading to flooding. Conversely, streams in this situation carry less base flow because of reduced interflow and groundwater contributions. Overland runoff occurs if rain falls on ground that is unable to absorb this quantity of water, perhaps because the ground is composed of rock or pavement with very low porosity or is fully saturated or frozen, or the rain is too intense for the ground to absorb. Fast overland runoff causes massive soil erosion and the loading of watercourses with washed out soil containing high nutrient content. Around 50% of all arable land is threatened by water erosion in the Czech Republic. The total runoff from the Czech Republic accounts for 28.8% of the precipitation (~15.6 billion m^3 of water), while annual runoff leaving the Czech Republic varies between 8 and 19 billion m^3 [23].

4.4 Catchment as a Management Unit

Catchments constitute logical units for management of the water cycle [29], throughout which all decisions and actions have interdependent ecological, social and economic implications [30–32]. Unsustainable decisions relating to river systems commonly arise from a perspective shaped purely by human utility [33, 34], including resource extraction, land use and planning decisions that ignore the implications for water in the landscape [22, 35]. Poor management decisions that degrade catchment functions can give rise to substantial social harm, economic costs and unsustainability [29, 34].

Good ecological status of watercourses plays a key role in the water balance of the landscape. In the past, however, many streams have been regulated, shortened and deepened which resulted in an increased runoff from the catchment and reduced infiltration into underground aquifers and reduction of water's self-purification processes. In the Czech Republic, for instance, 14 thousand km of small streams were straightened, truncated and incised, of which 4.5 thousand km were drained by pipes in the past 50 years [26]. Deepened, strengthened and fortified river beds may exacerbate flood wave dynamics. Thus, restoring the water cycle in the landscape is unattainable without restoring alluvial processes, river ecosystems and wetlands [36].

Researchers often recognize that human activities at the landscape scale are a principal threat to the ecological integrity of river ecosystems, impacting habitat, water quality and the biota [37–39]. In addition to its direct influences, land use interacts with other anthropogenic drivers that affect the health of stream ecosystems, including climate change [40], invasive species [41], and dams [42]. Effective ecosystem management of running waters necessitates a strong conceptual foundation that is based on understanding structural and functional attributes of river ecosystems, including longitudinal resource gradients, floodplain dynamics, interactions with ground waters and the role of disturbance regimes [43].

Unregulated rivers are networks of surface and groundwater flow paths that drain catchment landscapes [44]. Rivers are increasingly investigated from a landscape perspective, both as landscapes in their own right [43, 45] and as ecosystems that are strongly influenced by their surroundings at multiple scales [37, 39, 46, 47]. Hence, the catchment basin defines the spatial dimensions of river ecosystems [48]. Rivers and streams are influenced by the landscapes through which they flow and cannot be separated from the lands they drain [49, 50]. Understanding the linkages between terrestrial and aquatic components and processes within the catchment is essential to river protection and restoration [51].

Recognizing that rivers are complex mosaics of habitat types and environmental gradients, characterized by high connectivity and spatial complexity, river-dominated landscapes increasingly are viewed as '*riverscapes*' [46, 47, 52], *riverine landscapes* [53, 54] or *hydrological landscapes* [55]. The riverine landscape or river corridor corresponds to the surface area composed of interacting terrestrial and aquatic units that are directly influenced by the river (i.e. aquatic habitats, floodplain surface and riparian zone). Also, [56] introduced the term *fluvial stygoscape* as a subterranean equivalent of the landscape to designate aquifers beneath alluvial flood plains.

The term *riverine landscape* implies a holistic, geomorphic perspective of an extensive interconnected series of habitats and environmental gradients that, along with their biotic communities, constitute fluvial systems [43]. This type of landscape is highly dynamic, exhibiting a constantly changing mosaic of habitats [51, 57] (Fig. 4.3). In spite many of the key elements (e.g. bars, islands, floodplain waterbodies) are rapidly turned over, leading to continual (re-) combination and hence changes in small-scale patterns; from a large-scale perspective, the relative proportions of the elements may remain fairly constant over time [52]. The balance between destruction, formation/rejuvenation and developmental processes contributes to the metastability of the total system and can be viewed as one of the primary traits of the ecological integrity of riverine landscapes. Riverine landscapes thus can be viewed as expansive systems, whose functional and structural elements are determined by the river and its flow regime, yielding an intricately interrelated system consisting of the river and its surroundings [58].

Hydrological processes (e.g. flood pulses) and geomorphological processes (e.g. sedimentation and erosion) are key functions of natural river systems. Channel morphology is determined mostly by the flow regime. Large floods fill channels with

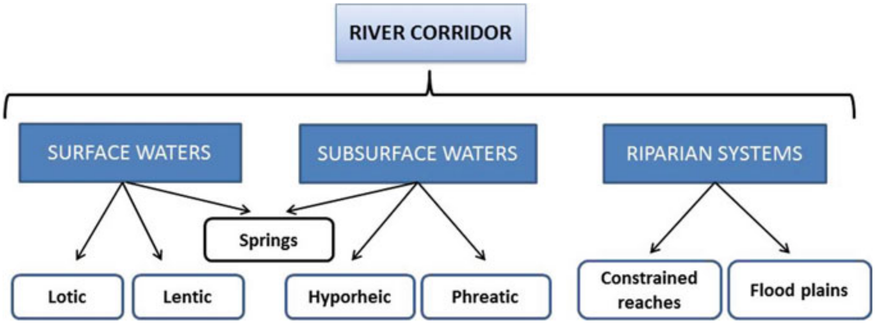

Fig. 4.3 Major environments within river corridors that contribute to biodiversity (modified after [59])

inorganic and organic materials eroded laterally and vertically from upstream locations, thereby producing a continuum of instream structures (pools, runs, riffles, gravel bars, avulsion channels, islands, debris jams) and lateral floodplain terraces in many shapes and sizes. River ecosystems have three important spatial dimensions that are temporally dynamic [43, 55, 60, 61]; compared to the longitudinal dimension. However, these important lateral and vertical dimensions and connections are often overlooked or ignored.

Our perception of streams evolved dramatically over the last 20 years thanks to the gradual convergence of stream ecology and groundwater ecology [62, 63]. Whereas streams have traditionally been delineated as part of the landscape that contains flowing surface water, we have expanded their spatial limits vertically to include subsurface zones (e.g. [64]). Today, rivers are viewed as existing wherever water flows over or under the landscape (see [65]). This expanding view of lotic systems has emerged because several studies demonstrated that streams continuously exchange water, nutrients, organic matter and organisms with underlying groundwater [66].

4.4.1 Effects of Catchment Development on Runoff

Urban development (*urbanization*) adversely affects the water balance of the landscape (e.g. [14]). A dominant feature of urbanization is a decrease in the perviousness of the catchment to precipitation, leading to a decrease in infiltration and an increase in surface runoff. As the percentage catchment impervious surface cover (ISC) increases to 10–25%, runoff increases twofold, 35–50% ISC increases runoff threefold, and 75–100% ISC increases surface runoff more than fivefold as compared to forested catchments [20]. In non-urbanized watersheds, evaporation accounts for 40% of the precipitation, while 50% of the rainfall recharged groundwaters and only 10% of the precipitation is lost due to surface runoff (Fig. 4.4). Urbanization of the landscape considerably changes these figures: paving areas and channelizing of the rivers lead to

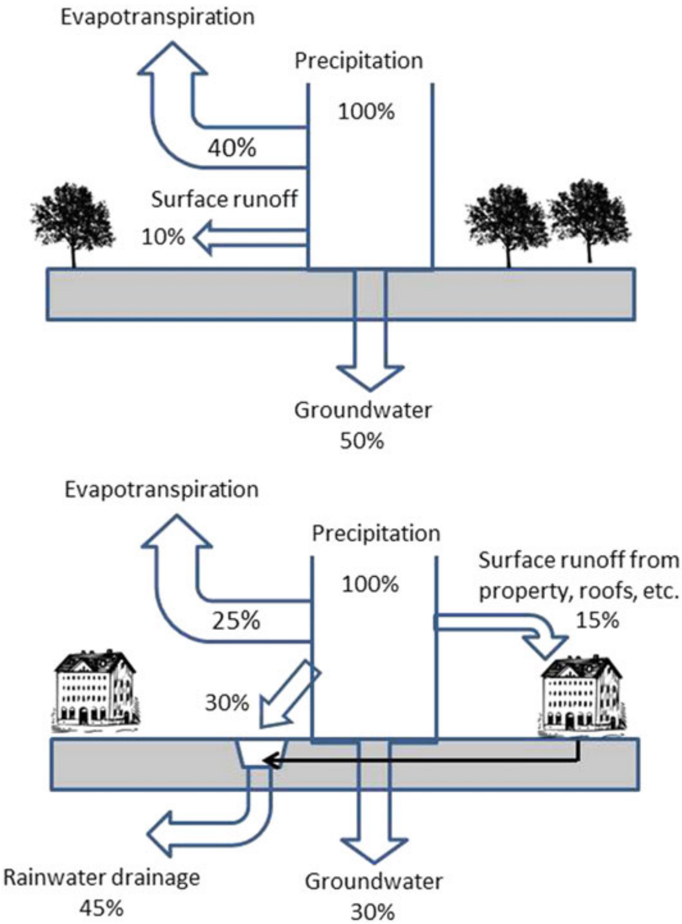

Fig. 4.4 Water balance in natural (top) and urbanized (bottom) catchments (modified after various sources)

an increase in the runoff volume. Thus, only a small amount of the water remains in the same place where it falls as rain and is available for evapotranspiration or groundwater recharge. Paving by concrete and asphalt occurs mostly in urban areas; whereas, in the agricultural landscape, soils are usually compacted by heavy machines and tractors and allow almost no infiltration of rainfall. Moreover, agricultural soils lack organic matter and humus which strongly bind the water. Hence, instead of the accumulation of water within the soil horizon and increasing the storage capacity of the groundwater, water is lost from the landscape by overland runoff or rainwater drainages.

4.5 Wetlands and Climate

4.5.1 Role of Wetlands in Landscape

Wetlands occur where water is present on or near the land surface at a sufficient duration for aquatic communities to develop. Such localities typically occur where surface runoff is slow, infiltration of water is restricted, or groundwater discharges at or near the land surface. Wetlands also have a substantial exchange with atmospheric water in the form of precipitation and evapotranspiration. Therefore, understanding why wetlands form where they do requires an understanding of the flow of water over and through the earth, as well as water exchange with the atmosphere. It is proposed that understanding the sources and losses of water to and from wetlands in the context of their position within hydrological landscapes is fundamental to evaluating the effect of climate change on these ecosystems [67]. Wetlands are well known as important units of the landscape for their role in regulating the hydrological cycle through flood retention and moderation. Other functions of wetlands include facilitation of biodiversity, accumulation of organic matter, recycling of nutrients, trapping of sediments, recreation function, food provision, and biomass production. A largely unrecognized service, but potentially the most important of all those known, is their direct role in regulating water and air temperature—hence climate change—through evapotranspiration. The cooling effect of wetlands is regarded as an important ecosystem service [68, 69]. In relation to greenhouse gasses, investigators refer to the indirect effect of wetlands on climate, with wetlands functioning as either a source or a sink of greenhouse gasses such as CO_2 (carbon dioxide) and CH_4 (methane) (e.g. [70]), thus playing an important role in carbon sequestration (e.g. [71]).

The sun's energy drives our water cycle, plant growth and all other living processes in the biosphere. There is a large difference between the distribution of solar radiation in functioning natural ecosystems of high plant biomass well supplied with water compared to dry, biomass poor ecosystems with far more non-living physical surfaces—because of the impacts of solar energy upon water molecules. The incoming solar radiation is dissipated at the surface (and at other strata) by evapotranspiration–condensation. Latent heat flux represents the energy that is released or absorbed from the surface during the phase transition process. The transition of a liquid into a gas consumes energy and thus is accompanied by local cooling. *Latent heat flux* is generally referred to as evapotranspiration, which describes the total evaporation from land surface and transpiration by plants. Evapotranspiration from wetlands is on the order of several hundred Watts (W) m^{-2} on a sunny day [72–74]. *Sensible heat flux* represents the sum of all heat exchanges between the surface of the landscape and its surroundings by conduction and convection. The proportion of sensible heat in the energy balance of an ecosystem increases when water is not present since the capacity for evaporative cooling by latent heat is diminished. On dry surfaces, the sensible heat flux may reach values of several hundreds of W m^{-2} on a sunny day [75] (Fig. 4.5).

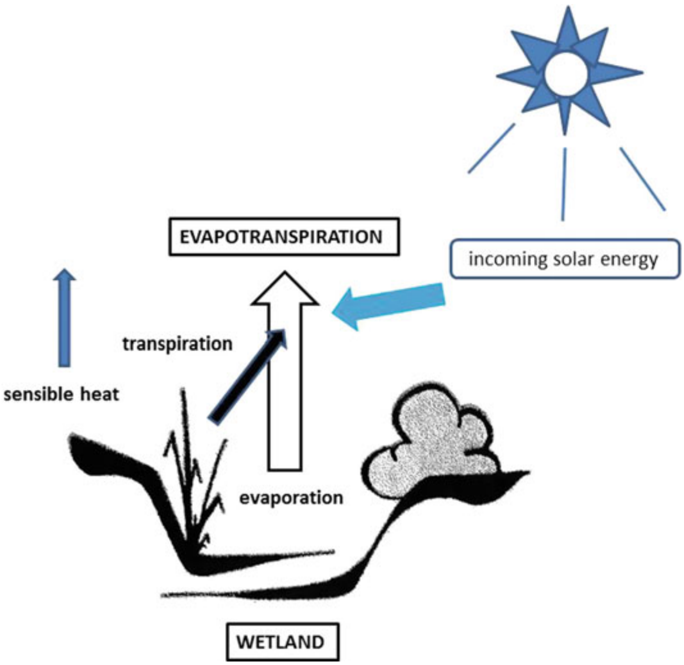

Fig. 4.5 Cooling effect of wetlands in the landscape where water is available (original)

Evapotranspiration (ET) is a powerful cooling process, having a double air-conditioning (gradient reducing) effect upon the landscape: (a) evaporation provides cooling by consuming solar energy for transfer of liquid water into water vapour; and (b) subsequent condensation of water vapour warms air where it occurs, releasing latent heat when the dew point is achieved on cool surfaces. The following example may help to understand the combined cooling effects of ET: The decrease in ET from 1 km^2 (100 ha) as a result of drainage is approximately 250 W m^{-2} (equivalent to 100 mg s^{-1} of water vapour), and this 250 MW of solar energy in 1 km^2 is thus released into the atmosphere as warm air (sensible heat). In August 2015 in the Czech Republic, the total surface area of harvested wheat and rapeseed fields was about 18 thousand km^2 (1.8 million ha), and sensible heat released from this dry surface area was thus at least 4.5 million MW. Human generation of such heat from electricity production would require 4500 nuclear power stations, each producing 1000 MW [76].

The evapotranspiration–condensation process slows down when there is a shortage of water; solar energy is consequently converted into sensible heat (H). The sensible heat warms the air, which rises in a turbulent motion creating atmospheric instability. The drainage of wetlands causes a shift from latent heat to sensible heat flux, which results in an increase in temperature and thus water loss from the landscape [77]. The distribution of latent and sensible heat between a wetland and dry (drained) land differs by several hundred W m^{-2} during a sunny day. In wetland ecosystems, latent heat prevails and uses about 60–80% of net radiation, sensible heat uses about 20–30%, while ground heat flux is 10–20%. The amount of sensible heat released as a consequence of land cover changes is much higher than heat caused by increased carbon dioxide concentrations, leading to the greenhouse effect. Thus, wetlands influence the local climate through evapotranspiration; wetlands moderate extreme day and night temperature in a similar manner as forests [72, 73].

4.6 Conclusions

The traditional or old water paradigm dictating water management in developed countries around the world during the last two centuries was based on perceiving the water cycle separately from the soil, vegetation and above all atmospheric processes. Engineers have worked with water as a measurable entity in river channels and reservoirs, precipitation was evaluated incorrectly, and water in the soil and landscape was treated as an obstacle to remove. Problems with water in watersheds (e.g. flooding) were primarily solved by adjustments to downstream river stretches while ignoring the synergic effects of thousands of small changes in the upper part of watersheds [78]. Those many small modifications and subsequent loss of retention capacity in the upper watershed lead to compounding impacts of increased discharge and flood events. An additional consequence of draining vast portions of the landscape has been the decline of groundwater levels, acceleration of water runoff, lowering of the river's self-purification capacity, attenuation of small water cycles, and—last but not least—degradation of water and wetland habitats essential for aquatic biodiversity. The old paradigm no longer has the ability to inform urgent tasks of today, such as climate adaptation measures (e.g. mitigation of extreme floods and drought, ensuring enough drinking water, and sewage water treatment), inhibiting climate change drivers (stabilization of the carbon cycle and fortifying the small water cycle) and protection of vanishing water and wetland habitats.

Solving these complex questions is possible only by using a new water paradigm that is responsive to the role of water in the landscape (see [78]). This new paradigm is based on the integration of all processes affecting water in the watershed, not only in the channels or reservoirs. It means considering water vapour, transpiration and groundwater recharge. Evaporation from the water and plant surfaces should not be perceived as a loss, but rather as critical components of the water cycle necessary for climate stabilization [73, 74]. Only a few years ago, the Czech Republic was a region where streams flowed with water year-round. Today, many small streams become dry during the summer on one hand, and flash floods are more common on the other hand. Both of these extreme events have catastrophic consequences for human infrastructure and ecosystems. There are two main strategic goals for restoration of the full water cycle: first the restoration of drainage patterns with natural hydromorphology, and second the improvement of water retention capacity across the landscapes of Czech Republic—water needs to infiltrate the soils at the same place where it falls as rain [5, 6, 11]. Both of these approaches aim to restore the full water cycle, similarly as developed in Portugal through the *Water Retention Landscapes* programme [79]. 'The basic principle of a water retention landscape is that no rainwater should run off, but rather infiltrate into the soil where it falls' [79]. The absorbed rainwater infiltrates the aquifer and is purified, energized and mineralized. 'All outflowing water is spring water, steadily supplying humans, flora and fauna with liquid life—even during long periods without rainfall' [79]. Retention of the water in the landscape is considered a tool to create conditions for water self-purification, biodiversity conservation, recreational and aesthetic properties of the landscape.

4.7 Recommendations

During the writing of this chapter (August 2018), one of the infamous 'hunger stones' became exposed on the River Labe (Elbe) at Děčín, Czech Republic, near the German border. Hunger stones are boulders that are normally submerged but become exposed during periods of extreme low water. Over time, people have commemorated periodic droughts by carving inscriptions into the stones, for example: *Wenn du mich siehst, dann weine* ('If you see me, weep'). Hunger stones have thus become long-standing indicators of hydrological extremes [80], but also vivid reminders that our society is engaged in an intimate relationship with water and its myriad cycles; therefore, our management actions, policies and future investigations should honour this relationship.

The principles outlined in this chapter call for alternative approaches to land use and land management. Widespread agricultural practices in Czech Republic that reduce the soil's capacity to retain water (e.g. through soil compaction, reduced organic matter, etc.) should be replaced with strategies that work within the confines of the hydrological cycle. In particular, the European Commission's Climate-ADAPT programme suggests checking and rebuilding old drainage systems; establishing variable water flow regimes; rehabilitating and reconstructing/adapting morphological structures in rivers; and adopting crop rotation, minimal or no-tillage systems, and improved soil cover management practices; in addition to other recommendations [81]. Unchecked growth of urban areas, often coinciding with increased area of impervious surface, should be put in check and/or developed in a manner allowing maximum water retention in the landscape. Riverine elements within or adjacent to the stream (floodplains, wetlands, alluvial ecosystems) have a disproportionately large impact on water storage capacity relative to their small surface area as compared to uplands and should therefore be granted special protection where they exist and prioritized as areas for restoration where they have been degraded.

Future research should strive to elucidate a better understanding of how water functions at both global and local scales. Many controversies about the most basic functions of rivers still exist; for example: whether restoration of wetlands adjacent to small streams and subsequently increased water retention translates directly into increased late-summer streamflow and reduced water temperature, both vital to aquatic life (see [82, 83] for differing viewpoints). Increased understanding of aquatic-terrestrial linkages would help provide the knowledge basis for difficult decisions about managing uplands, floodplains, wetlands and river ecosystems in general. Studying the connections among wetlands, floodplains and small water bodies to climate change—for example, their complex role in acting as carbon and methane sources and/or sinks—would further aid managers and policy makers in balancing the needs of (and benefits from) ecosystems with a growing human population.

Finally, we recommend engaging stakeholders and professionals from diverse disciplines in discussions about how to manage water on the landscape in a manner beneficial to all parties, including humans but also wildlife and ecosystems. For example, in Czech Republic the default solutions to water scarcity or flooding tend to include protective reservoirs, dams or increases in river channel capacity; all of which can degrade river ecosystems [84] and even amplify the original problem—such as increased flooding downstream of armoured channels intended to prevent floods in the first place [85]. One fundamental barrier to coordination is the disparate world views of the respective disciplines dating to the nineteenth century. Engineering solutions are often employed when an ecosystem service is perceived as not being able to provide for humans' comfortable lifestyle [86]. Despite their demonstrated benefits, it has become obvious that purely technical solutions in water management are not sufficient; moreover, they are often contradictory [36]. The growing pressures for sustainable approaches to water management have precipitated a shift in perspective from 'control by construction' to 'stewardship and dynamic/adaptive management;' in the latter view, both ecosystems and economics are given due consideration [87, 88]. These various disciplines, having apparently disparate objectives, will need to find common ground if productive dialogue will ensue about scarce water resources in Czech Republic and elsewhere, especially in the face of a rapidly changing climate.

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Chapter 5
Small Water Reservoirs, Ponds and Wetlands' Restoration at the Abandoned Pond Areas

M. Rozkošný, M. Dzuráková, R. Pavelková, V. David, H. Hudcová and P. Netopil

Abstract Small water reservoirs are one of the basic elements of the agricultural landscape in the Central European space. They are one of the most valuable nature-loving elements of the cultural landscape. In the Czech Republic, they have a long historical tradition. Artificial water reservoirs were probably built in our country in the eighth and ninth centuries AD. Since the beginning of the 1990s, new SWRs, including ponds for fish farming, or the restoration of existing and abandoned ones, have been implemented, thanks to various subsidy programmes, especially the river network revitalization programme. The chapter summarizes the procedures for identification of areas of historic ponds using maps of military mapping on the territory of the Czech lands and their interpretation in connection with water revitalization and restoration projects of the small watercourses, carried out in the Czech Republic since 1992.

Keywords Small water reservoir · Subsidies · Abandoned ponds · Watercourse restoration · Wetland restoration

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M. Rozkošný (✉) · M. Dzuráková · H. Hudcová
T. G. Masaryk Water Research Institute, Public Research Institute, Mojmírovo nám. 2997/16, 612 00 Brno, Czech Republic
e-mail: milos.rozkosny@vuv.cz

R. Pavelková · P. Netopil
Faculty of Science, Palacký University in Olomouc, Olomouc, Czech Republic

V. David
Faculty of Civil Engineering, Czech Technical University in Prague, Prague, Czech Republic

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5.1 Introduction

5.1.1 *Historical Development of Ponds Within the Czech Lands*

Small water reservoirs are one of the basic elements of the agricultural landscape in the Central European space [1, 2]. They are one of the most valuable nature-loving elements of the cultural landscape. In the Czech Republic, they have a long historical tradition. Artificial water reservoirs were probably built in our country in the eighth and ninth centuries AD. The first written record of the ponds in the Czech Republic is in writing, "Kladrubská listina" of 1115. According to another record from 1227, the abbot of a Premonstratensian monastery received permission from the Czech ruler Premysl Otakar I to buy the Lovětín forest in southern Moravia in order to costruct ponds. From the mid-fourteenth century construction techniques advanced considerably allowing higher earth dams to be built in the floodplains and ponds to be constructed in the marshy plains. Ponds, created in the thirteenth and fourteenth centuries, contributed to changing the landscape and the road network built on their dykes helped to develop trade with neighbouring regions and countries [3]. The beginning of the fifteenth century saw the first major era of ponds construction, due mainly to the Hussite wars. It was only in the 1570s that the interest of the nobility (ponds of the Pernštejn noble family in Moravia, ponds of the Rosenberg noble family in Třeboň and the surrounding estates in eastern and southern Bohemia), but also burghers (the pond network around the towns Blatná and Lnáře, City of Prague, North Bohemia territory—around the town of Doksy and in the Českomoravská vrchovina highland—e.g. Dářko pond) focused on fish farming. The most advanced Moravian pond production area was south of the Brno city and stretched to the Austrian border (Pohořelice and Lednice areas). At the time of the greatest boom in the fifteenth and sixteenth centuries, the number of ponds was estimated to be between 75,000 and 78,000 , covering an area of over 180,000 ha [4]. Political changes in the country, culminating in the Thirty Years' War, contributed to the stagnation of ponds construction [5] in the seventeenth century. This period of inactivity lasted until the nineteenth century. In the second half of the nineteenth century, an interest in ponds was again revived in the Czech lands, due also to the development of a scientific approach to some basic questions of fish farming. The reconstruction of ponds started with the use of modern techniques, specifically after September 1890, when a catastrophic flood swept a number of ponds away in South Bohemia [3]. Other substantial changes occurred with the emergence of the independent Czechoslovakia in 1918, particularly with the land reform of 1919, according to which most ponds were nationalized. However, only large pond systems, which form the basis of state fishing with a total area of 120 km^2, were taken in this regard. After 1945, in connection with the changes in the border mountainous strip of the country named Sudetenland, there was a temporary abundance of land suitable for the recovery of numerous previously abandoned ponds. In addition, several small special-purpose reservoirs were built. However, contrarily, in some areas of this strip these changes led to the disappearance of ponds due to lack of farming.

5.1.2 Small Water Reservoirs and Ponds in the Twentieth Century

Authors [3] mention an estimation of the number of ponds and other small water reservoirs ("SWR" in the following text) in 1970. According to statistical data from this year, the Czechoslovak water management plan ("Směrný vodohospodářský plán") mentioned about 24,000 of ponds and SWRs with a total cadastral area of about 550 km^2 and a volume of almost 520 million m^3. In the territory of the Czech Republic there were about 23,400 of such water bodies with an area of 518 km^2 and a volume of 486 million m^3. For the year 1950, the authors present an estimate for the territory of the Czech Republic of about 21,800 water bodies (10,800 within the Vltava River basin, 3,000 within the Morava River basin, 2,800 within the Berounka River basin, 2,500 within the upper and middle Elbe River basins, 2,300 within the lower Elbe River basin and 500 within the Odra River basin) with a total surface area of 480 km^2 and volume of 452 million m^3. Only 69 ponds remained in the Pardubice town pond network from the wide-ranging pond system of up to 350 ponds established in the fifteenth and sixteenth centuries. Detailed information about other catchment areas in the South Moravia region was published by [6]. Subsequent changes in the water management were connected to social changes after 1989. These changes also brought fundamental alterations in property conditions and plans for the renovation and construction of SWRs.

5.1.3 Small Water Reservoirs, Ponds and Wetlands After 1989

Since the beginning of the 1990s, new SWRs, including ponds for fish farming, or the restoration of existing and abandoned ones, have been implemented, thanks to various subsidy programmes, particularly the river network revitalization programme [7, 8]. At present there are approximately 22,000 ponds in the Czech Republic. Thanks to a wide range of positive rules in the landscape, small standing surface water bodies belong to the indispensable elements in terms of water management. Their economic importance (fishing) is still relevant. SWRs, including ponds, can be an essential elements for the landscape planning as defined by its principles [9]. In the Czech Republic and also abroad they are built for different purposes and provide a variety of benefits for the landscape as well as aiding the containment of pollution nad supporting biodiversity [2, 10]. As a basis for the further development of the restoration and revitalization of small water reservoirs, including ponds, information on their historical localization can be provided. They can contribute to knowledge of local hydrological conditions, which is important in times of climate change.

5.1.4 Aim of the Chapter

The aim of the chapter is to present possible ways of the identification of abandoned pond areas suitable for the implementation of new ponds, different types of small water reservoirs, wetlands and pools. It summarizes the experience with the use of historical maps for the identification of small water reservoirs in the past in the Czech Republic territory, focusing on the small water catchment areas, where measures funded by the mentioned revitalization programme were placed in the period 1992–2006. The use of historical maps in combination with other sources of spatial information in example 27 of such catchments is assessed. The next sources were used for the analyses: available databases, the maps of the historical landscape utilization, the digital database of water management data, the basic database of the Czech geographic data and the results of the landscape features mapping in the catchments displayed in the geographic information system. It was done a comparison with the results of revitalization works, which in many cases included the renovation or construction of new small water reservoirs [6, 11]. The chapter presents three detailed case studies of abandoned pond areas possible utilization within landscape and watercourses revitalization works.

5.2 Methods

5.2.1 Survey of Historical and Abandoned Ponds Areas

In order to determine the actual land use of the abandoned historical pond areas, the basic database of geographic data of the Czech Republic [12] was selected as the most appropriate (accessibility, topicality, spatial resolution). The database was created by the digitization of the Basic Map of the Czech Republic in the scale of 1: 10,000 and the S-JTSK coordinate system until 2004 and is regularly updated. The next step was to work with spatial data in the GIS environment, in particular, ArcGIS 9.3.1 software. First, all attribute layer tables were modified according to a predefined schema, which meant deleting some fields (columns) from the original ZABAGED database, which were irrelevant for the purpose of determining the land use of the areas or renaming the necessary fields. The refinement of the surface area of flowing and standing water was made using the Digital Water Database (DIBAVOD) as the thematic water management superstructures of the ZABAGED [13].

Old maps and aerial photographs are used and are a suitable tool for comparing the state and localization of landscape elements, including the use of GIS tools [14–18].

Information from the maps can be examined and studied by researchers from many sciences and bring an overview about the landscape state which no longer exists for. Such information can be used for the proposal of future landscape changes [19]. The 2nd Military Survey ("2MS" in the following text) map files were used to create map databases of abandoned ponds. Military mappings are accessible via the WMS service, with a preview in the Land Cadastre views accessible through the Web interface (Data Source: © 2nd Military Survey, Section, Austrian State Archive/Vienna Military Archive, © Geoinformatics Laboratory JE Purkyne University—http://www.geolab.cz, © Ministry of the Environment of the Czech Republic—http://www.mzp.cz). The drawings were further elaborated in ArcGIS 9.3 [11]. Based on GIS analyses and manual verification of the accuracy of localization of historical small water reservoirs from 2MS maps, it was decided to present and further analyse sites of historical ponds with an area of over 0.5 ha [20]. The problems of scale, differentiation and interpretability of landscape structures using GIS tools are dealt with by [21].

5.2.2 Cluster Analysis of Abandoned Pond Areas

The cluster analysis of abandoned pond areas by the group of selected variables was chosen as a next step of the work focusing on the definition of possible utilization of the areas within the implementation of the measures for better landscape water management.

Cluster analysis is one of the multidimensional statistical methods used to classify objects. It can be used to sort the units into groups (clusters) so that units belonging to the same group are more similar to objects from different groups. Clustering can be performed on both a set of objects (in our case, water areas), each of which must be described by the same set of variables that are relevant in the set to be monitored, as well as on a set of variables that are characterized by a particular set of objects (e.g. water areas). This ability to monitor similarities between variables was used in this work. The basic breakdown of cluster analysis is hierarchical and non-hierarchical [22]. In the exploratory nature of examining similarities between variables, where the number of clusters is unknown, the hierarchical methods that lead to the branching of the classification are more appropriate. From the hierarchical methods, the "agglomerative" approach appeared to be the best fit, based on the knowledge of the variables, which this approach gradually connects to each other, respectively to the created clusters until one cluster is created after all variables have been joined. The simple link metric was chosen as a method of distance between variables study. The merging algorithm was based on the Ward method, which is based on the minimum sums of squares of distances [23].

5.2.3 Restoration and Renewal of SWRs and Ponds Analyses

The assessment of the development of small water reservoirs since 1990 is based on the analysis of the databases of projects supported by the river network revitalization programme (1992–2006) and the first Czech Operational Programme "Environment" (2007–2013). In 1992, the revitalization programme was launched in the Czech Republic, financially supported from the state budget and methodically managed by the Ministry of the Environment of the Czech Republic. Large numbers of measures were implemented within the framework of this programme, mainly as a restoration of regulated sections of water streams and the restoration or revitalization of small water reservoirs and the implementation of accompanying pools, wetlands and plantations [7]. Due to the fact that a large part of the measures consisted in the realization of a combination of river bed modifications and the construction of small water reservoirs, we focused on the assessment of the location of new or revitalized water reservoirs within the studied parts of catchment areas of revitalized small water streams with the occurrence of historical ponds in these catchments and the analysis of the current use of the area on the abandoned ponds.

The overview of the evaluated water catchments with performed water revitalizations in the period from 1992 to 2006, including the basic descriptive characteristics, is given in Table 5.1. As in the other tables in the chapter, the districts of the Czech Republic are listed with abbreviations based on official sources [24]. The water catchment areas were chosen with a view to the best possible coverage of individual types of watercourses with regard to morphology and geography and with regard to the type of revitalization performed. The effort was to make the complete revitalization carried out in the given period.

5.2.4 Landscape Stability Mapping

The results of the landscape mapping were used to analyse the current status in individual river basins in terms of landscape features and ecological stability. Landscape mapping in 2006 and 2010 in selected river basins was carried out according to the methodology of Pellantová et al. [25]. The selected method works with certain associated mapping units according to the current vegetation types, the so-called physiotopes of the current vegetation. It also includes the investigation of the degree of ecological stability of mapped units. Mapping was standardized on 1:10,000 map sheets. The resulting output is a map of physiotopes of the current vegetation and a map of the ecological stability of the area. Landscape areal and linear structures were mapped, and the result map layer was used in the analysis of the relation between historical ponds and new water bodies, as shown in Figs. 5.1 and 5.2 for the Haraska and Slupský potok watercourses, which represent different types of landscape with small water reservoirs and revitalization (Haraska—intensively agriculturally managed catchment, Slupský potok—a catchment with predominantly

Table 5.1 Characteristics of the small water stream catchments with accomplished restoration works

Name of the stream	Average altitude (m)	Type of stream	Czech district	Year of restoration works	Coordinates of the closure profile	Length of restoration (km)	Catchment area (km^2)	"P-Kes" coeffi-cient
Borová	630	Montane	CK	1999	48.8751433N14.2202508E	1.700	17.792	31.16
Brodec	460	Uplands	BN	2002–03	49.6165322N14.8996208E	0.500	13.027	0.06
Buchlovický potok	220	Lowland	UH	1996–98	49.0720647N17.3402472E	0.700 and 1.500	16.543	0.06
Čížkovský potok	480	Submontane	PJ	1997	49.5395847N13.6756933E	3.141	18.088	0.16
Halenkovický potok	200	Lowland	ZL	2002–03	49.1486686N17.4776419E	4.500	5.026	0.14
Haraska	210	Lowland	BV	2002–04	48.9768469N16.8027406E	1.000	31.815	0.23
Heroltický potok	250	Uplands	BO	1999	49.3165181N16.4120675E	7.312	7.312	0.90
Chrudimka	640	Submontane	CR	1996	49.7394592N15.9767242E	0.890	11.407	0.10
Kněhyně	540	Montane	VS	2004	49.4532814N18.2731719E	0.420	18.579	3.29
Krasovka	430	Submontane	BR	2001–02	50.0866603N17.5922383E	3.600	38.312	0.17
Liboc	240	Submontane	CV	1995	50.3064814N13.4171150E	2.413	2.208	–
Lubnický potok	360	Uplands	UO	2004–05	49.8704853N16.6561833E	1.000	10.716	0.07

(continued)

Table 5.1 (continued)

Name of the stream	Average altitude (m)	Type of stream	Czech district	Year of restoration works	Coordinates of the closure profile	Length of restoration (km)	Catchment area (km^2)	"P-Kes" coeffi-cient
Lužní potok	750	Submontane	CK	2001	48.6807519N14.1234800E	2.500	5.238	25.54
Martinický potok	440	Submontane	CR	1995	49.8254069N16.0708978E	1.221 and 0.638	12.41	0.47
Mašovický potok	360	Lowland	ZN	2000–01	48.8594447N15.9831092E	9.968	9.968	–
Mlýnský potok	780	Submontane	CK	1998	48.5993094N14.1213356E	1.692	8.882	20.82
Modla	170	Lowland	LT	1995–96	50.4618408N14.0297414E	2.346	47.36	–
Moravický potok	520	Montane	BR	1998	49.9763967N17.3242136E	4.820	10.453	0.97
Olšovka	200	Lowland	HK	1996–03	50.2758958N15.8145042E	2.000	16.478	0
Postřelmůvek	310	Lowland	SU	2002–03	49.9156247N16.8900539E	0.860	7.801	0.28
Tributaries of the Moravice River in the "Lučiny" area near Dolní Moravice village	600	Submontane	BR	2000	49.9612286N17.3322175E 49.9594894N17.3332475E	1.290	6.300	0.25

(continued)

Table 5.1 (continued)

Name of the stream	Average altitude (m)	Type of stream	Czech district	Year of restoration works	Coordinates of the closure profile	Length of restoration (km)	Catchment area (km^2)	"P-Kes" coefficient
Příbramský potok	400	Uplands	BO	2000–01	49.1992306N16.3000625E	1.363	6.721	0.76
Tributaries of the Divoká Orlice River in the Orlické Záhoří cadastre	680	Montane	RK	2003	50.2632175N16.4937106E 50.2666467N16.4888611E 50.2806900N16.4747850E	2.676 and 0.460	59.929	1.60
Slubice	550	Lowland	CR	1997	49.7298019N15.8640231E	0.783	8.104	0.87
Slupský potok	530	Uplands	BN	2003–04	49.6101792N14.7013786E	0.700 and 1.500	16.487	0.92
Včelnička	620	Uplands	PE	1992–97	49.3311178N15.0189267E	3.941	6.785	2.38
Zbytinský potok	700	Submontane	PT	2004	48.9400958N13.9693067E	0.500 and 1.000	9.718	20.13

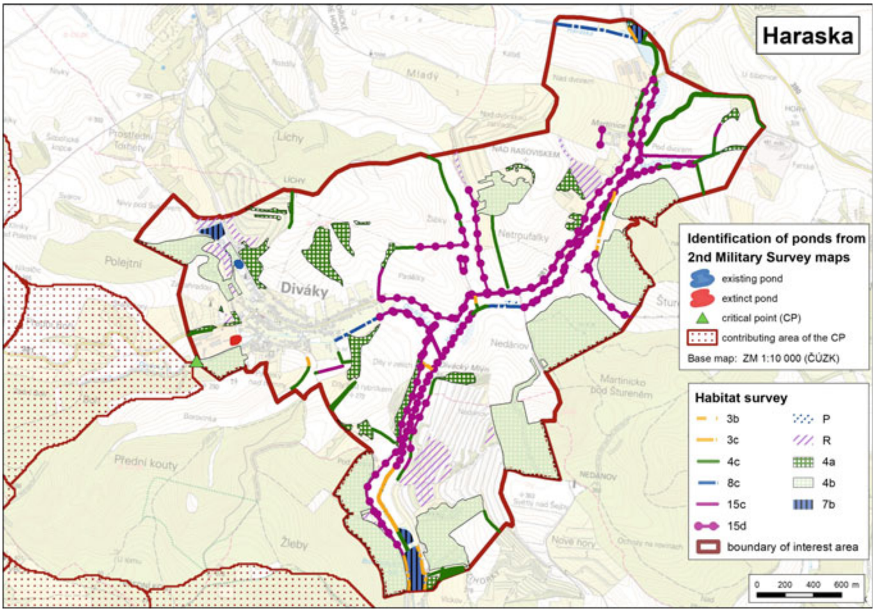

Fig. 5.1 Selected part of the Haraska stream catchment with the display of the water bodies' occurrence after the restoration works and from the 2MS maps' analysis

extensive agriculture). The procedure for determining the ecological stability of the area and the calculations of the ecological stability coefficient was carried out according to the method described by Klementová and Skálová [26]. The procedure was published at Web pages [27]. The coefficient P-Kes values are included in Table 5.1 for the localities listed in the table. The ecological stability coefficient was calculated only for the mapped parts of the catchments. These parts of them have relevant relationship to the revitalized section of the water streams, including related anthropogenic pressures. Overall prospective approach to the study of ecological stability was published by Donohue et al. [28]. An investigation of the selected methods of assessing landscape services, including description of the rules of the ecological stability rating, is mentioned by Skokanová [29].

5.3 Results

5.3.1 Cluster Analysis Result

Hierarchical clustering has served as a guideline for the number of clusters because we were working with a database of water areas containing more than 10,000 records. The assessment consisted of a visual evaluation of the dendrogram. The indicative

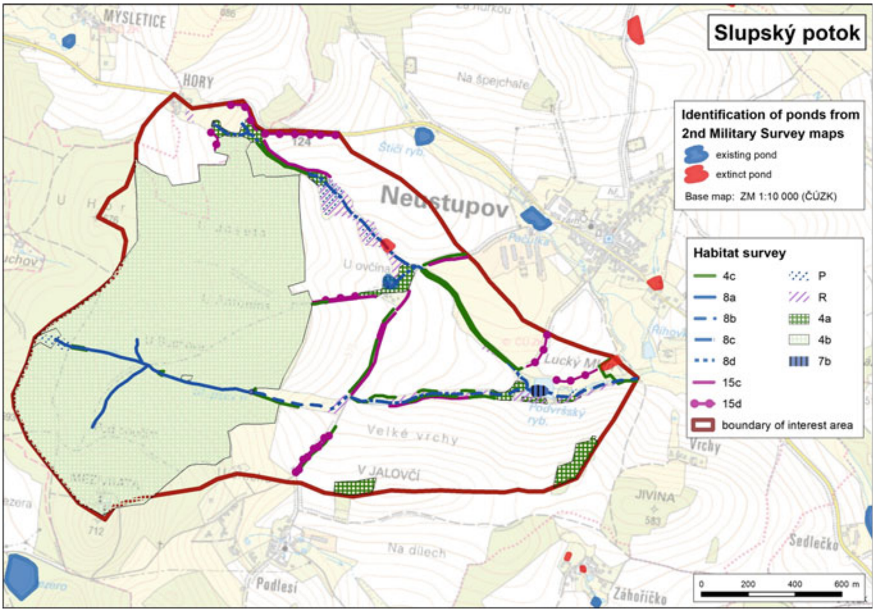

Fig. 5.2 Selected part of the Slupský potok stream catchment with the display of the water bodies' occurrence after the restoration works and from the 2MS maps' analysis

number of clusters derived from the hierarchical method was the criterion for the non-hierarchical k-diameter method. This allowed the water areas to be divided into a predetermined number of clusters. The criterion of the quality of the division of the regions was the minimization of intragroup variability. Cluster analysis was performed on standardized z-score values. The whole datasets were standardized by simple average and standard variation. The result was a dataset of spaceless values.

Among the studied variables were included: the area of historical pond/variable 1/, types of utilization (agricultural area /variable 2/, permanent grassland /3/, built-up area /4/, forest /5/, water /6/), altitude /7/, average annual temperature /8/, average rainfall /9/and land price relative to the year 2013/variable 10/. The aim of the analysis was to classify the selected group of areas of abandoned ponds (with an area over 0.5 ha) according to selected variables into clusters with a certain type of properties for which it would be possible to define suitable variants of the utilization in the frame of the soil and water resources management. The procedure for creating a selected group of abandoned ponds over 0.5 ha for analysis is described in detail in [21].

Created clusters are as follows:

1. Cluster, 423 abandoned pond areas
   Description of the cluster:
   Ponds in middle altitudes at built-up or forest areas with surface areas round the average value

2. Cluster, 337 abandoned pond areas
   Description of the cluster:
   Grassed ponds in low altitudes with temperatures above average, but low precipitations and soil properties slightly above average
3. Cluster, 543 abandoned pond areas
   Description of the cluster:
   Ponds utilized for agriculture, but of smaller area and located in a higher altitude
4. Cluster, 897 abandoned pond areas
   Description of the cluster:
   Grass-covered ponds in higher altitudes with worst-quality soils
5. Cluster, 395 abandoned pond areas
   Description of the cluster:
   Largest water bodies, agricultural management of the areas in lowlands with high-quality soils

The surface area of ponds did not play an important rule in the cluster analysis, with one exception, the cluster 5. The spatial distribution of individual areas within all the clusters in the Czech Republic territory is shown in a map as in Fig. 5.6.

5.3.2 Results of the Historical and Abandoned Ponds' Determination

Table 5.2 presents an overview of the identified water bodies of historical and abandoned ponds with the water surface above 0.5 ha.

The graphical dependence of the number of abandoned ponds on the number of historical ponds was elaborated on the basis of the analysis of the number of areas of historical and abandoned ponds in individual districts of the country.

The result of the analysis is best described linearly with the correlation equation:

$$y = 0.26 * x$$

where x is the number of historical ponds, y is the number of abandoned ponds.

Regression coefficient value was calculated $R^2 = 0.8$. That indicates a strong regression relationship between the two variables. The result can be interpreted to mean that a quarter of the historic ponds in the district have disappeared on average. Following statistical characteristics were calculated from the dataset: 43% of ponds were abandoned in average with the standard deviation of 20.5%, median value of the dataset 39, 25% percentile of dataset is 28 areas and the 75% percentile of dataset is 52 areas.

Due to the varying numbers of historical ponds in districts between several areas and hundreds areas, this analysis was further elaborated. The maximum value about 1,600 ponds was calculated for the Jindřichův Hradec district.

Table 5.2 Numbers of historical and abandoned ponds within the territories of the Czech Republic districts

Czech district	Number of historical ponds	Number of abandoned ponds	Czech district	Number of historical ponds	Number of abandoned ponds	Czech district	Number of historical ponds	Number of abandoned ponds
BN	332	50	KI	107	85	PT	99	26
BE	52	21	KD	41	18	PV	27	10
BK	39	17	KT	257	50	PR	35	26
BM	4	2	KO	66	27	PB	342	49
BO	42	32	KM	18	14	RA	72	20
BR	11	7	KH	148	49	RO	66	19
BV	47	27	LI	28	6	RK	65	34
CL	89	29	LT	24	8	SM	24	12
CB	712	147	LN	28	9	SO	99	79
CK	103	28	ME	15	5	ST	410	45
DC	62	14	MB	192	77	SY	59	14
DO	155	49	MO	40	30	SU	20	14
FM	78	70	NA	69	36	TA	559	117
HB	282	109	NJ	46	17	TC	248	37
PHA	53	15	NB	97	46	TP	46	24
HO	59	49	OC	38	26	TU	27	16
HK	151	78	OP	59	24	TR	254	77
CH	203	60	OV	158	138	UH	21	19
CV	62	29	PU	189	105	UL	9	3
CR	137	43	PE	501	157	UO	73	30
JN	5	3	PI	357	65	VS	4	2
JE	15	10	PJ	175	28	VY	14	7
JC	133	67	PM	18	4	ZL	5	4
JI	369	96	PS	108	31	ZN	74	34
JH	1579	417	PY	90	24	ZR	482	122
KV	234	74	PZ	46	15			

List of Czech districts [24]

BN Benešov, *BE* Beroun, *BK* Blansko, *BM* Brno-město, *BO* Brno-venkov, *BR* Bruntál, *BV* Břeclav, *CL* Česká Lípa, *CB* České Budějovice, *CK* Český Krumlov, *DC* Děčín, *DO* Domažlice, *FM* Frýdek-Místek, *HB* Havlíčkův Brod, *PHA* Hlavní město Praha, *HO* Hodonín, *HK* Hradec Králové, *CH* Cheb, *CV* Chomutov, *CR* Chrudim, *JN* Jablonec nad Nisou, *JE* Jeseník, *JC* Jičín, JI Jihlava, *JH* Jindřichův Hradec, *KV* Karlovy Vary, *KI* Karviná, *KD* Kladno, *KT* Klatovy, *KO* Kolín, *KM* Kroměříž, *KH* Kutná Hora, *LI* Liberec, *LT* Litoměřice, *LN* Louny, *ME* Mělník, *MB* Mladá Boleslav, *MO* Most, *NA* Náchod, *NJ* Nový Jičín, *NB* Nymburk, *OC* Olomouc, *OP* Opava, *OV* Ostrava-město, *PU* Pardubice, *PE* Pelhřimov, *PI* Písek, *PJ* Plzeň-jih, *PM* Plzeň-město, *PS* Plzeň-sever, *PY* Praha-východ, *PZ* Praha-západ, *PT* Prachatice, *PV* Prostějov, *PR* Přerov, *PB* Příbram, *RA* Rakovník, *RO* Rokycany, *RK* Rychnov nad Kněžnou, *SM* Semily, *SO* Sokolov, *ST* Strakonice, *SY* Svitavy, *SU* Šumperk, *TA* Tábor, *TC* Tachov, *TP* Teplice, *TU* Trutnov, *TR* Třebíč, *UH* Uherské Hradiště, *UL* Ústí nad Labem, *UO* Ústí nad Orlicí, *VS* Vsetín, *VY* Vyškov, *ZL* Zlín, *ZN* Znojmo, *ZR* Žďár nad Sázavou

The following percentage groups of the number of abandoned ponds versus number of all historical ponds were selected: ≤25%, ≤50%, ≤75%, >75%. In addition, the number of groups of historical ponds was selected: ≤20, ≤100, ≤500, >500. The specific group was allocated below twenty historic ponds within an individual district, given the fact that they are districts around large towns, possibly districts with the submountain geography, where the ponds did not occur historically.

In the group of up to 20 historical ponds within a district, the following distribution of the abandoned ponds percentage ratio was found out:

≤25%—PM district,
≤50%—districts BM, ME, UL, VS, VY,
≤75%—SU district,
>75%—districts KM, ZL.
In the group 20 to 100 historical ponds, the following distribution was found out:
≤25%—districts DC, LI, SY,
≤50%—districts BE, BK, CL, PY, PHA, CV, KD, KO, LT, LN, NJ, NB, OP, PY, PZ, PT, PV, RA, RO, SM, UO, ZN,
≤75%—districts BO, FM, HO, SO, TU, UH.
In the group 100 to 500 historical ponds, the following distribution was found out:
≤25%—districts BN, KT, PJ, ST, TC, ZR,
≤50%—districts CK, DO, HB, CH, CR, JC, JI, KV, KI, MB, PS, TR,
≤75%—districts HK, PU,
>75%—OV district.
In the category of over 500 historic ponds, the distribution was following:
≤25%—districts CB, PI, TA,
≤50%—districts JH, PE,
≤75%—no districts,
>75%—no districts.

5.3.3 Overview of the SWR Restoration Projects in the Czech Republic

The overview of the projects supported by European funds (Operation Programme "Environment") is shown in Table 5.3. The approved and financially supported projects were divided into three categories (types of measures): 1—new small water reservoirs and ponds; 2—small water reservoirs and ponds' sediment removal; 3—revitalization and/or restoration of small water reservoirs and ponds.

In total, 342 "type 1" projects, 186 "type 2" projects and 174 "type 3" projects were supported in the territories of 68 districts of the country. The highest number of projects was supported and implemented in the JI, JH, PE, TR, ZR and HB districts, where there were a large number of fish ponds historically (see Table 5.3). It is important to emphasize that the data in the table does not correspond exactly to the official information, what was not possible to study. It is only an analysis based on the

Table 5.3 Summary of the number of projects approved under the Operational Programme "Environment" in the individual Czech Republic districts in the period 2007–2013, connected with small water reservoirs and ponds management, including expenditures

TU	1		2		3			1		2		3	
OK	PP	CNP	PP	CNP	PP	CNP	OK	PP	CNP	PP	CNP	PP	CNP
BN	9	23,970	6	107,983	7	38,683	NB	3	25,706	3	14,352	2	9,193
BE	2	6,188	2	7,393	1	1,135	OC	3	13,497	0	0	3	12,560
BK	5	36,517	2	9,152	3	15,256	OP	0	0	0	0	1	2,793
BO	9	41,206	1	16,840	4	18,079	OV	0	0	1	1,268	1	8,072
BR	3	19,464	1	5,716	2	17,448	PU	2	11,161	5	22,021	4	95,372
BV	6	31,237	0	0	2	9,954	PE	26	96,157	17	72,828	2	3,057
CL	1	1,993	0	0	2	24,751	PI	8	41,522	8	21,791	1	1,534
CB	7	29,329	5	18,484	8	21,962	PJ	2	4,810	4	10,382	7	69,610
CK	6	14,126	1	1,483	6	10,301	PS	6	47,657	1	1,295	8	24,844
DC	1	1,578	1	15,921	3	27,045	PY	2	47,190	2	2,634	7	40,318
DO	5	10,870	3	68,523	4	6,598	PZ	2	6,319	0	0	3	5,186
FM	1	11,015	1	1,048	0	0	PT	1	3,286	1	22,369	3	10,794
HB	14	44,600	13	75,787	1	456	PV	3	13,899	0	0	1	9,306
HO	4	15,058	0	0	2	3,035	PR	4	24,752	1	2,607	2	2,573
HK	0	0	1	9,972	0	0	PB	4	19,228	3	8,703	5	35,338
CH	2	3,488	1	299	2	2,963	RA	0	0	5	10,929	1	1,404
CV	0	0	1	5,797	1	3,932	RO	1	1,279	2	18,987	3	5,708

(continued)

Table 5.3 (continued)

TU	1		2		3			1		2		3	
OK	PP	CNP	PP	CNP	PP	CNP	OK	PP	CNP	PP	CNP	PP	CNP
CR	6	20,375	2	9,261	2	7,006	RK	2	7,558	0	0	0	0
JE	1	4,699	1	3,194	0	0	SM	4	5,197	0	0	1	1,073
JC	2	23,934	0	0	0	0	SO	0	0	1	4137	0	0
JI	38	144,390	11	58,923	4	26,929	ST	5	14,901	4	10,558	4	7,490
JH	16	72,446	11	47,971	5	14,110	SY	2	8,100	0	0	2	8,902
KV	2	11,136	3	9,996	1	2,885	SU	1	2,484	0	0	0	0
KD	1	1,696	3	17,355	0	0	TA	9	38,619	4	25,423	2	470,409
KT	4	11,388	4	25,229	6	34,023	TC	4	20,380	2	9,772	1	2,368
KO	4	33,416	0	0	2	17,006	TU	3	8,457	0	0	0	0
KM	6	21,835	3	16,355	5	25,747	TR	25	161,712	18	106,416	11	35,227
KH	6	42,904	2	8,209	1	7,769	UH	3	5,881	1	3,427	1	2,207
LI	1	7,672	0	0	3	71,416	UO	1	3,616	0	0	2	17,268
LT	1	2,714	1	3,195	0	0	VS	4	14,137	2	19,745	1	1,792
ME	0	0	0	0	1	2,239	VY	11	87,263	2	12,765	1	6,177
MB	1	3,342	1	1,321	3	9,114	ZL	3	5,399	0	0	2	1,279
NA	0	0	0	0	2	73,556	ZN	9	51,868	7	43,381	0	0
NJ	3	17,345	0	0	1	756	ZR	22	98,628	11	39,479	8	20,440

Annotations
TU—Type of measures; OK—Abbreviations of the Czech Republic districts; PP—Number of projects; CNP—Total cost of the projects (thousands of the Czech crown/CZK/)

available documents. However, numbers and funds show a relatively large amount of work supported by European funds connected with the renovation of small water reservoirs in the Czech Republic during the subsidy period 2007–2013.

5.3.4 Landscape Mapping of the Catchments

For the three water stream catchments, the landscape mapping and P-Kes calculation were not executed, so there is no value in Table 5.1. Among the stable catchments belong the basins of streams: Borová, Kněhyně, Lužní potok, Mlýnský potok, small tributaries of the Divoká Orlice River in the Orlické Záhoří cadastre, Včelnička and Zbytinský potok. Among the very unstable were ranked basins of the streams: Brodec, Buchlovický potok, Čížkovský potok, Halenkovický potok, Haraska, Chrudimka, Lubnický potok, small tributaries of the Moravice River within the locality Lučina, Olšovka and Postřelmůvek. The catchments of following streams show a potential for improvement of ecological stability according to the analysis results: Chrudimka, Krasovka, small streams in the locality Lučina, Martinický potok, Moravický potok and Postřelmůvek. The change of the agricultural management into a more extensive way with larger areas of ecologically stable elements was identified as possible there.

Figures 5.1 and 5.2 show the results of the mapping of the landscape mapping and the identification of historical and abandoned water bodies in the catchment areas of Haraska and Slupský potok as an example of the analysis carried out for all 27 catchments of the studied water stream restoration project. Revitalization works in both basins included the construction of small water reservoirs (code according to landscape mapping is "7b"—see Figs. 5.1 and 5.2). There was no overlap of the newly built standing surface water bodies in the catchment area of the Slupský potok stream with the areas of abandoned ones. But the new small water reservoir is situated in similar places from the hydrological network point of view. The reason for the shift of the location was property ownership. Two areas included in the database of historical ponds (identifier "ID_ryb" in Table 5.4) are located in the Haraska stream catchment. In this example, it can be proven that the areas of abandoned water bodies can be used for designing protection features as part of complex systems of flood-protection and anti-erosion measures in the landscape. When selecting suitable sites that are potentially affected by the point of view of flood risk, it is possible to use the results of the application of the so-called Methods of Critical Points [30]. Critical Points (identifier "CP" in the Figs. 5.1 and 5.2) are the closure profiles of areas that are decisive for the formation of concentrated surface runoff and the transport of erosion soil particles from torrential precipitation, which have adverse effects on built-up areas of municipalities. Interaction of the defined critical point (CP) within the Haraska catchment area is shown on the map in Fig. 5.1. One identified critical point is located at the edge of the urbanized area of the Diváky village, downstream the area of an abandoned pond. A variant solution to flood protection may include the use of this area, as illustrated by the land use analysis presented in Table 5.4.

Table 5.4 Results of the up-to-date land use of the historical ponds identified from the 2MS maps within the studied stream catchments

Locality stream	ID_ryb	L-U 1 (%)	L-U 2 (%)	L-U 3 (%)	L-U 4 (%)	L-U 5 (%)	L-U 6 (%)	L-U 7 (%)	L-U 8 (%)	Abandoned ponds
	19,367		31.7			68.3				Yes
Brodec	24,834	1.8	31.9		4.4		61	0.9		No
	24,836				9.2	15.5	75.2			No
Čížkovský potok	26,176					100				Yes
	26,182				33.3	0.2			66.5	Yes
	15,587		9.2				90.8			No
	15,588	21.2			1.5			77.3		Yes
Krasovka	10,482					100				Yes
Lubnický potok	16,557			100						Yes
Martinický potok	15,165			100						Yes
	15,166			100						Yes
	15,167			3.9		27.5	68.6			No
	15,168	26.6			40.9				32.5	Yes
Olšovka	9,722		51.7	16.7			31.7			No
	9,723	2.7					68.2		29.1	No
Příbramský potok	8,772	14.9			50.5		5.7		28.8	Yes
	8,773		85.4	1.3		13.3				Yes
Slubice	15,133		1			19	78.5		1.6	No
	15,134				78.7				21.3	Yes
Slupskýpotok	411					100				Yes

(continued)

Table 5.4 (continued)

Locality stream	ID_ryb	L-U 1 (%)	L-U 2 (%)	L-U 3 (%)	L-U 4 (%)	L-U 5 (%)	L-U 6 (%)	L-U 7 (%)	L-U 8 (%)	Abandoned ponds
	417			4.5		49.8	45.7			No
	418			28.4		71.6				Yes
Včelnička	28,391		20.9			18.6	60.5			No
	28,411				8.5	61.8	14.8		14.9	No
	28,412				91.5	5.7			2.8	Yes
Zbytinský potok	18,861	24.8							75.2	Yes
	18,862					70.5		29.5		Yes

Annotations
L-U 1—category of the land use in the ZABAGED "Budova, BlokBudov"—a built-up area
L-U 2—category of the land use in the ZABAGED "LesniPuda SeStromy"—forest land
L-U 3—category of the land use in the ZABAGED "OrnaPuda AOstatniNeurcenePlochy"—arable land
L-U 4—category of the land use in the ZABAGED "OstatniPlocha Vsidlech"—other areas within settlements
L-U 5—category of the land use in the ZABAGED "TrvalyTravniPorost"—grasslands
L-U 6—category of the land use in the ZABAGED "VodniPlocha"—water areas
L-U 7—category of the land use in the ZABAGED "Areal UceloveZastavby"—purpose-built areas (commercial, industrial, etc.)
L-U 8—category of the land use in the ZABAGED "Zahrada SadPark"—gardens, orchards, parks

5.3.5 Intersection of Historical and Abandoned Ponds with Catchment Restoration Measures

Table 5.4 gives an overview of the areas of historical ponds identified by the above-mentioned procedures within the studied stream catchments. The "ID_ryb" identifier corresponds to the items in the database, which is available in the form of a Web map application [31]. Of the total number of 27 catchments, the areas of historical ponds, shown in 2MS, were identified in 13 of them.

Table 5.4 shows:

(i) The identification data identical to the database of historical ponds created under the research project QJ1220233,
(ii) The percentage of aggregated land use categories determined from the analysis of existing land use,
(iii) The indication of whether the pond area is classified as "abandoned" or "existing".

The areas of historic ponds, where the residual water area represents currently less than 10% of the original area identified from maps of the 2MS, were also included among the "abandoned". The 10 of the 28 areas of historical ponds in the 13 of the 28 studied catchments are included in the category "existing". Standing surface water bodies are located at the present time at the places (pond or another type of small water reservoir with a primary purpose other than commercial fish farming).

Land use categories: L-U 2 (forest land), L-U 3 (arable and other unspecified areas), L-U 5 (permanent grassland) and potentially, according to local conditions, L-U 8 (gardens, orchards, parks), can be potentially used for the standing surface water bodies. There are seven areas in the L-U 5 category (70 to 100% overlays) of the abandoned pond areas. The other two, with the predominant coverage of L-U 8, could be considered for the restoration of smaller water areas with the purposes of landscape aesthetics or retention. Three areas currently represent 100% arable land. These are the catchments of the Lubnický potok stream and Martinický potok stream. There would be required implementation of the flood and erosion measures and measures to support biodiversity according to the results of landscape and water management analyses. One area in the Příbramský potok stream basin is currently covered by 85% of the "forest land" category, where the potential for small reservoir restoration is problematic. Although the area is located on the stream and it would be advisable to implement water quality improvement measures, including a small water reservoir, the space for such reservoir is limited and lies outside the area of a historic pond.

5.3.6 Utilization of Abandoned Pond Areas—Case Studies

This part of the chapter resumes the results of a theoretical consideration of modifications in the use of selected abandoned pond areas in the three pilot locations and an economical consideration of the area utilization. Pilot locations were selected after the cluster analysis. The objective of these case studies is to propose scenarios and their theoretical solutions for the utilization of the areas of abandoned ponds (pond systems) in order to improve the quality of the landscape, support a sustainable economy in the sector of agriculture, fish farming, and water management in the landscape in compliance with the principles of valid European and national legislation, taking into account challenges arising from climate evolution and rainfall–runoff processes. The main focus of this work is an overview of detailed analyses of changes in the utilization of abandoned pond areas in three pilot territories, and also their evaluation in terms of economic indicators for different solutions of utilization of these areas in the landscape. The work was based on the application of theoretical methods for assessment of the potential renewal and the utilization of abandoned ponds in several scenarios: (i) renewal of a pond or small water reservoirs with a purpose other than fish production; (ii) or, as the case may be, wetlands; or (iii) other utilization within the sustainable management of soil resources.

5.3.6.1 Case Study No. 1—Pond Area in Extensive Agricultural Landscape

The first location is an area of the "Wozlitzer Teich" historical pond, situated in the Central Bohemian region, near Benešov, approximately 1 km east from the community of Popovice. The pond used to be located directly on the Chotýšanka watercourse (Fig. 5.3). According to the cluster analysis, this location belongs to cluster no. 4, i.e. "Grass-covered ponds in higher altitudes with worst-quality soils" (Fig. 5.7). As for the area utilization, this is a landscape with a significant proportion of arable land and permanent grasslands and forests. The probably flooded area of the historical pond itself is currently used as permanent grassland without intensive exploitation. The floodplain under the profile of the original dam to the point where the Chotýšanka joins the "Popovický rybník" pond is used in the same way. In the past, there used to be a number of mostly small ponds in the Chotýšanka basin (Fig. 5.3). The final change took place at the beginning of the twentieth century in connection with the Chotýšanka regulation after the flood of 1906. However, the pond had become abandoned at that time. It is probable that it disappeared in the second half of the nineteenth century since it is still marked in the maps of the 2nd Military Survey.

The area of the abandoned pond is 3.68 ha. It includes three land blocks with permanent grassland and without ecological farming. The location lies in a potato-growing area. The final contribution for the given area amounts to CZK 4,114 per ha, representing the yield from the given area of 1 ha (in prices of the year 2015),

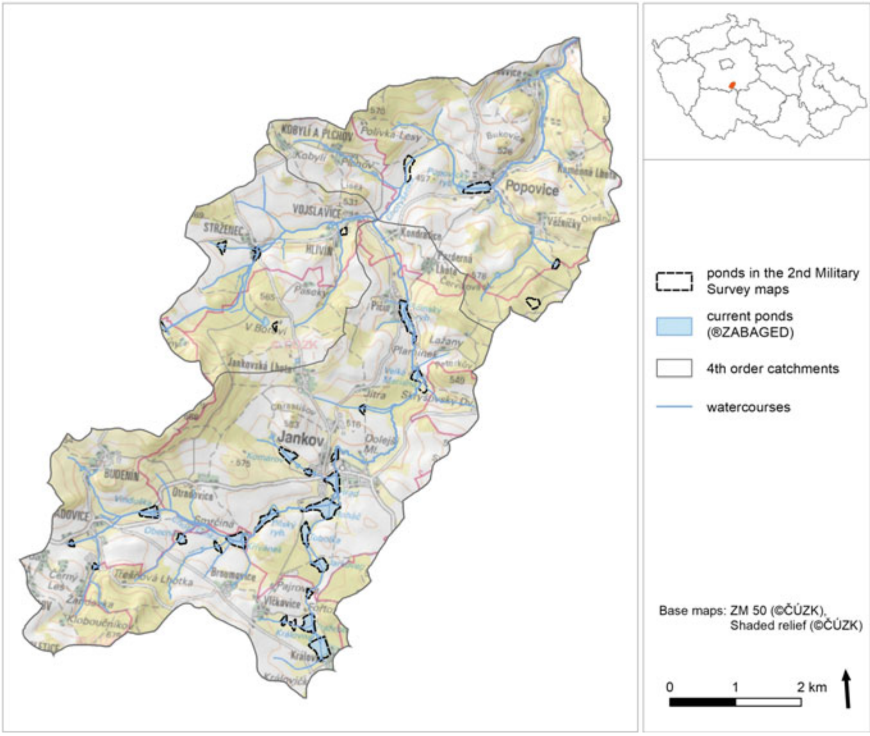

Fig. 5.3 Map of the first locality surrounding landscape near the Popovice village

after the deduction of variable costs, for common agricultural utilization. For the total area of 3.68 ha, this represents an annual yield of CZK 15,138.

The water management analysis showed that the volume of the reservoir for the considered level is almost 59 thousand m^3 with the flooded area of 4.0 ha, and 109 thousand m^3 with the flooded area of 6.2 ha, up to the considered top of the dam. The profile of the former dam is very suitable for the construction of a water reservoir. From the hydrological point of view, the Chotýšanka is a stream with relatively high water content. Floods on the Chotýšanka represent one of the most important natural risks. The 100-year flow Q_{100} is 28 $m^3\ s^{-1}$, representing more than one hundred times the average flow. According to the calculations, the possibilities to use the area for the transformation of flood flows are negligible under the given conditions, since the highest attainable efficiency is about 11%. The volume of the reservoir (59 thousand m^3) may be considered as significant with respect to water retention in the landscape, even though it corresponds to less than three days of average flow. In case of the flow Q_{355d} (average yearly daily flow), this is already a volume corresponding to twenty days, and therefore, it would be possible to use the retained water for the improvement of the Chotýšanka flow during drought. In terms of water management, a possible renewal of the water reservoir function in the area of the abandoned "Wozlitzer Teich" pond is important particularly for retention of water in the landscape, for creation of a new landscape element and for creation of water environment with related biotopes.

The option involving realization of wetlands (wetland biotopes) in the area of the abandoned pond was based on a survey of water quality of the Chotýšanka and local tributaries. With respect to the limits for swimming water (Czech Government Decree 401/2015 Coll.), in the profile of the abandoned pond, the quality of water of the Chotýšanka was satisfactory. The "Strženecký potok" brook, a left tributary of the Chotýšanka above the area of the abandoned pond, represents a risk for water quality. High concentrations of total phosphorus, between 0.3 and 0.5 mg l^{-1}, were found in both tributaries. From the point of view of water protection, it is therefore not necessary to consider the option of wetland creation in the entire area of the abandoned pond. The consulted territorial planning materials did not involve any small water reservoirs planned in the Chotýšanka basin as a part of the area protection strategy. The planned measures include near-nature flood-protection measures in the unbuilt territory as the decrease of bed capacity by revitalization and the increase of retention capacity to the floodplain, which affect the transformation of flood flows. The best solution of this option includes revitalization of the Chotýšanka floodplain in the stretch between the confluence with the "Strženecký potok" brook and the culvert connected with a field road above the "Popovický rybník" pond. The stretch is about 2.1 km long. The costs for the given stretch could amount to approximately CZK 2.1 million, without the purchase of plots. The second option is realization of a littoral zone within the small water reservoir mentioned in the option of water management assessment. A support of biodiversity by creation of wetland biotopes may be expected here, but not a substantial impact on the quality of water running into the reservoir. For approximately 15% of the reservoir area, i.e. 0.6 ha, the investment could amount to CZK 900 thousand.

Another option of the area utilization includes a theoretical assessment of the exploitation for production of wood biomass on a plantation of fast-growing woody species producing woodchips. However, this option is not practically profitable unless the area forms a part of a larger unit. Given a 20-year lifespan, the average price and production of woodchips, the yield would be CZK 48,576 for one rotation and CZK 242,880 in total. In addition, this would imply introduction of a monoculture of non-indigenous woody species, which is not a particularly suitable option for the territory in question. In the event, the small water reservoir is not realized, or the watercourse is not revitalized, and it is convenient to preserve the current utilization of the territory. There is no problem to combine this utilization with the revitalization option.

5.3.6.2 Case Study No. 2—Pond Area in Urbanized Landscape

The second location is situated near the residential area of the municipality of Kopřivnice (Figs. 5.4 and 5.8). This is an abandoned pond system out of which the Kamenný rybník pond was selected as the examined area. The pond area in question (marked as "Nohlycze Teich" in the maps of the 2nd Military Survey) lies in

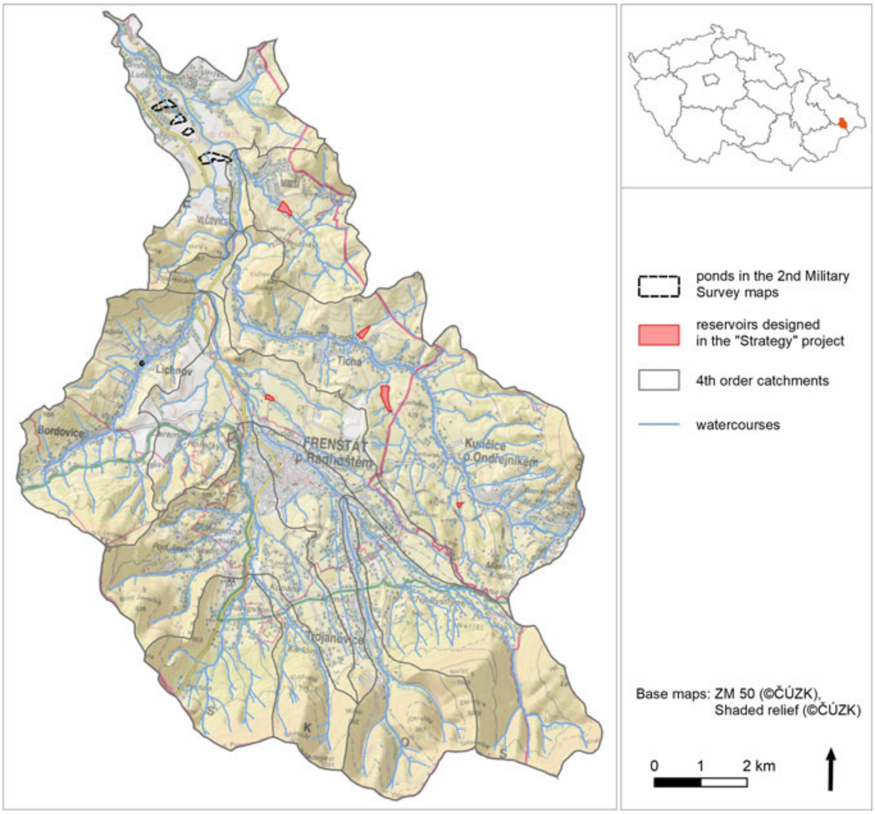

Fig. 5.4 Map of the second locality surrounding landscape near the Kopřivnice town

the eastern part of the rural area of Kopřivnice in the cadastral area of Vlčovice in the Lubina River floodplain. According to the cluster analysis, this area belongs to cluster no. 3, i.e. “ponds utilized for agriculture, but of smaller area and located in a higher altitude” (Fig. 5.8). Water from the area of the abandoned Kamenný rybník pond is drained by the “Babincův potok” brook, passing through the area of the abandoned pond and formerly used as a feeding canal for the whole pond system. During the first half of the sixteenth century, a pond system was built in the Lubina floodplain in the then domain of Hukvaldy. Five of the ponds were in use until the last quarter of the nineteenth century (Figs. 5.4 and 5.8).

The current utilization of former pond areas in this location predominantly involves intensively and extensively used agricultural land. A minor part of the area is built up. In terms of a future renewal, it is the area of the Kamenný rybník pond that seems to be the most suitable. On the one hand, its dam is mostly preserved, and there is a preserved part of the canal (the Babincův potok brook). The use of the dam body is questionable. A hydropedological assessment of its properties needs to be performed. Today, the area of the abandoned Kamenný rybník pond is divided into 39 plots, and it is intensively utilized as agricultural land. The location lies in a potato-growing production area. As for agricultural activity, two land blocks extend to the area of the abandoned pond. In the last decade, the first has been regularly sown with alfalfa grass or clover grass mixes. In the second block, a crop rotation system is applied, alternating winter wheat, winter barley, maize and winter oilseed rape. The final contribution for the given area amounts from CZK 10,120 to CZK 11,920 per ha, representing the yield from the given area of 1 ha, after the deduction of variable costs, for common agricultural utilization. For the whole area of 9.19 ha, this corresponds to CZK 93,000–109,500 annually in total. For easier comparison of different area utilizations, subsidies actually increasing the profitability of the crops are deliberately excluded from the calculation. With respect to lower quality of the arable land, options counting with grassing of 6.2 and 2.99 ha were proposed. The annual rate of subsidy from the Czech Rural Development Programme 2014–2020 for grassing of arable lands can theoretically bring CZK 99,250 for an area of 9.19 ha.

The water management assessment, in terms of a renewal of the reservoir function, was the most complicated one out of the three areas in question, due to the fact that a part of the dam is preserved. According to the historic drawing, the pond used to have a large flooded area of 9.3 ha. This corresponds to a volume of approximately 111 thousand m^3. This is a considerable space, but, when compared to the length of the dam and the corresponding volume, the profile cannot be considered as the most suitable. With respect to the area's potential, a more extensive area, representing water accumulation almost 5 m deep, was analysed for the assessment of a renewal of the water body function. If the reservoir was conceived this way, it would require the construction of a lateral dam. The newly flooded area would represent the volume of 656 thousand m^3 of water with the water surface of 26.9 ha; and 955 thousand m^3 up to the top of the dam, with the surface of 32.3 ha. Hydrologically, the "Babincův potok" brook is a stream with a very small drainage basin. The long-term annual flow is $Q_a = 30\,\mathrm{l\,s^{-1}}$. The value $Q_{100,}$ reaching $16\,\mathrm{m^3\,s^{-1}}$ represents more than five hundred times the value of the average flow. Any level of flow can be achieved in this location by transformation since the wave volume is approximately one-third of the conceived reservoir volume. This is why there is no sense in calculating the transformation since the efficiency of such space would be close to 100%. With regard to a very low number of water areas in the "Lubina" drainage basin, a renewal of a small water reservoir is a suitable solution. The only significant water area in the drainage basin is the "Větřkovice" water reservoir with a surface of 21.5 ha. Apart from its meaning for the solution of drought and floods, more benefits may be expected, e.g. creation of a landscape element, use for recreation, fish breeding and other functions the water area could fulfil. The researched conception materials, however, recommend the location of small water reservoirs elsewhere in the drainage basin as the best solution of flood protection. Hence, for the given area, it is better to consider other function than flood protection.

Unlike other pilot locations, an option involving wetland as a littoral zone of a small water reservoir was not considered in this case. According to the water management solution, the reservoir would have an area of 20 ha. Here, the littoral zone would probably be created, but its area would have to correspond with the border of flooding, and it would also be realized with respect to recreational use. As for the water quality in the "Babincův potok" brook within the abandoned pond, our examination showed that the quality was insufficient. The potential water reservoir would be at risk of eutrophication. The recreational benefit of the reservoir (swimming and watersports) would be arguable. Without a solution of the inflowing water purification or unless water is brought from the Lubina River, the realization of a small water reservoir seems an inappropriate solution for the given area.

The first option of wetland solution consists in creation of a 50-m-wide floodplain strip of the Babincův potok brook (optimum solution in terms of soil loss intake and the shelterbelt width) on each side from the axis of the current brook bed. The buffer zone was calculated with the help of GIS tools as 2.25 ha. Hence, the costs of the mentioned measure should be approximately CZK 3,375 thousand. The second option consists in creation of wetland biotopes, pools, side channels and accompanying vegetation around the newly realized bed passing transversely through the abandoned pond area from the Lubina bed towards the Babincův potok bed. Costs of this measure could amount to approximately CZK 13,950 thousand.

In case of transformation of this location into a plantation of fast-growing woody species, the estimated investment costs would amount to CZK 205 thousand. The yield from the entire pond area, at the 20-year lifespan of the plantation and average price and production, can be set as CZK 122,760 with one rotation, i.e. CZK 613,800 in total.

To sum up, the options for the area utilization are: (i) production (permanent grassland, fast-growing woody species, both with yields); (ii) water management solution, support of biodiversity of the landscape, self-cleaning, and, as a last resort, realization of water area with the necessity to solve the water quality. The function of flood protection, formerly fulfilled by the Kamenný rybník pond, would probably not play a substantial role nowadays since the Lubina river bed in this location has been modified to take over a 100-year flood. It is arguable whether the renewed water area could be used as a water reservoir for the Vlčovice industrial park located nearby. Landscape diversity support is a possible solution with costs amounting from CZK 3 to 14 million depending on the complexity. It can bring new elements to the urbanized landscape, also suitable for recreation and relaxation of inhabitants. The studied conception materials recommend implementation of more than one standing surface water bodies within the Kopřivnice town surroundings (Fig. 5.4).

5.3.6.3 Case Study No. 3—Pond Area in Intensive Agricultural Landscape

The last examined location is a territory near the community of Dolní Bojanovice in the South Moravia in a landscape intensively used for agriculture (Fig. 5.5). In this case, it is the area of the so-called Horní rybník pond ("Oberer Teich") classified in the cluster analysis as no. 2, i.e. "grassed ponds in low altitudes with temperatures above average, but low precipitations and soil properties slightly above average" (Fig. 5.9). The original pond was set on the Prušánka stream. The stream passes

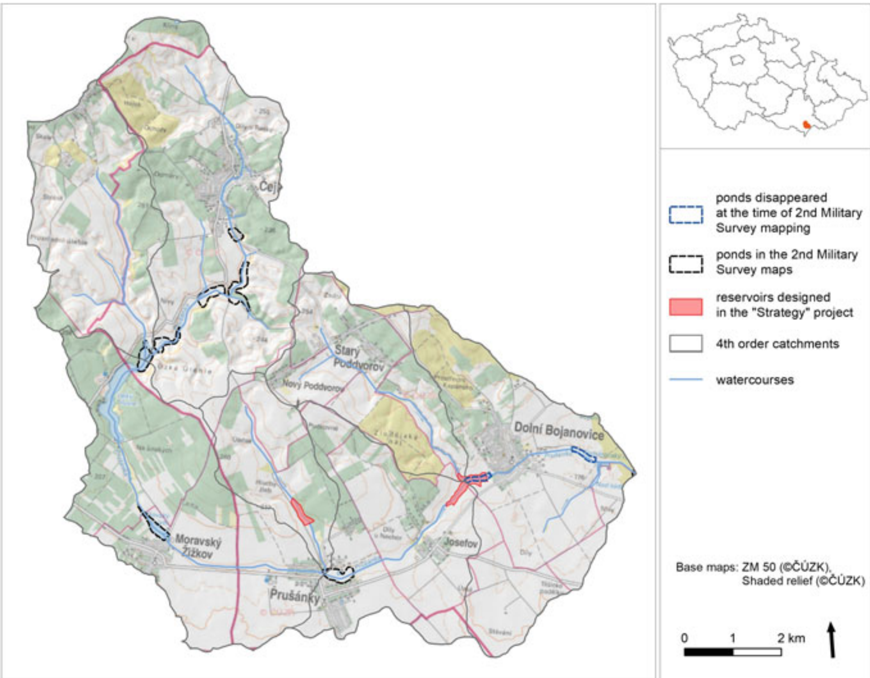

Fig. 5.5 Map of the third locality surrounding landscape near the Dolní Bojanovice village

through an agricultural landscape. On the Prušánka or in its floodplain, small ponds and wetlands can be found above the community of Čejkovice, below the "Velký Bílovec" water reservoir and in the community of Josefov. Archival sources mention the existence of a small pond in Dolní Bojanovice as early as in 1415. The original dam is still noticeable in the terrain, and currently, there is a street aptly named "Na hrázce" (i.e. "At the dam"). In the eighteenth and nineteenth centuries, Dolní Bojanovice was a community with developed fish farming and wine growing. The "Horní rybník" pond served for fish farming. The "Dolní rybník" pond was a bit newer, both, however, had been gradually aggregated and around 1850 there were probably wetland biotopes and wet meadows in the areas. This is why they are not found in the maps of the 2nd Military Survey. Currently, the area of the "Horní rybník" pond is utilized predominantly as arable land. Recently, it has also been utilized for cultivation of fast-growing woody species and as private gardens. There is sporadic full-grown greenery, concentrated mostly along the watercourse and on the thalweg slopes. Construction of a retention basin is planned in the location of the "Horní rybník" pond which, according to the regional development plan, should fulfil the function of an important landscape element apart from the flood-protection function. In the planned flooded area, the "Hrabincova stružka" brook joins the Prušánka on the left side (Fig. 5.6, 5.7, 5.8 and 5.9).

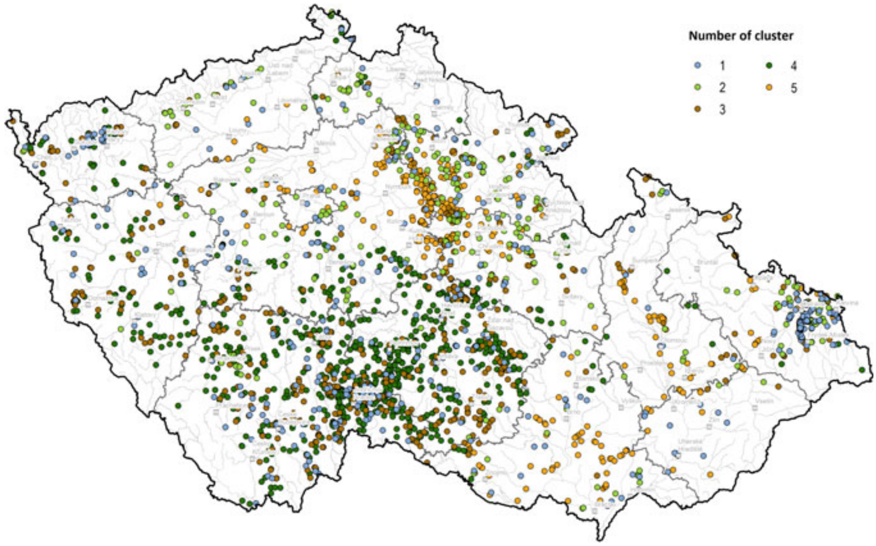

Fig. 5.6 Distribution of identified abandoned pond areas over 0.5 ha within the Czech Republic territory based on the cluster analysis

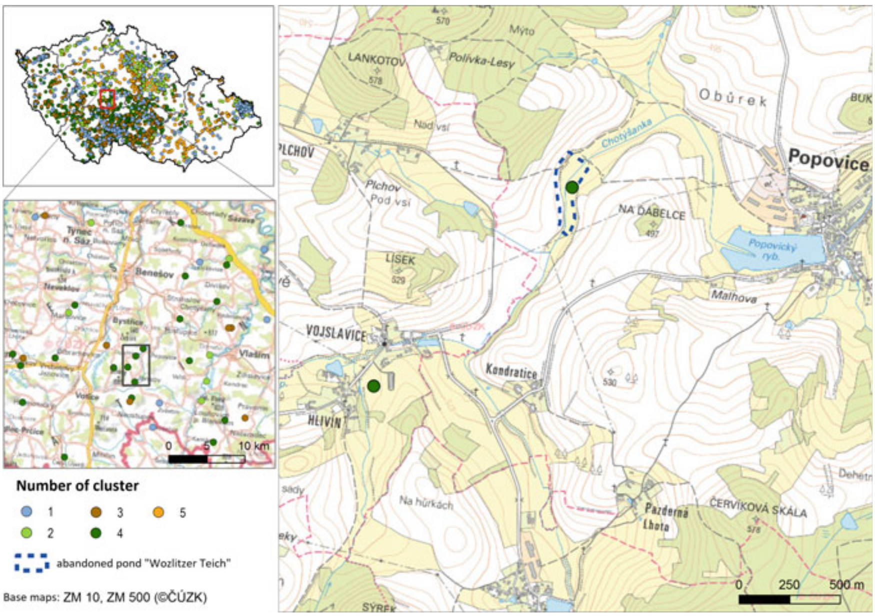

Fig. 5.7 Case study No. 1—location of the former "Wozlitzer Teich" near the Popovice village

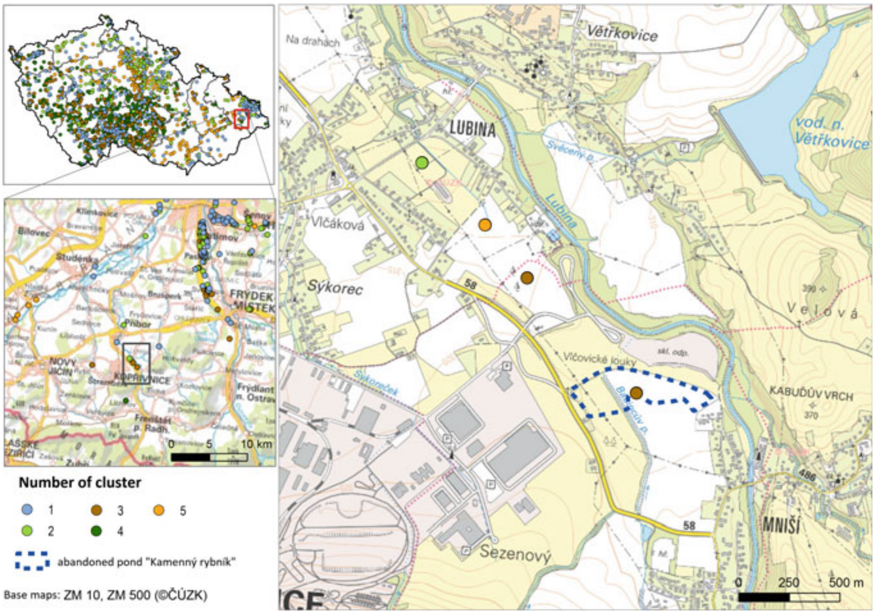

Fig. 5.8 Case study No. 2—location of the former "Kamenný rybník" near the Kopřivnice town, suburb "Lubina"

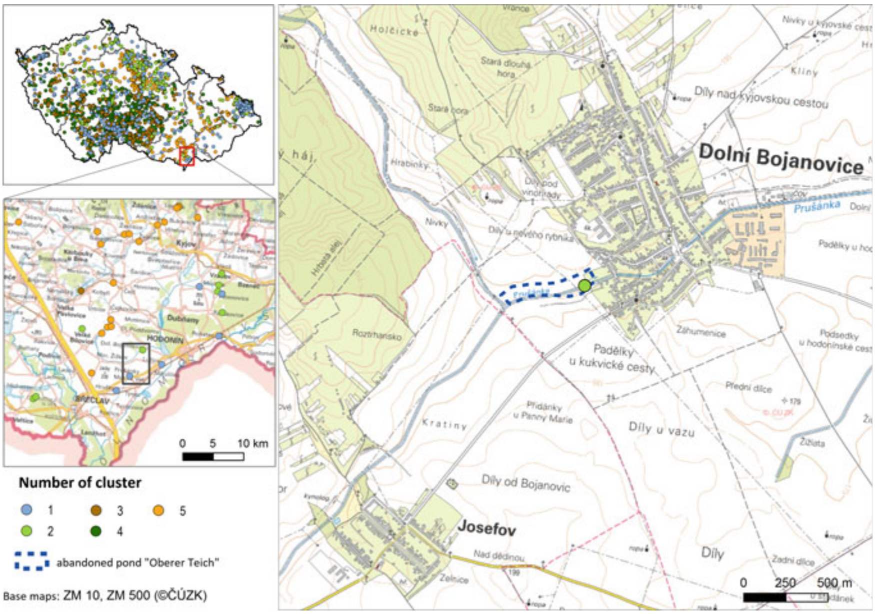

Fig. 5.9 Case study No. 3—location of the former "Oberer Teich" near the Dolní Bojanovice village

The area of the former pond of 5.88 ha belongs to a maize-growing production area. In the case of production utilization of the area, two theoretical options were considered: its preservation as arable land and realization of a plantation of fast-growing woody species on the entire area with the exception of littoral vegetation. The model of crop rotation simplified due to a small pond area, excludes potatoes. The quantity of other crops was proportionally increased (winter wheat, spring barley, grain maize, silage and forage maize, sugar beet, winter oilseed rape). According to the estimate of intensive conventional farming, a contribution of CZK 18,500 per ha is possible for the former pond area, amounting in average to CZK 109,000 per year for the entire area of 5.88 ha. In case of grassing, the probable loss would amount to CZK 7,700 for 1 ha per year, amounting to CZK 45,500 for the entire area. In this location, costs of a plantation of fast-growing woody species would be approximately CZK 130 thousand. The yield from the entire pond area, at a 20-year lifespan of the plantation and average price and production, can be set as CZK 77,600 with one rotation, i.e. CZK 388,000 in total.

Calculations of the water management assessment show that the volume of the reservoir for the considered level is almost 69 thousand m^3 with the flooded area of 7.4 ha, and 162 thousand m^3 up to the level of the considered top of the dam, corresponding to an area of 11.4 ha. Hence, the profile may be considered as ideal for the construction of a water reservoir. In terms of hydrology, the Prušánka has a very low water content, with a value of the average annual long-term flow $Q_a = 0.238\ m^3\ s^{-1}$. Flood flows in this profile are relatively low. The value of a 100-year flow Q_{100} is $27.4\ m^3\ s^{-1}$.

A possible utilization of the pond area for flood protection is relatively restricted. The calculation of the flood wave transformation in both considered options shows that the value of flood peak may be decreased by 30% in the better case and only by 11% in the worst case. Due to the fact that this territory has poor precipitations and low outflows, even the above-mentioned volume has to be considered as significant. However, the importance consists in the creation of a water reservoir utilizable in periods of drought for various purposes, in particular for irrigation of farming lands that will become more and more important with respect to the expected climate change. The irrigation balance, however, is only for approximately 17 ha of farming lands, also due to low water content in the watercourses. For instance, the nearby "Velký Bílovec" water reservoir is fed by water transferred from the Dyje River. Water supply may be used for sanitary flows in periods of drought, improvement of the Prušánka water environment, and for the support of final water purification.

The option of realization of wetlands (wetland biotopes) in the area of the abandoned pond was based again on the analysis of the water quality of the Prušánka and its local left tributary. The contamination of the Prušánka is relatively significant, both as for the contents of nutrients and microbial and organic contaminants. The wetland mentioned in a small water reservoir design project prepared for the Dolní Bojanovice municipality is separated from the watercourse bed by a small dam, and its purpose is the support of biodiversity, creation of wetland biotopes with prevailing stagnant water. This solution leaves out a possible self-cleaning ability of the wetland. The economic aspect of this solution, based on our methodology, corresponds to an estimate of CZK 1.1 million for the left-bank wetland with an area of 0.7 ha, excluding the purchase of plots not owned by the communities of Josefov and Dolní Bojanovice. The solution of wetland areas having an ability to pre-clean the incoming water before the reservoir itself, particularly in periods of low flows, would require a realization of a wetland with a loose shallow bed in the entire area of the upstream reservoir, i.e. in the area of 0.94 ha. The economic aspect of this solution corresponds to an estimate of CZK 1.4 million, excluding again the purchase of a part of plots.

5.4 Conclusion and Recommendations

This chapter summarizes the procedures for identification of areas of historic ponds using military mapping in the territory of the Czech lands and its interpretation in connection with water revitalization and restoration projects of small watercourses, carried out in the Czech Republic since 1992. The analyses have shown the appropriate use of digitized historical maps for assessing changes in the status and localization of landscape features, as [15, 17, 32, 33]. In total 33,713 ponds of an area of 63,923 ha were identified and plotted in. From the number of historical ponds not less than 22,649 ponds were smaller than 0.5 ha, creating 67% of the original layer of ponds. However, the sum of the total area of these small ponds represented only 5.4% (3435 ha) of the historical ponds total area.

Various systems of subsidies acted as specific propelling forces in pond restoration after the year 1989. Those new or restored ponds are no longer used only for fish farming, but have other functions such as water retention, flood and erosion protection, biotope restoration, recreation, angling etc. One example is the River Network Revitalization Programme from which approx. CZK 343 million was spent for this purpose. As soon as the original programmes supporting landscape restoration originating in 1990s were terminated, this effort continued from the Czech Operational Programme "Environment" with the help of financial support from European funds targeting small water bodies' construction and restoration. The supported projects included the construction of new ponds as well as restoration, renewal and sediment clearing of old water bodies. The highest number of these projects took place in Southern Bohemia and Vysočina, two Czech regions with a historically highest abundance of ponds.

A new small water reservoirs or/and wetlands were built within six of the 13 catchments of the studied watercourses as a part of the restoration projects. However, even in one of the cases, areas of historical abandoned ponds were not used. The reason was mainly their existing land use and a property situation which did not allow placing any standing surface water element there. The results of the analysis show that a number of areas of abandoned ponds have the potential for restoration either in the form of a pond whose primary purpose is fish farming or in the form of a SWR with another primary purpose (flood protection, water retention, recreation, biodiversity support, water quality improvement etc.). Šálek et al. [3] and Šálek

[1] found that without substantial costly modifications, approximately 10–15% of SWRs which disappeared in different time periods could be restored. The analysis carried out using the water management revitalization basin were used in the project QJ1220233 to define a catalogue of criteria for the use of historical ponds areas with a view to promoting the sustainable development of the agricultural landscape [34, 35]. Map outputs, follow-up databases and Web application can thus contribute in the next subsidy periods to targeting funds for landscape restoration aimed at sustainable development, use of natural resources and better management of water sources as well as reducing impacts of periods of drought on the landscape water balance [36]. The regulations for optimal land use must be applied to sector plans and it is recommended to implement an integrated approach to sustainable land use management [37].

The survey of the three pilot locations showed the following facts:

The abandoned pond areas often have soils which is qiute unsuitable for intensive agricultural production (e.g. the area near Dolní Bojanovice). Options in such a case include the transformation to permanent grasslands (the area near Popovice) or plantations of energy species (fast-growing woody species). However, it is necessary to consider the suitability of plantation of non-indigenous species in watercourse plains where most of these areas are located. Grasslands may also be included in the anti-erosion measures. They can also serve as buffer zones preventing soil entry into watercourse beds. Contrarily plantations of woody species may cause problems during floods: spillage regulation, creation of barriers etc.

The implementation of small water reservoirs, including production ponds, will probably remain a possible option only for some of the abandoned pond areas. In some cases, the reservoirs can fulfil flood protection and retention functions. These function may be restricted by field modifications and adaptations, as in the case of the area near Kopřivnice. Recreation represents another function. This function, however, is dependent on the water environment quality, level of contamination, which is, unfortunately, high in the Czech river network in terms of eutrophication. Eutrophication represents a considerable risk for the recreational function. On the contrary, for utilization as fish ponds, it is relatively marginal. Due to the fact that intensive fish farming may imply higher contamination by nutrients [38], it is not possible to apply this utilization for all the renewed reservoirs. Besides the functions mentioned above, the main function will probably be creation of a water supply in the landscape and support of the creation of water-related biotopes. Virtually all three studied areas may fulfil both functions in the case of a change of utilization, including the retention of contaminated substances, and may also be complemented with the function of sport fishing or the breeding of regulated and targeted fish quantities.

To conclude, it may be said that small water reservoirs are currently one of the fundamental elements of the agricultural landscape. They are also one of the most valuable near-natural elements of the cultural landscape. Many locations are currently in protected areas, some of them within Natura 2000. One of the possibilities of increasing or preserving the ecological stability of the landscape, and, at the same time, improving its aesthetic, urbanistic, water management and agricultural functions, is to restore roles and functions of small water reservoirs and ponds, together with landscape revitalization (projects of complex field adaptations and elements of territorial systems of ecological stability).

The cases of the three pilot locations document the process of selecting the best way of utilizing abandoned pond areas. This process, when applied in planning and in state and local administration, as well as by the plot owners, will facilitate the selection of the correct functions of the planned small water reservoirs and their construction and technical design. It may also help to eliminate the negative phenomena potentially occurring after the implementation of the reservoir (pond), unless previous in-depth surveys and the correct assessment of input conditions (climatic, hydropedological, hydrogeological, hydrological and qualitative) were performed.

Particular attention in the field of a pond or small water reservoir restoration should be paid to water environment contamination and quality. Since this factor is difficult to connect with general tools and indicators of abandoned pond area assessment, it is necessary to provide local monitoring of pollution sources and water quality of the water network. A detailed observation, with comparable results of the survey of fish ponds [38, 39], has brought important data for projects of renewal or the construction of small water reservoirs in the landscape so that they do not become a source of contamination within their drainage basin, as it often happens nowadays.

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Chapter 6
Small Bodies of Water Which Have Disappeared from the Czech Landscape and the Possibility of Restoring Them

B. Šarapatka and R. Pavelková

6.1 Introduction

Ponds significantly shape the character of the landscape in the Czech Republic and are the legacy of our ancestors. We can look at them from various viewpoints. In ecological terms, we can appreciate the role of ponds in the network of regional systems of ecological stability. Hydrologically, ponds form important retention areas and contribute to the formation of micro- and topo-climates. From a historical point of view, ponds provided an important source of economic income. It is also important to consider their phenomenological aspect, as the view of the water's surface often evokes a range of emotions in people, and this can help to create a certain "genius loci".

Ponds are a very specific category of small water reservoirs intended especially for breeding fish. These pond systems have been integrated into ecological bonds within the landscape and have become an inseparable part of that landscape. Ponds fulfil a whole range of functions—productive and non-productive (ecological, aesthetic, recreational, water retention, nature conservation, etc.), which are presented as multifunctional utilisation of ponds. It is well known that pond management is closely connected with the surrounding environment, with pond management influencing the environment, and reciprocally being itself influenced by the environment [1].

As an important element in the hydrological system of surface water in the Czech Republic, ponds naturally integrate all the effects of management activity in a catchment area. At the same time, the actual management of ponds can significantly con-

B. Šarapatka (✉)
Department of Ecology and Environmental Sciences, Faculty of Science, Palacký University, Šlechtitelů 27, 771 46 Olomouc, Czech Republic
e-mail: borivoj.sarapatka@upol.cz

R. Pavelková
Department of Geography, Palacký University in Olomouc, Olomouc, Czech Republic

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tribute to the quality of surface water and the overall hydrological regime. From the surrounding agricultural land, nutrients get into the ponds and contribute to eutrophication. In Central European conditions, the capturing and binding of such nutrients is an important function of ponds and has been discussed in numerous published studies [2–5].

Ponds are also an important form of the biotope, and in Czech conditions, the occurrence of many endangered species of organisms is dependent on them. The government therefore protects many pond localities. They represent one of the most valuable near-natural features of the cultural landscape.

Following their boom, and subsequent demise, especially in the eighteenth and nineteenth centuries, since the 1990s there has been growing interest in CZ in the establishment of new small reservoirs (among which we can now include ponds) or the renewal of existing or defunct reservoirs, with the help of various grants. Information on the historical location of such reservoirs can prove useful as the background to further development in the renewal and revitalisation of small water reservoirs including ponds and for the revitalisation of existing and establishing new flood prevention measures. For this purpose, we set the task of briefly documenting the historical development of pond systems in CZ. The areas on which ponds were traditionally located were mapped. The current use of this land was then described. This helped to reveal the potential of certain areas for the renewal of ponds or other forms of water bodies, with the aim of retaining water in the landscape.

6.2 Pond Management in the Czech Republic

6.2.1 History of Pond Management

Credit for the spread of knowledge about pond management in Central Europe probably goes to the Romans, who built artificial reservoirs and kept fish in many of them. Pond management gradually became the traditional method for breeding fish in many European countries, and a current 340,000 ha of ponds within the EU supplies 25% of total fish production [6]. The overall area of European fish ponds is currently estimated at around 540,000 ha, and production of fish from these ponds is most important in Austria, the Czech Republic, Hungary, Poland, Serbia and Ukraine, while it is significant in France, Romania, Croatia and Germany [7].

Opinions vary about the origin of pond management in the Czech Republic, but the most likely theory relates to the monastery colonisation [8]. In some locations, the development of a pond may have been related to the draining of wetlands and channelling the water into artificially formed reservoirs, as documented, e.g. in the activities of the Order of German Knights [9]. In some localities, e.g. in depressions on forested land, ponds may have formed naturally [10]. The first records of ponds in the Czech lands date from about 1000 years ago when there was mention of them in the “Chronica Boemorum” by Cosmas of Prague or the name of the settlement of

Rybníček u Prahy (The Little Pond near Prague) from the end of the first millennium. In the late twentieth century, the existence of this pond was proved by archaeological research [11].

The first Czech ponds were associated with human settlements and were simply constructed. They consisted of earth-built dams on small streams. Their economic potential was discovered in the fourteenth century, which necessitated the construction of bigger ponds, which were costlier and therefore only within the scope of the wealthy estate or the nobility. Ponds began to serve various functions, perhaps as a form of defensive or as a supply of water, and later came to be regarded as a significant part of the landscape [12] with important historical ecosystem links to the agrarian landscape [13]. By the fourteenth century, there were records of up to 75,000 ha of pond area within what is now the Czech Republic [14].

These ponds also served for the production of fish, as carp were now reared in them. There are several known theories about the domestication of this fish [15]. One theory would take us to the Roman settlements by the Danube and the subsequent development in monasteries, while a second theory points to the Burgundy era of the twelfth century. Regardless of which theory is correct, the introduction of artificial breeding of carp was, in any case, a significant fishing development. The construction of ponds for the breeding of carp and other functions was an equally important development.

6.2.2 Development and Decline of Pond Management

The greatest boom in pond management in CZ was at the turn of the fifteenth and sixteenth centuries, by which time up to 25,000 new ponds had been built [14]. At that time, there was a move towards the economic use of newly acquired land, and from a long-term view, ponds came to be regarded as a profitable investment. In relation to the construction of ponds on their estates, we can mention the nobility and representatives of the church; for example, the noble families of Pernstein, Rožmberk and Vratislav of Mitrovice, or the bishops of Olomouc, Stanislav I Thurzo and Jan Dubravius. At that time, the ponds had ceased to be purely a matter for the nobility and were being built by towns and villages. It is estimated that, during this so-called golden era of pond management, an average of 500 ponds were built per year within the Czech lands [16]. Construction of ponds is essentially linked with the people who managed them. Among the most famous of these in the Czech Republic are the names of Štěpánek Netolický, Mikuláš Ruthart of Malešov and Jakub Krčín of Jelčany.

Just as quickly as the ponds were established, so too was their extensive demise. Numerous authors [17, 18] link the beginning of the decline in pond management to the Thirty Years' War (1618–1648), during which there was a great loss of human life, economic disruption and the effective cessation of pond management. The problem lay in the gradual loss of viability of ponds, and the large estates gradually began to use the regained land for the production of commodities that could be sold abroad.

Another important influence was the decline in the popularity of fish and the stagnation in price compared with other products.

Pond management thus became economically unsustainable and, especially from the mid-eighteenth century, was significantly curtailed. A number of factors came to bear on this decline. Apart from the acknowledged innovation in agriculture and cultivation of new crops [19], there were also reforms of enlightenment [17, 20], where, e.g. the abolishment of serfdom led to a hunger for land, or the dissolution of monastic orders led to a reduction in demand for fish as a food for fast days. Technical innovations in land management also had an influence, along with the poor technical state of ponds, etc. The cancellation of ponds thus would not be due to one single factor, but the result of their general unviability.

As with the establishment of ponds, so too in their liquidation can we see an element of mass activity: whereas the ponds had originally been a symbol of economic advance and technical development, two centuries later they had become a symbol of certain backwardness. There are currently around 22,000–24,000 small reservoirs within the Czech Republic. This conforms with data from a survey of ponds and reservoirs in the Czech Republic carried out in 1996 in which a total of 22,000 reservoirs are recorded, with an overall area of 50,000 ha [21]. This also conforms with data from the FAO [22], which records ponds covering an overall area of 52,000 ha, of which 41,000 ha used for the production of fish. Average production is in the region of 450 kg/ha, ranging from 200 to 800 kg/ha. This is about a tenfold increase per hectare in comparison with the end of the sixteenth century, and the total is almost 20,000 t, with carp being the most common type of fish (up to 88%).

The current extent of ponds represents about a third of the area covered at the turn of the sixteenth and seventeenth centuries, of which authors [14, 23] state that, at the time referred to as the golden age of pond management, there were around 36,000 such ponds with a total area of about 180,000 ha. This corresponds with data from Pokorný and Hauser [24] who report the overall area to be 160,000 ha. It is, therefore, possible to say that, during the eighteenth and nineteenth centuries, roughly two-thirds of the ponds within what is now the Czech Republic were cancelled (Figs. 6.1 and 6.2).

6.3 Database of Historical Ponds Within CZ

6.3.1 Basis for Development of Database

Of the historical maps available for the study of historical ponds within the Czech Republic, it is worth mentioning the First Military Survey (also known as the Josephinist Survey) to a scale of 1:28,800, which arose in response to the need for more detailed mapping of the Habsburg monarchy in the years 1764–1768 and 1780–1783 (rectification). Due to technical limitations, the result was a somewhat distorted and cartographically inaccurate picture of the landscape, further interpre-

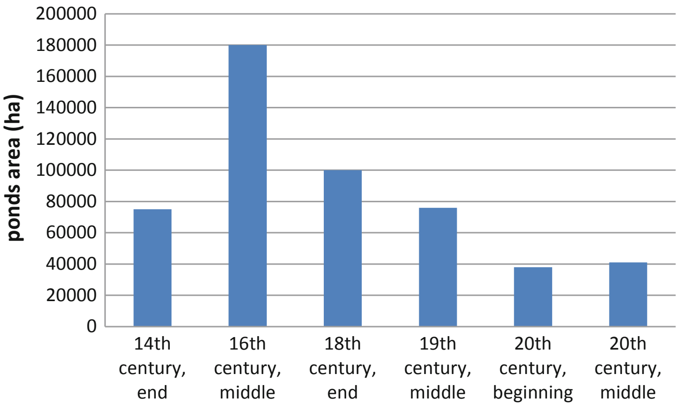

Fig. 6.1 Development in overall area of ponds in the Czech lands [23, 25]

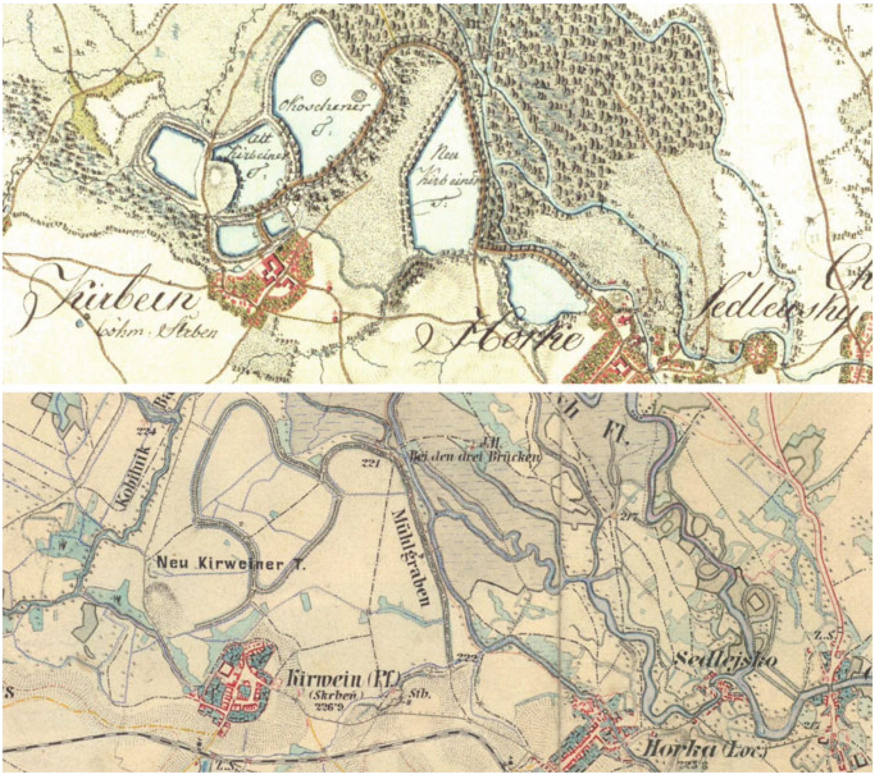

Fig. 6.2 Example of defunct bodies of water in the landscape NW of Olomouc in the district of Skrbeň, from the First Military Survey (1764–1768 and 1780–1783—rectified) up to the Third Military Survey (Moravia—1876–1878) (*Sources* Austrian State Archive/Military Archive, Vienna, Geoinformatics Laboratory, University of J. E. Purkyně, Ústí nad Labem)

tation of which, by means of the geographical information system (GIS), is quite disputable, as stated by authors Veverka et al., Mikšovský and Zimová, Pešťák and Zimová, Frajer and Geletič [26–29]. Deviations in accuracy in recordings of objects could vary in the region of 160–2200 m.

The subsequent Second Military Survey, to a scale of 1:28,800, arose in the years 1836–1852 via the pantographic method from detailed cadastral maps of the stable cadastre, drawn up to a precise trigonometric network. There was less deviation between the mapped position and actual location of objects, in the range of 29–50 m [26, 28, 29]. In this survey, however, we find fewer ponds than in the First Military, as the first wave of cancellation was in the period between these two military surveys.

The most precise available identification and localisation of historical ponds are provided by maps of the stable cadastre (SC). This mapping survey was carried out in the years 1824–1843, and on the website of the State Administration of Land Surveying and Cadastre (ČÚZK), it is possible to view scanned pages of the so-called compulsory imperial record of the stable cadastre filed in the archive in Vienna. Despite being of good quality, colourful and well-arranged, these maps are not available for the entire Czech Republic and are not orthorectified.

6.3.2 Bodies of Water—Subjects of Database

In the mid-nineteenth century, there was no clearly defined difference between a reservoir (e.g. fire prevention, commercial) and a pond (exclusively for breeding fish), with both terms falling into the same category. We can take them as being equal. All artificially created bodies of water were considered to be ponds, if equipped with a dam, or if dug by humans.

On the maps used in the study, there were also other bodies of water which had to be differentiated. These were oxbow lakes, which are not counted as ponds, even though fish were often introduced to them. In the case of an oxbow lake being fitted with a dam, or having been altered in some way by humans, it was drawn in and included in the database. Unlike pond-type reservoirs, oxbow lakes tend to be oval, irregular or bean-shaped. Ponds and reservoirs tend to be more geometric in shape (especially in village or town locations), unless the shape is irregular with one distinctly straight side formed by a dam. At the time of the Second Military Survey, there were only two reservoirs, in the modern sense of the word, within the Czech Republic. Another category of bodies of water is that of natural lakes, which was also not included in the database. On the maps of the Second Military Survey, these were marked with the German word “See”, meaning lake. There were a considerable number of these, including river lakes, within the Czech lands.

The most conclusive proof of the existence of a pond is its name (hydronym) marked on a map. In the Second Military Survey, ponds were either marked only with an adjective, e.g. “Deep”, or with an adjective and the German noun “Teich”, or simply the letter “T.”. There could also be a mill near to the pond, which would

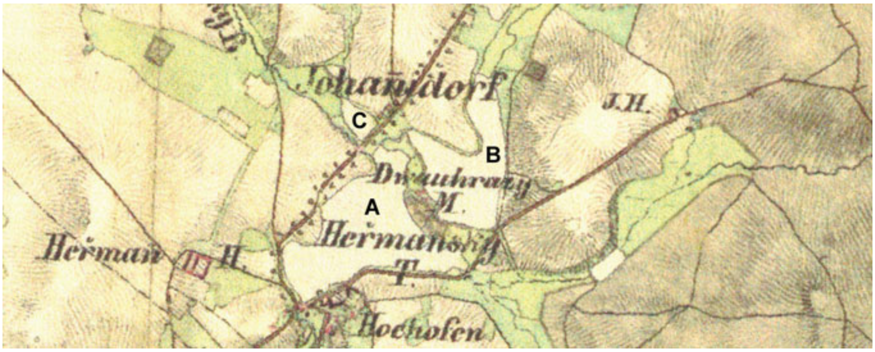

Fig. 6.3 Three ponds near the village of Johansdorf—south pond (A) is marked "Heřmanský T.", pond (B) is untitled, but its existence is indicated by the word "mill" nearby (Dwauhrazy M, i.e. Two-dam Mill). The name off the mill shows that it stood near two dams, i.e. two ponds (*Source* WMS Military Survey, Czech National Geoportal CENIA, Czech Ministry of the Environment)

use the water as a power source for milling grain. Mills (Mühle in German) were marked with an adjective and the letter "M", e.g. "Dubnitzky M." (Fig. 6.3).

On the maps of the Military Survey, local names can appear, even if a pond has been cancelled and drained, or merely "summered". This method of management involves draining a pond, where favourable conditions then develop for many species of flora and fauna, littoral communities are regenerated, mineralisation of sediment occurs and the anaerobic processes in deeper layers are minimised. In this case, the land was not included as an old pond and was assigned to the category of "other types of the land" (usually meadow or arable land). The exception is the case of areas which, on stable cadastre maps, are recorded as ponds, while on maps of the Military Survey they figure as cancelled, partly overgrown, overgrowing or summering. Areas were drawn in according to the Second MS only in the case of there being an evident boundary to the area, and a note on the condition or state of the pond was added to the attribute table (summering, drained, only in SC, etc.).

Original maps of the Second MS, to a scale of 1: 28,800, were hand-coloured. Over the course of time, this colouring has faded due to exposure to light, making it difficult to identify bodies of water. If the determining factor was not colour, it was necessary to take into consideration other indicators of the possible existence of ponds [30].

The essential prerequisite for the existence of a pond is a dam. Most ponds feature a dam, which is marked on maps with a bold line, or with a line and slanting cross-hatching. The dam can vary in shape, for example, a straight dam perpendicular to a watercourse, convex, concave or angled. In some cases, a dam can divide two ponds. In most cases, a path or even road would lead along with the crown of a dam, thus bypassing difficult waterlogged terrain.

Another factor which indicated the existence of a pond was an interrupted water-course. This was mainly cases of a faded colour of land, which suddenly interrupted a watercourse. After drawing these in, information was included in the attribute table

Fig. 6.4 Example of a pond (cross-hatched) moved to correct position (grey shading) based on a current body of water and cadastral maps

on the flow capacity of the pond, obtained on the basis of visual interpretation of the maps.

6.3.3 Parameters and Inclusion of Ponds in Database

Drawings in the layer of ponds were carried out to a scale of 1: 5000, and during processing, these objects were drawn from a size of approximately 0.1 ha. When processing the final form of the map, however, ponds under 0.5 ha were not included for further spatial analysis due to the inaccuracy of drawing on historical maps. Although ponds were drawn with the maximum possible precision, their recorded position did not always conform with the actual position on the ground. The reason for this inaccuracy is the drawing on maps in the Second MS. Further reasons could be due to the transformation of maps and the deformation of paper, which were highly apparent in objects of defunct bodies of water (Fig. 6.4).

Considering the amount of graphic data, automatic correction using spatial analysis in GIS seemed to be the most appropriate method. The other option was a manual correction. Both methods were tested in pilot areas. In order to verify the accuracy of drawings, it was decided to carry out the correction of drawings of all objects manually.

On the basis of the corrected layer of historical ponds, a cross-reference with water bodies was conducted in the ZABAGED database (geographic database for CZ). On the basis of the percentage presence of bodies of water (standing), in the areas drawn on the maps, it was determined whether each body was a current pond

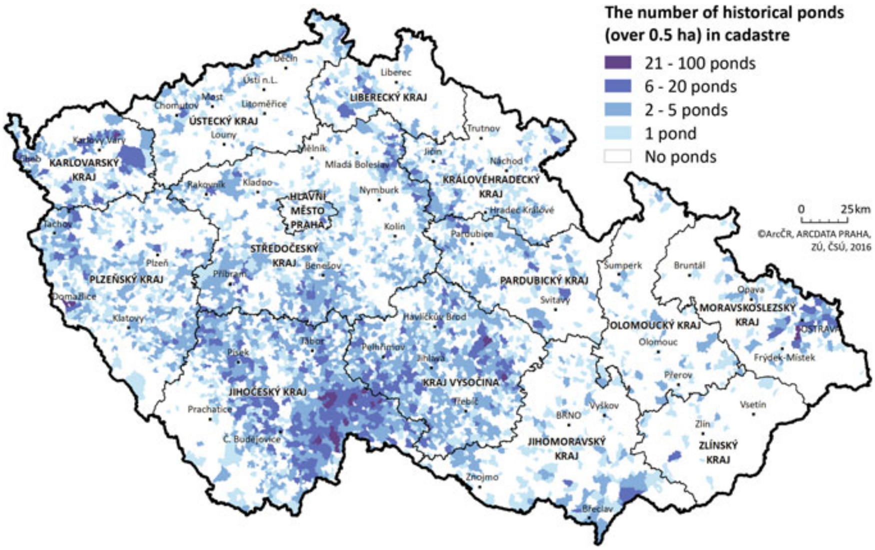

Fig. 6.5 Number of historical ponds (over 0.5 ha) in the Czech Republic

in its original size (preserved), a current pond of a considerably different extent, or a defunct pond.

Several options were available for further analysis of the recorded polygons of an emerging layer of defunct ponds (identification of defunct ponds, change in the extent of water area, qualification of ground cover, soil type, etc.). For the drawn areas of defunct ponds, the current use of these areas was identified in the following categories: permanent grassland, combined category—arable land, hop fields, orchards and gardens and other land, forests, parks, built-up land, water bodies and others. This categorisation was carried out with the use of the Geographic Database for CZ (ZABAGED®) and the Land Parcel Identification System (LPIS).

6.3.4 Map and Database of Historical and Defunct Ponds in the Czech Republic

In the course of our research, with the assistance of maps of the Second Military Survey, we drew in the historical ponds of the Czech Republic. These were given attribute tables with information about the area, the presence of a dam, flow capacity, the type of drawn object, the source of the drawing and the current use of the area. Figure 6.5 presents the resulting map giving the location of historical ponds from the Second MS with an area greater than 0.5 ha in individual cadastral areas, while also showing the location of defunct ponds.

Table 6.1 Land use representation according to ZABAGED combined categories in areas of defunct historical bodies of water in CZ (over 0.5 ha)

% in category	Arable land, vineyards, orchards	Permanent grassland	Forest	Park	Body of water	Built-up area	Other
Ponds	28.9	38.8	18.9	1.2	2.6	7.4	2.2
Lakes	41.8	5.5	27.3	–	14.5	9.1	1.8
Other	25.0	37.5	37.5	–	–	–	–

Within the Czech Republic, in the course of our study, we have drawn in and updated current information on 33,713 historical bodies of water (existing before the year 1836), of which 10,952 are ponds with an area of more than 0.5 ha. Their overall area is 59,643 ha. On maps, we have also identified 102 lakes greater than 0.5 ha with an overall area of 809 ha. We mapped 22,649 objects smaller than 0.5 ha, with an overall area of 3435 ha. During GIS spatial analysis, we found that, since the period 1836–1852 when the Second Military Survey was carried out, a total of 3479 bodies of water within CZ have become defunct, of which 3416 were ponds [31].

Table 6.1 gives a summary of the current use of land in locations of defunct bodies of water greater than 0.5 ha. From this, it is apparent that, in these areas, permanent grassland currently predominates with a share of 38.8%, followed by 28.9% of combined category—arable land, hop fields, vineyards, orchards and gardens, i.e. agricultural land, and 18.9% is forest category.

From the consequently developed database, it is possible to display, using GIS, specific further information on a given location of a defunct pond, and use this in planning and decision-making processes.

The database created for the Czech Republic provides a whole range of valuable information, but it does have certain limits. These relate mainly to the fact that the Second Military Survey, as a primary source, does not reflect every defunct pond in the country, as a considerable percentage of ponds became defunct at the turn of the eighteenth and nineteenth centuries, and are recorded in the First Military Survey. Due to its positional inaccuracy, however, the First MS cannot be of adequate use and does not record all historical ponds either, as shown in more detailed studies from individual regions. Within detailed research into defunct ponds, it is therefore also necessary to work with archive material on a local and regional level.

6.3.5 Former Pond Areas on Agricultural Land

Ponds have become an important part of our landscape, fulfilling the role of the significant biotope. After the cancellation of many of these, their use changed largely to agricultural land, either arable land or permanent grassland. Altitude played an important role in subsequent use as agricultural land, with the proportion of arable land falling as the altitude increased, replaced by an increasing proportion of permanent grassland and forest. A certain border in this difference in land use is the altitude of 350 m a.s.l.

After cancellation as ponds, and depending on their location in the landscape (e.g. according to altitude), these areas are quite diverse from a pedological perspective. Analysis of soil in these areas was based on estimated pedologic—ecological units (EPEU, source: Research Institute for Soil and Water Conservation), where mainland units were identified within the evaluation of soil quality. Within our research analysis of soil type representation was carried out in the mainland units in areas of defunct ponds greater than 0.5 ha.

Among the most common soil types or groups of soils, under current use as arable land, are Fluvisol (30.3%), with Phaeozems (16.2%), Gleysols and other hydromorphic soils (16.3%) and Stagnosols (12.6%). Chernozems make up about 10%. In permanent grassland on former pond land, three groups of soils are in the proportion of more than 10%. These are Gleysols and other hydromorphic soils (50%), Fluvisols (19.1%) and Gleysols (17%).

In areas of defunct ponds, other characteristics of soil properties were evaluated, such as soil type, soil hydrological group and soil bonification. In the following text, the selected characteristics are given separately: for agricultural soils without permanent grass cover and for grassland.

If we conduct an evaluation of soil texture in areas of former ponds in CZ, we find that, in these localities, both in arable land and permanent grassland, the lowest proportion is that of lighter soils (sandy, loamy-sand soils). On arable land, heavier soils dominate in areas of defunct ponds (clay-loam, clayey soils and clays), while in permanent grassland the soils are medium-heavy to heavy (from sandy-loam—loamy soils, to clays). In terms of hydrological groups, the dominant position, with ca 80%, is that of soils with a low and very low infiltration speed.

Soil on defunct pond sites can also be evaluated from an economic point of view, i.e. on the basis of the production potential of soils (Fig. 6.6). Soil yield capacity is expressed in points, in the range of 6–100 points. The bottom value of 6 points is for e.g. grassy vegetation in cool, humid climatic regions, while a value of 100 points is for Chernozem on loess with a favourable water balance, in warm, moderately humid climatic regions, in a flat area, not endangered by water erosion. In our study, we have divided the production potential into five categories. On defunct pond sites, categories 3 (40–60 points) and 4 (20–40 points) are dominant (60–70%). Category 2 (60–80 points) accounts for up to 27% in grassy vegetation.

6.3.6 Former Pond Areas on Forest Land

The influence of forest and forest management on the water balance within the landscape is very important, and appropriate use of water in these ecosystems should become a fully valued aspect of forestry and related activities. Forest, as a significant

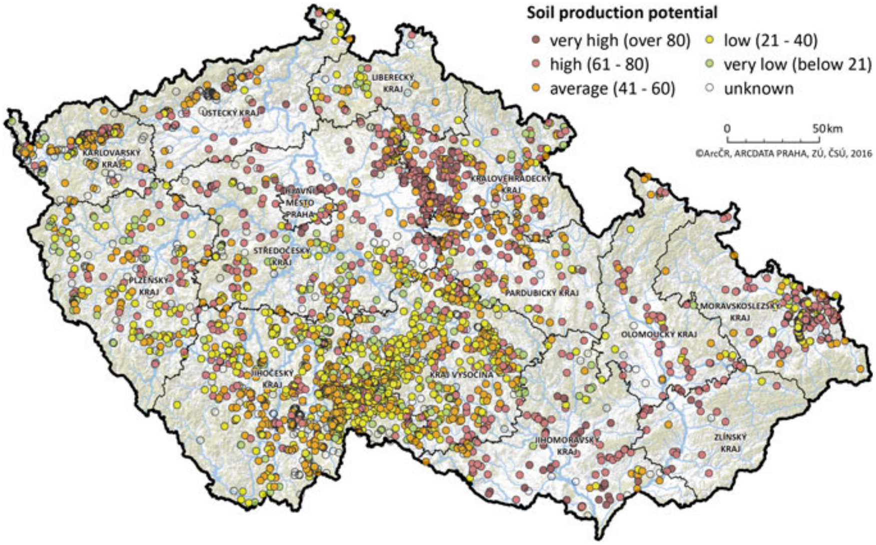

Fig. 6.6 Categories of soil production potential on defunct pond sites

landscaping element, is quite vulnerable in relation to climatic change bringing great fluctuation in temperature and precipitation including long dry periods. In a forest ecosystem, there is a distinct momentum, with only barely noticeable short-time reactions, so the long-term influence can be more dangerous, or possibly even result in a collapse of the whole system.

In terms of water balance, the measures implemented in forested areas should, among other effects, aim to stabilize such localities which have a high potential to retain water (localities with remarkably active water balance). This requires efficient operative measures that will help retain rainwater on these sites. Unlike former attitudes aiming towards rapid drainage, e.g. from forest logging paths, timber stockpiles and other manipulation sites, conducting water into holding reservoirs and further, out of forested areas, it is vital to change the approach to support the retention and use of water coming to forested areas. Such measures can vary from quite simple steps, e.g. piling loppings in heaps along contour lines, or allowing, to a certain extent, small-scale natural changes in topography, up to more complex technical measures such as connecting run-off ditches and grooves to drains, revitalisation of watercourses and building small water reservoirs.

All the aforementioned measures in forests usually also positively affect the ecological state of watercourses. These measures especially focus on retaining rainwater in forest vegetation and water infiltration into deeper layers of aquifers and transferring surface runoff to underground drainage [32].

When proposing technical measures to support water retention in forested areas it is possible to start from historical maps showing sites of former water bodies and old dams. In our research, it was found that 645 ponds with an overall area of 2164 ha

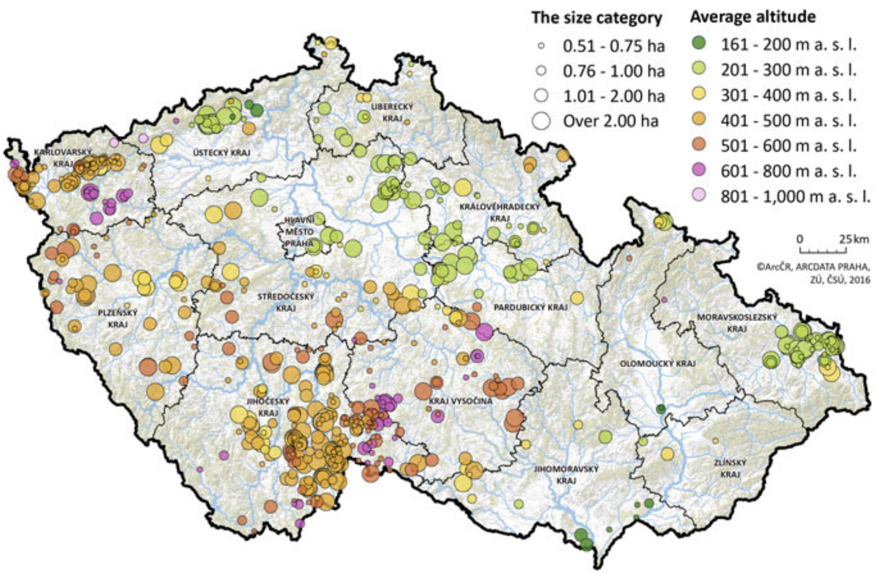

Fig. 6.7 State of defunct ponds in forested areas within the Czech Republic, according to altitude and size

(Fig. 6.7) have disappeared from current Czech forests since the Second Military Survey.

Most of the forest ponds which have disappeared, 256, were at an altitude of 400–500 m a.s.l. The layout of defunct ponds shows a great disproportion between individual Czech regions. The highest number of ponds disappeared in the region which is currently the pond-richest (in terms of number and size) in the Czech Republic, i.e. South Bohemia. As regards size, it is apparent (Fig. 6.8) that the most extensive forest ponds have disappeared at altitudes up to 300 m a.s.l. and also between 400 and 500 m a.s.l. In the category of the smallest bodies of water (0.5–0.75 ha), where the highest number of ponds have disappeared (196), most of them were at an altitude from 400 to 500 m a.s.l., a total of 75 ponds.

6.4 Restoration Measures for Defunct Water Bodies

After the disappearance of ponds in the Czech landscape, and within the subsequent changes in the use of these areas, we can consider the following options [33]:

(a) retaining the current state
(b) possible renewal of pond (reservoir)
(c) near-natural adaptation (e.g. wetland)
(d) use of the area for flood prevention measures

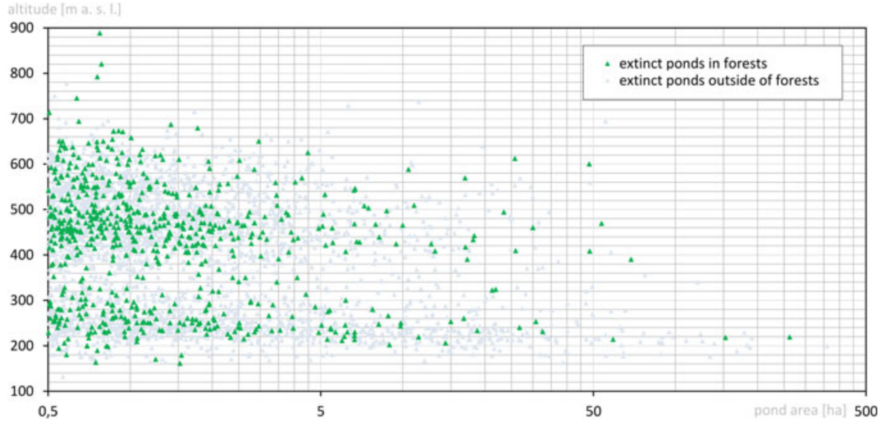

Fig. 6.8 Relationship of altitude and size to the disappearance of ponds from Czech forests

(e) change in the use of land e.g. permanent grassland, afforestation, change of form of land management, etc.

It is apparent that, according to current use of areas of defunct ponds and their natural or socio-economic conditions, certain types of change can be seen as inappropriate right from the start. From a technical, administrational perspective, it is always necessary to consider changes in land use with regard to legal regulations and other binding or conceptual documents (e.g. cadastral maps, agricultural land databases–LPIS, zoning plans and strategies, etc.) or limits to land use (conservation belts of water sources, protected areas, existing infrastructure). Any contemplated changes off land use must be resolved in the context of the wider environment, ideally the catchment basin. In guidelines by David et al. [34], criteria are proposed for evaluation of such land, which can be elaborated on the basis of data sources available for the entire Czech Republic, as well as criteria which can be evaluated on the basis of surveys of given localities or by gathering specific and locally available data. It is therefore necessary to gather and analyse e.g. data characterising the hydrological, pedological, hydrogeological and climatic conditions of the given locality. Of equal importance is information on the quality of surface water, which, along with other criteria, can determine the suitability of establishing bodies of water, and their subsequent function within a given locality. In Central European conditions, this important function could be, e.g. capture of phosphorus and nitrogen.

6.5 Conclusions and Recommendations

There has been intensive discussion in recent years on close-to-nature measures in both catchment areas and watercourses themselves, as such measures contribute to a reduction in flood risk and loss of soil, and they also support infiltration and accumulation of water in the landscape, thus slowing down surface run-off. A sophisticated approach to the issue of water retention, i.e. combining all suitable and mutually compatible measures, will be an optimum solution for the landscape as a whole. Such measures should be set in successive order with regard to the current state of a particular area. "Soft" measures must be preferred on farm and forest land, such as establishing wetland areas, etc. The construction and renewal of reservoirs, as a technical measure, should only be a subsequent step in a complex system of solutions. Among these measures in individual catchment areas within the Czech Republic, ponds have a fundamental role, their main benefit being their ability to retain and accumulate water for use in periods of drought. As is apparent from the preceding text, many of these water bodies have disappeared from the Czech landscape, and it is vital to consider their renewal in many areas.

The greatest proportion of defunct pond land is now used for agricultural purposes, and it seems that the current use is far from optimum in a number of these localities. This is why a more detailed evaluation of soil conditions in former pond areas will be important in the future, as well as considering the possibilities for changes in the use of some of these areas towards the restoration of water bodies, with respect for natural conditions and socio-economic criteria. Soil conditions will be fundamental in the decision-making process and available data shows that the soil in many of these areas is heavy, not highly productive, with low infiltration ability etc., making such areas more suitable for the renewal of bodies of water.

In terms of the renewal of some ponds within forests, their benefit is mainly in improved water management in upper parts of catchment areas. This can have a positive effect in dry periods and also reduce flood damage. Forest owners and companies managing forests would welcome better access to water supplies in the case of forest fires and nature conservationists can appreciate the creation of suitable conditions for the development of communities bound to a water environment or wetland.

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Chapter 7
Protection of Water Resources

P. Oppeltová and J. Novák

7.1 Historical Development of Water Protection in the Czech Republic

Water, which is a valuable raw material whose significance for society is quite extraordinary, is the basis of the right of the public and the main subject of its interest. Without water, neither life nor the development of society is possible. For millennia, people have met with water as a necessity of life, as a basic element of the environment in which they lived, but also as an indomitable element. Gradually, they learned to use water, protect themselves from its devastating effects and also influence its natural state.

Water law regulates legal relationships with waters. The content of water law is determined by natural, economic and social conditions and needs. Water law passes through individual development stages depending on the historical development of socio-economic assumptions. The issue of water law is increasing, and its importance increases mainly due to the problems arising from the growing demands on water resources and the limitation of the extent of its natural reserves on the earth, whose total quantity and cycle in the macro environment remain the same, given by the physical laws of the hydrological cycle [1].

Legislation on water management initially concerned only the interests of individuals and for that reason was considered from the private law. Wider interests began to be followed later, and the relevant regulations became part of public law.

P. Oppeltová (✉)
Department of Applied and Landscape Ecology, Faculty of Agronomy,
Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic
e-mail: oppeltova@mendelu.cz

J. Novák
VODÁRENSKÁ AKCIOVÁ SPOLEČNOST, a.s., Brno, Czech Republic

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It took a long time to create a legal framework for the management of groundwater and surface water. The legislation was inconsistent and, in essence, constantly evolved as the technical possibilities for its use developed. The need to protect water resources and the need to regulate their drainage and to regulate the binding rules of ownership have led to the emergence of new legislation. This was the result, for example, of the obligation for landowners in the vicinity of streams to maintain their banks.

Roman Water Law had a fundamental and unimportant influence on the development of water law. For example, this right has brought us a significant principle of public running waters.

The beginnings of the codification of the protection of water resources originated in the present territory of the Czech Republic came from 1210 to 1275, from the period of the first Czech cities during the reign of the Premyslids. However, its beginnings were very shy and protected water resources in most cases only from intentional poisoning [2].

The first Czech codification occurred in the Land of Vladislav in 1500, where there is the only water law clause in Article 552 that navigable rivers, as well as roads, are public—so they are a general good. This principle was also included in the so-called Restored Land of Ferdinand II. of 10 May 1627.

The first water regulations in the modern sense of the term contain the mill orders that were issued separately for each country. For example, Matyáš's Mill Order from 1618 or the one from 1775, which has already determined that the role of mediator in water disputes, be performed by regional authorities [3].

Throughout the Middle Ages and the beginning of the Modern Age, there has been no uniform legislation in the territory of the state. Only in the early nineteenth century, and to a greater extent in the second half of the century, there was a further development of water legislation.

Water law provisions are found in the General Civil Code of 1811, which uses the term 'public thing'. Every citizen was allowed to move on a public road or on a ship to ride a public river that was accessible to everyone. The amendment to the Water Code, which stipulated that water law is only a matter of public law, occurred in 1850. The modification of that time was the overall fragmentation and obsolescence of water standards, and for this reason, reform was proceeding. In the Czech Lands of Austria-Hungary, the first River Basin Water Act (No. 93/1869 z.ř.) was issued in 1869, which stipulated that more detailed water regulations be reserved to the provincial laws. He served the Czech amendment in particular by the fact that it had been cited in the provincial laws by individual paragraphs. On the basis of this, in 1870, the first Czech water law was drafted under No. 71 on how to use water, ties it up and defend it, the Moravian Water Act (No. 65/1870), and the Silesian Law no. 51/1870. All provincial laws are very close to the content. The main importance of water under these laws was seen primarily in connection with agriculture and technical activities on waterways. The Hungary Statutory Act XXIII/1885 was in force in Slovakia [4].

In 1918, with Czechoslovakia establishment, the Water Act of Austria–Hungary Monarchy was incorporated. At the same time in Slovakia, the Hungarian adjustment was applied.

In 1926, attempts were made to unify and reform all existing water regulations, a commission for the elaboration of a single water law consisting of legal and technical experts from the Ministry of Agriculture and the Ministry of Public Works was set up for this purpose. Efforts ended in 1937 with failure.

During the "First Republic", some generally binding regulations concerning water management were issued, such as the Water Tax Act, Government Ordinance Regulating Facilities and Water Books Management, State Fund for Water Management Improvements and the State Fund for River Riding, construction of ports, construction of reservoirs and use of water. Water law ranks under the notion of wider business.

For further development, it was essential to elaborate the State Economic Plan in 1949–54, including the State Water Management Plan of the Czechoslovak Republic (SVP 1953). The endeavour to apply the principles mentioned here gave rise to the new regulation No. 11/1955 Coll., on water management which ended the long validity of both the Austrian Water Act in the Czech Regions and the Hungarian Article XXIII/1885 in Slovakia. Act No. 11/1955 Coll., states that all surface and groundwater serves to secure economic and other social needs.

The basic principles of Czechoslovak Water Law include the fact that the rights to surface and underground waters are governed exclusively by the Water Act. In this sense, water rights are not deduced from land ownership. The watercourses, including their troughs, and the water located in the blind arms of the watercourses, the constitution expressly declares the national property [5].

The historical break in terms of the protection of water resources occurs with the adoption of Act No. 20/1966 Coll., on the care of public health and, in particular, it's Implementing Directive No. 51/1979 Coll., Basic Hygienic Principles for the Designation, Determination and Use of Protected Areas of Water Resources for the Collective Supply of Drinking Water and Production Water and for the Establishment of Water Reservoirs, with effect from 1 September 1979. Along with the new Water Act No. 138/1973 Coll., effective from 1 April 1975, creates an entirely new and for the first time in the history of water supply an effective framework for water protection. Including the legal regulations and ČSN 83 06 11 and ČSN 75 71 11 closes an almost perfect circle of protection, production and supply of drinking water. Act No. 138/1973 Coll., on waters, reads the wording of Act No. 11/1955 Coll., that '… surface and groundwater serves to secure economic and other (other) social needs', but has a significant addition (with regard to the time then), which stated that '… water forms an important component of the natural environment'.

After 1989, a number of laws on the protection of individual environmental compartments began to emerge. E.g. Nature and Landscape Protection Act, the Environmental Protection Act, the Agricultural Soil Protection Act, the Waste Act and others. Also, in the field of water management, it was necessary to amend the current regulations. Amendment to the Water Act No. 138/1973 Coll., took place in two stages. First, the so-called Little Amendment—Act. No. 14/1998 Coll., it concerned only a few paragraphs of the Water Act, especially the protection zones. Details deal with Sect. 7.3.3 Special Water Protection, including, among other things, the establishment of water protection zones. Later, the current Water Act No. 254/2001 Coll., which repealed the Water Act No. 138/1973 Coll., and most of its implementing regulations, as well as the Act No. 130/1974 Coll., on State Administration in Water Management and also a Little Amendment, i.e. Act No. 14/1998 Coll. [6].

Another significant period, when there are changes in the water regulations, is the entry of the Czech Republic into the EU after 2004. Amendment to the Water Act No. 20/2004 Coll., in practice called 'Euronovela' of the Water Act, implemented EU legislation into our nation. During its period of validity, there were dozens of amendments to the Water Act, especially Act No. 150/2010 Coll., is one of the most important.

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, the so-called Water Framework Directive (WFD) dealing with atmospheric, marine, coastal, surface and underground water, both standing and running, is the most important European water law. Its principles are based on the sustainable use of water. The main objective is to prevent further deterioration of water quality and to protect and improve the status of all aquatic ecosystems. The need to integrate sustainable water management into other economic sectors such as energy, transport, agriculture and fisheries using the precautionary principle through the implementation of appropriate preventive measures is a prerequisite for success in implementing the requirements of the WFD. As stated above, Water Act No. 254/2001 Coll., as amended, is the most important current water law in our country. In its present form, it has a relatively complex arrangement, which results from the number of novelties mentioned above.

The objective of the WFD is to achieve not only the chemical quality of water but also good ecological status. This is not just about regulating the amount of pollutants discharged from a particular source but about the overall effect of anthropogenic impact on recipient ecosystems. The ultimate result is the ecological quality of the receiving system, and the individual member states must do everything necessary to adapt not only the agricultural but all their activities to achieve good ecological status [7].

7.2 Water Protection Legislation

As mentioned above, the most important current water management regulation in the Czech Republic is a special law—Act No. 254/2001 Coll., as amended (from now on referred to as the Water Act). In its present form, it has a relatively complex arrangement, which results from the number of novelties mentioned above. The Water Act addresses in detail: water management, surface, and groundwater status, water planning, protection of water and water resources, watercourses, river basin management, waterworks, flood protection, fees, state administration and administrative delicts. Dangerous Substances are listed in Annex No. 1. Annex 2 deals with charge rates. The text of the Water Act contains a number of references to implementing regulations. These are primarily the decrees of the relevant ministries (Ministry of Agriculture, Ministry of the Environment—both as central water authorities or other ministries), as well as the Government's order for certain specific problems. Another degree of lower legal power is methodological guidelines, directives, etc.

From the point of view of conflicts of interest between water protection and intensive agricultural use of the landscape, the provisions on water protection are important. For this area, the Ministry of the Environment is the central water authority, which issued the Decree No. 137/1999 Coll., on Issues of the Protected Areas of Water Resources. However, this Decree was issued to the now invalid Water Act of 1973 and is ineffective, some of the provisions of this Decree are also inconsistent with the applicable Water Act. Because the content is overcome and legal in some provisions is invalid, a completely new decree on his subject is being prepared.

Government Decree 262/2012 Coll. on the definition of Vulnerable Areas and the action programme, as amended (Amendment No. 235/2016 Coll.) is another important legislative regulation in the field of water management. The issue of Vulnerable Areas is addressed in more detail in Sect. 7.3.2.2.

Decree No. 252/2004 Coll., as amended, laying down hygiene requirements for potable and hot water and the frequency and scope of drinking water control is very important.

In terms of quality assessment of surface water, two important government regulations have to be mentioned:

Government Ordinance No. 401/2015 Coll., as amended, on indicators and values of permissible pollution of surface waters and wastewater, the requirements for permits for discharging wastewater into the surface and sewage water and on Sensitive Areas. Also, emission standards for discharged wastewater and so-called Environmental Quality Standards (EQS) for surface water quality are set out here. These are the maximum allowable values of surface water pollution indicators in units of mass, radioactivity or bacterial contamination per unit volume.

Government Decree No. 71/2003 Coll., as amended, on the determination of surface waters suitable for the life and reproduction of native species of fish and other aquatic animals and on the assessment and assessment of the status of these waters.

Unlike the previous regulations, water management now has a separate branch in the field of drinking water supply and wastewater drainage—water and sewerage. In the past, legal issues in this sector have been dealt with by the Implementing Decree on the Water Act. Currently, the second special, separate Act No. 274/2001 Coll., as amended, on public water supply and sewerage systems and the amendment of some Acts (hereinafter ZVAK) is valid. Following the Water Act (particularly issues permits for water use) and Administrative Procedure defines ZVAK duties of owners and operators of water supply and sewerage systems for public use, care of the property, its protection and related issues of public administration and sanctions for breaches of statutory provisions. A single implementing decree of the Ministry of Agriculture No. 428/2001 Coll., as amended, has been issued to this Act, and it was also amended.

7.3 Water Protection

The term water protection was first introduced in the Water Act No. 138/1973 Coll. Apart from the fact that water is a good source of public use, it is also the most important asset for the environment. Public use must be regulated in a certain way in favour of preserving this farm. Regulation of public water use regulates water law as a general and special water management.

The basic obligations in general water management are laid down in Sect. 5 of the Water Act. It states that everyone who deals with surface or underground water is obliged to take care of their protection and to ensure their economic and efficient use under the conditions stipulated by the Water Act. They must also to ensure that their energy potential is not impaired and that other public interests are violated protected by special regulations (e.g. Act No. 17/1992 Coll., on the environment).

It is a measure to ensure the quantity and quality of water in the natural environment, to reduce and eliminate the consequences of pollution and to prevent 'looting' (overdraft, i.e., intervention in the so-called static groundwater reserves—only dynamic reserves of water). The main objective of protection in the Czech Republic is, in accordance with the requirements of the European Union, the improvement of the state of water resources, aquatic ecosystems, support for the continuous use of water and mitigation of the adverse effects of floods and droughts. These objectives are respected in individual river basins and groundwater zones through integrated protection of the quantity and quality of surface and groundwater. It is a complex activity consisting in the protection of the quantity and quality of surface and groundwater, in accordance with the requirements of both the Czech and the EU law (transformed into national legislation). Directive 2000/60/EC (Water Framework Directive) and Directive 2009/128/EC of the European Parliament and of the Council—the so-called Community Action Directive on the Sustainable Use of Pesticides is a basic legal regulation of the European Parliament and of the Council establishing a framework for Community Action Member States' water policy.

Diffuse pollution originating from agriculture is one of the biggest ecological challenges faced by European waters that do not achieve good ecological status [8]. Nutrients (carbon, nitrogen, phosphorus and their compounds), heavy metals and agrochemicals (pesticides, industrial fertilizers), drug residues and sediments are the main pollutants in agriculture that pollute surface and groundwater [9].

The protection of water, its use, and rights are regulated in the above-mentioned Water Act No. 254/2001 Coll., as amended, and its implementing regulations (Government Ordinance, Decree). The Ministry of the Environment together with the Ministry of Agriculture annually submits to the Government a Report on the state of water management in the Czech Republic, which describes and evaluates the quality and quantity of surface and groundwater as well as the related legislative, economic, research and integration activities. The Water Act, for example, requires that landowners be required to ensure that the drainage conditions are not deteriorated, the soil is discharged by water erosion and that it should take care to improve the retention capacity of the landscape.

The sets of measures that aim to ensure water protection can be divided into three basic forms from a legal, economic, technical and practical point of view:

- General Water Protection,
- Particular Water Protection,
- Special Water Protection.

7.3.1 General Water Protection

General Water Protection is based on all generally applicable and binding provisions that must be observed in all circumstances, and no financial compensation is required for such compliance. These provisions are defined by a number of regulations, mainly from a substantial part of the present Water Act (e.g. protection of the quality of underground and surface water, wastewater, water management planning, etc.). As well as other legal regulations from other areas and departments relate to General Water Protection (Building Act, Nature and Landscape Protection Act, Environmental Protection Act, Waste Management, Soil Protection, and others). As with most general legal provisions, even in the case of General Water Protection, everyone must comply with it everywhere, everywhere and under all conditions (regardless of whether it is water sources for drinking water supply and their protection zones) and there is no financial compensation for this. Water resources are part of the aquatic environment (water), so this General Protection is also valid. Before 1989, there were almost no laws protecting individual components of the environment, and the principles ofGeneral Protection were often part of the management regime in buffer zones of water resources—that means that General Protection was supplanted by Special Protection [6].

7.3.2 Particular Water Protection

The Particular Water Protection , considered from the point of view of the interests of the state, serves to protect the specific area; it is for a variety of reasons to ensure a higher degree of protection than General Protection. They are primarily Protected Areas of Natural Water Accumulation, Sensitive Areas and Vulnerable Areas.

7.3.2.1 Sensitive Areas

Sensitive Areas are defined in § 32 of the Water Act as surface water bodies in which a high concentration of nutrients occurs or may occur in the near future to an undesirable state of water quality. That water bodies are being used or are expected to be used as a source of drinking water in which the nitrate concentration exceeds

50 mg l^{-1} or where a higher degree of wastewater treatment is required for the interests protected by this Act. Government Regulation No. 401/2015 Coll., as amended, on indicators and values of permissible pollution of surface water and wastewater, on permit requirements for discharges of sewage into surface waters and sewage and on Sensitive Areas. According to the regulation above § 10 (1), all surface waters in the territory of the Czech Republic are defined as Sensitive Areas. This regulation must be reviewed at regular intervals of no more than four years. For Sensitive Areas and for discharging wastewater into surface water affecting water quality in Sensitive Areas, the government will set a permit for indicators of permissible wastewater pollution and their values.

7.3.2.2 Vulnerable Areas

Nitrogen is an essential nutrient to help grow plants and crops, but its high concentration is harmful to humans and nature. Therefore, in 1991, Council Directive 91/676/EEC was adopted by the European Union to protecting water quality throughout Europe by preventing nitrates from agricultural sources from being leaked to surface and groundwater, which is necessary not only to ensure sufficient quality drinking water but also to limit eutrophication of surface water. The creation of a legal instrument to regulate the excessive application of nitrates as organic and chemical fertilizers was one of the main reasons for the creation of this directive.

According to the Directive, the Czech Republic had to implement the directive into the national legal order (specifically Article 33 Act No. 254/2001 Coll., on Water, as amended) for EU accession. On the basis of authorization in the Water Act, Government Decree No. 103/2003 Coll., on the determination of Vulnerable Areas and on use, storage of fertilizers and manure, crop rotation and implementation of anti-erosion measures in these areas, as amended, was adopted by the Government. Part of the requirements of the Nitrate Directive is also applied by Act No. 156/1998 Coll., on Fertilizers, as amended.

At present, the issue of Vulnerable Areas is regulated by Government Decree 262/2012 Coll., as amended, on the definition of Vulnerable Areas and the action programme (again, a four-year update of the Water Act is required here). This legislative act is effective from 1 August 2012 and repeals the previous Government Decree No. 103/2003 Coll., including all its amendments.

Vulnerable Areas are those areas in river basins where nitrate contamination of underground and surface waters has already exceeded or could exceed a limit of nitrate concentration of 50 mg l^{-1}.

Vulnerable Areas are designated as individual cadastral areas, subject to revisions and reviews every four years from their publication. A list of territorial units belonging to Vulnerable Areas is included in the Annex to the Government Act No. 262/2012 Coll. Detailed information is available at www.nitrat.cz.

In Vulnerable Areas, the compulsory management modes are set by the action programme. The Action Programme is a mandatory way of meeting the natural conditions and management practices of different types of vulnerable zones, which must include mandatory measures to reduce nitrate levels in waters. The first Action Programme was announced for the period 2004–2007 by Government Regulation No. 103/2004 Coll. Lastly, Vulnerable Areas were revised in 2016. The new 4th Action Programme for the period 2016–2020, containing the new conditions resulting from the Government Decree No. 262/2012 Coll., And its amendment, Act No. 235/2016 Coll., in force, was also drafted. Changes in the Action Programme stemmed from the results of monitoring, new scientific knowledge, and EU requirements.

The most important measures listed in the action programme governing the management of Vulnerable Areas include:

- the period of the ban on fertilization,
- limits for fertilizing crops,
- fertilization in summer and autumn,
- fertilization of permanent grassland,
- prohibition of fertilization under unfavourable conditions,
- the requirement for uniform fertilization,
- restrictions on the use of organic nitrogen,
- storage of livestock manure,
- crop rotation in Vulnerable Areas,
- farming on sloping agricultural land and on agricultural land near to surface waters [10].

Businesses in Vulnerable Areas may use a maximum of 170 kgN/ha/y (including all farm, organic and mineral fertilizers). The Klír Methodology [11] includes principles of good agricultural practice for water protection against nitrate pollution from agricultural. The methodology clearly outlines management requirements that reduce nitrogen losses to water. These include mainly the exclusion of nitrogen fertilization in an inappropriate period, on waterlogged, flooded, frozen or snow-covered agricultural parcels. The Klír methodology describes the principles of farming on sloping land, near-surface waters and principles of fertilizer use with regard to soil-climatic conditions, the need for stands and nutritional state of the soil.

In the context of the Nitrate Directive, cross compliance has to be mentioned. This is a system of agricultural controls for paying direct payments and is related to the observance of good management. Part of the cross-compliance checker is the so-called GAEC—Good Agricultural Environmental Condition. GAEC is defined as a standard that ensures agricultural management in line with environmental protection. It contains seven main points. Farming in line with GAEC is a condition for providing direct payments (subsidies).

Statutory Management Requirements (SMR) are the results given by selected European Union regulations and directives. The results or goals are set, and it is up to each country to reach them. Under SMR, there are three areas of rules: Environment, Climate Change and Good Agricultural and Environmental Status; Public health, animal and plant health; Animal welfare.

Two important cross-compliance points on water protection issues are:

GAEC I—water protection from nitrate pollution from agricultural sources

The applicant on the part of the soil block used by him adjacent to the surface water body meets the conditions for the application of fertilizers and plant protection products in the defined zones defined around the water bodies by:

- preserves within and outside the Vulnerable Areas a non-fertilized belt of land with a width of at least 3 m from the shoreline,
- for a part of the soil block with an average slope of 7° preserves protection strip shall at least 25 m wide from the bank line, not using liquid fertilizers with rapidly releasing nitrogen,
- when applied to plant protection, he maintains a specified protection distance from the shoreline to protect aquatic organisms.

SMR I—water protection from nitrate pollution from agricultural sources

Among the individual controlled requirements are above all:

- records of fertilizers used on agricultural land,
- violation of fertilization during the ban,
- violation of fertilization during the ban,
- protective strips at least 3 m from the shoreline,
- the use of nitrogen fertilizers on flooded, saturated water, frozen or covered with snow,
- the physical occurrence of the fertilizer in the protection strip.

Certain requirements of the Action Programme have become a direct condition for providing subsidies. Applicants for subsidies must comply with the selected requirements for the protection of water against nitrate pollution from agricultural sources. The fulfilment of these subsidy conditions is also binding for applicants outside the Vulnerable Area.

If the applicant does not comply with the conditions set, the subsidy may be reduced or, in the most extreme case, not granted at all. Reducing the amount of the subsidy does not replace the administrative penalty or any other sanction that may be imposed by a control organization or a court for violation of national law.

Farmers included in the Land Registry (LPIS) have the opportunity to obtain information on the methods of farming on individual soil blocks or their parts in the LPIS on the Farmer's Portal.

7.3.3 Special Water Protection

Special Water Protection is a certain superstructure over Particular and General Protection. This is to protect the quantity, quality and health of surface and groundwater which are or may be used as sources of drinking water. For this reason, protection zones (PZ) are established for water resources. At present, the protection zones are determined in accordance with the applicable Water Act No. 254/2001 Coll. The method of determination is different from the previous legislation—the Water Act

No. 138/1973 Coll. At that time, the PZ was established in cooperation with the authorities of the hygienic service, and at that time, the hygienic term of the hygiene protection zone (HPZ) was used. Implementing regulations to the law on public health care—Decree of the Ministry of Health No. 45/1966 Coll., and Directive 51/1979 of the Ministry of Health divided HPZs as follows:

- HPZ 1st stage
- HPZ 2nd stage—inner and outer
- HPZ 3rd stage—only for surface sources.

It was so-called surface or zone protection where the respective hydrological or hydrogeological basin of the water source (i.e. the area between the water source and potential sources of danger to the distribution system) was always a part of the individual stages of the HPZ. Taking into account the fact that it was a period when General Water Protection was not at a sufficient level, it is understandable that HPZ had to protect as much territory as possible and set a considerable number of specific conditions and measures to ensure the protection of water resources.

The strictest conditions were always in HPZ 1st stages—most bans. For other HPZ grades, conditions have been gradually mitigated. There was no financial compensation for adhering to the special regime in each HPZ.

This state of implementation of the Special Protection of water resources (basically to some extent replacing the insufficiently functional General Water Protection) lasted almost 20 years. It was completed after 1989, in connection with the emerging democratization of the company.

The new concept of Special Protection of water resources (adopted by the so-called small amendment to the Water Act, i.e. Act No. 14/1998 Coll., And subsequently Act No. 254/2001 Coll., As amended) consists in determining the protection of so-called zonal in contrast from the original solution of the bandwidth. Changes in the legislation (not only water law) have significantly increased the General Protection of environmental components after 1989. Therefore, it is currently possible to propose Special Protection only in those areas where local conditions, together with the current development of water quantity and quality, require just beyond General Water Protection (or even Practicular Protection). This principle does not mean a weakening of the overall protection of waters but, on the contrary, its consolidation and strengthening, which always consists of an assessment of the specific conditions of the given site.

The protection zones are dealt with in Section 30 of the Water Act and then the Decree of the Ministry of the Environment No. 137/1999 Coll., which establishes the list of water reservoirs and the principles for determination and modification of protection zones of water resources (this is already overcome and is expected to change it cancellation see Chap. 2). Protected areas means areas designated to protect the quantity, quality or medical harmlessness of water sources of surface and groundwater used or usable for the supply of drinking water (from now on referred to as ‘water source’) with an average annual collection of more than 10,000 m^3 per year.

Fig. 7.1 Warning boards of PZ I. stage

As the conditions are generally given for each stage of the PZ do not apply, as previously set out in Directive 51/1979, it is necessary to assess each site of the water resource individually.

At present, there can be no limitation for individual stages of the PZ, or for individual types of water resources. These conditions may be quite different e.g. for PZ II. st. two water sources, often located and close together, however, if they are in different local conditions.

Protection zones around surface and groundwater sources are divided into PZ I. stage and PZ II. stage (Fig. 7.1).

PZ I. stage

- serves to protect a water source near the receiving or abstraction facility,
- must always be marked with warning boards,
- for underground sources, it is mostly fenced (without fencing in forest stands),
- in the case of surface resources, it is fenced only exceptionally,
- the most stringent conditions apply here, most of the prohibitions of activity,
- the law prohibits entry for unauthorized persons,
- the territory of PZ I st. is part of the water supply property owned by the owner of the water main—mainly underground sources.

PZ II. stage

- serves to protect the water supply in the areas designated by the water authority so that the quality, quality or health of water in the water source cannot be compromised,
- it may not immediately follow up on PZ I st. and may not be a contiguous territory,
- it is possible to determine several areas—PZ II zones within the hydrogeological region or hydrological catchment area. st., with the individual territories of PZ II. st. may be determined sequentially,
- shall not be stipulated in cases where the territory of the PZ I st. in the given conditions, sufficiently ensures the protection of the quality, quality or health of the water resource,
- it does not fit, but it must be marked in the field with warning boards,
- the farming regime is milder than in PZ I.st—always according to the specific conditions of the site.

The protection zones were set up by 1.8.2010 by the decision of the water authority, i.e. the territorial scope, the regime of management and various restrictions were valid only for the participants in the water management proceedings. It is now set, repealed or amended by general measures, that is, the proposed measures are generally valid for all measures of a general nature is based on the Administrative Procedure Code.

Measures of a general nature are at the interface between the decision because it addresses specific issues (protection zone of a particular water resource) and legislation because it has an indefinite range of addressees (generally designated). Measures of a general nature cannot be subject to ordinary appeals (appeals). However, it is possible to bring an action in the administrative judiciary or to review the compliance with the legislation in the review procedure (assessed by the superior water authority) [12].

The proposal for the determination (or modification) of the PZ is submitted by the person who applies for the permission to take water from the water source, except for the water reservoirs, where this is the responsibility of the tank owner. In the process of establishing or amending the PZ, the Water Authority shall always assess activities that are subject to prohibitions in accordance with the provisions of the Act. This includes in particular:

- in which the production, storage or handling of substances endangering the quality or health of the waters occurs,
- substances with toxic, carcinogenic, mutagenic or teratogenic properties,
- breaking the soil layer and reducing the thickness of cover layers, earthworks breaking the soil cover, the use of explosives, mining, mining and operating facilities that may affect the aqueduct mode.

These activities and prohibitions are determined by the water authority after consultation with the relevant state administration bodies in measures of a general nature determining or modifying the PZ.

Each proposal for an PZ must contain two basic information:

- proposal of scope and management of the boundaries of individual stages of PZ (No. 137/1999 Coll., § 2). The boundaries of the PZ must be processed in the cadastral map so that it is unambiguous which plot belongs to the OP and which is outside. If it is necessary to divide the plot, it must be documented by the so-called detailed measurement record. Furthermore, it is advisable to lead the border of the PZ as far as possible after natural or artificial boundaries in the field (such as a brook, path, field—forest interface, etc.).

- proposal for protective measures (No. 137/1999 Coll., § 2) to protect the quality, quality or health of the water source. In view of the experience with the substitution in the PZ as well as with other experiences, it is advantageous to divide all protective measures in the PZ in the draft PZ documentation, namely:

  1. activities damaging or threatening the profitability, quality or health of the water resource and therefore cannot be implemented in this PZ.
  2. technical measures in the PZ that are required to make those who are entitled to withdraw water from this water source.
  3. the way and the period of limitation of the use of land and buildings in the PZ.
  4. demonstrated limitation of the use of land and buildings in the PZ for which compensation may be granted.
  5. possible additional conditions for the protection of the quality, quality or health of the water source, monitoring, verification of the effectiveness of the PZ, etc.

The design of the PZ documentation, which is the basis for the water authority, must comply with the requirements of the Implementing Decree and in particular assess the specific conditions of the water source: type of source and collecting object, quantity of collected water, water quality, local conditions and groundwater, especially expert hydrogeological assessment of the site [13].

Changes or abolition of the original HPZ of individual water resources could not have been made by the amendment to the Act; the change can only take place after a new water management procedure, when the Water Authority issues new measures of a general nature, cancelling the original HPZ and setting new PZs. That is why we are currently experiencing both the original HPZs and the new OPs. In areas where the band has not been revised under the new regulations, the current HPZ is still in effect. Revised or newly established PZs (for non-HPZ water sources) already represent zonal protection. As mentioned above, a number of unfulfilled guidelines have previously shifted to Special Protection—HPZ farming regimes. At the time, this was of considerable importance and brought about a number of improvements in environmental conditions.

Modern protected areas should, therefore, be processed in a form that reflects more realistically the landscape in relation to the source of drinking water. Datel [14] states that currently, water protection zones are primarily set up to protect water quality, while water protection is often only marginally solved. During the drought, attention should be paid to protecting the quantity.

Knowing the processes influencing the water source would be an indisputable standard for the design of protection bands. Only such an approach can bring to reality a demanding objective such as the consideration of the reduced need for drinking water treatment in line with the provisions of the WFD. To determine the optimal protection of water resources, it is crucial to carry out a risk analysis that evaluates its own water resource, its catchment area, risks and justifies the proposed conservation measures [15].

Owners and operators of water infrastructure are making considerable efforts and, above all, investing resources in technologies that lead to a continuous supply of high-quality drinking water. In addition to improving the quality of materials and equipment for collecting objects and water mains, it is above all the modernization of water treatment technologies, which must not only deal with the quality of raw water under 'constant conditions', but must also be able to eliminate any accidental conditions in the river basin or directly in water sources. However, the preventive protection of water resources cannot be neglected and must be carried out at the same time as other technical and technological measures. This means that it is necessary to perceive in the water basin the historical situations and conditions that can influence the development and the quantity of water resources in the source (natural and polluted rock environment, soil profile, sediment in tanks, etc.), as well as new trends, technology [15].

7.3.3.1 Financial compensation in protection zones

The earlier legislation did not allow for compensation for any constraints on management, and land users were parties to the HPZ determination procedure. HPZ has so little of its ownership rights. The current valid water legislation has changed the situation in that it allows the granting of compensation for proven restrictions on the use of land and buildings in the PZ. An important provision of the Water Act is that the quoted refund issues also apply to the original HPZ (since the entry into force of a small amendment to the Water Act—Act No. 14/1998 Coll., i.e. from 6.3.1998). However, the legislators have failed to combine the original provisions and practices with the new legal provision. The Water Act says that if the parties do not agree on the amount of compensation, the court will decide on a one-off compensation. The case was completely overlooked that the parties would argue about the essence, whether or not any compensation should be provided, that is, whether it is a restriction on the use of land and buildings that can be proven [6].

Meanwhile, the operator of the water supply (or the water reservoir manager) is the person liable for payment of the compensation, but it is ultimately one of the water cost items, that is, the water consumer pays it. The state should consider all the connections and accept the solution. Water is a materially regulated price, it is also socially bearable, it is often a 'pre-election promise', but is not sufficiently perceived to be a vital and strategic resource in the case of drinking water.

The practical journey is clearly based on cooperation and understanding between water farmers and farmers, as well as the involvement of researchers from universities who are independent experts. Priority will be given to optimizing the PZ (scope and protection measures), optimizing the use of fertilizers (N, P) and chemical plant protection products, ensuring soil fertility and reducing erosion. State support is very important, as well as monitoring compliance with proposed measures at the level of General, Particular and Special Water Protection.

For example, a flat-rate solution for substitution in buffer zones of water reservoirs in the Czech Republic currently seems to be inadequate in a number of entities and would rather demonstrate the actual level of constraints under a particular measure regime in individual buffer zones [12].

Novák and Fučík [16] recommend an open dialogue of all stakeholders, which alone can lead to a concordance of setting restrictions on farming activities in the catchments of water reservoirs and subsequently ensuring the required water quality for future generations.

Experience from abroad also states that good cooperation between farmers and water suppliers can only be achieved through the active participation of farmers in the definition of water protection programmes and agricultural contracts [17].

If there is a change of the HPZ to the PZ under the new legislation (or for the establishment of the PZ for new sources), it is recommended that the questionnaire is already addressed in the cases where and for which conditions of the measures of a general nature are restrictions on the use of land and buildings.

7.4 Protection of Water Resources in Practice—Vysočina and South Moravia Regions

The system and the conditions of supply of drinking water to the population stem from the ZVAK, which states, among other things, that public water supply and sewerage systems are established and operated in the public interest (§ 1 (2)). Similarly, the Water Act stipulates that the designation of buffer strips of water resources is always a public interest (Section 30 (1)).

In practice, it is necessary to perceive the basic sequence of the system. The population needs to be supplied with sufficient quantity of drinking water in a regular and continuous manner, as is the case with water supply systems. The basic part of each water supply is the water source. It must be adequately secured and protected, properly cared for, and must be invested accordingly. All the conditions mentioned above must be fulfilled in a legislative way—the above-mentioned special laws (Water Act No. 254/2001 Coll., As amended and ZVAK No. 274/2001 Coll., As amended, and their implementing regulations).

At present, municipalities in the Czech Republic are responsible for supplying the population with potable water. Owners of the property have been transferred free of charge to the infrastructure for privatization. These entities can provide their operations either on their own or through special and professional operators. The system thus set up significantly undermined the area where there are currently 6500 owners and 2500 water infrastructure managers [18].

For optimal operating systems, there are a number of circumstances, such as:

- to ensure a smooth supply of the population with good drinking water in the required quantity,
- comply with all legislation,

- to respect the ever-increasing hygiene requirements for drinking water,
- to perceive risk anthropogenic activities threatening water resources,
- to take into account unfavourable climatic conditions (increased frequency of floods and droughts), etc.

The safest way is to focus on water supply system and water supply group, if possible, interconnected and prospective water resources. Large operating companies, unlike small (municipal) operators, can secure this trend.

Among the largest and most important operating companies in the Czech Republic are VODÁRENSKÁ AKCIOVÁ SPOLEČNOST, a.s. (from now on referred to as VAS), which provides the operation of water supply infrastructure in a substantial part of the Jihomoravský and Vysočina regions—always in three districts. Through water supply for public use it supplies more than 540 thousand drinking water inhabitants, drinking water produces both surface (about 54%) and underground (about 46%). The care of water sources of surface water, the so-called water reservoirs, belongs to the state enterprises of Povodí, in other cases, all the operational care, maintenance and provision of preventive protection of these sources, to the operator of the water supply infrastructure—VAS.

Due to the nature of this operating company and its social function, it is clear that the VAS prefers the construction of water supply systems and water mains. Together with the owners of the infrastructure, they are trying to invest in these systems and, above all, into promising water resources that would be as interchangeable as possible within the systems. Such water resources must be adequately provided with preventive (special) protection, i.e. protection zones of water sources (see Sect. 7.3.3).

Due to a number of legislative changes, tightening of requirements for drinking water quality and also according to local conditions and needs, changes of protection zones are made, so-called optimization of the PZ, both their scope and the protective measures in them. The situation in the VAS is as follows:

- The VAS operates all the infrastructure under the ZVAK provisions, i.e. public water supply,
- all used water resources have established valid preventive protection (PZ), either according to the previously used concept of so-called 'full-area protection' or according to the currently used concept "zonal protection".
- the optimization of the PZ is tailored to the needs of individual regions, i.e. according to the development of the quantity and quality of raw water in the sources, the water needs for the development of the region, the occurrence of risks for the water resources, the requirements of the entities operating in the water basin.

VAS provides a complete agent for protective earth of groundwater sources and surface water abstractions outside water reservoirs. In the case of water reservoirs, the Povodí State Enterprise is such a compulsory entity, VAS as the customer of raw water is always a participant in the related negotiations.

In individual regions, the situation surrounding the risks to water resources is the following [19]:

District Jihlava

Fig. 7.2 Nová Říše reservoir

A substantial part of the district is supplied from surface water sources, which are water reservoirs: Hubenov—for Jihlava and its surroundings, Nová Říše for Telč and adjacent municipalities. The protection of these water resources is provided by the Povodí Moravy, s.p., the relevant water authority is the environmental department of the RA Vysočina Regional Authority. Both group waterworks (Jihlava and Nová Říše) are connected to the system.

- district of Jihlava is a significant part of the area of Vulnerable Areas,
- both water reservoirs have been set up at the request of Povodí Moravy, s.p.,
- the risk for the Hubenov reservoir is mainly the extensive agricultural and forest management, namely the amount of nitrates in surface water and the residues of pesticides used, therefore optimized PZ,
- Nová Říše reservoir (Fig. 7.2) was built in the 1980s, and after filling, the residues of organic materials from the original stands were buried, therefore surface aeration equipment was developed and put into operation (Fig. 7.3).

A complimentary water source for the Jihlava water main line is the Rytířsko underground water spring. The highway D Prague–Brno passes through this water resource, and its section was integrated into PZ II. st. There have been several accidents in the past that have threatened the quality of underground water (Fig. 7.4).

District Třebíč

Fig. 7.3 Surface aeration equipment in Nová Říše reservoir

Fig. 7.4 Consequences of the accident-petroleum products contamination

Fig. 7.5 Floating ponton in Vranov reservoir

Group water main Třebíč supplies the majority of the district. This water main has three main sources:

- water inlet from the water treatment plant Mostiště (water reservoir Mostiště)
- from water treatment plant Štítary [water supply from Vranov multi-purpose tank (Fig. 7.5)]
- underground sources of Heraltice (25 collecting galleries with a total length of over 3000-m perforated piping).

The majority of the district (outside the eastern margin) is part of the Vulnerable Areas. The utilized water resources have been set PZ:

- VN Mostiště upon request Povodí Moravy, s.p.,
- Heraltice already according to the current concept of protection and already a measure of a general nature to the application of the VAS in 2013
- the water supply from the Vranov reservoir has the original PZ changed by a measure of general nature in May 2018, to the application and design of the VAS documentation.

Extensive recreation on the Vranov reservoir and its surroundings, including a large number of recreational huts and cruise on the reservoir, is a risk to the source of raw water Vranov. In the catchment area above the reservoir, there is a risk of the small village without WWTP [20].

Fig. 7.6 Collection gallery in Heraltice spring area

The Heraltice source has very good groundwater shallow subsurface aquifer (Fig. 7.6), but it is vulnerable to anthropogenic activities. Natural protection is provided mainly by extensive forests in the catchment area.

District Žďár nad Sázavou

Again the main sources are surface water and the water reservoirs (WR) Vír and Mostiště. WR Vír serves mainly for the northern part of the district, WR Mostiště for the region around Velké Meziříčí and also for the district and group water main Třebíč. Supplementary sources are groundwater, rather of local significance—the example of Bohdalov (Fig. 7.7).

- The risk part of the WR Vír catchment area is around the town of Polička with several WWTPs (City, Masokombinát (Fig. 7.8), Brewery, Poličské strojírny),
- over the WR Mostiště, there is a large number of ponds with semi-intensive fish breeding (the volumes and areas of the ponds of these ponds are close to the same at WR Mostiště). Frying fish and using other preparations is a risk to this surface water,
- smaller sources of groundwater are located in recreational landscapes (skis, cross-country skiing, bikes, etc.) with a large number of recreational and boarding facilities, often threatening shallow groundwater used to supply the population. In these hydrogeological conditions, there is also a risk of extensive agricultural management, threats and pollution by nitrates, possibly even pesticides (Fig. 7.9),

Fig. 7.7 Collection gallery in Bohdalov spring area

- the western part of the district belongs to Vulnerable Areas (https://geoportal.gov.cz).

District Blansko

The towns of Blansko, Boskovice, and their surroundings are supplied by group waterworks with groundwater sources—Velké Opatovice, Lažany, Spešov, etc. The two water mains are interconnected. In smaller settlements, local waterworks predominate for individual municipalities. The operation, care and protection of water resources are ensured by the VAS.

- the middle part of the district belongs to Vulnerable Areas (https://geoportal.gov.cz),
- the original preventive protection of water resources was ensured by the HPZ from the 1980s, and now PZs are gradually being optimized according to the current concept and legislation,
- large-scale farming is the main risk for shallow groundwater,
- mining in quarries (Fig. 7.10), wastewater discharges, agricultural objects, petroleum stuffing (pumping stations) are point sources of danger,
- part of the district has complex hydrogeological conditions—the Moravian Karst.

District Brno—venkov

Fig. 7.8 Contaminated watercourse below defect WWTP

Because of its distribution around Brno, there are very different local conditions. The population is supplied with water from underground sources, often treated. Pollution originating mainly from the natural rock environment (odorizing, demagnetization, removal of ammonium ions, disinfestation, etc.) is eliminated.

- jthe southern part of the district belongs to Vulnerable Areas, the north-eastern edge is part of the Moravian Karst PLA,
- large-scale farming, production and insufficient wastewater treatment, transport, and other anthropogenic influences are local risks,
- in some localities there is a shortage of water resources, e.g. for the Ivančice—Rosicko area, natural and artificial infiltration (Fig. 7.11)—enrichment of groundwater by surface water from the Jihlava River (Fig. 7.12).

District Znojmo

The main source for a significant part of the district is the Znojmo Highway on the Dyja River. For smaller settlements, local sources of groundwater serve. The area in the north of the district is affected by the pollution of groundwater by uranium of natural origin.

- The whole district of Znojmo belongs to Vulnerable Areas (https://geoportal.gov.cz),

Fig. 7.9 Dung-pit in WR Vír catchment area

Fig. 7.10 Abandoned quarry in Dolní Lhota spring area

Fig. 7.11 Artificial infiltration in Ivančice spring area

- It is an intensely agricultural and greenery area,
- On the contrary, it is an area wherein the recent dry years there is lower atmospheric rainfall and which is affected by drought.

In recent years, when droughts are repeatedly occurred, and there is no replenishment of groundwater reserves, or even refilling reservoirs, the operation of infrastructure in VAS regions are affected and hampered by this hydrological phenomenon. The rotation of extraordinary events—droughts and floods (Fig. 7.13)—occurs much more frequently.

7.5 Conclusions

The protection of water resources is very important in whole of the world. All the people need to realize that water is a basic natural resource, without which life would not exist.

Water quality standards, and what we may consider to be pollution, depend not just on what is in the water but also what the water is used for (e.g., drinking water, water for bathing, water for irrigation and industry) [21].

Fig. 7.12 Water intake from the Jihlava River

Nowadays, the Czech Republic, like many other countries, is struggling with the drought. The problem is not only the water quality, but also the availability of drinking water and the availability of water for irrigation.

The irrigation water quality is a matter not only of irrigation management. It is also an issue of food quality. Meeting the criteria for irrigation water quality requirements, we can assure healthy and safe food or livestock feeds. Charge of irrigation water quality also provides content of substances in the topsoil horizon and groundwater protection. Therefore, the cost of monitoring the quality of irrigation water is reflected in the quality of agricultural (cultivated) crops, and human and animal health. Agricultural production, food production, forestry and irrigation water itself is not possible without providing enough fresh and quality water in the landscape. Therefore, the need for water treatment and purification of the wastewater generated before discharge into the streams becomes a priority [22].

In Europe, several types of resources are used to produce drinking water. The position of the Czech Republic in the Europe is very special, belongs to the three European river catchments. It means: Elbe catchment (North Sea), Danube catchment (Black Sea) and Odra catchment (Baltic Sea). For this reason, it is very important to protect the quality and quantity of surface and groundwater used in the Czech Republic, but also anthropogenic pollution of water spreading to neighbouring countries

Fig. 7.13 Spring area Vojkovice—flood protection

must be prevented. It needs to treat water resources in accordance with the principles of sustainable development.

To ensure both the quality of water intended for human consumption and the drinking water standards, public bodies usually tend to give preference to curative methods. However, only preventive measures aiming at protecting raw waters from diffuse pollution may help to protect water resources in a sustainable way and to limit water treatment costs. This notably implies the implementation of better agricultural and non-agricultural practices in the whole catchment areas that provide drinking water [8].

7.6 Recommendation

In a lot of catchment areas, the agriculture is the most important polluter for surface and underground water, because of that we have to find a way with target to provide for people enough quality drinking water.

Protection zones like preventive protection are necessary, their importance we have to support with conducting education, however, there is needed legislation and political wish and support.

As far as legislation is concerned, it is primarily necessary to solve problem with the Decree No. 137/1999 Coll., which is ineffective, some of the provisions of this Decree are inconsistent with valid Water Act. In this way, it is absolutely necessary for the Central Water Protection Authority to add activity and novelize or at least abolish that Decree.

In relation to climate change and the effects of drought, we recommend specifying in more detail the protection of water resources for season droughts, i.e., to solve in more details the protection of water resource efficiency.

The valid legislation needs to be elaborated, supplemented, updated and in practice adapted to a wide variety of natural and economic conditions (depending on the location, soil conditions, hydrology, hydrogeology and the way water is used).

The goal is not to recreate unified methodology, according to which should be proposed the protection zones of water sources. Suggestion of PZ in counter should be processed in a form which real shows attitudes in the landscape above the source of drinking water. The proposal of regime and scope of the PZ should always be solved individually according to specific conditions.

However, it would be advisable to devote more the problem of financial compensation in protection zones, the development of a methodical approach could be beneficial. This issue needs to be elaborated. The failure to solve the current situation is not a starting point for farmers operating in the PZ, for water companies, it is not for improving the quality of drinking water.

The practical journey is clearly based on cooperation and understanding between water farmers and farmers, as well as the involvement of researchers from universities who are independent experts.

One of the possible tools for the protection and rational use of land in the protection zones are Land consolidation, which offers the potential for the creation of a flexible, ecological and sustainable agriculture. Combined with the protection zones optimization, this could be an effective tool for solving conflicts between agriculture and water management in the protection zones of water sources.

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Chapter 8
Groundwater Flow Problems and Their Modelling

J. Říha

8.1 Introduction

Groundwater-related issues represent a wide range of both technical and environmental problems. In order to keep sustainable groundwater and environmental conditions, human interventions into the groundwater regime have to be carefully discussed, studied and reliably predicted. Such interventions may influence groundwater flow characteristics, its quantity and quality. This concerns extraordinary withdrawals for water supply purposes, affecting groundwater regime in urban areas via subsurface structures or local permanent pumping, groundwater level drawdown due to temporal pumping for construction purposes and the existence of hydraulic schemes like dams, weirs or levees. Of a great significance are agricultural activities like drainage and irrigation, dewatering of quarries and pits, construction of tunnels and deep foundations, spilling polluted water into groundwater and many other human interventions changing the character of groundwater flow and properties of groundwater.

In the following text, only particular technically oriented problems affecting the groundwater flow characteristics are discussed. These are, namely the influence of hydraulic and other structures on groundwater regime, changes of the groundwater flow during floods and an impact of flood protection measures. Special attention is paid to the groundwater-related problems in urban areas. For individual issues and cases, respective groundwater flow modelling techniques are demonstrated on examples from technical practice.

J. Říha (✉)
Faculty of Civil Engineering, Institute of Water Structures, Brno University of Technology, Veveří 95, 602 00 Brno, Czech Republic
e-mail: riha.j@fce.vutbr.cz

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8.2 Typical Problems in Groundwater Management

8.2.1 Water Supply

In the Czech Republic, similarly to other countries, the importance of groundwater as a natural freshwater reserve increases. According to the Water Act [1], groundwater resources are reserved particularly for the drinking water supply for municipalities, less frequently for industrial and agricultural purposes. The rebalance of groundwater resources [2] of 58 hydrogeological regions in the Czech Republic performed in the period 2010–2015 indicates the potentially available yield of about 24.5 m^3/s. The trends show a gradual decrease in available groundwater resources.

While the industrial and agricultural sources do not require any special arrangements and treatment, groundwater sources for drinking purposes are subject to special protection according to the Water Act [1]. The protection consists of protective zones of two orders in terms of their extent at which selected activities are restricted according to the law. The protective zone of the first order surrounds the source (water well, gallery) to the distance of 10 m, the area is fenced. The protective zone of the second order is demarcated based on complex and diversified protection according to the character of the water source, natural conditions, namely geological and hydrogeological and on the degree of exposure of the aquifer. Important issues are groundwater flow direction, detention time in aquifer before entering the source, pollution hazards and vulnerability of the aquifer. For the delimitation of the second-order protective zones, the thematic Geographical Information System (GIS) maps are used with layers depicting hazards, vulnerability and risks in the area. The layers showing groundwater regime characteristics are developed using hydrological groundwater flow modelling [3–6]. For the solution, essentially 2D groundwater flow models in large horizontal aquifers [7] are used. In more complex geological conditions represented by permeable layers of different properties, 2D layered models or 3D models are effectively used.

Special techniques should be used in case of water take-offs located in the abandoned or even active gravel pits at floodplains and influencing the regime in aquifers. Typical examples are the pits at the Morava river floodplain like Tovačov, Troubky, Kvasice or Ostrožská Nová Ves counting tens or even single hundreds square hectares of surface area. Essentially, these pits are supplied by groundwater and are regarded as groundwater bodies. In some cases, 2D horizontal and also 2D vertical models are being successfully applied for the design of systems with artificial infiltration like at the Kárané (drinking water for the city of Prague), Ivančice (see Fig. 8.6) and other localities too. Here, the raw water is taken from the river. It is accumulated in the surface ponds and infiltrated to the aquifer. In a certain distance of the ponds, groundwater is pumped from the system of wells or is captured by horizontal drains.

Hydraulic modelling of groundwater flow together with the risk-based approach and GIS techniques enable to optimize the extent and shape of the second-order protective zones and such reduce the cost of a buy-out of the land and compensation expenses of water supply companies.

8.2.2 Hydraulic Structures

Hydraulic structures, namely those changing water levels in streams and developing reservoirs or pools, may significantly influence the groundwater regime of the adjacent areas. The water infiltrating from the reservoir usually results in an increase of phreatic surface and change in the groundwater flow direction. The deepening of the channel bed below the structures or due to river regulation usually gives rise to groundwater drawdown along the relevant river reach. In flat floodplains with highly permeable aquifers, this may affect large areas by lowering the groundwater level which may reduce the yield of groundwater sources in the locality.

Vice versa groundwater may significantly affect behaviour, stability and safety of hydraulic structures subject to seepage. The most significant is the development of pore pressures decreasing effective stress and herewith a shear strength. Another issue concerns pressure gradients which may cause filtration instability of the soil in the embankment and its sub-base.

Both the impact of hydraulic structures on surrounding areas and the effect of seepage water on the hydraulic structures may be effectively solved by various types of groundwater flow models which are nowadays incorporated into the computer codes used at soil mechanics and stability assessment [8–10]. Nowadays, the sophisticated coupled models combine groundwater flow techniques, soil consolidation and earth structure time behaviour solutions for the safety assessment of proposed and also existing earth structures like embankment dams and hydraulic structures located at the places with complicated foundation conditions.

Recently in the Czech Republic, numerous small dams have been proposed and constructed at complicated geological conditions, e.g. Dams Krsy, Lichnov or Višňová. At these dams, comprehensive seepage analysis was carried out using 2D models combining horizontal and vertical flow approach.

As mentioned above, groundwater flow modelling is a part of stability analysis of hydraulic structures like dams and their foundation. In case of embankment dams, combined saturated/unsaturated approach is used when finding a phreatic surface in an embankment and assessing pore pressures in a dam body [9, 10]. These techniques have become standard in periodical safety assessment of dams and also in case of their reconstruction [11, 12]. Typical examples at which groundwater flow models were coupled with geotechnical stability solutions are the dams Mostiště, Žermanice, Šance, Olešná and Baška in the Moravian and Silesian parts of the Czech Republic. The most frequently used are 2D vertical flow models, in case of more complex and complicated conditions 3D models are applied [12, 13].

8.2.3 Groundwater Flow Regime During Floods

Changes in groundwater flow regime during floods and also due to flood protection structures are caused by various factors. Excessive seepage may endanger both flood protection elements and structures in protected urbanized areas. The description of geological conditions usually suffers from a poor understanding of the historical development of towns along river zones, the anthropogenic geological layers, river training including flood protection structures, quai walls, the drainage of groundwater into the sewerage and others. These factors may influence the change in groundwater regime during floods and should be taken into account when assessing the effects and impacts of designed flood protection measures.

During no flood periods, open channels usually drain adjacent aquifers. With the significant increase in water level in streams during extreme flood events, the direction of groundwater flow changes from the river to the aquifer and is accompanied by rising water level, respectively, piezometric head in the aquifer in the protected area. The adjacent aquifer is then subject to groundwater flow from upper terraces as well as from the river. The rate of the seepage depends on the permeability of aquifer materials, the saturation rate of the soil and the flow regime (confined, free flow). In Fig. 8.1, a scheme of groundwater flow during flooding is shown for a river without (a) and with (b) flood protection measures [14, 15]. It can be seen that in case of no flood protection, the pore pressure in the aquifer is compensated by the weight of overbanked flood water. After installing flood protection, the pressure in the aquifer acting usually on the bed of relatively impervious topsoil layer may exceed its weight which may cause the uplift failure of the topsoil behind the flood protection arrangements.

Various groundwater flow models are used to assess the impact of flood protection measures and their subsurface elements on natural groundwater regime and also the course of groundwater level rise during the flood events. To project flood hydrograph to groundwater level, it is necessary to use unsteady flow models. However, 1D model can be used for the first estimate of the propagation rate, namely in the case when parallel flow conditions are satisfied. In case of more complex non-homogeneous aquifers and diverse flood protection structures, 2D horizontal flow models are a standard tool. For a detailed proposal, verification of the effect of slurry walls, drainage system and optimization of individual elements 2D vertical or even 3D models are applied. As the shape of the flood hydrograph is rather uncertain input parameter affecting the course of the piezometric head significantly in the aquifer, the conservative technical design is recommended based on results obtained from steady-state groundwater flow solutions taking into account "infinite" duration of the flood peak discharge and water stage.

8.2.4 Groundwater-Related Problems in Urban Areas

The occurrence and the flow of groundwater in urbanized areas depend on both natural conditions and anthropogenous activities. Natural conditions mean here morphologically broken relief with a network of natural currents, some of them "buried" and usually draining the adjacent aquifer. Anthropogenous interference means changes in the geological composition of the territory, such as anthropogenous geologic layers

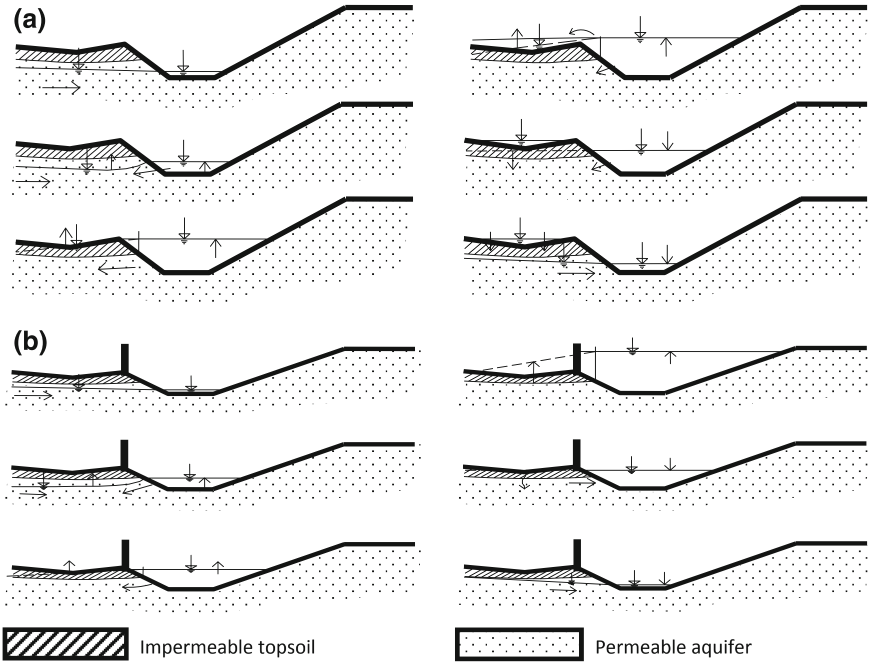

Fig. 8.1 Scheme of groundwater flow during the flood. **a** No flood protection measures, **b** with flood protection measures

(backfills), leakage from water supply piping, drainage of cellars and subterranean parking sites or collectors in city centres. An important local source replenishing groundwater in urban areas are losses from water supply system which, e.g. in the Brno city (Czech Republic), amount approximately 100 l/s (about 10% of the water demand) [16]. In other localities, this amount may differ according to the age and material of the water piping, maintenance procedures, performance of the system and other factors.

Subterranean objects, or parts of buildings, have a significant impact on the regime of groundwater flow, while, on the other hand, the occurrence and the regime of groundwater flow is a condition for the technical solution of the subterranean parts of buildings and their construction methods. Typical human interventions damming groundwater in the urban areas are deep foundations, cellars also comprising historical cells, dungeons and tunnels, subterranean parking lots and linear collectors. In many cases, technical arrangements are necessary to keep groundwater table at an original level to avoid inadmissible waterlogging of existing buildings. These measures involve modifications in the planned subsurface structures, special drains, local pumping, etc.

At some naturally waterlogged parts of cities, permanent pumping from cellars of low elevated basements is necessary and the only possible measure to assure groundwater table drawdown to an acceptable level. For example in the city of Brno pumping is in progress from the basements of the Morava palace where 1 L/sec is permanently pumped into the sewer system. This represents annual cost corresponding to cca 50,000 USD mainly for the sewage charge. Similar amounts are pumped from Scala cinema, Alpha arcade and other places in the city of Brno.

If interaction exists between an aquifer and surface water bodies, the rise of the groundwater level in the protected area is an important factor during flood episodes (Sect. 8.2.3). Increased water level, respectively, piezometric head in the area acts on the outer surfaces of the side walls and on the floor of cellars and in many cases results in their deformation. To propose arrangements eliminating negative effects of groundwater on structures and in the opposite of subsurface interventions on the groundwater regime in urban areas mathematical models are used, namely 2D models solving conditions in the horizontal plane. For more detailed solutions, 2D vertical or 3D models may be used.

8.2.5 Other Issues

In hydrology, subsurface run-off plays a significant role in water balance calculations. To obtain cumulative knowledge about the groundwater phenomena, its overall role in the hydrological cycle, its amount, flow characteristics and change in storage, regional groundwater flow models based on 2D horizontal approximation are effectively used. A necessary component of reliable hydrological modelling is the field monitoring of time behaviour of water stages and yields of springs. In the Czech Republic, the monitoring is performed by the Czech Hydrometeorological Institute [17] via the system of observation facilities (Fig. 8.2).

From Fig. 8.2, it can be seen that observation wells are located dominantly in the areas providing considerable groundwater yields like in the Morava, Dyje, Elbe, Lužnice, Oder and Opava river floodplains with highly permeable quaternary aquifers. At these localities, most of the groundwater-withdrawal areas are located to provide high-quality groundwater for drinking purposes.

The values obtained from groundwater hydrological monitoring are used for the calibration and verification of numerical models. Especially valuable are the monitoring results during extreme hydrological events like floods and also long-term droughts. Here, the information about the baseflow in rivers plays a significant role in regional groundwater flow models’ verification. At groundwater-withdrawal areas regular, usually annual monitoring of groundwater characteristics is provided by water companies.

In agriculturally exploited areas in the Czech Republic, typical problems are linked to groundwater abstraction for irrigation or are dealing with drainage of waterlogged areas. Water supply for irrigation is only scarcely provided by groundwater which is reserved primarily for drinking water supply. In case of drainage, simplified 1D methods are used for the technical proposals of drains, their span, depth and capacity.

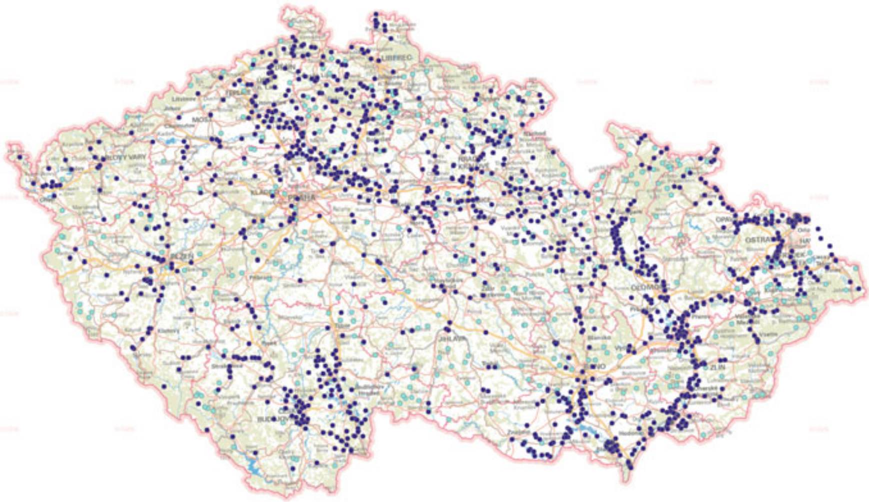

Fig. 8.2 Facilities for groundwater observation in the Czech Republic (light blue—springs, dark blue—observation wells) [17]

Groundwater modelling is frequently the part of Environmental Impact Assessment carried out in case of important structures and interventions into nature according to the law [18]. The impacts of anticipated installations like large dams, mines, landfills, large wastewater treatment plants, groundwater supply systems, etc. on the groundwater regime may be predicted and compensating precautions it may be optimized with respect to the requirements on the sustainability of groundwater conditions (water stage, flow direction, quantity and quality of water). An example is the assessment of an impact of quarrying of gravel–sand in large pits at quaternary floodplains with the use of the 2D horizontal model. When simulating the effect of excavation of sand/gravel the annual amount of excavated material has to be converted to the "pumping amount". In some cases, these activities are combined with groundwater extraction for water supply like in case of gravel pits Tovačov, Troubky or Hulín in the Quaternary aquifer of the Morava River. In such cases, the pit behaves like large diameter well. At the modelling total withdrawal consisting of converted excavation rate and water take-off from the lake should be applied in the model at which the lake area is provided with significantly higher permeability (e.g. hydraulic conductivity about 1 m/s).

8.3 Overview and Applications of Groundwater Flow Models

Generally, "model" may be defined as "simplified version of the real system that approximately simulates the excitation-response relations" [7]. Here, the real system is an aquifer—groundwater—external impacts. Historically for the solution of groundwater problems, physical models were used like sandbox models, Hele-Shaw models and various analogues employing similarity between the mathematical description of groundwater flow and electric current [19, 20]. In the following text, the groundwater flow modelling relates to the numerical solutions only which completely substituted experimental laboratory methods by the end of the sixties of the last century.

Thus, groundwater flow numerical modelling is a standard discipline in continuum mechanics since early seventies of the twentieth century [3, 7, 19, 20]. As the physical background, assumptions and mathematical formulation are sufficiently described and discussed in the relevant literature; this text contains an only brief description and general characteristics of individual models with a focus on their use in practical applications. The description concerns preferably the flow in the saturated zone. One-dimensional (1D), two-dimensional (2D) models in the vertical and horizontal plane and three-dimensional (3D) models and their practical applications are discussed.

The modelling procedure comprises the set of following standard steps:

- The description of a real system where the area of interest is identified and management problems are formulated.
- The objectives of the modelling have to be carefully defined, expected outcomes are usually spatial and temporal distribution of water levels, specific discharges, further on yields of wells and maximum acceptable pumped amounts, isochrones around the sinks and other hydraulic variables. Special techniques not discussed in this text are used to model groundwater quality, to determine land subsidence due to the groundwater level drawdown, etc.
- The conceptual model consists of a set of assumptions converting the reality to the simplified version in terms of state variables describing the system, the geometry, shape, and boundaries of the domain, materials of an aquifer and their properties (homogeneity, isotropy, porosity, hydraulic conductivity, compressibility, etc.). According to the expected character of the flow, the dimension (1D, 2D, 3D) and time dependence (steady, transient) of the model are defined. At the same time, sources and sinks have to be identified and quantified, conditions along the boundaries are also specified.
- The mathematical formulation (model) expresses the conceptual model by the set of governing equations (mass conservation, Darcy law), initial and boundary conditions.
- The computer code appropriate for the solution of given problem has to be selected. Here the necessary part is to be acquainted with the theoretical basis of the code (theoretical manual) and user skills (user manual) including pre- and

post-processing procedures and conversion of results to powerful graphical environments (CAD, GIS). Advisable step in testing the computational code is its validation using examples with a known solution (e.g. analytical).

- The pre-processing step represents the generation of the flow domain, incorporation all sources and sinks and other elements influencing groundwater flow. Based on the expected flow conditions, namely hydraulic gradients, the meshing of the domain to the finite difference, finite volume or finite element grid is carried out. Here the advantage of dense mesh is provided namely by the finite element method. The pre-processing also contains the incorporation of material properties on the individual parts of the flow domain and setting initial and boundary conditions.
- The obtained numerical model should be subject to calibration and verification. For this purpose, sufficient data from groundwater level observation and corresponding pumped amounts has to be acquired. It is necessary to provide homogeneous sets in terms of time of observations and measurements. The accuracy of the monitoring data should be assessed in order to set down the convergence criteria for model calibration. As a rule, model verification is carried out using another data set than for calibration.
- The calibrated model may be used for the simulation of scenarios serving for answering the questions and achieving defined goals and objectives.
- Very important point is an acquisition of the results, their processing, analysis and interpretation. For this, engineering approaches are combined with efficient methods of post-processing which enable spatial and temporal data displaying using CAD systems and thematic maps within GIS tools.

8.3.1 One-Dimensional Models

One-dimensional models are applied at confined aquifers or where conditions for a Dupuit–Forchheimer approximation for phreatic aquifers are satisfied. Generally, parallel or cylindrical flow is a prerequisite. In case of simplified conditions, e.g. for horizontal impermeable sub-base, homogeneous and isotropic strata, simple boundary conditions, etc., analytical methods may be used. When applying the principle of superposition and conform mapping even systems of multiple wells and problems with more complicated domains may be analytically solved. In case of more complex situations, numerical techniques using, e.g. finite difference (FDM), finite element (FEM) or other methods, should be used.

A typical application is the transient flow simulation of the propagation of the flood wave from an open channel into an aquifer. Here, appropriate numerical method may be used. In Fig. 8.3, the time course of the piezometric head is shown in the area behind the levee (like that in Fig. 8.4). The boundary condition at the channel side (the Vltava River in Prague) is governed by the time-dependent water stage in the stream (Fig. 8.3). The boundary condition at the land side may be introduced as steady-state piezometric head prescribed far enough from the stream, its location should be verified parametrically as a point at which piezometric head is not affected by the flood wave. From Fig. 8.3, it can be seen that behind the levee even more than 120 m from the Vltava River, the piezometric head exceeds the terrain which may cause the rupture of impermeable topsoil layer, or in case of permeable backfills, the leakage of groundwater may occur. Just behind the levee (50 m), this is achieved in time 186 h calculated from the beginning of the solution or about 120 h after the arrival of the first flood wave.

Even if 1D models provide sufficiently accurate results in terms of water level, piezometric head and yield, they cannot be applied for the assessment of local condition where good knowledge about hydraulic gradients is necessary. In such cases, the details with anticipated high hydraulic gradients have to be solved by a more complex model like 2D model in the vertical plane or by 3D model.

8.3.2 Two-Dimensional Models in Vertical Plane

Models in a vertical plane are used in cases of linear structures with the parallel flow where Dupuit–Forchheimer approximation cannot be applied. They may be applied for confined aquifers situated below the relatively impermeable structures or layers, e.g. long flood levees (Fig. 8.4), weirs or concrete dams or for the analysis of the flow with the phreatic surface in embankments (Fig. 8.5) usually including flow in the sub-base.

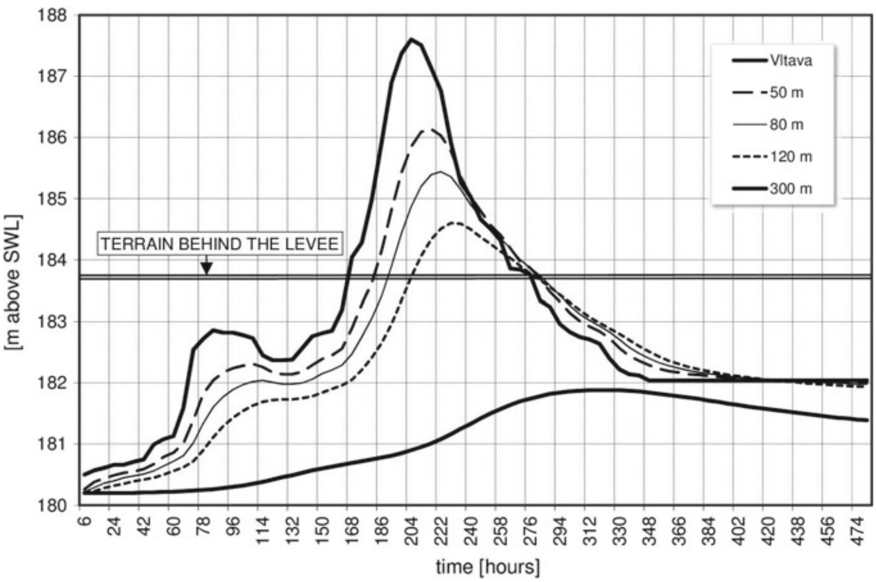

Fig. 8.3 Simulated time course of the piezometric head in the Vltava River floodplain aquifer during the flood in 2002, distance measured from the river bank

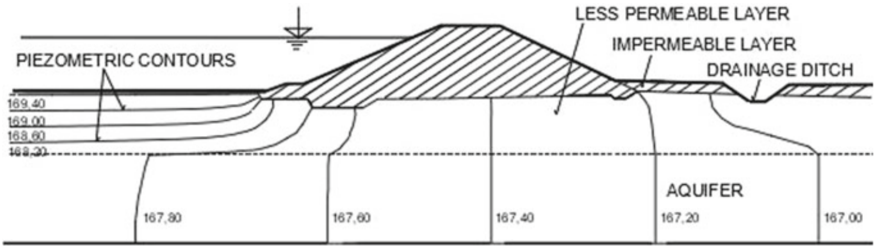

Fig. 8.4 Vertical confined flow in an aquifer below the relatively impermeable dam

In the groundwater flow software, the phreatic flow models are presently usually conceived as unsaturated flow models, where the unsaturated zone is characterised by negative pore pressure, and the phreatic surface is defined as zero pressure line. It is necessary to remind that negative pore pressures are increasing effective stress and thus overall stability of an embankment. Therefore, when transferring pore pressures from seepage analysis to the slope stability assessment, it is recommended to annul the negative pore pressures to shift stability results on the safe side.

One-dimensional models give acceptable results in terms of water level in shallow aquifers. One of the 1D applications may be in the design of artificial groundwater recharge or for the design of agricultural drainage systems. When information about the local flow conditions, namely hydraulic gradients, close to the single conduits (e.g. drains, infiltration canals) is needed, a more complex model should be used. In Fig. 8.6, the section of the linear groundwater recharge facility is shown. Water infiltrates from the infiltration ditch (on the left) and also from the river (on the right out of Fig. 8.6) and is captured by the drain located between infiltration ditch and the river. It can be seen that between the ditch and the drain and also between the river (on the right) and the drain the flow may be fairly approximated by 1D model indicated by approximately vertical contours (Dupuit–Forchheimer assumption). Close to the ditch and namely at the drain the flow is more complex. Here, the real conditions

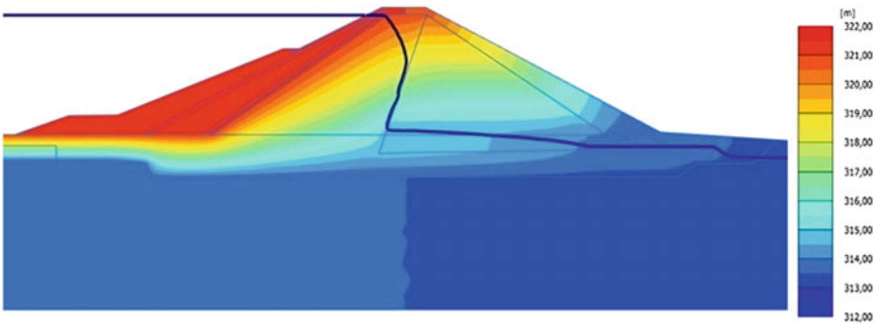

Fig. 8.5 Phreatic surface and piezometric contours in the embankment dam [12]

have to be simulated by a 2D vertical model of the confined aquifer on the left and the phreatic one close to the drain. Such solution allows determining of local hydraulic gradients in the aquifer and filter layers protecting the drain pipe against suffosion and siltation.

8.3.3 Two-Dimensional Models in Horizontal Plane

Groundwater flow in large-scale confined, phreatic or leaky aquifers may be simulated by 2D models employing essentially horizontal flow approximation. Sometimes such approximation is denoted as “the hydraulic approach” [7, 19] or “Dupuit–Forchheimer assumption”. Such models are frequently used in large abundant aquifers counting the area of several square kilometres occurring at alluvial plains adjacent to large rivers. In such areas, water supply systems have frequently been located and operated. An example of such plain is Quaternary of the Morava River where along the Morava River and its tributaries more than 20 groundwater-withdrawal facilities are located with a total exploited amount exceeding 3 m^3/s of high-quality groundwater.

Such models are convenient for the simulation of impacts of groundwater depletion by water supply systems and for quantification of parameters necessary for the delimitation of protective zones of groundwater resources. Models had to be calibrated using a consistent set of groundwater levels measured in observation wells and interpreted to the piezometric contours (Fig. 8.7). The calibration procedure consists of changing values of input parameters in order to match field conditions represented by observed piezometric heads [21] and pumping amount. The methods of calibration incorporated in existing software contain automated parameter estimation, many a time more realistic results, are obtained by “manual” step-by-step trial and error adjustment of parameters.

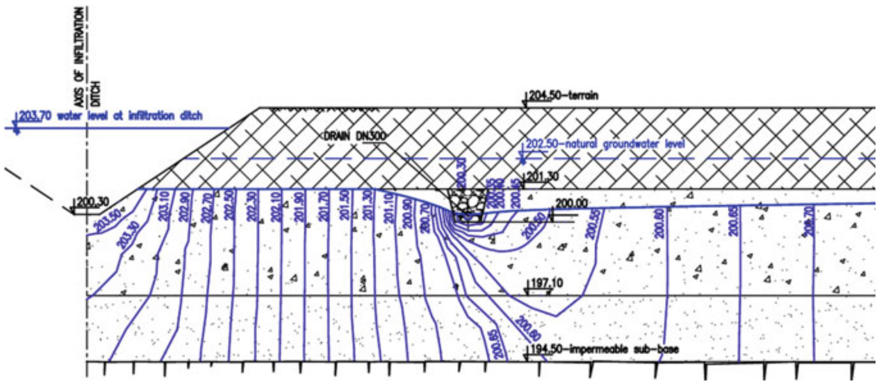

Fig. 8.6 Comparison of 1D and 2D vertical approximation at the infiltration facility

The models are frequently used for the assessment of both environmental and technical impacts of groundwater level drawdown [18]. Into these models, localities with groundwater pumping may be included by the relevant withdrawal amount interpreted as point source/sink. Large gravel pits may be incorporated as the zones (parts of an aquifer) with significant permeability represented by hydraulic conductivity in the order, e.g. about 1 m/s. An effect of subsurface structures like slurry walls may also be simulated (Fig. 8.8) also with the combination with hydraulic barrier serving as active groundwater protection against aquifer contamination [22]. The groundwater flow model calibrated for the conditions without any intervention into the aquifer (Fig. 8.7) was applied for the simulation of an impact of interventions at the military airport which was the source of groundwater pollution. In Fig. 8.8, completely penetrated protecting slurry wall creates the barrier against the contamination transport to the water supply withdrawal area (down-left). Other simulations contained additional pumping at the upstream side of the slurry wall and also below the slurry wall which had to capture the pollution close to its source.

Two-dimensional hydraulic approach is also convenient for the unsteady simulations of the propagation of flood in open channel into the adjacent aquifer. The use of 2D horizontal flow models is substantiated when 1D models are not fitting more complicated conditions of the locality where the parallel flow approximation is no more applicable. In the model, meandering river bank may be incorporated together with anti-seepage measures like slurry walls, drains, relief wells, etc. Model of this type has been successfully used for the safety assessment and optimization of flood

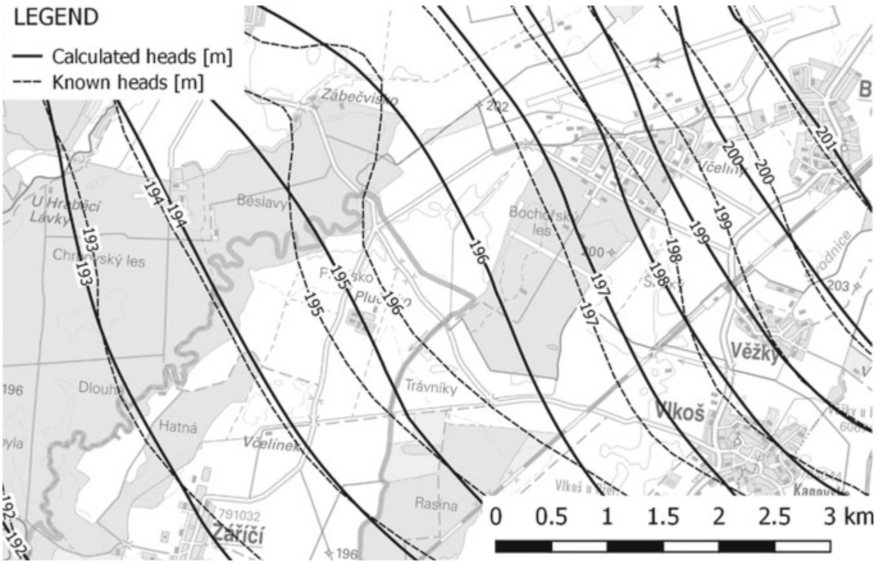

Fig. 8.7 Results of calibration of the groundwater flow model at the locality Vlkoš and Zaříčí at the Moravian Quaternary Aquifer [22]

Fig. 8.8 Simulation of the effect of protecting subsurface wall and groundwater pumping in localities Bochoř and Troubky [22]

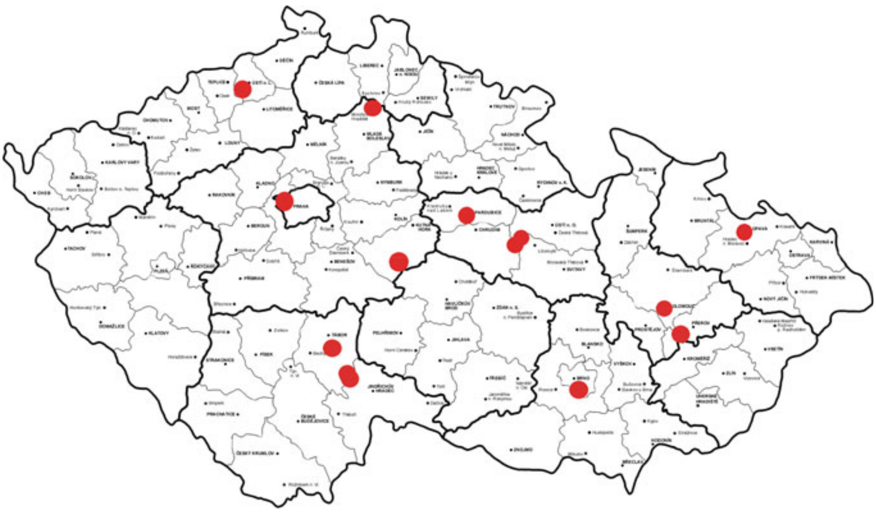

Fig. 8.9 Localities where groundwater issues at flood protection where modelled using hydraulic approach

protection measures at numerous localities in the Czech Republic like in the cities of Prague, Brno, Ústí nad Labem, Olomouc, Pardubice, Veselí nad Lužnicí, Vysoké Mýto, Choceň, Troubky and others. According to local conditions, anti-seepage and drainage elements were recommended at the flood protection lines—levees and floodwalls. Also, the management of waters behind the flood protection barrier was proposed based on calculated seepage amounts, pore pressures and hydraulic gradients. An overview of localities where the 2D horizontal model was applied in the Czech Republic for flood protection design is depicted in Fig. 8.9.

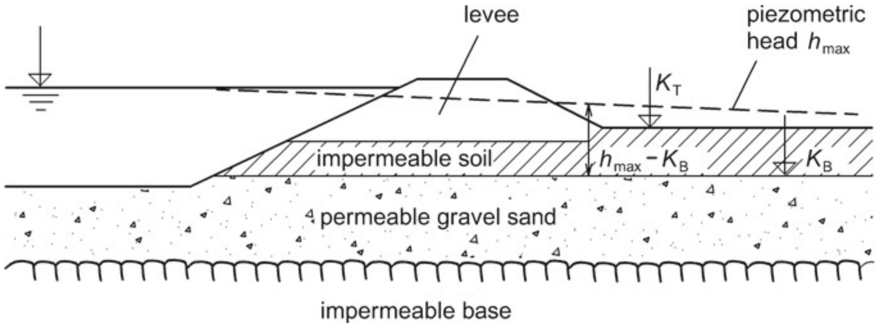

Fig. 8.10 Scheme of levee and typical geological conditions at the Morava River floodplain

The results of 2D horizontal models are efficiently graphically analysed, manipulated and displayed via GIS mapping techniques. The following maps are relevant in the case of groundwater flow in the flood protection context:

- maps of the terrain level (digital model of terrain—DMT),
- maps of the results of present state modelling–calibration scenarios,
- maps of groundwater levels calculated for selected scenarios,
- maps of differences between the present state and the state influenced by subsurface elements of flood protection measures,
- maps of the maximum water table (piezometric level) during the flood,
- maps of differences between the maximum groundwater level and the terrain,
- maps of waterlogged areas during the flood,
- maps displaying reliability factors (see below).

The GIS techniques also enable processing results of modelling and safety and reliability assessment of the area behind the flood protection structures (levees, floodwalls). Following example deals with the use of the results of groundwater flow model for the spatial assessment of the safety related to the rupture of the topsoil due to uplift which is the initial phase of external suffosion, backward erosion and piping failure [23]. For the assessment, the limit state method (method of partial reliability factors) is applied, the results are processed in the form of "reliability maps" [24]. In a situation corresponding to Fig. 8.10, the flood levee is founded on the relatively impermeable topsoil layer formed by fluvial loams overlaying a highly permeable gravel–sand aquifer. The maximum piezometric head h_{max} in the aquifer behind the levee has been determined by a transient 2D horizontal groundwater flow model. The levels of the terrain and base of the topsoil may be interpreted from land and geological survey data. The assessment using limit state method is described in the following text together with a practical example.

The following limit state condition may be used for the assessment [8]:

$$\gamma_1 \gamma_{fv} \gamma_W (h_{MAX} - K_B) \leq \gamma_{fg} \cdot \gamma_S (K_T - K_B), \quad (8.1)$$

where γ_1 is the importance factor expressing potential losses in case of levee collapse, γ_{fv} is the load reliability factor corresponding to the uncertainty of the method of determining h_{MAX} and K_B, γ_W is the unit weight of water, $h_{MAX}(x, y)$ is the maximum piezometric head $h_{MAX}(x, y) = \max h(x, y, t)$, $K_B(x, y)$ is the level of the top stratum base, γ_{fg} is the resistance factor covering uncertainty in K_B and the soil's saturated unit weight γ_S and $K_T(x, y)$ is the terrain level. The values of partial reliability factors depend on the uncertainty of input data, the numerical method used, etc. For spatial processing the "reliability parameter" RP(x, y) is proposed:

$$\mathrm{RP} = \frac{\gamma_{fg}\,\gamma_S\,(K_T - K_B)}{\gamma_n\,\gamma_{fv}\,\gamma_W\,(h_{MAX} - K_B)}. \tag{8.2}$$

RP(x, y) expresses safety reserve, respectively, deficit towards the condition (8.1). When spatially processed, the areas with RP$(x, y) \geq 1$ represent safe localities, while the values RP$(x, y) < 1$ indicate areas susceptible to topsoil layer rupture and to the initiation of an internal erosion process.

The procedure mentioned was carried out in most of the localities mentioned above (Fig. 8.9). An example is shown at the flood protection proposal for the village of Troubky at the Bečva River basin close to its confluence with the Morava River. Based on the results of hydraulic modelling, the zones were marked out in the area surrounded by a ring system of flood levees (Fig. 8.11). It can be seen that at most of the protected area condition (8.1) is not satisfied (RP < 1).

To decrease water pressure in the aquifer and to satisfy safety condition (8.1), namely in the areas behind the levees and close to the dwellings at the village, the system of 41 relief wells, the system of collecting ditches and pumping stations were proposed (Fig. 8.12). The effect of such measures on the reliability parameter RP is shown in Fig. 8.13, wherein most of the protected area condition (8.1) is already satisfied and only a small portion of the uninhabited area of the Troubky village is susceptible to topsoil layer uplift failure. The negative feature of such arrangement is relatively high seepage amount into the protected area released by numerous wells. The overall seepage discharge into the protected area exceeds 1.5 m^3/s of water during the flood peak. Obviously, this amount is significantly smaller before and after reaching the peak discharge and corresponding water level in the Bečva River. The seepage amount has to be pumped back to the stream during the flood discharge. In case of Troubky, the necessity of excessive pumping called for the search for other possibilities of flood protection of the municipality.

8.3.4 Three-Dimensional Models

In geometrically complicated configurations, geological conditions and boundary conditions where dimensional simplifications are not applicable 3D models have to be used for the groundwater flow solutions. The practical examples are seepage through and below large embankment dams and under the weirs, flow around large and

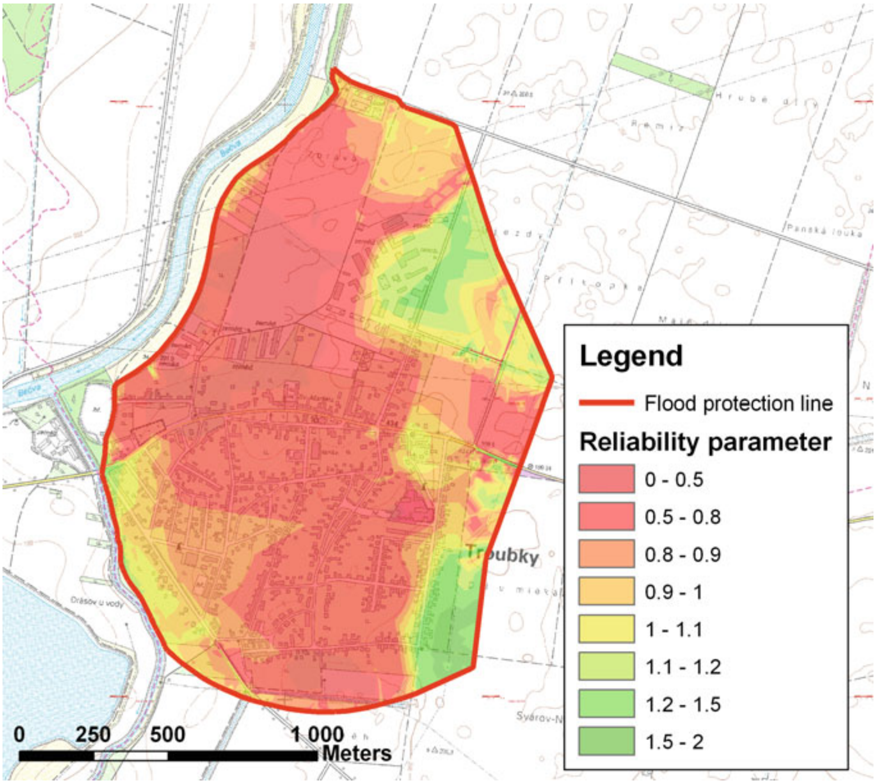

Fig. 8.11 Map with RP parameter—without relief wells

complicated subsurface foundations, seepage conditions at rugged flood protection arrangements with broken relief, namely in complex urban areas, etc. It is obvious that the conceptual design, flow domain geometry assemblage and specification of material properties and boundary conditions are demanding and sophisticated tools for efficient pre-processing are needed. The same requirements are posed on the post-processing and tools for the depicting analysis of the results and their transfer into CAD or GIS systems.

As an example, complicated 3D model layout at the crossing of flood levee at the right bank of the Vltava River in Prague-Troja and the highway tunnel crossing the Vltava River can be shown (Fig. 8.14). Resulting piezometric head at the entire flow domain and in detailed view at the submerging highway to the aquifer is shown in Figs. 8.15 and 8.16 where the scenario of steady-state flow in 3D during the flood peak is shown. In Fig. 8.16, the detailed view of piezometric head surfaces (contours) at the section through the domain perpendicular to the flow in the Vltava River is shown. At this place, the highway excavation continues further to the tunnel entering the impervious neogeneous sublayer and continuing below the Vltava River to its

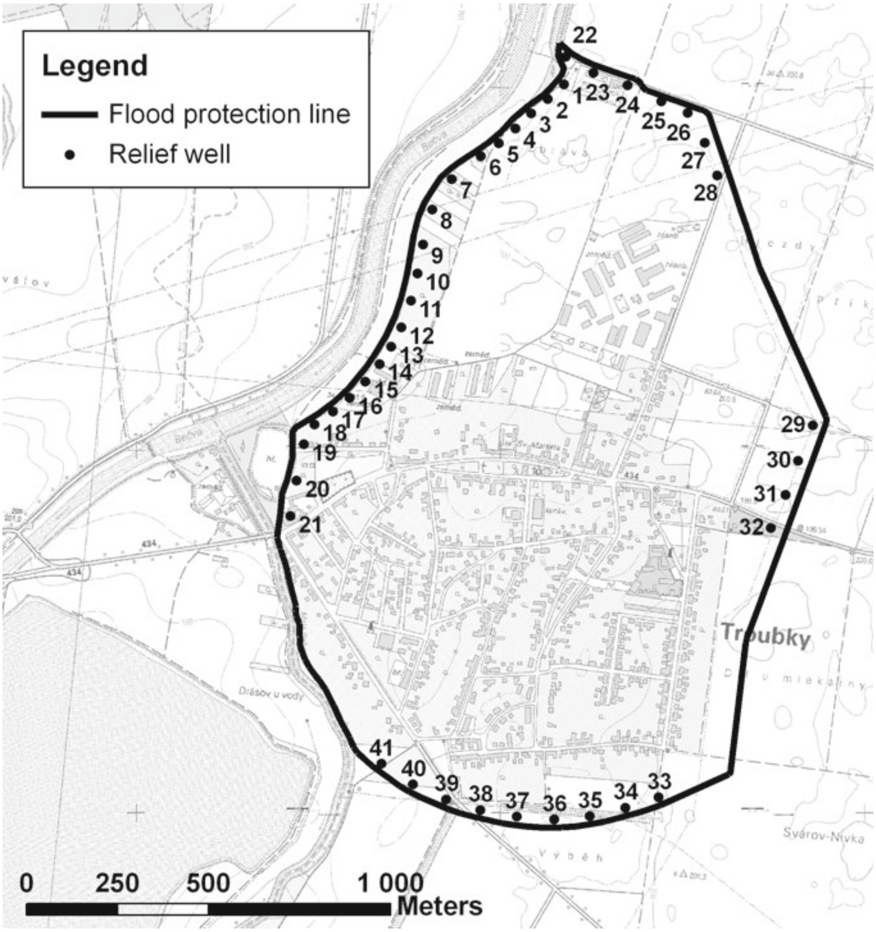

Fig. 8.12 Layout of relief wells

left bank. Here the lowest piezometric heads and highest hydraulic gradients occur. The numerical solution was carried out using multipurpose finite element software ANSYS [25].

8.4 Conclusions

Groundwater flow models significantly contribute to the sustainable management of groundwater resources. Numerical simulations focus on optimization of groundwater withdrawal and assessment of negative impacts of phreatic surface drawdown due to groundwater exploitation. Hydraulic models are a crucial part of soil stability

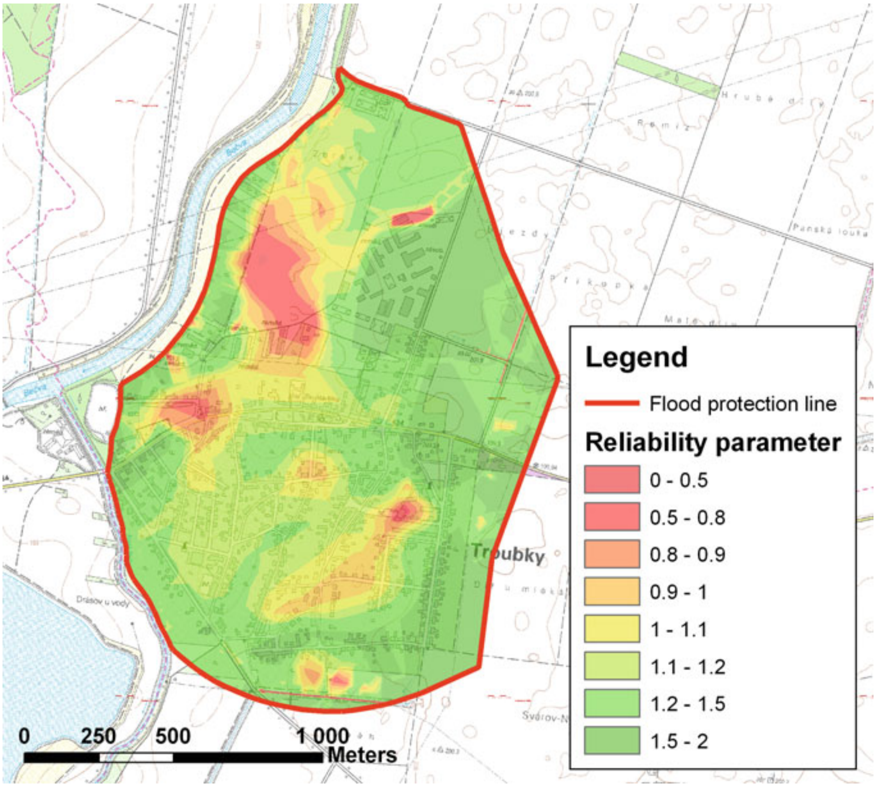

Fig. 8.13 Map with RP parameter—set of wells was applied

calculations and necessary step in further modelling of contaminant transport in aquifers and enable quantification of an effect of groundwater protection measures.

The significant role of the models is the assessment of subsurface structures impact on groundwater regime, namely in urban areas. The effect of groundwater on the civil and hydraulic structures subject to its action via pore pressures, buoyancy and drag forces may be also effectively investigated. The summary of the models applicable to the solution of individual problems is shown in Table 8.1. The summary of assumptions and considerations when using particular groundwater flow models is shown in Fig. 8.17.

Geological and hydrogeological conditions are often complex. Field testing and surveying are expensive and time demanding and the knowledge about the aquifer properties may be fairly limited. Therefore, it is crucial to deal with the uncertainties in the data entering the model. The accuracy and reliability of inputs directly influence the quality of outputs. Therefore, one of the most difficult tasks of modellers and interpreters is to estimate the error and uncertainty in the results achieved to specify margins for the decision makers. For this purpose, sensitivity analysis is frequently

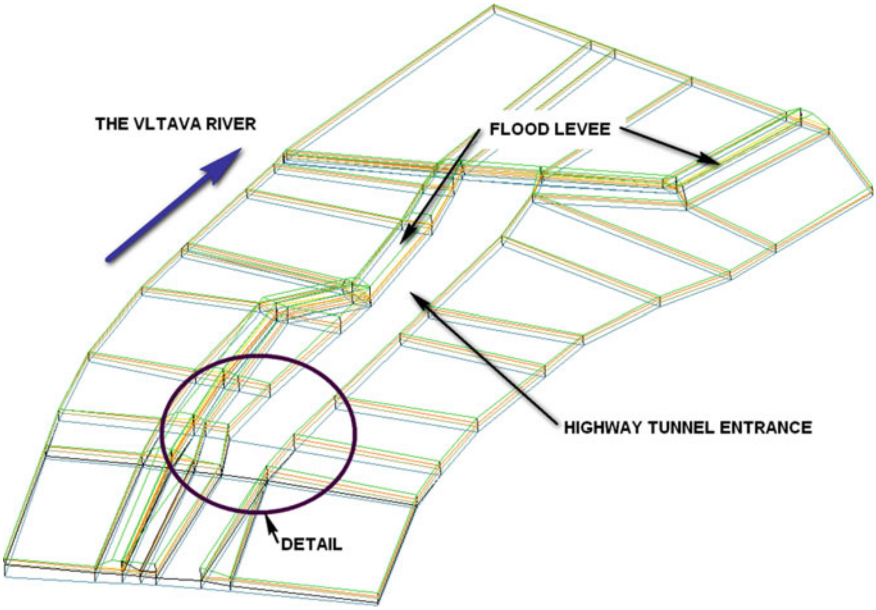

Fig. 8.14 Concept of 3D macroelements as a base for the groundwater flow model

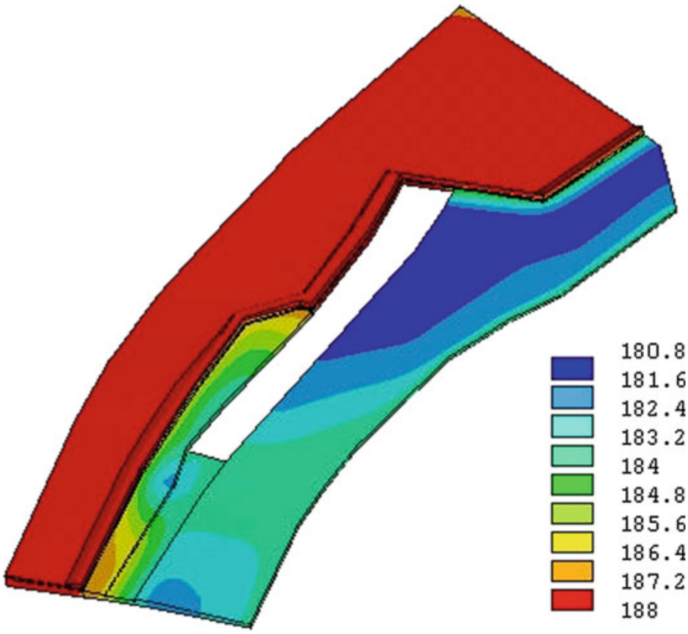

Fig. 8.15 Resulting piezometric heads at the surface of the entire area depicted in Fig. 8.14

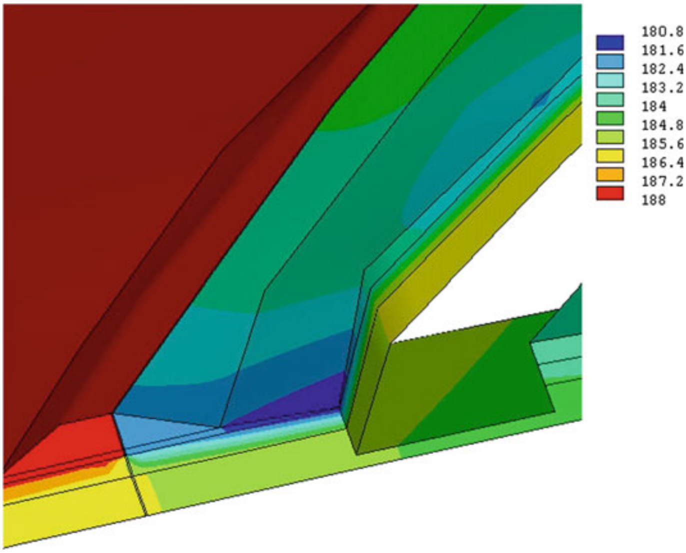

Fig. 8.16 Piezometric heads at the detail of the domain depicted in Fig. 8.14

applied. Sophisticated techniques like interval analysis and stochastic modelling are being studied and tested. Unfortunately, mostly due to the necessity of special software, amount of input data for probabilistic solutions and time requirements for extensive random sampling simulations (Monte Carlo, Latin Hypercube) these techniques have not been widely used for practical applications until now and are rather an issue for scientific and research activities.

8.5 Recommendations

For practical calculations, it is crucial to choose and provide appropriate existing groundwater modelling software. There are numerous computer codes on the market [5, 6, 9, 25–27] solving groundwater flow and contaminant transport using numerical methods like finite difference, finite volumes or finite element methods. Solving practical problems needs, except theoretical background [7], skill and familiarity with the software used. Before using commercial codes, it is advisable to search for relevant professional reviews [28].

It is necessary to emphasize that the groundwater management and seepage modelling is a multidisciplinary issue at which significant role is played by geologists and hydrogeologists, water managers, hydraulic and civil engineers, for the development and adjustment of computer codes the co-operation with mathematicians and programmers is necessary.

Table 8.1 Summary of the application of groundwater flow models

Problem	Type of model	Method of solution
Water supply		
– Preliminary assessment of the yield of single well or set of wells, simplified conditions	1D—steady state	Analytical
– The yield of single wells or set of wells at complex conditions	2D horizontal—steady state	Numerical (FDM, FEM)
– Evaluation of pumping tests, single well, the system of wells, gravel pits	2D horizontal—unsteady state, transient	Numerical (FDM, FEM)
– Isochrones, delimitation of protective zones of groundwater sources	2D horizontal—steady state	Numerical (FDM, FEM)
– Protection against contamination, slurry walls, hydraulic barriers	2D horizontal—steady state, transient	Numerical (FDM, FEM)
Hydraulic structures		
– Preliminary assessment of flow below hydraulic structures, homogeneous, isotropic strata	2D vertical—steady state, confined	Grapho-analytical—flow net
– Flow below hydraulic structures (dams, weirs), complex conditions	2D vertical—steady state confined flow	Numerical (FDM, FEM)
– Shallow flow around hydraulic structures (dams, weirs)	2D horizontal—steady state, confined/unconfined flow	Numerical (FDM, FEM)
– Flow in embankments with the phreatic surface (e.g. for stability assessment)	2D vertical—steady/transient flow, mostly unsaturated zone approach	Numerical (FDM, FEM)
– Flow at hydraulic structures at very complex geological and seepage conditions	3D—steady state, transient	Numerical (FDM, FEM)
Flood events		
– Preliminary assessment of the propagation of the flood wave into the aquifer	1D—transient	Analytical—simplified conditions Numerical (FDM, FEM)
– Complex assessment of the propagation of the flood wave into the aquifer	2D horizontal—transient	Numerical (FDM, FEM)

(continued)

Table 8.1 (continued)

Problem	Type of model	Method of solution
– Overall assessment of the impact of subsurface parts of flood protection measures during no flood period	2D horizontal, 2D vertical—steady state	Numerical (FDM, FEM)
Urban areas		
– Impact of subsurface structures on the groundwater level	2D—horizontal, steady state	Numerical (FDM, FEM)
– Impact of groundwater flow on the subsurface structures	2D horizontal, 2D vertical—steady state, 3D	Numerical (FDM, FEM)

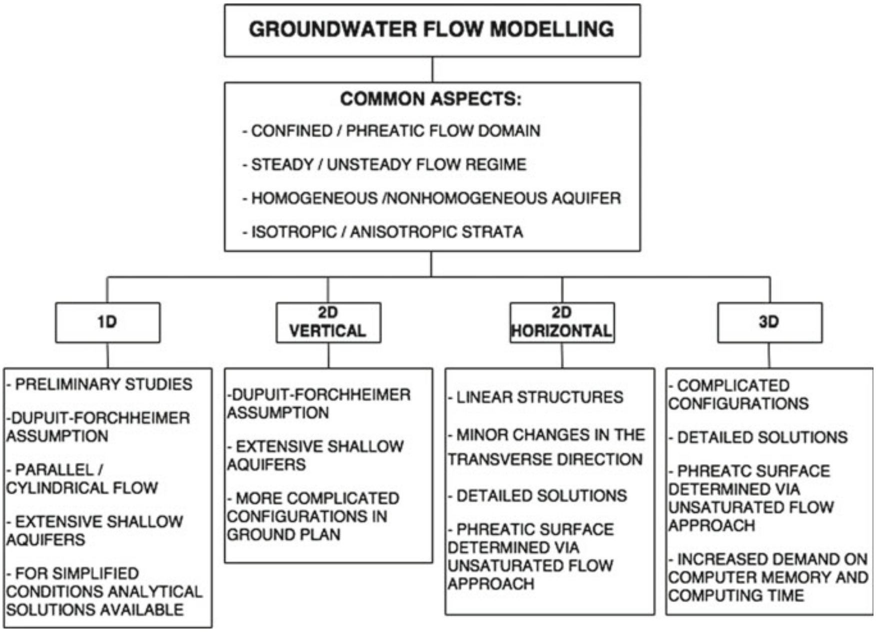

Fig. 8.17 Summary for groundwater modelling for several special cases

Practical experience shows that many times the role of computers and numerical modelling is overestimated and traditional engineering feeling is frequently abandoned. It must be remembered that one of the most important activities at the modelling is the definition of objectives, conceptual formulation of the problem and relevant interpretation and rational explanation of results achieved. Based on them, final decisions and technical proposals are carried out. All these items need experienced staff with good knowledge about the necessary data for the solution and clear vision about the results and their application.

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Part III
Water in the Landscape

Chapter 9
Hydrological Mine Reclamations in the Anthropogenically Affected Landscape of North Bohemia

P. Vráblík, J. Vráblíková and E. Wildová

9.1 Introduction

Various kinds of mining of raw minerals from the lithosphere lead to the deformation of the relief and depressions in the terrain, while spoil tips are formed from the waste. It leads to interference in the lithosphere, pedosphere, hydrosphere, and atmosphere. The main adverse effects of mining on the environment include undermining, the creation of mounds and sludge beds, the formation of sewage, and physical and chemical changes in water, soil, and the rock environment. Anthropogenic burden brings with it a whole range of troubled relationships among the economic, environmental and social pillars of the sustainability of economic growth. The area beneath the Ore Mountains is the location of the North Bohemian Brown Coal District where brown coal has been mined for almost 200 years using the surface method in the Most Basin (formerly the North Bohemian Brown Coal Basin). The negative reality is that the intensive mining and industrial activity caused the devastation of nature and the environment, which was connected with an entire range of environmental problems (deteriorating health of inhabitants, higher mortality, migration of inhabitants, impact of emissions on forest ecosystems, reduction in agricultural production by the effect of emissions, and a relatively high devastation of settlements). In terms of economic measures, the transformation process in the Czech Republic after the 1990s saw changes in the level characterized by economic and social indicators, as well as the origin of significant regional disparities which manifested themselves by differences in employment, GDP, the proportion of investments, etc. Regional disparities (inequality, dissimilarity and the imbalance of various phenomena) can be found in an entire range of causes. The problem of their origin is a fundamental question for the development of society. We most frequently encounter the issue of

P. Vráblík · J. Vráblíková · E. Wildová (✉)
Faculty of Environment, Jan Evangelista Purkyně University in Ústí Nad Labem, Pasteurova 3544/1, 40096 Ústí nad Labem, Czech Republic
e-mail: eliska.wildova@ujep.cz

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Table 9.1 Model area and population data (situation as of December 31, 2016) [2]

District	Area in ha	Number of inhabitants	Number of inhabitants per 1 ha
Chomutov	93,500	124,249	1.33
Most	46,700	112,881	2.42
Teplice	46,900	128,476	2.74
Ústí nad Labem	40,500	119,296	2.95
Total	227,600	484,902	2.13

disparities in the Czech Republic in regions which are connected with mining and energy production; one of these is the Podkrušnohoří region.

The model area of Podkrušnohoří (the districts of Chomutov, Most, Teplice, and Ústí nad Labem) is an area that was once ranked among the most highly developed industrial regions until the beginning of the 1990s. Over 76% of all coal mining took place in this region, and it produced more than 35% of electrical energy in the Czech Republic [1]. The territory of the model area covers 227,600 ha and is home to over 484,000 inhabitants. It is an area with a high population density, concentrated predominantly in cities (Table 9.1).

The area was part of the so-called Black Triangle, referred to at the time as the devastated area in Central Europe. Large-scale coal mining and industrial activities have led to significant damage to the environment, landscape, and settlements in this area. The landscape in the area of interest is the result of anthropogenic actions connected with the surface mining of brown coal. However, the formations which were created (spoil tips, surface quarries) are gradually being integrated into the surrounding landscape thanks to the processes of reclamation and revitalization. The area of interest has a unique opportunity to adapt the surrounding environment to the requirements of nature and society with regard to sustainable development. The presented chapter begins with a description of the history and the present of coal mining in the North Bohemian Brown Coal District. It is also necessary to explain the general procedures and types of reclamation which aid the reintegration of anthropogenic formations into the surrounding landscape, and the manner in which they participate in reshaping the model area's landscape. The primary task is to explain hydrological reclamation, which is the only logical and economically effective possibility of integrating residual pits into the surroundings after the surface mining of coal. The lakes which are created are used for both recreation and the maintenance or improvement of biological diversity. Hydrological reclamation in the area of interest is in its initial stages; so far, only three residual pits have been flooded, but thanks to inspiration from abroad (Germany), we can ensure the correct development of this type of reclamation, so that its effect on the surrounding environment is economically, environmentally, and socially sustainable.

9.2 Coal Mining in the Most Basin

The landscape in the area of interest was formed gradually, over millions of years. During the younger part of the Tertiary Period, wealth was formed in the basin in the form of brown coal deposits, and the subsequent volcanic activity created hills and mountains, predominantly in the southern part of the basin.

9.2.1 History of Coal Mining in the North Bohemian Brown Coal District

Initially, the extraction of coal did not have fundamental importance, and it only developed slowly. Its mining and significance were still overshadowed by the extraction of ores, particularly copper and silver, in the nearby Ore Mountains. In the year 1803, coal mining in North Bohemia had still not exceeded a level of 20,000 tons annually. Only the second half of the nineteenth century sees a turnaround. The development of industry and construction of a railway, which after the year 1870 connected the Mostecko region with the interior and with Saxony, ushers in a new era for mining, transport and the utilization of coal on a larger scale. At that time, annual mining in the district reaches a total volume of 1.6 million tons. The year 1871 sees the establishment of Mostecká společnost pro dobývání uhlí [Mostecko Coal Extraction Company]. The year 1876 sees the founding of the Imperial Royal State Brown Coal Mines. Gradually, other large mining companies, which control mining and the coal trade in the Mostecko region and the entire basin, are created or transformed. Mining in the basin steadily increased, and in the year 1899, the North Bohemian Brown Coal Mines extracted 15.5 million tons and employed over 26,000 workers. At that time, the North Bohemian Brown Coal Basin was a significant source of brown coal for the entire Austro-Hungarian Empire, and in the year 1913, it produced 18.4 million tons. It retained its significance even after the formation of the First Czechoslovak Republic; in the year of its formation—1918—12.8 million tons were extracted. It did not lose its important function even during World War II, when the German machinery used brown coal from the Mostecko region, among others, to produce petrol for its army. In the year 1945, for various reasons, mining decreased to 11.8 million tons. In that year, there were 38 underground mines and 24 surface quarries in operation in the North Bohemian Brown Coal District. However, the new Czechoslovak Republic and the nationalized industry required more and more fuel and energy for the country's post-war restoration and orientation on heavy industry. Therefore, the nationalized mines and their center of Mostecko region gradually became the fuel and energy base for the entire republic. At that time, the area was ranked among the most polluted territories in Central Europe [1].

The supplies of brown coal in the model area, which have been mined industrially since roughly the year 1850, have brought about growth in electricity production, the chemical industry and metal processing in the region. From its beginning until the present day, the surface mining of brown coal has affected an area of roughly 250 km^2. The most intensive mining in the district took place in the year 1984 when 74.7 million tons were extracted. After the social changes in the year 1989 and the subsequent privatization of the coal industry in the year 1993, there are also extensive changes within our economy in the structure of the industry and the development of power engineering, which subsequently manifests itself in the mining and consumption of brown coal.

9.2.2 Present-Day Coal Mining in the Area of Interest

In the year 2016, mining in the Most Basin reached 31.07 million tons, with this production in the territory beneath the Ore Mountains ensured by the following surface quarries:

- ČSA (Czechoslovak Army quarry)—Severní energetická a.s. [Northern Energy, joint-stock company],
- Vršany–Šverma quarry—Vršanská uhelná a.s.[Vršany Coal, joint-stock company],
- Libouš quarry—Severočeské doly a.s. [North Bohemian Mines, joint-stock company],
- Bílina quarry—Severočeské doly a.s. [North Bohemian Mines, joint-stock company].

The last underground mine in the basin, the Centrum (Kohinoor) mine, last extracted coal on April 1, 2016, and the mine is currently being gradually closed down. An overview of mining in individual quarries and the Centrum mine is presented in figure no. 4 for the period of the last ten years. According to current plans, mining in the North Bohemian Brown Coal District (SHR) should end during the period of 2050–2055. The end will be defined by mining of the last coal supplies in the Vršany and the Bílina quarry, which the government decided should continue, while complying with the originally stipulated limits, in October 2015 [3]. In the year 2016, approximately 89% of brown coal in the Czech Republic (31.07 million tonnes) was extracted in the model area, and approximately 40% of the installed power generation capacity output of the Czech Republic is concentrated here on the basis of solid fossil fuels (steam power stations), of whose fuel base brown coal comprises approximately 85%. The indicated concentration of manufacturing activities leads to an enormous emission and air pollution burden on the region's landscape and plays a part in the low comparative evaluation of the region's environmental quality factor within the scope of the Czech Republic (Fig. 9.1).

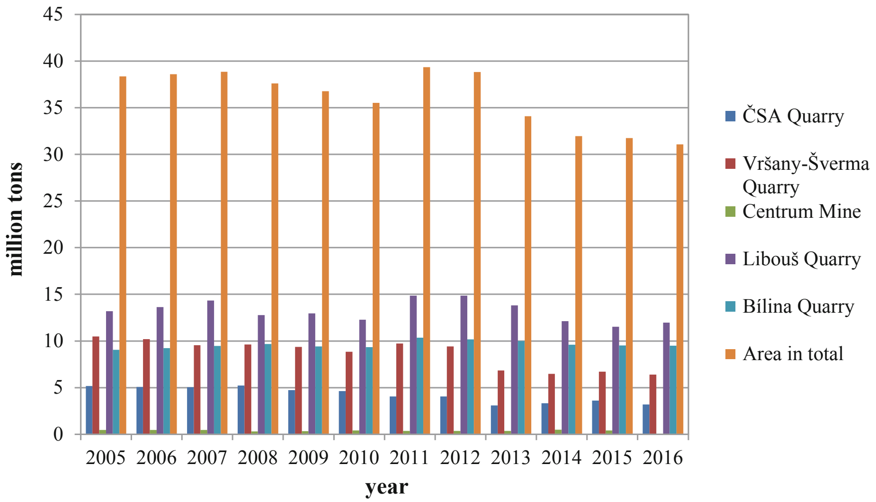

Fig. 9.1 Brown coal mining in the Most Basin in the year 2016 [4]

9.3 Reclamation After the Mining in North Bohemia

Landscape reclamation is a human activity that aims to restore the natural properties and values of a region which was disrupted by man [5]. It can also be defined as the cultivation of destroyed land (e.g., after the mining of raw minerals) for its return to agricultural production or reforestation [6]. The general term which is superior to the term of reclamation is what is called revitalization. For example, we understand revitalization to mean functional involvement in the landscape, or the final treatment of a devastated area which will ensure the creation of an aesthetic regional phenomenon and restoration of the ecosystem's natural functions, while at the same time enabling the full utilization of the area in accordance with the territorial plan [7]. Furthermore, we understand the term revitalization to mean the return of a landscape with a disrupted rock environment to the state before human intervention. Even when it cannot be an actual return to the original state, it can be a kind of compromise or adjustment that will respect nature, human settlement and human activity [8]. We encounter a somewhat narrower concept in the definitions of Lisicky [9] and Klinda [10], who present revitalization as a revival of the environment and a restoration of the conditions for heterogeneousness of species. Prokopova and Cudlin [11] understand the term of landscape revitalization to mean increasing its ecological stability.

The effects of mining affect all landscape-forming elements and basic regional components in the area of the lithosphere, hydrosphere, troposphere, pedosphere, and biosphere, including social environment components, with a restriction of residential and industrial development, and technical infrastructure. The restoration of areas devastated by mining activity ensures the return of the regional system's

function. New agricultural land, forests, water bodies, biocenters, and biocorridors are created in areas devastated by mining activity, and the area integrates into the original landscape. The main disparities caused by coal mining are the following:
Landscape transformations:

- Formation of a new relief.
- Change in stratigraphic conditions.
- Disruption of hydrogeological conditions.
- Devastation of the pedosphere—topsoil and subsoil layers.
- Effects on the atmosphere, microclimate, and air environment quality.
- Disruption of the biosphere (phytocoenoses, zoocoenoses, and microbial coenoses).

Recent formations:

- Residual pits.
- Spoil tips.

The anthropogenic formations created during and after the end of coal mining are ecologically labile, i.e., unstable, and simultaneously unproductive ecosystems. The mining of coal and subsequent renewal of the area and reclamation are connected with a pronounced change in the landscape. This includes deforestation, liquidation of agroecosystems and other greenery, and river liquidation and its engineering; the aforementioned activities lead to significant drainage of water from the area. Settlement formations and transport infrastructure have been significantly affected. Recultivation processes are the only solution to the consequences of coal mining.

9.3.1 General Mine Reclamation Procedures

Reclamation solution proposals should be based on a landscape-forming concept of the target utilization of the area and should ensure the fulfillment of the landscape's basic functions, i.e., ecological balance, hygienic safety, effective and potential production capability, aesthetic appeal, and recreational effectiveness.

During the optimization of reclamation methods, one must take into consideration:

- the natural character of the devastated landscape and its surroundings,
- the character of the mining and devastation which changes the landscape's original nature,
- the set of socioeconomic factors, particularly the intensity of non-mining industrialization and urbanization of the landscape, population density, and area and structure of the agricultural and forest land fund,
- possibilities of the economic utilization of the area before reclamation and after the end of the reclamation process.

The basic reclamation methods are agricultural, forestry, hydrological, and others. Agricultural reclamation includes arable land, fruit orchards, and vineyards.

Forestry reclamation is addressed predominantly as special-purpose forests with a polyfunctional orientation. Water management alternatives are realized as ponds or polyfunctional water reservoirs in residual quarries, supplemented by wetlands and the restoration of rivers. Spoil tips in the vicinity of settlements are dealt with within the scope of the "other" reclamation category. This mainly involves playgrounds, sports grounds, parks, gardening settlements, and landscaped areas for various forms of development.

The decision regarding the specific type of reclamation is primarily dependent on the requirements of the surrounding environment—both environmental and social. Therefore, a thorough analysis of the area is necessary so that the demands of all subjects which were affected by the mining in any way are fulfilled.

Phases of the reclamation process

The reclamation process is divided into four phases:

- **Preparatory phase**. This phase involves the preparation of territorial planning documentation, which addresses the commencement and method of mining, as well as the methods of minimizing and smoothing over the damage after mining. In this stage, it is crucial to decide on the direction which the post-mining landscape will take so that it is integrated into the region. This is where the principle of sustainable development should be most taken into consideration.
- **Mining-technical phase** has a preventive character, addressing technically feasible, and economically tolerable conditions for subsequent reclamation activity (locating waste fills, spoil tips and dumps, the method of shaping mining spaces, any overburden elimination work, etc.).
- **Biotechnical phase** includes technical and biological procedures that eliminate the negative impacts of mining. The technical work includes shaping the formation and contours of reliefs, backfills of fertile and potentially fertile soil substrates, modifying hydrological and runoff conditions in the area, the technical stabilization of slopes and a system of anti-erosion measures, as well as the construction of roads which make reclaimed areas accessible, and so on. The biological work is a collection of forestry and agro-technical work. This principally involves establishing and maintaining green areas, which are dependent on the type of reclamation and target cultures (agricultural, forestry, orchard-landscape gardening, natural types of communities, etc.).
- **Post-reclamation phase** is associated with handing over reclaimed land to its future users and owners.

As part of compliance with the social pillar of sustainable development, the concept of the **resocialization** of the region is very important; it means the return of man to the reclaimed and revitalized area [5].

Stages of revitalization

As part of the revitalization project methodology for compliance with the principles of continuous sustainability, one must abide by the individual stages of revitalization:

1. **Stage**—analysis of area and reclamation. The first step of this stage involves an important comprehensive analysis of the area on the basis of the territorial plan and territorial development principles, by which the overall redevelopment and reclamation plan must subsequently abide.
2. **Stage**—actual procedure and realization. To fulfill the area's revitalization objectives, one must evaluate the initial state for its revitalization. After that, revitalization methods and procedures can be proposed with regard to the sustainable development of the landscape. This stage also involves the resolution of subtasks for the realization of revitalization.
3. **Stage**—evaluation of results. The last stage involves the evaluation of individual revitalization procedures. It evaluates the interim and final results of territorial monitoring, which are put into practice [12].

9.3.2 Proportion of Individual Types of Mine Reclamation in the Area of Interest

For every specific locality, it is necessary to stipulate how the newly formed landscape will be moved toward a climax to minimize energy subsidies and sustainability. Addressing a specific location needs to be subordinated to complex integration into the surrounding landscape. All environmental problems and the relationships between individual components need to be addressed complexly. The specific location should be able to fulfill ecological functions independently. The proposed revitalization measures must be feasible, and their consequences must be socially acceptable. At present (6426.39 ha) and in the future (10,546.81 ha), the most significant proportion will be taken up by forest reclamation. Although it includes more demanding technological procedures (supply and cultivation of land, planting, and protection of seedlings, monitoring), the result is forest growth whose functions are indispensable in nature. At the same time, within the scope of forest reclamation, smaller parts can be left to natural succession. At present, in terms of area, agricultural reclamation is second in order of precedence (4064.88 ha), but it is not expected to be realized to a greater extent in the future. In the case of this type of reclamation, the technological procedures are even more demanding, particularly in terms of soil quality and relief modification. At present, they are mostly used for the construction of vineyards, because the shape of the spoil tip does not have to be modified as much. On the contrary, "other" reclamation, which mainly includes the creation of recreational areas, will be very popular. Today, their share is over 2200 ha, but in the plan, the proportion is larger by 4000 ha. Specifically, for example, a hippodrome, autodrome, aerodrome, and golf course have been constructed on former spoil tips. The last, but certainly not the least important, is the proportion of hydrological reclamation, which is approximately 985 ha today, but the gradual end of mining will lead to the flooding of residual pits, and its area will increase to slightly over 4000 ha (Fig. 9.2). It is important to add that the future areas of individual types of reclamation

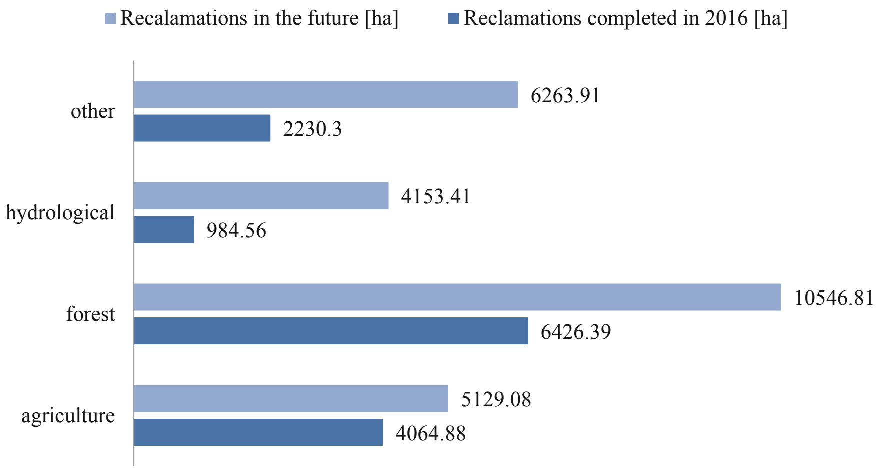

Fig. 9.2 Planned and completed reclamations in the year 2016 in the model area (ha) [4]

may differ slightly, as they may also be affected by other factors such as changes in society needs, technological development, the issues associated with the protection of species, and climate change.

9.4 Hydrological Mine Reclamation in North Bohemia

Aquatic (hydrological) reclamation methods are an important part of the newly formed landscape. They fulfill an ecological and aesthetic function as well as a technical one. They increase ecotope diversity and create important biocenters and biocorridors. At the same time, they increase the environment's evapotranspiration. Significant aquatic reclamation of a local character is usually located in places where mining took place in the past. Also, a number of "heavenly pond" type water bodies have been created and are being created on spoil tips, in depressions formed during filling, or in shallow wetlands connected with the consolidation of spoil tip bodies. An essential form of smoothing over the consequences of mining activity, whose importance will increase shortly, is the flooding of residual quarry pits. Within the scope of hydrological reclamation, the most crucial task is to secure both a suitable shape for the future reservoir, and an adequate and permanent source of quality water for filling it, while simultaneously also creating conditions for the prevention of the entry of excess nutrients into the lake (anti-eutrophication measures) and support for the lake's self-cleaning function. Apart from the flooding of residual coal mine pits, it is also appropriate to create water bodies designed for suburban recreation and sports purposes on spoil tips and modified quarry bases.

9.4.1 Aspects of Hydrological Mine Reclamation

One of the critical aspects of hydrological reclamation is compliance with the Czech Republic's water management policy, whose main priority is the creation of conditions for the sustainable management of the Czech Republic's limited aquatic wealth. In particular, this means:

- supporting water retention in the region and in the area of individual basins,
- systematic protection of the quantitative and qualitative state of surface water and groundwater in relation to the condition of aquatic ecosystems,
- facilitation of the sustainable and balanced utilization of water sources,
- and supporting the reduction of adverse agricultural effects.

The realization of hydrological reclamation is always connected with a number of tasks and measures which are executed within the scope of an entire complex of demanding works. The area's geomechanical and hydrogeological conditions must be resolved with the objective of preventing landslides and ensuring slope stability. The coal bed, lake bottom, and permeable horizons must be sealed against the future water level. Suitable technological and biological measures must be used to ensure the stability of shores and the entire shoreline. Water quality must be ensured and monitored. A number of other measures must be implemented, which are addressed within the scope of the project and the conditions issued for the realization. When using this reclamation method, sufficient attention must be devoted to redevelopment works (e.g., sealing of bed and bottom, stabilization of shores, etc.). A major problem is also the securing of a sufficient number of quality water resources for filling the residual pits and ensuring conditions for maintaining high water quality in the created lakes. Ditches, furrows, terraces, retention reservoirs, and polders have been constructed in the reclaimed areas as essential technical measures for hydrological stabilization. Among the measures connected with the creation of a new aquatic regimen in the transformed landscape, we can also include elements which drain away shallow groundwater, thereby stabilizing sloping areas. These are stone drainage canals or drains. The hydrotechnical measures connected with the creation of a new aquatic regimen in a landscape disrupted by mining activity are also an important article (Fig. 9.3).

Stages of water management reclamation:

1. Preparatory—similarly as in the case of agricultural and forestry reclamation.
2. Elimination of causes of the devastation of aquatic regimen
   - anti-erosion protection,
   - drainage of wetlands, sloping areas, landslides–drainage.
3. Modification of watercourses—ditches, creeks, streams, rivers
   - creation of water bodies in abandoned mines, depressions, etc.,
   - utilization of water from reclamation for the irrigation of fields, meadows, pastures/grazing lands [1].

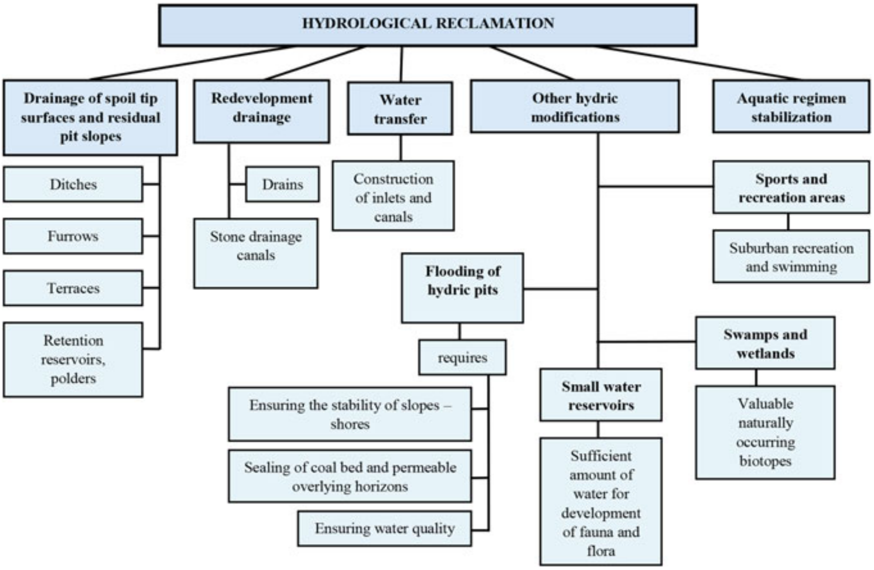

Fig. 9.3 Technical hydrological reclamation procedures

Hydrological reclamation also involves the creation of formations other than large water bodies, which significantly contribute to the restoration of the aquatic regimen in an anthropogenically burdened landscape. However, artificial lakes created by the flooding of residual pits have a socioeconomic effect as well as an environmental one. In the first stage of the filling, it is mostly assumed that the water will not correspond to the quality of the water with which the lake is filled. This is given by the large contact surface between the water and the bottom and slopes of the reservoir, the leaching of soil combined with the leaching of coal, and in part also the imperfect insulation of the coal bed. However, these effects will gradually recede, and over time, as the lake is filled, they will become less significant, to be replaced by biochemical and physical processes that will lead to the improvement of the water in the filled lake. A large number of external and internal factors will affect the quality of the water in the newly created reservoirs and residual pit lakes. Of course, not every factor will affect the quality of the water in the reservoir to the same extent. However, today we know that despite the many chemicals, physical and biological processes taking place in the newly created lake, one of the decisive factors will be the quality of the water it is filled with. The greatest threats to the lake may be redundant soil content, increased eutrophication or excessive acidification. When addressing water quality in lakes which are being formed after residual mining pits, an individual approach should always be chosen. In the case of large residual pits which will be flooded, most of the factors can be significantly influenced so that the best results possible are achieved while obtaining the best water quality possible. Of particular importance is the treatment of shore sections, which to a large extent decide on the usability of the lake itself. In terms of fishing use, it is good to create many diverse wetlands with developed littoral. In most cases, developed littoral areas also provide very favorable conditions for the presence of water birds. Of great importance is the knowledge of the future use of the residual pit while the mining is still taking place, when individual aspects can be adapted to the future requirements for the area where the lake will be created, according to the project's visions for the given locality.

On the basis of the comprehensive stipulation, the information set forth below must be ascertained as additional calculation parameters for the design, preparation, and subsequent realization:

- expected use of the lake,
- determine whether the lake will be flow-through or endorheic,
- volume of water retained by the lake and height of the lake surface,
- speed and manner of filling,
- method of draining excess water from the lake,
- method of water subsidy necessary for filling.

To optimize the lake's function, the following must also be ensured:

- geotechnical stability of the lake's slopes, before and after filling it with water,
- protection of slopes against waves and abrasion,
- protection against vapors, fire, and flooding of the residual pit connected with the limitation of undesirable leaching from the coal bed and the remains thereof when flooding the residual pit,
- ensuring the optimal volume and quality of the lake water,
- Resolution of complex hydrogeological issues connected with residual pit lakes [13].

9.4.2 Examples of Hydrological Mine Reclamation in the Area of Interest

So far, the flooding of residual pits in the Mostecko region has been realized in smaller mining localities. These are the Vrbenský quarry, which today is home to the Matylda water body that is 38.7 ha in size, the Chabařovice quarry (Lake Milada, 252 ha in size), and the third and simultaneously largest lake so far—Lake Most, which is 309 ha in size. However, the importance of this form of smoothing over the aftermath of mining activity will continue to increase in the future. The aquatic form of reclamation has been proposed for future use in the ČSA (Czechoslovak Army) quarry, and the Vršany and Bílina quarries. In the case of the large water bodies designed in this manner, the newly created deep lakes are expected to be permanently oligotrophic with high water quality. Given their crucial future role as water sources, the importance of these large lakes, with a total water volume of over 25,000 million m^3, does not have to be emphasized. The largest artificially created lake will be formed by flooding the residual pit of the ČSA (Czechoslovak Army)

Table 9.2 Completed and planned hydrological reclamations in the area of interest [14]

Quarry	Acreage (ha)	Cubic capacity (mil. m^3)	Maximum depth (m)	Filling period
Chabařovice (Lake Milada)	252	35	25	2001–2010
Bílina	970	698	170	2055–2075
ČSA (Czechoslovak Army)	1259	760	130	2020–2050
Hrabák	310	25	20	2036–2045
Vršany	264	61	40	2060–2066
Most-Ležáky (Lake Most)	309	70	75	2008–2014
Libouš	640	110	52	2030–2034
Vrbenský (Lake Matylda)	38.7	7	4	1992–1995

quarry, which will be 1259 ha in size. The lake with the highest maximum depth of 170 m will be formed by flooding the Bílina quarry. It should be added that after the relaxation of the mining limits in the Bílina quarry, which was approved by the Government of the Czech Republic in the year 2015 [3], the date of commencement of the flooding of the residual pit will be moved and its size will also change (Table 9.2).

Lake Milada and Lake Most, which are the latest additions to hydrological reclamation in the area of interest, have been selected as examples with a more detailed description.

Lake Milada

Mining in the Chabařovice quarry started in the year 1977. An extensive change of the mining areas was performed by dividing and merging the areas into the resulting Chabařovice mining zone. The main reason for the opening of the Chabařovice quarry and the priority task of mining was the need to provide coal of the required quality for the Úžín Pressure Gasworks and the Trmice Heating Plant. Due to its low content of sulfur (0.35%), which is unrivaled in the Czech Republic, as well as other carcinogens, Chabařovice coal was ideally suited to the conditions for minimizing the burden on the environment during a period of inverse conditions. During mining in the Chabařovice quarry, a total of 61.5 million tons of low-sulfur quality brown coal was extracted, as well as 9.3 million m^3 of waste material and 256.1 million m^3 of overburden. The quarry then continued to operate until the year 1991, when the Government of the Czech Republic ruled that mining in the Chabařovice quarry should cease. The mining was terminated prematurely. There are still around 100 million tons of coal in the ground.

However, during the gradual restriction of coal and overburden mining, the question of the method of liquidation of the residual pit itself remained open. Fundamentally, two variants were being addressed: wet and dry. The dry variant consists of filling the residual pit with soil. However, this variant was shown to be highly ineffective. On the basis of a meeting of the "Association for the Revitalization of the Region Affected by Mining in the Chabařovice Quarry," the wet variant was approved. The choice of this variant was influenced not only by the need to construct a missing recreational area for the inhabitants of Ústí nad Labem and the surrounding villages in an area devastated by long-term mining activity, but also the disproportionately high costs which would have to be incurred when filling the pit to the level of the original terrain. In April 1999, the Ministry of the Environment of the Czech Republic issued a decision (updated in July 2004) approving the Master Plan of Reclamation, according to which the Ústí nad Labem Combined Fuel Company (PKÚ, s.p.) performs redevelopment and reclamation works within the scope of smoothing over the consequences of mining activity in the area of the former Chabařovice brown coal mine.

On June 15, 2001, the filling of the Chabařovice quarry residual pit commenced. The Js 300 former anti-fire water pipeline, using water from the Kateřina reservoir, was used for the filling. The main water intake from the Kateřina reservoir into the lake was the reconstructed Zalužany stream which flows through the Zalužany reservoir, and then via an intake trough into the lake. In August 2008, there was a change in the system by which the lake is filled. In the section from the Zalužany reservoir, a new trough was constructed which leads to an anti-eutrophication reservoir; the water flowed from this reservoir into the lake via the "N" ditch. Another filling source was the overflow borehole on the northern side of the lake. On August 8, 2010, upon attaining the planned operating level at the height of 145.7 m above sea level, the filling of Lake Chabařovice was complete.

The reclamation is currently in a phase of gradual completion. The total revitalization and reclamation works are realized on an area of 1457 ha and include landscaping, construction of drainage ditches, access paths, and other greening (672 ha) and forest (470 ha), agriculture (58 ha), and hydrological reclamation including reservoirs and the main object created within the scope of hydrological reclamation Lake Milada (257 ha) (Fig. 9.4). The eastern, western, and northern parts of the slopes bordering the lake have been planted with trees and will also allow for dispersed recreation. The southern part of the area will primarily fulfill an ecological function [15].

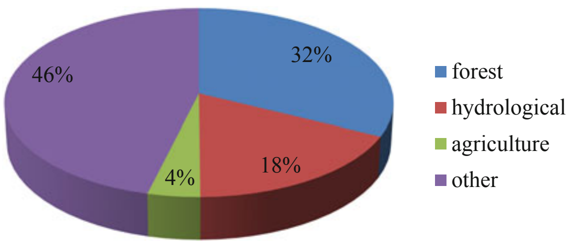

Fig. 9.4 Proportion of individual reclamation types in the Lake Milada area

The total reclamation costs after mining are still about 3 billion crowns (118 million €). Of that, about 250 million crowns (9.8 million €) were spent on bank fortifications and construction of breakwaters. Also, in the SE corner of the lake is planned construction of up to seven piers to break the breakwaters, both for swimmers and non-motor boats. In total, the budget cost for the piers is estimated at 30 million crowns (1.2 million €). Further, the central sewerage system, electrification, and water supply will be constructed in the SV and V part. Estimated costs are 80 million crowns (3.2 million €). In May 2015, the lake was open to the public. During the high heat season, there is a visit of up to 5000 people per day. For visitors, there are four parking spaces and stony beaches. Due to the quality of the water, there are no sandy beaches. Water quality has long been favorable. There are no reports of cyanobacteria. In the cold and under favorable conditions, the visibility of water is up to 13 m [15]. As far as the fish population is concerned, predatory fish (pike, catfish) are present there due to the reduction in fish that is alive with zooplankton, which is necessary for water purification. However, there is a ban on fishing throughout the lake area. A cycle path was opened there in 2006 which includes an educational trail informing about the history of coal mining in the region (Fig. 9.5). At the beginning of 2018, a student competition was announced for proposals for modifications at Lake Milada, which could be a basis for making the site more attractive.

Lake Most

The lake is located beneath the Hněvín peak, right beside the relocated Church of the Assumption of the Virgin Mary in Most. Lake Most was created on the site

Fig. 9.5 Lake Milada

of the former Royal City of Most, which had to give way to mining. Coal mining ceased definitively on August 31, 1999. Lake Most lies in the territory of the former Ležáky mining locality, which was initially established as the Richard mine in the year 1900 and renamed Ležáky mine in the year 1945. The quarry itself has been flooded by the creation of a non-draining lake. With regard to the surrounding area (particularly the level of the foundations and underground sections of the relocated Decanal Temple), the mine lake surface is set at 199.0 m above sea level, which is approximately 30 m beneath the level of the surrounding terrain. The flooded area is approximately 309 ha in size, with the maximum depth reaching 75 m. On October 24, 2008, the filling of the Most–Ležáky quarry residual pit (the future Lake Most) was ceremonially commenced, as extensive hydrological reclamation was performed by the state-owned enterprise Ústí nad Labem Combined Fuel Company within the scope of the revitalization of an area affected by mining activity, with the filling expected to be completed in the year 2011. From the year 2002 until the commencement of the filling, the water in the future lake accumulated from atmospheric precipitation and outlets in the quarry slopes after the pumping of mine waters in the lowest part of the residual pit bottom ceased. On the day that the filling commenced, the lake had an area of 21.6 ha, depth of 21.12 m and a surface level of 145.12 m above sea level. Since the commencement of the filling, the main water source has been water from the Ohře River, fed into the lake at a volume of 0.6–1.2 m^3/s from the Nechranice reservoir in the Chomutovsko region by a feeder from the Nechranice industrial water pipeline with a total length of 4.9 km. On June 25, 2012, the filling of Lake Most ended due to the fulfillment of the Water Supply Contract (filling of planned water volume), drawn up between the Land Fund of the Czech Republic and Povodí Ohře [Ohře Catchment area]. This situation lasted only until the completion of the modification, or more precisely repair, of the shore road and shoreline stabilization elements. The realization of the necessary modifications of the peripheral road and the anti-abrasion shoreline elements arising from the update of the water management balance was completed in September 2013. The filling of Lake Most commenced in May 2014 and was completed in September [15] (Fig. 9.6). Within the scope of the extensive project, the lake's individual effects on the microclimate, air environment quality, and the surrounding ecosystem were evaluated. At the same time, the lake's littoral tone and soil quality were assessed. On the basis of the results, a comprehensive methodology of the quantification of the ecological impacts of the hydrological reclamation of brown coal mines was prepared [16].

The entire reclaimed area has 1264 ha. Of this, 160 ha are agriculture reclamation, 280 ha are forest, and 460 ha of the area were used for other types of reclamation. The rest (315 ha) is hydrological reclamation, where 309 ha are the lake area, and the rest are areas of drainage that are important for the erosion protection of slopes [15]. A total of 226 ha are still in the development phase (Fig. 9.7). Fourteen hectares of the surrounding landscape have been left for natural succession, but the process is very slow, and mining cuts are still visible in these areas (Fig. 9.8).

The pine trees, larches, hornbeams, cranes, and alders were planted during the forest reclamations due to the need to strengthen the banks. Larch is a desirable tree because it elevates the height of the others and thus creates a favorable microclimate.

Fig. 9.6 Lake Most beneath the Hněvín peak

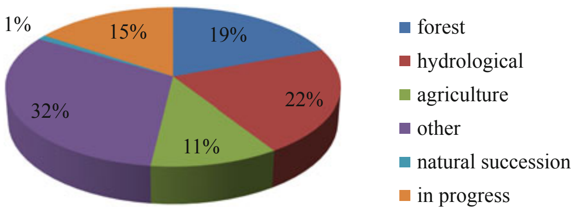

Fig. 9.7 Proportion of individual reclamation types in the Lake Most area

Fig. 9.8 Succession areas in the Lake Most area with visible mining cuts

Unfortunately, there are problems with bark beetle. The problem in the vicinity of Lake Most is also with the Japanese knotweed (*Fallopia japonica* Houtt.), as an invasive species. Every month water quality monitoring is carried out, as well as fish crew monitoring. There are mainly perch, catfish, and pike. Fishing is prohibited there for now. The SE part is at the stage of accessing the slopes. Further work will include building beaches, building piers for swimmers and boats and resting areas for fauna and flora (especially birds). The total renovation was around 4.5–5 billion crowns (177–196 million €). The lake is not accessible to the public. It is expected that the opening will take place at the end of 2019.

9.4.3 Examples of Hydrological Mine Reclamation from Abroad

The process of the redevelopment and revitalization of a region after the mining of brown coal in modern Germany is generally evaluated—despite certain minor failures—as a successful action with overlap into other countries. This comprehensive project has become a model example for a number of other countries around the world. What many people, mainly employees of brown coal mines and the power industry, initially perceived as a threat to their economic and social security, has been shown over time to be a unique opportunity for permanent positive change. 171.5 million tons of brown coal was extracted in Germany in the year 2016 [17]. Brown coal represents a 42% share of domestic primary energy production. The area which is a model for the planning of hydrological reclamation is located in the surroundings of Lusatia. The territory of Lusatia is located on the border between Brandenburg and Saxony. The northern part of the region, i.e., the area of Lower Lusatia, belongs to Brandenburg, while the southern part, Upper Lusatia, is part of the Free State of Saxony. Lusatia is home to the second largest brown coal district in Germany. The geological reserves of brown coal in Lusatia reach approximately 13 billion tons, of which roughly 2.5 billion occurs in operating and planned mines with a total annual capacity of over 60 million tons [17].

Reclamation in the former East German brown coal districts is connected with a significant change in the landscape, with the creation of new lakes, forest areas, grassy areas, and areas which are close to nature. Opportunities for their further utilization are thus created, whereby the expansion of the transport infrastructure continues to increase the number of these opportunities. Thanks to the transformation of the mining areas into a natural landscape of lakes, the regions have become attractive in terms of tourism and recreation. The largest set of artificial lakes in Europe is now being created in former mining areas. One of the pits—Lake Senftenberg—was flooded as early as the year 1972. The so-called Lusatian Lake District (Lausitzer Seenland), also colloquially referred to as the lake plateau (Seenplatte), with 23 touristically usable lakes, takes up a total area of roughly 14,000 ha. Ten of these artificial lakes in the center of the new lake region, with an area of roughly 7 thousand

Fig. 9.9 Complex of lake houses on Lake Geierswalde (Germany)

hectares, will be interconnected by 13 navigable canals. The interconnected lakes, lying east of the A13 motorway between the towns of Großräschen, Senftenberg, and Hoyerswerda, are referred to as the "Lake Chain" (Seenkette) [17]. The entire lake region is complemented by cycling paths, harbors, footpaths, observation towers, piers and information panels about mining and reclamations in the area. Unique construction is a complex of lake houses (Lausitz Resort) on Lake Geierswalde (Fig. 9.9).

Several factors contributed to the relative success of redevelopment in the former East German lands. It is mainly collaboration on all levels, funding system, control mechanism, institutional securing, comprehensive and systematic approach, correct planning, and participation of citizens and civic initiatives.

9.5 Conclusions

The power industry's dependence on fossil fuels persists, and the North Bohemian Brown Coal District has been home to the largest reserves of brown coal for almost 200 years. The surface mining method has irreversible effects on the landscape. After the mining ends, residual pits, which are an extensive anthropological formation, remain. Based on experience, it was evaluated that the most effective and economically suitable method is their flooding or hydrological reclamation. Hydrological reclamation represents an essential step toward the restoration of the aquatic regimen in an anthropogenically burdened landscape. It includes the creation of not only new lakes, but also wetlands, reservoirs, and smaller natural lakes, as well as river engineering. However, the lakes created by flooding quarries have the most enormous impact on the surrounding landscape thanks to their size, and also on society, as they have widespread recreational use. The hydrological reclamation of residual pits is accompanied by many technical measures, and the water quality is always connected with the quality of the watercourse used for the filling. Only three residual pits have been flooded in the area of interest so far, but there are plans to create an additional five lakes in the coming decades. The Matylda and Milada lakes are the most utilized for tourism. Given the ongoing technical works, Lake Most is not accessible to the public at present. An illustrative example of how the landscape in the area of interest could look in the future is the Lusatian Lake District in Germany. It is already home to 23 lakes, which are utilized for tourism. We should learn as much as possible from their integrated and comprehensive approach to reclamation after mining. The most important principle, which must be adhered to in all aspects of hydrological reclamation, and by extension all revitalization processes, is the principle of sustainable development to ensure the correct development of the anthropogenically burdened landscape from not only an environmental perspective but also an economic and social one.

9.6 Recommendations

Transforming residual mining pit into an artificial lake within the process of hydrological reclamations is the most logical and effective way how to integrate it into the surrounding landscape. Several aspects need to be taken into consideration to ensure the stable development of the lake. Essential is to provide a quality source of the filling water and to secure geotechnical stability of the lake's slopes. It is recommended to choose revitalization of the slopes by planting stabilizing tree species, and not to turn to natural succession. Natural succession is much slower process and the slopes are often endangered by erosion. As to the planning process, professional and non-professional public should be included in the decision-making process since the beginning. Participation of citizens and civic initiatives is important for the creation of recreationally attractive area. All decisions on reclamations and revitalizations should always be guided by the principle of sustainable development.

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Chapter 10
Modelling of the Water Retention Capacity of the Landscape

V. Pechanec, P. Cudlín, I. Machar, J. Brus and H. Kilianová

10.1 Introduction

The number of extreme hydrological events has rapidly increased in the last hundred years. The accrual of floods has been a consequence of increased runoff from the landscape and this runoff has been caused by a decrease in flood storage capabilities. The areas with low flood control capability have increased with more and more frequency in the watersheds because the diversity of the landscape has descended and the whole landscape structure has been weakened.

It is necessary for a project of structured changes in a watershed to rate the proportional representation of various land use forms, their spatial distribution, their shapes and the orientation of their segments. These projected landscape modifications should lead to an increase in flood storage capability. Optimally structured remedies with a precise localization should then be made after an extensive and thorough analysis.

V. Pechanec (✉) · J. Brus · H. Kilianová
Department of Geoinformatics, Faculty of Science, Palacky University, 17. listopadu 50, Olomouc, Czech Republic
e-mail: vilem.pechanec@upol.cz

P. Cudlín
Global Change Research Institute of the Czech Academy of Sciences, Lipová 9, 370 05 České Budějovice, Czech Republic

I. Machar
Department of Development and Environmental Studies, Faculty of Science, Palacky University, Olomouc, Czech Republic

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10.1.1 Influence of Landscape Segments on River Basin Retention Capacity

The condition of maintaining a balanced state of water in the landscape is its continuous circulation. A suitable unit for studying the hydrological cycle in the landscape is a small river basin [1], because it is drained from the surface and underground drainage water and its topographical distribution is identifiable. A small river basin is a river basin with a surface where the nature of the river basin, in particular, its geophysical properties and management, is fully utilized for the formation of runoff, and its influence is not suppressed by the characteristics of the flow capacity of the riverbed [2]. The term 'retention capacity of the landscape' is based on the definition [3], which means temporary retention of water on vegetation and objects in the basin, retention of water in the cover layer of soil, in soil, micro-depressions, polders and tanks in the so-called phase of the precipitation–runoff process. The retention capacity of the landscape depends on the depth of soil profile, soil grain composition, skeletal content, humus content, structural state and porosity and the type of landscape cover and its condition.

Forest areas fulfil a significant water management function. According to the forests division in the Czech Republic [4], the category of forests, which are of water management significance, account for 27.6% of the total forest area in the Czech Republic. These are declared protected areas of natural accumulation of surface water—CHOPAV (16%) and forests in the sanitation protection zones—PHO (9.6%) [4].

The water management functions of forests consist mainly in ensuring the permanence and yield of water resources, in decreasing flow fluctuations (retardation and retention, accumulation of runoff) and improving the quality of runoff [5, 6]. Decree No. 83/1996 Coll. defines the partial water management functions of the forest:

- water protection (ensures water quality and protection against erosion)
- anti-erosion (prevents surface runoff)
- infiltration (conditional to maximum infiltration of rainwater into the soil)
- detention (dampens extreme drains from small river basins)
- suction (drains excess water from the soil)
- precipitation-inducing (capture horizontal precipitations).

In particular, the vegetation component and the hydrophysical properties of the soil contribute to the fulfilment of the water management function of the forest.

The vegetation cover is used for the retention and change of surface runoff velocity, mainly by evaporation of water back into the atmosphere and evapotranspiration of crowns [6]. What is important is that the forest evaporates the water that the roots of trees intake from relatively deep soil horizons. The high infiltration capacity of forest soils is due to very good aeration thanks to the interconnection of the root system with soil organisms and soil. The pores occupy about half of the soil volume on average. Moreover, a high layer of humus horizons under the quality forest stands almost excludes the possibility of surface runoff [6]. The vegetation component, and land as well, can be influenced by economic measures, e.g. by choosing species composition, changing the representation of age classes, changing the density of crops, forest renewal, timber harvesting and concentrating technology, preparation of planting area and forestry mitigation measures [4]. Their influence on the hydrological functions of the river basin has been described in a number of works [4, 7].

Species composition of the forest. Restoration of the beech stand from 80% by Norway spruce has not contributed to the increase of flood waves. Only in the downstream part of the flow wave are drains from the restored river basin higher [7, 8]. When compared to spruce and beech stands, more favourable quantitative water balance was found in beech stands (in spite of the lower sum of interception and evapotranspiration in beech stands was lower by 30–145 mm/year) [6]. The intercept values varied, with the greater ability of spruce to intercept precipitation. Significantly, lower leakage into the subsoil was characterized by spruce stands [6]. In general, broad-leaved stands tend to exhibit higher infiltration values than coniferous stands.

Deforestation. Wood harvesting and changes in land use have resulted in increased peak flow rates [6]. This applies to permanent deforestation (pastures, roads, etc.). However, the forest soil after the extraction of old or calamitous stands, which are subsequently restored by planting, does not lose its retention and retardation abilities according to [6]; common cultivation and restoration measures can affect the genesis of flow waves to the extent that is barely measurable and conclusive [7]. Any reduction in evapotranspiration is very quickly replaced by the functions of a compact herbaceous layer [8].

Drainage. After dewatering, the depression curve and the minimum groundwater level (lower aeration of the soil profile in the root part and its release for rainfall) have changed; there was no deterioration in water conditions in dry soil [4]. For their hydrological significance, floodplain forests deserve a special chapter, thanks to their considerable retention capacity, adaptation to high groundwater levels and floods. However, since floodplain forests do not occur in the area under review, this issue is not discussed further.

Grasslands. Grasslands appear to be very perspective cultures, as they have many ecologically significant features from the hydrological point of view. The associated tussock stand has on average 10% greater porosity than the arable soil [9], which is a more favourable soil structure, which allows better flow and drainage of flood and rainwater [10] in their work point to significant differences in the infiltration capacity of different lawn grass species. In relation to hydrological conditions, the content of organic matter in soils under permanent grasslands is also important, which is reflected in their retention capacity [11, 12].

The biologically active surface of the plant matter is also important for the hydrological effect in the landscape. This year, this surface forms an intermediate between the soil and the air and its size varies from 1 to 10 m^2 of leaf surface per 1 m^2 of vegetation. The biologically active surface has significance in interception and evapotranspiration. [9] states that meso- to hygrophytic meadows have a very intense water operation, which has a transpiration effect that exceeds the evaporation from the water level. The use of grassland also has a significant impact. Lawn grassland usually uses water more rationally than on grassland. The reason for this is that the grassland is more frequent during excessive water consumption or loss of water [13]. It also forms an insulating layer that reduces direct evaporation from the soil and thus maintains greater soil moisture in the soil. Elimination of the turf pool results in volatile hydrological conditions. The transformation of grass biomass through animal production into animal fertilizers is also of great significance, which helps to improve the fertility and hydro-pedological properties of arable soils [12].

Arable land. Also, arable land is a significant hydrological factor contributing to the formation of the landscape water regime. Unlike other categories, agricultural land is characterized by intense seasonal dynamics of porosity, permeability, micro-relief structure or species structure, and thus in the quality of the vegetation cover.

Volume density, porosity and soil infiltration are closely related to the type of crops grown. Relatively high infiltration capability is characterized by the soil of the grain sites and the habitat of the manually treated meadows. The smallest infiltration capacities have mechanized-field meadows, soils with corn and Lucerne crops and land without vegetation, especially with the hardened surface after heavy rains [14]. In [14], relationship between causal rainfall and surface drainage on differently exploited experimental areas of agricultural land (bare soil, grassland, alfalfa, winter wheat and stubble) is treated. At regional rainfall, the values of surface runoff coefficients at all sites of individual crops were very low (<0.1000). Moreover, the occurrence of such long-lasting rains usually falls into the summer season, when the soil is already sufficiently protected by vegetation. Multi-year forage crops, winter wheat or berries do not, therefore, contribute significantly to floods. On the other hand, local rainfall (spring and early summer) caused mainly on bare soil, freshly agro-technically processed, many times larger surface drains and as such contribute to local floods [14]. Also, micrography produced by agro-technical soil treatment is characterized by some surface and internal retention ability.

Intensification of agricultural production often leads to a negative influence on the infiltration capacity of the soil (soil compaction, the addition of root crops at the expense of perennial forage and grassland). Depending on these changes, hydrological, especially rainfall-flow processes in the landscape change [14]. On the other hand, it is possible to use more sophisticated technologies of soil processing (soil preparation and sowing in one operation, sowing in a winter crop mulch, etc.) that do not deteriorate the water balance of the habitat (do not harden soil, soil cover reduces unproductive evaporation, etc.) [13].

Scattered greenery, linear communities. Significant hydrological functions in the landscape ecosystem can be fulfilled by elements such as scattered greenery, linear communities or other linear elements (shingles, singularity woods, boundaries, high limits, tapes, windbreaks, hedges, streams, trenches, avenue tree plantations, etc.). In the landscape, the surface flow is affected by the corresponding cause.

In varying degrees and configurations, line elements are scattered across the landscape: in lines; networks and clusters. Particularly in agricultural-managed river basins, they are important and often the only stabilizing elements. Even a multi-meter sinking strip, separating arable land, positively changes the conditions of the vat, thereby increasing the proportion of sub-surface runoff. Sajikumar and Remy

[15] states that the soil under mixed woody and grass vegetation of most of the eco-stabilization formations shows mentioned above is absolutely exceptional and hydrologically relevant, and has decisive volumes of influential soil infiltration capacity.

10.1.2 Geo-Information Technology

Geo-information technology (GIT) encompasses the modern processing of spatial data using information technology. The rapidly evolving information society sees GIT becoming an integral part of many fields of human activity, among them science subjects which study the spatial distribution of various phenomena, their characteristics and relationships. GIT has applications primarily in geographic information systems, remote sensing, global positioning systems and computer cartography [16–18].

The geographic information system (GIS) encompasses complex information systems that integrate tools from a number of science fields and are characterized by their ability to process spatial data actively and efficiently. One of the widely used definitions states that a geographic information system is a system designed to capture, store, transform and visualize spatial data representing the real world with respect to a specific application [19]. Also, a geographic information system allows the collection, processing, and management of geographic data related to natural resources, provides a more accurate representation of reality in a computer environment, decision-making processes easier [20, 21]. It also allows its users to model a number of natural processes, consequently, facilitating the planning of utilization and predictions of natural resource management development [22]. The term 'GIS' may be applied only to a system containing tools that fully cover the four key areas of functionality. Such a system allows the creation, utilization and updating of extensive databases of thematically diverse spatial data [23–25].

The broad application of GIS in environmental database management is driven by a comparison of GIS potential with other technologies. GIS is suitable for data management for the following reasons [26–28]:

- they are readily applicable to several different tasks,
- use identical data for different studies and save such data,
- is capable of fast processing of large data volumes,
- is capable of processing data in varying levels of detail (in different scales),
- allow easy conversions of raster and vector structures, making them flexible in data application in different data structures,
- help to standardize data from different sources.

The Czech Republic has a sufficient amount of data sources representing the landscape and its features. However, their availability, up-to-date and a very diverse structure (with respect to both content and format) pose a problem. 'The accuracy and detail of input data influence the quality of consequent analyses and outputs'

[29]. Overview of individual data sets available in the Czech Republic and suitable for landscape analyses are presented by [26, 30] or [31].

10.2 LOREP

The formulated LOREP model represents an application of the solution using a methodological approach for the identification and localization of areas with low flood storage capability. This makes it possible to compare the projected scenarios. The structured catalogue of non-technical solutions for the landscape is a part of the model.

The modelling approach is based on a study of storm runoff computing using spatially distributed terrain parameters published by the Center for Research in Water Resources at the University of Texas [1]. The main part of the water flowing from the basin is a widespread feature of the hydrograph unit. The study describes in detail how it is possible to refine the final value of the surface runoff. The terrain model is a loaded grid dividing the basins studied in the same parts, and each character is related specifically to the sub-areas mostly square. This division into several smaller parts is the result calculated with the inhomogeneity of the area, which was used in the calculations for the basin as a whole is mostly wiped away. It is a distributed hydrological model with a partial semi-empirical approach [1].

The fact that linear features (such as lines of trees) can be a part of land use analysis is the key element of the model. This is possible because the raster data of high resolution (pixel size 5 m) is used and because the modelling is focused on the hydrology of small basins [1]. The procedure for the computation of territorial-specific surface runoff is based on a combination of specific functions in GIS, hydrological equations of the runoff curve number method and spatially distributed unit hydrographs. The LOREP model is written in Python and is designed for ArcGIS. The input data are expressed as a grid of pixels in agreement with the rules of raster representation in ArcGIS. The spatial resolution of the pixels is selected so that it is high enough to identify the influence of linear features on the landscape on the extent of surface runoff [32].

10.2.1 Calculation of Specific Surface Runoff in the Territory

The computation of the area's specific surface runoff is a determinant step for the localization of areas with low flood storage capacity. These raster data of high resolution are input layers for the analysis of surface runoff in the model:

- hydrologically correct Digital Elevation Model [33],
- a raster of curve number method (CN-values),
- a raster of land use.

It is possible to use any method of producing digital elevation model (DEM), but it is necessary to adhere to the rules of creating a correct DEM (e.g. uniform format and resolution). Raster of CN-values is created according to the methodology recommended for the Czech Republic [34]. If the area does not contain forests, the CN-value is determined by combining data and land use categories plotted in the soil type map and in the complex survey of soils. If the area contains forests, hydrologic groups of soils are derived from the forest typology unit [35]. The process assumes and zero previous rainfall. The layer of land use is created/updated with the help of data sets ZABAGED (Fundamental Base of Geographic Data) and orthophoto map of the relevant basin. The field survey has to be realized in poorly identifiable areas. The values of Manning's roughness coefficient are determined by the land use categories according to the conversion tables [34].

10.2.1.1 Creating a Hydrologically Correct Digital Relief Model

The Digital terrain model (DMT) is a raster expression of the altitude gradient. Hydrologically correct DMT [36] means that it allows hydrological modelling. Some variants of DMT calculations do not take into account phenomena such as local depression or local elevations. On the contrary, they create 'fictitious' depression due to erroneous interpolation. The model thus created does not allow (or rather allow, but with errors) hydrological modelling, i.e. mainly direction and drainage calculation, drained area and so on.

Calculation of hydrologically correct DMT is based on a special variant of the spline interpolation method that, among other things, optimizes the calculation and permits rapid changes in terrain relief and applies algorithms to calculate dewatering. The model thus calculated has eliminated unreal pits and peaks.

10.2.1.2 Iteration Cascade

The principle of the cascade is the gradual calculation of the height of the direct runoff for each pixel in the basin according to the basic equation of the CN-curve method (formula 10.1), that is extended here about the influence of the terrain on the direction and length of the surface runoff. To apply a model, pixels throughout the river basin need to be 'categorized' into iterative orders. This is done by the combination of the derived drainage direction and the run length using the flow length command.

First, all local topographic maxima in the basin are determined. These are pixels whose altitude is close to 3×3 pixels highest, and identify vertices or divides—i.e. places where the drain begins, and there is no accumulation. From these points, the surface runoff path (direction and length) is determined. The distance from the topographical maximum divided by the width of the pixel then determines the order of the pixel (Fig. 10.1).

The division of the catchment into the iterative order ensures that the impact of the terrain is reflected in the calculation of the surface runoff and allows to track the direction and length of the runoff from the point of origin to the catchment point of the river basin. This greatly helps to better identify critical sites in the landscape [3]. The input layers in the iteration cascade are the possible retention raster, the pixel raster order and the design precipitation raster.

The draft precipitation represents the 24-h total precipitation H_S (in mm) in the area. To compare the retention capacity of different parts of the river basin, its value is constant for the entire catchment area. In this study, precipitation with a volume of 4 mm was used as mild rain and precipitation of 20 mm as torrential rain.

The iterative cascade routine is composed of N iterations, where N = number of pixel orders. In each iteration, the height of the direct flow H_{O_X} for Xth order pixels is calculated according to the equation:

$$H_{O\_X} = \frac{\left((H_{S\_X} + H_{P\_X}) - 0.2 * A\right)^2}{(H_{S\_X} + H_{P\_X}) + 0.8 * A}\ \text{(mm)} \tag{10.1}$$

where

A	the potential retention of 1 pixel unit in mm
H_{O_X}	the height of the direct outflow from the Xth order pixel area unit in mm
H_{S_X}	the height of the rainfall on the Xth unit pixel area unit in mm
H_{P_X}	the height of direct water inflow in mm from pixels of the order $X - 1$ depending on the direction of drain.

The direct inflow height value in the Xth order pixel H_{P_X} is calculated by summing the H_{O_X-1} pixels by one order of lower ($X - 1$) that flows into the given pixel based on the slope direction. Since zero water cannot flow from the higher positions to the 0th order pixels, their $H_{P\_X} = 0$. The output of the 'iterative cascade' is the raster of

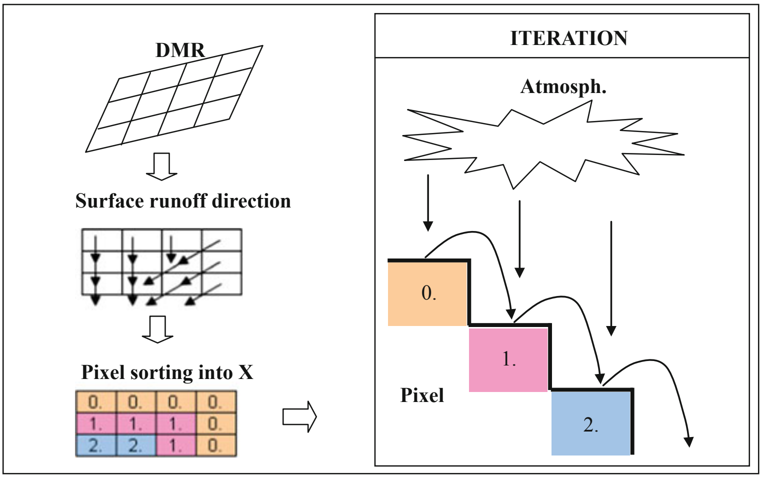

Fig. 10.1 River basin division into iterative order

the cumulative H_{OK} flow height in mm, which is given by the H_O raster sum of all iterations.

10.2.1.3 Drawing Direction

The calculation of surface flow into multiple directions is based on a solution based on the [37] topographical index, which is now successfully implemented in several hydrological models, e.g. in TOPMODEL [38].

The algorithm is based on the fact that the received part of the surface runoff from the monitored pixel, in each pixel downhill, is given by the percentage of the weighted impact distance of the precipitation and the geometric weight factor that depends on the direction of the drain.

$$A_i = A \frac{tg\beta_i * L_i}{\sum_{j=1}^{k} tg\beta_j * L_j} \tag{10.2}$$

where

A_i the share of the source region to neighbour i (m^2)
A upstream slope area possible for flood subsidy (source area) (m^2)
β_i slope gradient (= slope difference) towards neighbour i
L_i weight factor (0.5 for direct and 0.354 for diagonal direction)
k number of lower neighbours.

The basic benefit of this algorithm is that it divides the flow between several recipients. Most models use the D8 method [17]. Eight nearest neighbours for the given pixel is found, and the difference between the altitude values between individual pixel centres and the distance of individual centres (3×3 filter) is calculated based on the input DMT. Because the calculation is done in a regular grid, the distance is constant.

The direction of the drain is given by the steepest slope, and all the volume flows in only one direction. However, it is not so in nature, and it is much more advantageous to use the algorithm to calculate the surface runoff in multiple directions for a greater approximation to reality.

10.2.1.4 SCS Curve Number Method

The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology to predict direct runoff or infiltration from rainfall excess. The curve number method was developed by the USDA Natural Resources Conservation Service [1, 39], formerly called the Soil Conservation Service or SCS. The runoff curve number is based on the hydrological soil group, land use, treatment and hydrological condition. References, such as from USDA, indicate the runoff curve numbers for characteristic land cover descriptions and a hydrological soil group. The basic assumption of the SCS curve number method is that, for a single storm, the ratio of actual soil retention to runoff is equal to the ratio of direct runoff to available rainfall [1, 39]. However, the results of its application in larger river basins are well known [39].

The purpose of the method is to quantify the hydrological functions of landscape components. The method takes into account the dependence of the retention of the basins on the hydrological properties of soils, the initial state of soil saturation and the way of land use and hydrological conditions.

Outflow is primarily determined by the amount of precipitation, the infiltration of water into the soil, soil moisture, vegetation, impervious surfaces and surface retention. The basic input of the CN-curve method is the rainfall sum of a certain time division, assuming its uniform distribution over the river basin area. The amount of precipitation is converted to the volume of runoff by the number of drain curves. Their values depend on the hydrological properties of soils, the vegetation cover, the size of impermeable surfaces, interceptions and surface accumulation.

Drain curve numbers are tabulated according to the hydrological properties of soils divided into four groups: A, B, C and D on the basis of minimum water infiltration rates without covering after long-term saturation and utilization of soil, vegetation cover, cultivation and application of anti-erosion measures.

The method thus proceeds from the assumption that the ratio of runoff volume to total rainfall is equal to the ratio of the volume of water retained at runoff to the potential volume that can be retained. Drainage usually begins after a specific accumulation of rainfall, i.e. after a certain initial loss, which is the sum of interception, infiltration and surface accumulation estimated on experimental measurements at 20% potential retention ($I_a = 0.2$ A).

From the above-mentioned context, the basic relationship was derived:

$$H_O = \frac{(H_S - 0.2\ A)^2}{(H_S + 0.8)}\ (\text{mm}) \quad \text{for } H_s \geq 0.2\ \text{A} \tag{10.3}$$

where

H_o direct drain (mm)
H_s the sum of the draft (precipitation) (mm)
A potential retention expressed by CN curves.

as

$$A = \left(\frac{1000}{\text{CN}} - 10\right) \times 25.4 \tag{10.4}$$

Of which volume of direct drain O_{pH}:

$$O_{pH} = 1000\ .\ P_p\ .\ H_0\ (\text{m}^3) \tag{10.5}$$

where

P_p the area of the river basin (km^2),
H_o direct drainage (mm).

The basic step of the whole process is to create a raster that carries the CN-curve value. This layer is obtained by combining the following three factors that were captured in the raster form.

Land use. Combining the digital layers of the ZABAGED geographic database and evaluated colour orthophotograph images, land use grid was created. The spatial resolution of the raster was chosen at 5 m, taking into account the fact that the model was able to capture the influence of the linear elements of the landscape (road network, boundaries, reminders, etc.) on the formation of direct outflow volume in the landscape. The pixel resolution of 5 m, in reality, corresponds to 25 m^2 landscape. This section of the landscape is considered homogeneous. In case of occurrence of 2 categories in a given pixel, the value of a category with a larger share is taken after the pixel value. The raster has been verified and updated by field research. Categories of land use have been unified with the CN-curve categories.

Based on raster representation rules, line and planar entities are rendered as squares. In this detailed scale, line elements such as boundaries or paths form a series of pixels. The influence of their orientation on the direction of the surface runoff is captured at the time of the combination of the land use grid with the digital landscape model. A line that is represented by an entity of a given width, such as one pixel, influences the drain only in this narrow band. In contrast, a line that is at a sharp angle or perpendicular to the flow direction is represented by multiple pixels in width, and its effect is reflected on a larger surface (relative to the direction of the surface runoff).

The hydrological properties of soils were derived from the BPEJ (valuated soil-ecological unit) codes for agricultural and urbanized areas on the basis of existing transfer tables [34, 40] and for forest soils based on selected soil characteristics. The existing division into four groups was further specified on the basis of field measurements and expert estimates of up to eight sub-categories. On the basis of the measurements, the boundary between individual sub-categories in the field was also specified [41].

The transitions between the hydrological properties of the soils are in nature rather gradual, not sharp. Therefore, this layer falls into its non-shady set. Nevertheless, the pedological survey in the Všeminka basin has demonstrated an almost sharp boundary between individual hydrological types and their properties, mainly due to the geological and geomorphological characteristics of the area (Bayer, oral statement). For this reason, the hydrological properties of the model were presented as a sharp set of rays.

The moisture content of the soil before the precipitation is calculated based on the five-day sum of the previous precipitation (see [34]). This magnitude can also be ranked by fuzzy sets based on spatially variable precipitation totals. For simplicity, however, a raster containing the value of Antecedent Precipitation Index (API II) scalar variable was used.

10.2.1.5 Unit Hydrograph

A hydrograph is used to more easily represent the effect of rainfall in a particular basin. It is a hypothetical unit response of the watershed to a unit input of rainfall. This allows easy calculation of the response to any arbitrary input (rainfall) by simply performing a convolution between the rain input and the hydrograph output unit [1]. An instantaneous unit hydrograph is a further refinement of the concept. For an IUH, the input rainfall is assumed to all take place at a discrete point in time (this is not the case for actual rainstorms) [39]. Making this assumption can greatly simplify the analysis involved in the construction of a hydrograph unit, and it is necessary for the creation of a geomorphological instantaneous unit hydrograph (GIUH). The creation of a GIUH cannot be given more than topological data for a particular drainage basin. In fact, only the number of streams of a given order, the average length of streams of a given order and the average 'land area draining directly to streams of a given order are absolutely required (and can be estimated rather than explicitly calculated, if necessary)' [1].

10.2.1.6 Direct Runoff

The procedure core point is an algorithm of the direct runoff capacity $Q(t)$ with spatially distributed terrain parameters [42]. This algorithm (see formula 10.6) makes it possible to trace the direction of the surface runoff in the landscape and to specify the influence of the terrain on the runoff.

$$Q(t) = \sum_{i=1}^{Nw} \int_{0}^{\infty} A_i I_i(\tau) U_i(t - \tau) \mathrm{d}\tau \tag{10.6}$$

where

$Q(t)$ the direct runoff from the concerned basin
t time
N_{i-w} the number of sub-basins
A_i the area of sub-basin i
$I_i(t)$ the excess precipitation in sub-basin i (direct runoff from basin i, see formula 10.7)
$U_i(t)$ the flow-path response function (response at the basin outlet yield by a unit instantaneous input in sub-basin i, see formula 10.8).

It is necessary to divide the basin into uniform non-overlapping sub-areas (sub-basins in grid structure) and for the application of this algorithm and to calculate $I_i(t)$ and $U_i(t)$ for each sub-basin (see formulas 10.7 and 10.8).

$$I_i(t) = \alpha_i \; Pe(t) \tag{10.7}$$

where

$I_i(t)$ the excess precipitation in sub-basin i (based on the appraisal of the balance in the 'soil–water' system)
t time
α_i the compensative index
$Pe(t)$ the precipitation excess.

$$U_i(t) = \frac{1}{2t\sqrt{\pi(t/T_i)\Delta_i}} \exp\left\{-\frac{[1-(t/T_i)]^2}{4(t/T_i)\Delta_i}\right\} K_i \tag{10.8}$$

where

$U_i(t)$ the flow-path response function
t time
T_i the mean distribution value
Δ_i the scatter around the average of the distribution
K_i the flow-path loss factor (determines the loss of water along the flow path).

The curve number method is used for the calculation of excess precipitation in sub-basin i. This method takes into account the fact that the flood storage capacity depends on the hydrologic attributes of the soil, on the initial condition of the water saturation in the soil and on the land use activities in the landscape. A detailed description of the algorithm and its derivation is in [42].

10.2.2 Area of Hydrologic Zones in the Basin

The basin is divided into hydrologic zones. It is necessary to know in which zones the areas with high $Q(t)$ are located for the selection and application of appropriate flood control measures. Topography determines ecological conditions such as slope orientation, the gradient of slope and energy supply. This means that the trophic and water relations of the zone and the amount of transported solids from the zone are changing dynamically. Terrain can be differentiated into zones with different attributes as follows:

- Denudation zone—The supply of solids is minimal, and the loss of solids is considerable. The zone's resistance to extrinsic load is very low (an example of the zone: plateau),
- Transfer-denudation zone—The amount of solids supplied is less than the amount of lost solids. The resistance of the zone to the extrinsic load is low (an example of the zone: convex slope),
- Transfer zone—The amount of supplied solids and the amount of lost solids are equable here. The resistance of the zone to the extrinsic load is moderate (an example of the zone: plain),

Table 10.1 Classification of relief elements into hydrological zones

Relief	Zone
Peak	Denudation zone
Ridge	Denudation zone
Saddle	Accumulative areas
Flat	Accumulative areas
Ravine	Accumulative areas
Drink	Accumulative areas
Convex hillside	Transfer-denudation zone
Saddle hillside	Transfer-denudation zone
Slope hillside	Transfer zone
Concave hillside	Accumulative-transfer zones
Inflection hillside	Accumulative-transfer zones
Unknown hillside	Transfer zone

- Accumulative-transfer area—The amount of solids supplied is greater than the amount of lost solids. The resistance of the zone to the extrinsic load is high (an example of the zone: concavity slope),
- Accumulative zones—The loss of solids is minimal, and the supply of solids is considerable. The resistance of the zone to the extrinsic load is very high (an example of the zone: alluvial plain) (Table 10.1).

The relief classification is based on polynomial surface transformation for the 3×3 pixel region. The pixel characteristic is obtained as the second derivative of the fourth degree directional equation for the central pixel of the analysed area. The characteristic value includes information about the rate of change in the tangent ratio to the mathematically described curve in a straight and diagonal direction for orientation of the observed pixel. Since each pixel provides information on the shape in multiple scales, Fourier analysis techniques reduce the variability of the digital model of the territory and improve the calculation result for the solved area [43].

The algorithm of the hydrological zone grid in the basin is a part of LOREP and it is consistent with the work [44], which classified 11 basic landforms and reclassification to five hydrological zones.

10.2.3 Localization of Areas with High Surface Runoff and Detection of Reasons for Low Flood Control Capability

The next step is to create two grids. One grid is connected to the database of information for each pixel in the basin about its geographic conditions. The conditions are soil conditions, vegetation conditions in forests, gradients of land, land use, land cover and hydrological zones. The conditions in the database are deduced from GIS layers containing this information.

The second grid is connected to the database of information for each pixel in the basin about its direct runoff $Q(t)$. There are five categories for $Q(t)$: very high, high, middle, low and very low. It is possible, by using the tools of the map query in GIS, to find the pixels with a very high or high direct runoff and by using the tools of the database query in GIS for these pixels to find their geographic conditions.

We can determine the areas with a very high or high direct runoff thanks to the second grid and the information in its database. We can also detect the reasons for the low flood control of these areas thanks to the grid with the information about the basin conditions. Information about the conditions in the basins and the direct runoff in the basins is gathered from the third step of the procedure. The most important indicator is the amount of pixels in the categories 'high' and 'very high' whose direct runoff in various scenarios must be compared. When we combine the conditions and suggest the measures for each combination in LOREP, we design the scenario for this concrete situation. We simulated various scenarios for each area of low flood control capability found in the third step of the procedure, and we have modelled new layers in GIS with modified land use in the basin. We modelled each scenario with one layer, which always participated in the previous steps. The map of the potential surface runoff, the table with the amount of pixels can be prepared for each scenario. The results are compared, and a recommendation is made for the most appropriate measure for each area of low flood control capability.

10.2.4 Structure of Model

The model for the calculation of the runoff over each pixel has been created according to the above equations, the selected function unit hydrograph. Specifically, the tool can be connected freely through ArcToolbox, which was written in ArcGIS as a script in Python synta10. The resulting toolbox is called LOREP. The tool handles the layer showing the catchment areas in GRID format and shapefile. Its resolution is limited by the digital elevation model (DMR) input resolution. Schematic representation of the calculation of the surface runoff was created by ModelBuilder in the environment. The toolbox is a fully functional data over any river basin in the Czech Republic. This limitation is given only by the Czech name of the land use category in this layer.

The input data are vectors characterizing the area (elevation, water flows and land use) and a layer containing the special characteristics of the basin (the layer with the values of the CN curves and hydrological categories group soils). Other inputs represent the numerical value of the average flow rate, the total catchment area, the rainfall and the time at which the drain is to be found.

ArcGIS Desktop 10.x is a professional tool for creating and managing geo-information systems from Esri. It consists of a set of integrated and mutually cooperating software applications ArcMap and ArcCatalog. Geoprocessing is a fundamental part of working with ArcGIS. It includes all basic and professional operations on spatial data. When creating your own tools in the form of a script created by ModelBuilder, it is possible to use geoprocessing tools [45].

Python 2.5 is a dynamic, object-oriented programming language. This is a hybrid language—allows other programs to share the same letter code. He became popular and widespread due to his simplicity. The code is compared to other languages short and readable. Python code can be written in any text document. For easier use in the OS Windows platform is also available as Python Win [46].

10.3 Case Study—Všeminka

10.3.1 Study Area

Všeminka (21.51 km^2) was selected as an example of small watersheds in the agricultural-forest culture landscape. These watersheds are of IV order and mainly in the location of land use categories in watersheds. The watercourse of the upper part of the River Dřevnice (22.58 km^2) differs from Všeminka watershed in the forest cover (81%) and the type of watershed (Všeminka—valley type of watershed). More detailed testing of methods for retention ability and proposed measures of effectiveness was performed only in Všeminka watershed (Tables 10.2, 10.3 and 10.4).

10.3.2 Results

The CN-values (Fig. 10.2) were determined using the described methodology. Five categories of the actual surface runoff, computed by the 'direct' outflow model for two selected rainfall intensities (Table 10.5), together with spatially generated hydrological zones of catchment (zone of infiltration, transport zone and accumulation zone) entered the main process for identifying the source patches with an extreme runoff.

Table 10.2 Basic characteristics of the catchment areas GIS-derived bases

River basin (km^2)	21.51
Flow length (km)	9.2
The average slope of flow (%)	3.6
The mean slope of river basin (%)	19.4
Minimum altitude (m)	270
Maximum altitude (m)	620
Average height (m)	400
Afforestation of the catchment area (%)	48.2
River basin circumference (km)	23.64
Length of lineages (km)	13.81

The map database queries have been used over the raster layer to determine the possible causes of low retention in these patches (Table 10.6). A new spatial scenario of land use changes per hydrological zone was proposed, based on the findings of most possible low retention reasons and the attitude of precautions. The land use GIS coverage was updated according to this scenario and used again in the 'direct' runoff model per pixel to calculate a potential surface runoff for improved landscape structure under 4 and 20-mm rainfall.

The resulting areas of the simulated outflow categories for the recent land use of Všeminka catchment as well as for the proposed scenario of land use changes are shown in Table 10.5. From Table 10.7, we can conclude that the planned scenario of precautions significantly increased the landscape retention for a temperate rainfall; 66 ha of very high and 207 ha of high surface runoff were reduced to approximately 6 and 20 ha, respectively. Unfortunately, only a tiny reduction of the outflow occurred in the case of the storm rainfall. Stronger precautionary steps or other methods of soil protection leading to the surface runoff reduction shall be used for rainfall of such intensity.

Table 10.3 Land use in the catchment

Usage of territory	Area (ha)	Area (%)
1. Arable land, landfills	201	9.3
2. Meadows, permanent grasslands, lady	521	24.2
3. Public greenery, gardens, orchards, flower beds	117	5.5
4. Built-up areas	91	4.3
5. Reminders, racing greenery, shoreline	182	8.5
6. Forests	1036	48.2

Table 10.4 Classification of BPEJs into hydrologic groups of soils (HGS)

Occurring BPEJ	HGS	Occurring BPEJ	HGS
62041	Ca	72444	Cb
62044	Cb	73716	Ab
62414	Cb	73746	Ab
64168	Da	73846	Ab
64178	Db	74167	Da
65900	Da	74168	Db
72021	Ca	74177	Db
72024	Ca	74178	Db
72034	Ca	74189	Db
72041	Ba	74199	Db
72044	Ca	74911	Cb

(continued)

Table 10.4 (continued)

Occurring BPEJ	HGS	Occurring BPEJ	HGS
72051	Ca	74941	Cb
72054	Ca	75900	Da
72414	Cb	76701	Da
72441	Ca		

A, B, C, D—hydrologic groups of soils (HGS)
Index a—characterizes within a given HGS a higher retention capacity
Index b—characterizes within a given HGS a lower retention capacity
RWC—retention water capacity
Aa—RWC 50 mm and more
Ab—RWC 20–50 mm
Ba—RWC more than 100 mm
Bb—RWC less than 100 mm
Ca–RWC more than 80 mm
Cb–RWC less than 80 mm
Da–RWC more than 30 mm
Db–RWC less than 30 mm

10.4 Discussion

The submitted approach is based on a set of simple GIS methods. The main reason for this simplicity was the effort to make conflict analysis accessible to any GIS product used in urban planning practice. However, it is necessary to realize that high-

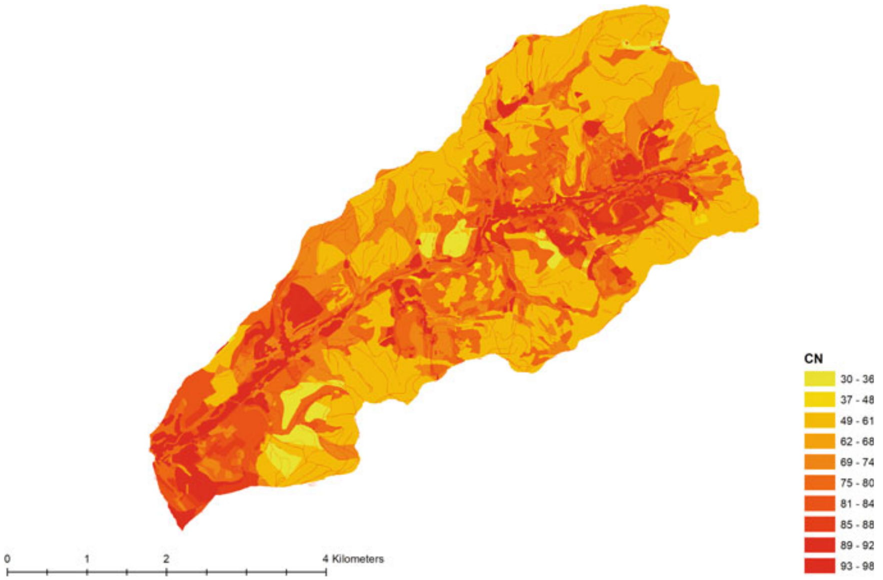

Fig. 10.2 Spatial distribution of CN-curve values in the Všeminka

Table 10.5 Total areas of the five classes of surface runoff for recent land use and a proposed scenario of precautions computed by the 'direct' outflow model per pixel

Surface runoff	Temperate rainfall of 4 mm			Storm rainfall of 20 mm		
	Interval (mm)	Recent area (ha)	Scenario area (ha)	Interval (mm)	Recent area (ha)	Scenario area (ha)
Very low	0–20	946.81	976.68	0–100	0	0
Low	20–40	620.12	761.96	100–200	0	0
Median	40–60	298.62	373.73	200–300	24.98	23.08
High	60–80	207.39	20.24	300–400	1278.29	1327.69
Very high	80–100	66.06	6.42	400–500	835.73	788.25

Table 10.6 Identification of areas with very high surface runoff in the catchment basin (shortened)

ID	River basin zone	Land use	Number of pixels	Area (ha)	Parcel number
5	1_denundation	Arable land	18	0.045	183
10	1_denundation	Road	3	0.0075	182.5
15	1_denundation	Watercourse	201	0.5025	1739
19	1_denundation	Swamp	136	0.34	56
21	1_denundation	Purposeful area	315	0.7875	0.56
46	1_denundation	Meadow	4	0.01	1388
44	1_denundation	Line greenery	3	0.0075	45
6	2_Transit-denudational	Deciduous forest	1	0.0025	365
7	2_Transit-denudational	Watercourse	189	0.4725	367
9	2_Transit-denudational	Swamp	50	0.125	751
12	2_Transit-denudational	Purposeful area	31	0.0775	75.23
35	2_Transit-denudational	Arable land	23	0.0575	85.56
38	2_Transit-denudational		12	0.03	96
40	2_Transit-denudational	Road	1	0.0025	1245
2	3_transit	Swamp	2	0.005	156
4	3_transit	Purposeful area	2	0.005	856
8	3_transit	Road	49	0.1225	66.1

quality digital data is crucial for the implementation of these GIS analyses. When inaccurate or incorrect data are used, the presented advantage of the model can lead to incorrect results and misleading interpretations. The precision of input data is very important in areas where the land use layer and the layers of environmental conditions overlap. The authors are aware of this fact, and that is why they strongly urge the observance of elementary GIS rules and the creation of data with the correct geometry, correct topology and correct attributes. The aim was not to develop a perfect hydrological model such as HEC, KINFIL or BASINS, but to provide a

Table 10.7 Designed optimal scenario of measures to increase retention capacity in the Všeminka basin

Location	Measures	Area (ha)
Infiltration zone of the catchment area		
Arable land	Grassed	38.8
Meadows and pastures	Wooded	74.1
Brownfields	Wooded	4.2
Forest stands	Improvement of species structure	4.2
River basin transport zone		
Arable land	Grassed	37.1
Meadows and pastures	Wooded	62.1
Brownfields	Wooded	6.2
Forest stands	Improvement of species structure	12.9
The catchment area		
Arable land	Grassed	37.1
Meadows and pastures	Change of technology	33.1
Brownfields	Wooded	20.6
Forest stands	Improvement of species structure	10.2
Total	Grassed	155
	Wooded	167.2
	Change of technology	33.1
	Improvement of species structure	27.3

simple tool for localizing the source of surface runoff, proposing measures to reduce it and simulating its effect in a commonly used program environment. Therefore, the absolute values achieved are rather informative, and more relevant information provides a comparison between scenarios or individual segments of the landscape. Despite these not so much ambitious objectives, this model has several significant features.

It works with a 5 m pixel, which represents a landscape cut of 25 m^2, allowing us to take into account the linear elements of the landscape (such as field paths) that are neglected in a number of models. The model not only takes into account their presence and type but also their spatial orientation towards the surface runoff direction [3]. The requirement is that the size of the element must be more than half of the pixel.

Another significant feature is the concept of multi-directional runoff. This concept more accurately simulates the real state of the landscape and is based on the assumption that the water flows from one point to several directions. This approach is based on Quinn's work (1991) and has so far been implemented in only a few models (e.g. TopModel, Usle 2d). On the other hand, the vast majority of models work with the drain concept most steeply, and if the results are compared, the sub-values will vary.

10.5 Conclusions

Flood areas have been used intensively for a number of social and economic activities these days, and so floods can easily damage property and public health within these areas. One possible solution is to limit human activities in floodplains; the second one is a prediction based on hydrologic modelling of floods and spatial conflicts in GIS. Planning materials and planning documentation are the only respected documents for urban development in the Czech Republic, but modern tools for spatial modelling are only very closely used during the creation of these documents. Presented approach (model) is an example of GIS implementation in the process of creating these documents. The model was tested in practice, and it helped to find spatial conflicts. The outputs of GIS analyses of the model were raster data sets, hydrographs and tables. The model can take into account the current state and applied measures to reduce flood risk on a very detailed scale.

LOREP is a useful tool for identifying and localizing areas with low flood regulation capabilities because it works in areas with a very high or high direct runoff. It can suggest different scenarios and assess them. The catalogue of remedies and non-technical solutions in the landscape is a part of the model, and these remedies can then be selected for an increase in flood control capabilities in the watershed. LOREP can be used for large or small watersheds, and its great advantage is that it is a part of GIS. Wide implementation of GIS to planning practice will be possible only if legislation will require such approach.

10.6 Recommendations

The modelling of the water retention function is currently subjected to new challenges. In the context with the ongoing climate change, with irregular alternation of flash abundant rainfall and long periods of drought, it is essential to well describe the current and future state of the landscape.

The following recommendations should be followed when modelling a water retention function: (i) work with a model that best simulates real water behaviour in the landscape (it means that the model works with an advanced multi-flow algorithm to simulate real water movement in the landscape); (ii) use a model with an advanced iteration algorithm to calculate infiltration, which can estimate at each step whether retention capacity is already achieved or not and iii) use the appropriate drain equation according to the evaluation of this state.

Static (GIS) data describing the state of the landscape should be integrated with sensor data (e.g. snow supply and soil moisture) to update hydrological/hydropedological conditions. Digital representations of all landscape components (terrain, land use and soil) should be current and at the same scale and for the same time period. The scale should be detailed enough to capture the small line elements in the landscape and their orientation towards the direction of the surface runoff. For the conditions of the Czech Republic, it is appropriate to scale 1:10,000. To identify the problem areas, it is necessary to work with the model in a raster environment in order to divide the studied area into sub-watersheds, not exceeding 25 m^2. This tool is really useful in the situation when almost all plots of concentrated surface runoff should be identified and multi-directional runoff, including runoff along small line elements, should be assessed.

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Chapter 11
Floodplain Forests—Key Forest Ecosystems for Maintaining and Sustainable Management of Water Resources in Alluvial Landscape

I. Machar, H. Hager, V. Pechanec, J. Kulhavy and J. Mindas

11.1 Introduction—Definition and Ecosystem Functions of Floodplain Forests

Floodplain forests belong among others to the most productive, dynamic and diverse ecosystems on the Earth [1, 2]. The floodplain forest quality and existence depend on the flow regime of the river [3]. The hydrological regime appears to be a key ecological factor influencing the species composition of floodplain forests in Europe [4]. High-disturbance regime of the river combined with a relatively warm and moist local climate of the lowland floodplain valley is one of the main factors responsible for the original features of European floodplain forest, which are: biodiversity richness, structural and successional complexity, high productivity [5]. In Europe, temperate floodplain forests [6] are considered as a part of European natural heritage and important biodiversity refuges in cultural lowland landscapes. Conservation efforts aimed at floodplain forest biodiversity are currently preeminent conservation targets

I. Machar (✉)
Department of Development and Environmental Studies, Faculty of Science, Palacky University, Tr. 17. Listopadu 12, Olomouc, Czech Republic
e-mail: ivo.machar@upol.cz

H. Hager
Institute of Forest Ecology, University of Natural Resources and Life Sciences, Vienna, Austria

V. Pechanec
Department of Geoinformatics, Faculty of Science, Palacky University, Olomouc, Czech Republic

J. Kulhavy
Department of Forest Ecology, Faculty of Forestry and Wood Science, Mendel University, Brno, Czech Republic

J. Mindas
Department of Ecology and Environmental Sciences, University of Central Europe, Skalica, Slovakia

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of the Natura 2000 European network [7]. Floodplain forests are critically linked to society's welfare and will rise immensely in value as water-related issues become increasingly important [8].

A new formalized classification of European floodplain forests [9], distinguished thirty vegetation associations, which belong to five alliances: *Alnion incanae*, *Osmundo-Alnion, Populion albae, Platanion orientalis, Alnion glutinosae.* European temperate floodplain forests provide many important ecosystem functions [10], e.g. reduction of water quality deterioration [11], maintaining riverbank stability [12], supporting the water retention in the landscape [13], flood prevention or mitigation for cultivated rural territories [14], reducing streambank erosion, nutrient and sediment loading [15] and supporting biodiversity [16]. Carbon sequestration is also one of the most important ecosystem services of forested lowland landscapes. The biggest amount of carbon is stored in hardwood forests with long rotation cycle and the unmanaged forest reserve because of large amounts of deadwood [17]. A tree species with the longest residence time of deadwood in European floodplain forests is pedunculate oak (*Quercus robur*) where the largest logs take for an average of 62 years to decompose [18].

Floodplain forests have proved extremely productive for agricultural utilization. Large areas of floodplain forests around the world have been changed into agriculture land in the past. As a consequence, we can find a disruption of floodplain forests ecosystem functioning. In many instances, these conversions to agricultural land use were following suite after flood protection measures and severe modifications of the river channel systems. The energy/slope gradient and channel conditions play a critical role in determining the nature and dynamics of floodplain woodlands and biodiversity. These factors also control the dynamics of materials and nutrients in forested floodplains. The biogeochemistry of floodplain forests is complicated by multidimensional interactions between substrate, hydrology and vegetation which include longitudinal interactions (up and downstream), and horizontal interactions across the floodplain perpendicular to the main channel (e.g. between channels and banks and live and dead-water zones). All of these factors complicate the application of the river continuum concept as do natural variations caused by geomorphological inheritance and multiple channels [19].

Functions of floodplain forest ecosystems are determined by natural hydrological and biological diversity, groundwater dynamics and fluvial dynamics [20, 21]. In summary, we can consider floodplain forests as key forest ecosystems for maintaining and management of water resources in lowland alluvial landscapes. This chapter deals with these unique ecological functions of floodplain forests in the landscape including some case studies from the territory of the Czech Republic.

11.2 Historical Context of Biodiversity Drivers for Floodplain Forests

Temperate floodplain forest ecosystems have been changed and significantly influenced by human activities for centuries [22, 23]. In floodplain forests, human interests and pressures in historical timescales interplay with the complex multiscale dynamics of fluvial systems and require integrative and multidisciplinary approaches to pinpoint drivers for their deterioration and loss of ecosystem services [24]. This means, for example, joining mathematical growth simulation models with acoustic tomography [25] and historical geography methods [26], applying of Ellenberg's indices with combination of LAI index assessment [27], using a remote-sensing method in partnership with natural resource managers [28], etc.

Based on the historical landscape analyses in floodplain areas proposals could be made for the re-establishment of lost floodplain forest, these proposals should also consider aspects of nature conservation and flood protection [29].

Agricultural practices in the river basins frequently lead towards increased nutrient loading in the floodplain environment, including suspended sediments, organic matter, nitrogen and phosphorus [30]. The negative impacts of floodplain forests removal in sequence with the development of agriculture have been studied in many parts of the world, e.g. South Africa [31], China [32], Japan [33], the USA [34] and Portugal [35]. In the Czech Republic, the study of historical land-use changes in the Morava River floodplain [36] revealed important changes in the landscape matrix in the past two centuries: In 1836, the landscape matrix of the floodplain landscape was composed of meadows and forests. In the present, the predominant landscape matrix consists of arable land and isolated floodplain forest remnants. Similarly, fragmentation of floodplain landscape in other parts of the Czech Republic has been seriously changed during the twentieth century [37]. Analyses of study [38] confirm that large hardwood floodplain forests are essential for the conservation of natural species composition and that strong fragmented areas are highly susceptible to invasion of non-native species. They also determined that small, compact fragments contain very valuable remnants of well-preserved natural hardwood floodplain forests with a high proportion of specialized species.

GIS analyses in a study [39] indicate that floodplain forests may be in jeopardy on both regulated and unregulated rivers and that information on historical forest extent is needed to understand better and interpret their current status. The unique water management history can explain differences in species richness and species composition between the riparian corridors [40]. For example, historical development and long-term impact of human activities on the succession of floodplain assemblages have resulted in a sharp impoverishment of terrestrial snail species of several hardwood forest sites [41]. Changes in land use, altered flow regimes, invasions by pests and pathogens, and climate change are, separately and together, altering ecological dynamics in the floodplain forests. Although habitat quality and physiographic area explain more in site occupation and vegetation variability in temperate floodplain forests, landscape configuration is a key factor influencing species composition and distribution of species traits [42].

Some floodplain forests have also experienced a faster rate of biotic homogenization. It may reflect relatively high connectivity among floodplain forests and control of hydrologic fluctuations via dams and/or river regulation [43].

The floodplain forests in Germany and its bordering areas were altered and established with a diversity of tree species, that is, significantly important in the European forestry context as a result of the modification and improvement of the alteration of river courses in the nineteenth century and the regulations of rivers in the twentieth century [29]. During this process, the silvicultural management system changed from a coppice forest to a coppice-with-standards forest to a high-value forest. A GIS-data-based delineation model and historical forest inventories were used for the floodplain forest from the nineteenth to the twentieth century in the district of Leipzig in Germany. Data show that the spatial extent of the floodplain forest remained considerably stable despite an overall decline in the entire flooded area, from the period when the city first experienced industrialization in the nineteenth century compared to now [44].

Authors of the paper [45] studied tree layer dynamics in hardwood floodplain forest in the Czech Republic, which had been left to spontaneous development since the beginning of the 1930s. Results showed that the most significant trend is a decreased representation of *Quercus robur* among all monitored species and conversely an expanding representation of *Acer campestre, Carpinus betulus* and *Tilia cordata*. The floodplain forest ecosystem exhibited a high level of stability in the total volume of tree biomass. However, this forest was accompanied by an essential change in the tree species composition, spatial structure and average stem volume of individual trees. This may point to a broader trend in temperate floodplain forests, e.g. as species composition may change, the newly replacing species may not fall back in their biomass production compared to the replaced ones.

Schnitzler et al. [46] investigated the mechanisms driving biodiversity in temperate floodplain forests within a historical context as well as concerning river-floodplain dynamics. Their comparison was based on “the warm-temperate floodplain forests of the lower Mississippi Valley and the cool-temperate floodplain forests of the lower Wisconsin and Rhine River Valleys” [46]. They compared “species, genus, and family diversity across regions with respect to species richness, numbers of species per family and genus, and a similarity index” [46]. They also studied productivity data and successional stages for each region. They found a lower species, genus and family richness in the cool-temperate forests of the Rhine compared to the cool-temperate forests of Wisconsin, a probable result from the loss of species due to the lack of available refugia along the Rhine in times of Pleistocene glaciation. Another reason may also be found in the longer lasting and severer impact of anthropogenic modifications of the Rhine River floodplains. These results indicated the role of river-floodplain dynamics in maintaining species diversity.

11.3 Response of Floodplain Forests to Changes in Fluvial and Water Regime in the Landscape

Geomorphological processes can alter river hydrology and thus influence floodplain forest growth and regeneration [47]. Continuous sedimentation of small particles from the river basin leads to the formation of alluvial soils. Results of a study [48] support the understanding to the flood-pulse concept of river-floodplain connectivity, because of the highest nitrification rates were found in areas and during times immediately the following inundation.

"Hydrologic connectivity between the channel and floodplain is thought to be a dominant factor determining floodplain processes and characteristics of floodplain forests" [49]. Large riparian trees may have fundamental roles in the physical and biotic structuring of river channels elsewhere in the temperate zone [49]. "Understanding the landscape-scale geomorphic and hydrologic controls on floodplain connectivity provide a basis for more effective management and restoration of floodplain forest communities" [50].

Zonation of vegetation is connected to distance from the closest stream which influences species distribution through ecological gradients of moisture and nutrients [51].

On the landscape level, floodplain forests can be considered as a transitional zone between the river aquatic ecosystems and terrestrial ecosystems [52]. Although floodplain forests are thought to serve as important buffers against nitrogen transport to aquatic systems [53], frequent flooding can also make these systems prone to invasion by exotic plant species with important environmental consequences. For example, the invasion by *Phalaris arundinacea* may make nitrogen more readily available and could help to reinforce this species' persistence in floodplain habitats.

Petrasova et al. [54] found out a significant increase in the number and cover of neophytes between the analysed periods in the floodplain forests in the Pannonian lowlands. The most important ecological factor, affecting the number of neophytes, is the amount of nutrients. Other significant factors are light, soil reaction, cover of herb layer and moisture.

Eutrophication can even influence well-preserved hardwood floodplain forest areas, as shown by [55] in Danubian hardwood floodplain forests. Despite the high beta diversity, the distribution of the plant functional types generally indicated equal habitat conditions, which were quite stable. The nutrient input into Danubian hardwood floodplain forests increased downstream, resulting in higher nutrient availability for plants. This promoted especially the growth of tall and competitive forbs, which outcompeted other plant species. To illustrate this Eberl [56] found in a macronutrient inventory in two floodplain forest sites approximately 15 km downstream of the city of Vienna total nitrogen stocks in a 120 cm soil profile which were between 17 and 20 t/ha of N_{total} and phosphorous of 9 t/ha P_{total}. These sites were colonized by *Urtica sp*. and *Impatiens sp.* of more than 3 m height.

Herb-layer species richness in floodplain forests is positively related to the soil pH and negatively to the concentration of soil iron [57]. Physiography (e.g. geographic province) and indicators of flooding regime (e.g. relative elevation and distance from the main channel) were consistently important in predicting the occurrence, community composition and abundance of trees in floodplain forests along the Wisconsin River, USA [21]. "Current landscape configuration only influenced species presence or abundance in forests that developed during recent decades. Land-cover history was important for tree species presence and the abundance of late-successional species. Comparison of statistical models developed with and without soils data suggested that broad-scale factors such as geographic province generally performed well in forecasting species composition" [58]. Anthropogenic land use has significantly altered sediment and nutrient dynamics at watershed-scales, resulting in significant redeposition within large floodplain ecosystems [58].

Vegetation composition of floodplain forests reflects both historical hydrologic regimes and disturbances, and thus complex relationships to channel modifications. Results of a study [59] suggest that both the subsidy (i.e. nutrient inputs) and the stress of flood events have been altered by anthropogenic activities, but these alterations were greatest in channelled systems compared to unchannelled systems.

Interruption of flooding caused a complete species turnover in the composition of the herbaceous layer. Whereas in the still flooded stands typical alluvial species prevailed, species composition in stands without flooding for 50 years showed a close relationship to the upland Stellario-Carpinetum [60]. The specificity of species composition in floodplain forests can only be maintained by regular flooding. Interruption of inundations leads to differences in the patterns of species composition and life history traits between ancient and recent forests.

Results of a study [61] confirmed that species richness of vascular plants in floodplain forests enlarged with increasing water availability. Flooding duration strongly affects species richness. The highest values of species richness were recorded in the intermediary zone of the hydrological gradient. The pattern of species richness of vascular plants originally increases with the duration of flooding (the highest in the range of 60–70 days of inundation), after which gradually decreased with the increase of the duration. This study suggested that species richness reaches a maximum at some "intermediate" level of "disturbance" by flooding.

Van Looy et al. [62] studied the effect of the disruption of the natural flooding regime on alluvial forests and their vascular plant diversity in the river Meuse floodplain in Belgium. "The Meuse river was channelized for most of its course in Belgium. This enabled us to sample forests along a gradient of isolation from the river" [62] and changed flooding frequency. Flooding frequency was the most important factor to influence community composition of the forests. Forests still under the influence of the river were significantly richer in riverine "species and significantly poorer in woody species than forests disconnected from the river. They also had a higher beta species diversity and tended to have a higher alpha diversity. This study suggested the two most important ecological processes behind this are (1) the poor colonisation capacity of typical forest plant species, which is mainly due to dispersal limitation and (2) the absence of natural disturbance events, which diminishes the dominance of certain competitive species in these forests. Only the re-establishment of lateral river connectivity and natural dynamics can stop this process" [62].

Water engineering projects conducted on rivers and in river valleys have contributed to these ecosystem degradations. Damming of the Warta river (Poland) has changed the river regime and flooding patterns downstream (reduced flooding area and decreased flooding frequency), initiating floodplain forest disintegration [63]. In response, a rehabilitation and protection project has been undertaken in Uroczysko Warta. The new water engineering system is supposed to improve and re-establish hydrological conditions similar to the natural ones and stop the disintegration processes occurring in floodplain forests.

The Danube floodplain between Neuburg and Ingolstadt (Bavaria) is characterized by the absence of flooding and marginal fluctuations in the groundwater level. The reaction of forest vegetation to such changes in water regime was sampled before the onset of restoration measures [64]. The analysis of the baseline data showed that successional forest communities rich in sycamore and hardwood forests rich in ash dominate, whereas alluvial softwood forests are practically absent.

Annual biomass production of the tree layer on poplar stands in the floodplain forests along the river Danube seems to be dependent upon the onsite photosynthetic active leaf mass, which in turn is related to the water supply of the site. A study of Hager et al. [65] have confirmed the individual correlation of leaf area index LAI with the independent variables water storage capacity of the soil ($r^2 = 0.47$), depth of the fine sediments ($r^2 = 0.51$) and the average duration of groundwater contact ($r^2 = 0.38$) was highly significant. Duration of groundwater contact with the fine sediment seems to play an even more pronounced role. From these results, it seems that LAI may be a useful and good bioindicator for site water supply in the poplar floodplain forests. In a later study, Schume et al. [66] could also prove that altered site hydrology in floodplain forest sites along the Danube, did not only lead towards decreasing basal area increment in Hybrid-poplars, but also diminished also the size of xylem vessel lumina while increasing the vessel density in the stem cross section. This means that softwood floodplain forest trees adapt to changed and drier site conditions not only by reduced growth but are also investing into ecophysiological safety features, by producing more xylem vessels with smaller lumina, which makes them saver against cavitation under water stress [67].

Species composition of Danubian floodplain forest land snail fauna mainly reflected differences between sites without floods and the others [68]. Changes in the floodplain forest flooding and moisture regime also significantly affect the community of small terrestrial mammals [69]. Natural disturbance of fluvial processes influence the natural succession of the floodplain forest geobiocoenosis, and thus it emphasizes the necessity of their protection [70].

Disturbances on wetter sites, e.g. related to the natural river dynamics, will favour the natural regeneration of *Quercus robur* compared to the non-native species (e.g. *Ailanthus altissima*), which are generally limited to the drier sites of the floodplain forests [71]. Deiller et al. [72] found in hardwood floodplain forests along the river Rhine that the germinating seeds originate from seedbanks in the litter layer and not from the soil itself. This shows the role of persistent seed banks for woody species regeneration is very limited in floodplain forests. For *Quercus robur* in a floodplain forest on the Elbe river, elevation and light availability interacted, resulting in mortality rates on higher elevated sites depending upon light availability; on lower lying sites mortality was rather independent of light, probably because of better access to water resources compensated for decreased light availability [73]. By contrast, this study indicated that the mortality patterns of common linden and red ash highly depended upon light availability on all sites. These species-specific mortality patterns were explained by different capabilities to access water resources due to different root-to-leaf biomass ratios being at least four times higher for pedunculate oak as compared with the other species. This life history trait allows *Quercus robur* germinants to better access the water resources than common linden or red ash.

The floodplain forest did not take water directly from the water table but from the unsaturated zone through the effect of capillarity [74]. A trade-off between flood and shade tolerance underlies tree species-specific responses to flooding and light, which drive forest regeneration. A study [75] tested the trade-off hypothesis in an old-growth bottomland hardwood forest. On average, shade-tolerant species were found in shaded areas that were also drier, whereas less shade-tolerant taxa were found in wetter and longer flooded but more open areas, suggesting a trade-off between flood and shade tolerance tree species. It was found that three taxa (*Fraxinus pennsylvanica, Quercus* spp., and *Ulmus americana*) had patterns of distribution in the floodplains which were consistent with a flood-shade tolerance trade-off, while a number of other species were found to be positively related to decreases of flooding and shade.

Stojanovic et al. [76] have studied in floodplain forests dominated by *Quercus robur* in Serbia along the Sava River. Due to the decreases in the groundwater levels, precipitation and temperature increase over the last 30 years, a general decline in the growth of oak was observed. Responses of the various tree groups due to a different age, sites and management (flooded versus non-flooded, virgin versus managed forests) were observed, although all tree groups displayed fundamentally the same negative responses to the above-described variations in environmental conditions. Based on the obtained results, e.g. decrease growth and enhanced mortality, the authors see a great threat for the preservation of the floodplain forests along the Sava River. Thus, authors suggested the following main guidelines for forest managers: to increase, if possible the groundwater levels in the floodplain ecosystems during prolonged drought periods; to promote regeneration, with a species composition which is closer to nature; and to promote mixed-species forests.

11.4 Changes in Water Regime of Floodplain Forests in the Czech Republic

In the twentieth century, multiple changes in the water regime occurred in the lowland region of the Dyje River and Morava River floodplain (south-eastern part of the Czech Republic). The regulation of the two large rivers, the construction of groundwater wells and the specific climatic conditions markedly changed the moisture regime of soils [77]. These ecologically important consequences in the floodplain forests were published in two scientific monographs, which deal with floodplain forest ecosystems in detail before water management measures [78] and after water management measures [79].

The process of revitalization in this area began at the 90s. Based on detailed measurements, the study [80] indicated an important role of the hydrological and climatic factors for the overall soil moisture regime in the floodplain ecosystem.

A paper [81] documented the response of the herb layer to these changes in nine permanent experimental plots representing the three most common groups of geobiocoenosis types of floodplain communities situated in the Cahnov-Soutok National Nature Reserve. Time series of phytosociological inventories from 1973, 1994 and 1998 were evaluated in relation to conditions of the water regime. In natural communities, the proportion of hydrophilic plant species was gradually decreasing in the absence of floods and with the sinking groundwater table. After artificial flooding, however, the representation of the hydrochoric and hydrophilic plants rapidly and substantially increased in these plots. Authors of study [82] suggested that some growth responses and trends in oak and ash can also be explained by changes in the water regime.

Stand water balance was also calculated in this area. A model was applied to actual and theoretical scenarios of climate and soil water supply [83]. Input data characterized both the period of regular natural flooding and the period when floods were interrupted for over 20 years because of the channelling of rivers in the region. Under non-limiting groundwater supply, net precipitation supplied only between 50 and 25% of water for actual evapotranspiration, under the mild and the dry weather, respectively, and the other 30 and 60% came from underground sources. The model also was done for the theoretical situation of no groundwater supply; then evapotranspiration may decrease significantly. An important limit for water supply to the trees may be the maximum soil hydraulic conductivity, which is crucial to the horizontal water transport in heavy soils because a small decrease in soil water content causes a large drop in hydraulic conductivity, which may become supply-limiting before soil water potential becomes a limiting factor. Under such conditions, trees with smaller or damaged root systems or lower root/shoot ratio were especially threatened by drought even on relatively moist heavy soils.

Similar effects could be observed in the floodplain forests along the Danube on the border between Slovakia and Hungary. Monitoring of abiotic and biotic changes together with dynamics of groundwater levels is essential to identify and mitigate long-lasting effects, and as such the 23-year dataset from the Gabcikovo Waterworks provided a rare opportunity to assess the impact of groundwater regimes on vegetation [84]. After the completion of the Gabcikovo dam, the Danube was diverted along a section of almost 40 km in October 1992. In 1995, a water recharge system was put into operation, but no floods have ever been experienced since 1992. As a consequence, tree growth dropped in many places at varying rates shortly after the diversion. Damaged trees appeared mainly along the main riverbed and trees lost their leaves abnormally early. Diameter growth patterns also became abnormal within the vegetation season [85]. Results of the study [38] demonstrate that the Danube inland delta and the floodplain forest remnants were very negatively affected by the Gabcikovo construction, this was particularly extreme for sites outside of the artificial compensatory water supply systems.

In contrary, authors of a paper [86] investigated the course of diameter growth and increment of 70-year-old pedunculate oak in the region of the Gabcikovo hydropower plant. The results indicate that diameter growth and increment of pedunculate oak showed correspondence to general growth regularities with a tendency to long-term periodical swings and a significant influence of rainfall during the vegetation period. A negative influence of Gabcikovo hydropower plant on diameter growth was not confirmed in this study. It seems that under these site conditions rainfall during the vegetation season can be a more important ecological factor for the growth of pedunculate oak than changes in the underground water regime. It could also be assumed that the sampled oak trees were originally stocking in a site which was not significantly influenced by flooding or groundwater oscillations. Schume [87] found also that diameter increment of hybrid poplar in the floodplain forests on the Danube river: In sites which had lost their connectivity to the river (groundwater and flooding), started to show significant correlations with the amount of annual precipitation. This process indicated a coupling to the climatic water balance instead of to the annual course of hydrological stages in the river.

The above findings may indicate that the predicted future shifts of forest vegetation zones [88] and intense drier climates with low precipitation rates may cause grave changes in forest ecosystems in European lowlands [89]. Thus, climate change may pose an important stress factor for European temperate floodplain forests in the future.

11.5 Case Study: Monetary Value of Floodplain Forests Habitats Threatened by the Danube–Oder–Elbe Water Channel in the Czech Republic

Currently, floodplain forests in the Czech Republic are threatened by the plan of the establishment of the Danube–Oder–Elbe Canal (DOEC). DOEC is aimed to connecting the three major Central European rivers (the Danube, Oder, and Elbe) by an artificial water transport route. This project is incorporated in a planned trans-European transport network system by the European Commission. In this section, a brief monetary valuation of floodplain forests habitats influenced by DOEC is presented.

11.5.1 Methods and Material

The analyses are based on the DOEC route, adjusted to meet the specifications of the current Development Principles of individual Czech regions. Based on the given map data, the DOEC route was digitized using ARC GIS 8.2 on a scale of 1:10,000. The

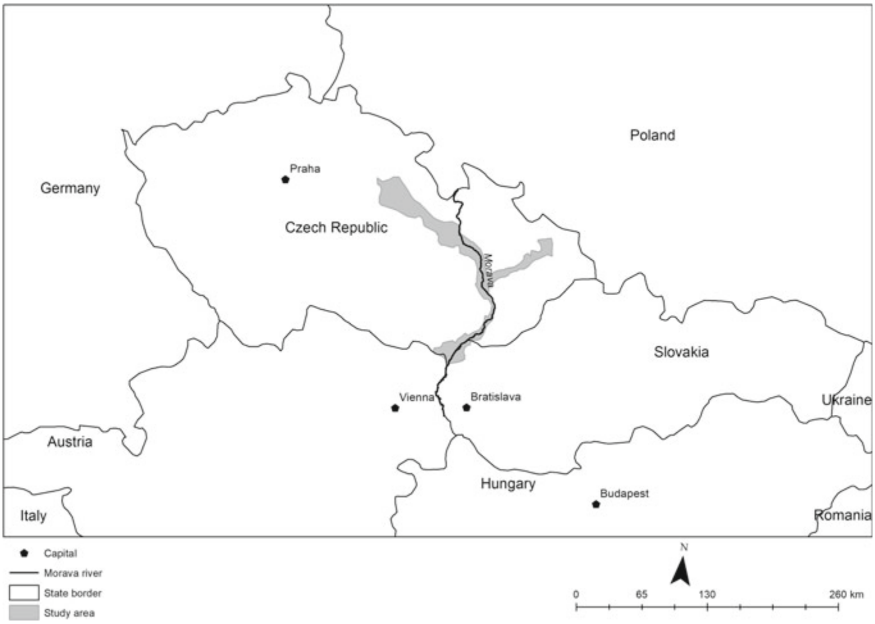

Fig. 11.1 Study area (lowland alluvial landscapes in the Czech Republic hydrologically affected by DOEC)

digitized route of the DOE Canal within the territory of the Czech Republic measures a total of 418.1 km, with the longest section (44.6% of the waterway length) situated in the Elbe River basin, and the shortest section in the Oder River basin (24.8%). The Morava River basin encompasses 30.6% of the total waterway length. For the analyses presented here, the technical parameters of the DOEC in the Czech Republic were adopted in detail from a paper [90].

The initially published study [91] delineated areas of lowland alluvial landscapes in the Czech Republic, which will be hydrologically affected by DOEC (Fig. 11.1). All of the natural habitats of floodplain forests were defined and located in these hydrologically affected areas using the results from national field mapping of habitats, which was done during the establishment of the Natura 2000 European network [92].

The monetary evaluation of the affected segments of floodplain forests habitats is based on original Czech methods, which were developed for the valuation of natural habitats in the frame of environmental impact assessment [93]. A detailed description of monetary valuation method for forest habitats is presented in the study [94].

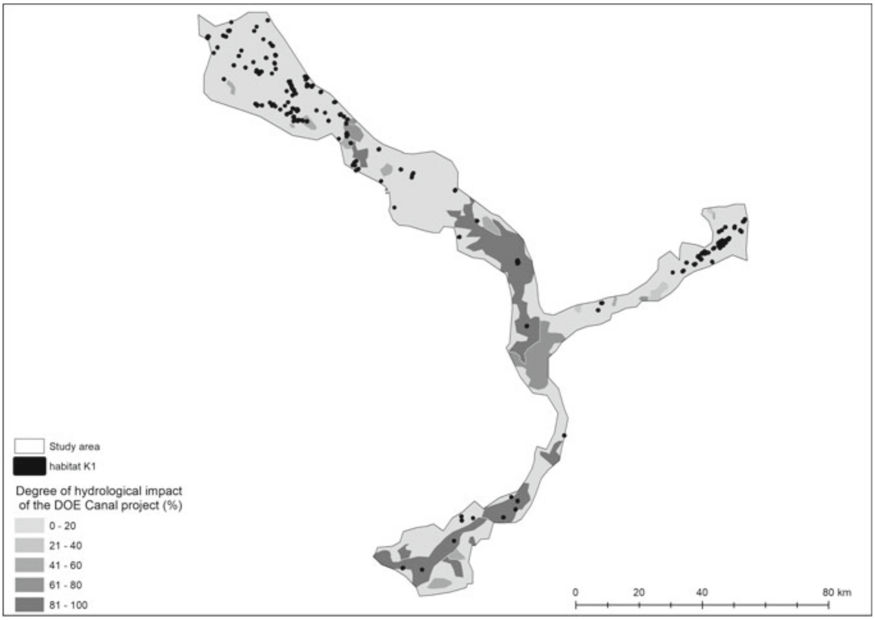

Fig. 11.2 Location of Willow carrs habitats (K1) hydrologically influenced by the DOEC in the Czech Republic

11.5.2 Results

Visualization of floodplain forest habitats localities, which can be hydrologically influenced by the DOEC, is shown in Figs. 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9 and 11.10. Monetary values related to both distinct habitat types of floodplain forests and affected by the DOEC presents Table 11.1.

The presented results of the monetization of floodplain forest habitats are based on a preceding detailed analysis of real expenses spent on environmental services provided by the evaluated natural habitats contrary to most previously published studies on monetary evaluation of biodiversity supported ecosystem services [95].

Awareness of real monetary value is an important motivation for floodplain forest biodiversity conservation [96] in the frame of environmental impact assessment of the DOEC.

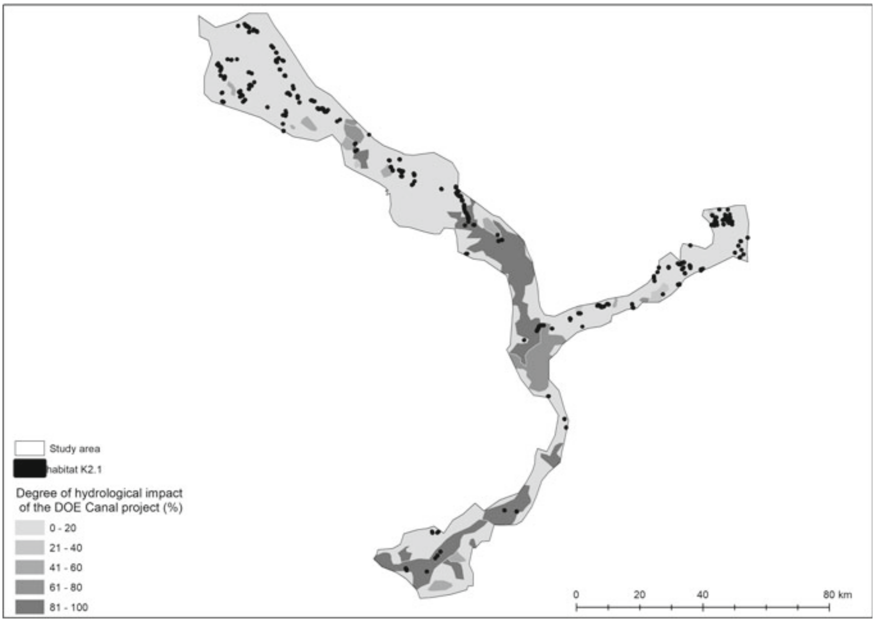

Fig. 11.3 Location of Willow scrub of loamy and sandy river banks habitats (K2.1) hydrologically influenced by the DOEC in the Czech Republic

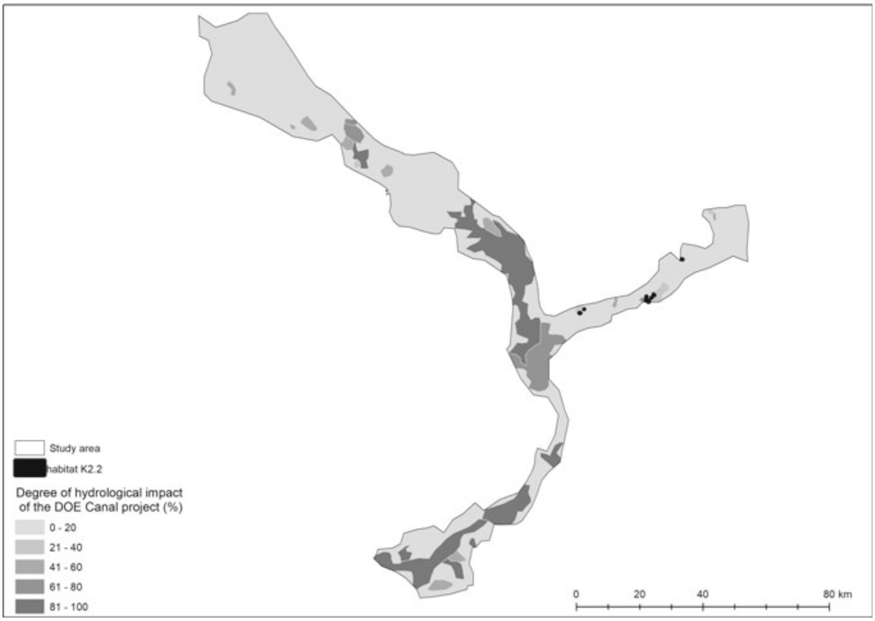

Fig. 11.4 Location of Willow scrub of river gravel banks habitats (K2.2) hydrologically influenced by the DOEC in the Czech Republic

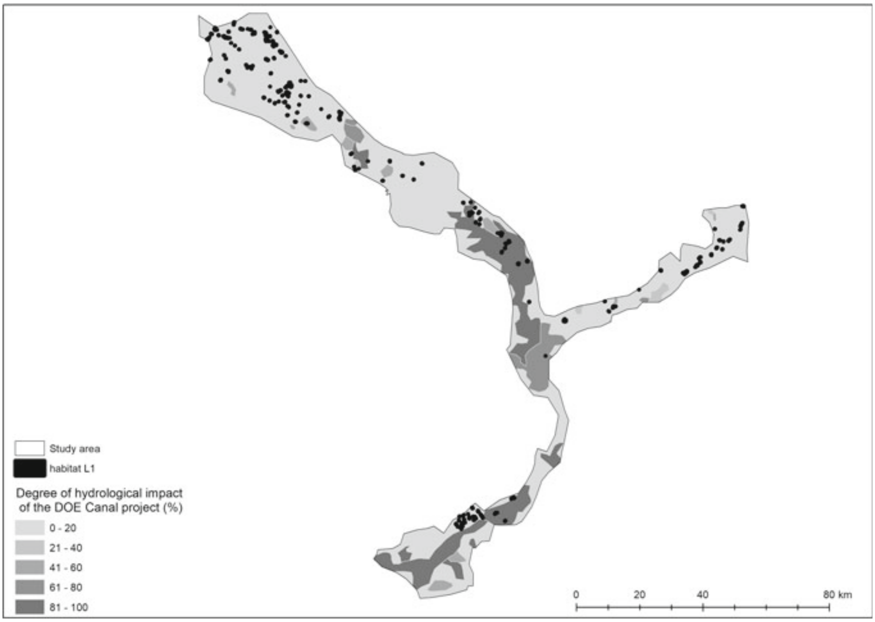

Fig. 11.5 Location of Alder carrs habitats (L1) hydrologically influenced by the DOEC in the Czech Republic

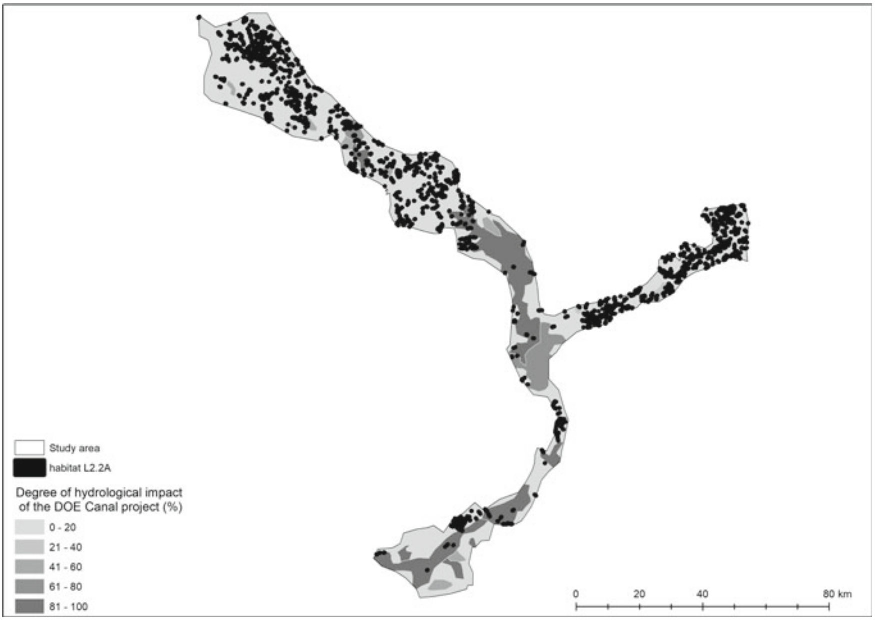

Fig. 11.6 Location of Ash-alder alluvial forests habitats (L2.2A) hydrologically influenced by the DOEC in the Czech Republic

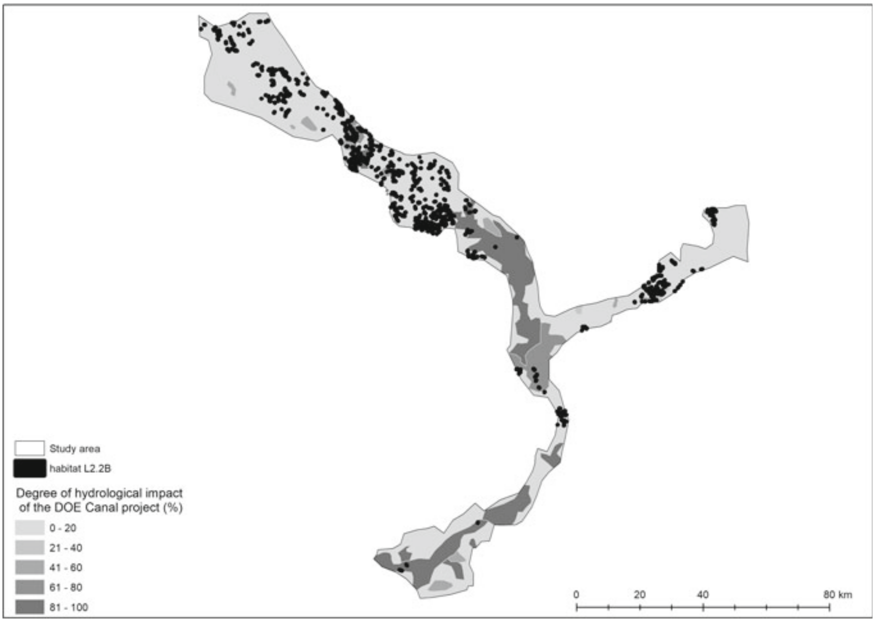

Fig. 11.7 Location of Brooks and degraded alluvial forests habitats (L2.2B) hydrologically influenced by the DOEC in the Czech Republic

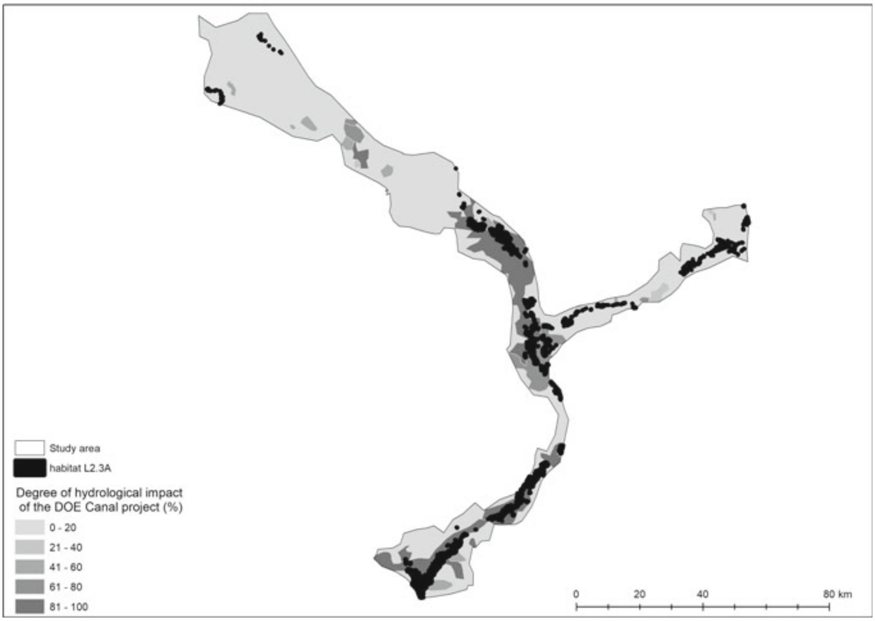

Fig. 11.8 Location of Hardwood forests of lowland rivers habitats (L2.3A) hydrologically influenced by the DOEC in the Czech Republic

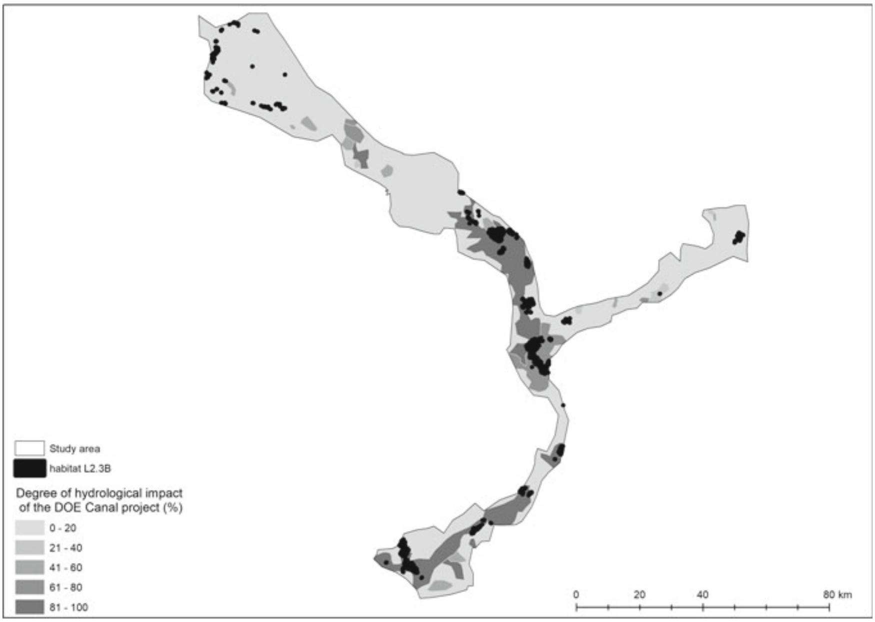

Fig. 11.9 Location of Hardwood forests of lowland rivers, degraded by humans habitats (L2.3B) hydrologically influenced by the DOEC in the Czech Republic

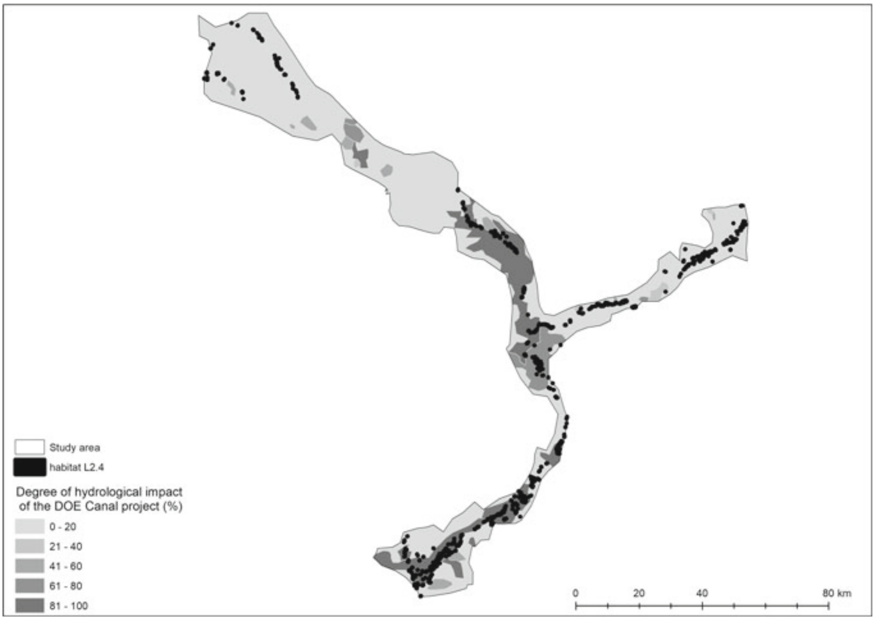

Fig. 11.10 Willow-poplar forests of lowland rivers habitats (L2.4) hydrologically influenced by the DOEC in the Czech Republic

Table 11.1 Monetary evaluation of floodplain forests habitats in the Czech Republic, located in areas hydrologically affected by the DOEC

Habitat name	Habitat code	Area (m^2)	Monetary value of habitat (Euro)
Willow carrs	K1	666434.42	14191054.47
Willow scrub of loamy and sandy river banks	K2.1	900864.49	19183008.32
Willow scrub of river gravel banks	K2.2	25255.28	776801.9
Alder carrs	L1	2363535.89	76891731.46
Ash-alder alluvial forests	L2.2A	17125880.92	425458259.68
Brooks and degraded alluvial forests	L2.2B	5519093.10	107729937.8
Hardwood forests of lowland rivers	L2.3A	96711381.51	3775515622.64
Hardwood forests of lowland rivers, degraded by humans	L2.3B	28723803.13	849506477.71
Willow-poplar forests of lowland rivers	L2.4	4346969.22	167130099.01
Total		156383217.95	5436382992.99

11.6 Notes to the Hydrological Restoration of Floodplain Forests

Hydrological restoration of floodplain forests is limited by many stressors (e.g. substantial increases in the frequency and extent of flooding, improvements in groundwater conditions), which interacting at the landscape level [97]. Important role in water regime of floodplain forests plays also past and current human activities, as shown in previous sections (Sects. 11.2 and 11.3). Thus, floodplain forest restoration from both an ecological and hydraulic point of view needs an interdisciplinary approach [98]. Key abiotic constraint on successful tree recruitment and survival during restoration is a flooding, as pointed Krzywicka et al. [99].

Generally, hydrological restoration of the floodplain is aimed at the overall turning of ecological conditions to be wetter. The restoration projects in floodplain focus very often on raising of average groundwater level, while the amplitude of water levels remains dampened. Consequently, the vegetation responds to these hydrological changes with an increase of wetland plant species occurrence and abundance. Thus, a very useful indicator for an integrated prediction of ecological change in restored floodplain forests can be the Ellenberg moisture index [100]. This indicator also can help to measure the functional progress in the restoration projects based on monitoring of understorey vegetation. A good example of applying this approach is the study [101] related to temperate floodplain forests restoration along the Mississippi River: Attribute and floristic variation among restoration sites were related to variation in canopy development and local moisture conditions, which in turn reflected both intrinsic site features and outcomes of restoration practices.

Surprisingly, restoration potential of temperate floodplain forests probably cannot represent a soil seed bank as the ecological memory of plant communities. A study [102] from floodplain forests in Northern Italy indicated that the regeneration of near-natural forest vegetation from the soil seed bank is not feasible in the case of softwood floodplain forests, where the seeds of the tree dominant species (willows and poplars) exhibit a very short period of viability in the soils. Taking into account alien invasive plants potential (see next chapter), this study recommended minimizing disturbances that may activate the soil seed bank in floodplain forests.

Floodplain forests are characterized by a high-risk level of invasion by alien plant species. A study [103] implies that increased management efforts are necessary to reverse the spread of alien tree species in the strictly protected floodplain forests in Donau-Auen National Park and to maintain the high conservation value of the national park, which protects one of the largest floodplain forests in Europe. Reduced flood frequencies in floodplain habitats induce vegetation changes favouring increased abundance of exotic, sexually reproducing plants. In the Danube floodplains, a second woody shrub layer dominated in drier mature forest stands without flooding, while in the frequently flooded sites such a layer is only sparsely represented [20]. Forest sites of low flood frequency are more sensitive to future exotic weed invasion and will require restoration management effort [104, 105].

11.7 Conclusions: Sustainable Forest Management Principles for Temperate European Floodplain Forests

The current state of temperate European floodplain forests has been strongly influenced by different forest management practices [106]. Consequences of forest management errors from the past may play an important role in current and future management perspectives of floodplain forests, as presented study [107] in the case of Slovenian floodplains.

The concept of sustainable forest management (SFM) combines conservation and management of forest ecosystems in the landscape (by the definition of the Lisbon Conference of Ministers of forestry in 1998) and applies principles of forest sustainability [108]. SFM identifies the term “forest” with the term “forest ecosystem” and considers the timber production as a using of renewable natural resource [109].

SFM, based on the ecosystem approach under the Convention on Biological Diversity, can be applied if temperate floodplain forests via two main types of forest management practice:

(A) Species-based management. This type of management is based on the concept of focal species (umbrella species, keystones species, rare species, flagship species, etc.). Saproxylic beetles may act as bio-indicators of high-quality mature floodplain forests, and their conservation is strongly linked to the quality and quantity of deadwood in a habitat. The main factor predicting saproxylic species richness is the amount of deadwood measured by both log diameter and volume [110]. Lying deadwood is more important for lichens then standing deadwood and vice versa is standing deadwood is more valuable nesting habitat for woodpeckers than lying deadwood. Thus, in managed floodplain forests, the regular cutting of trees should be focused on retention of deadwood continuity. Deadwood and live tree stem supported similar numbers of snail species per item in floodplain forest, but beta diversity is significantly higher on deadwood [111].

(B) Ecosystem adaptive management. This type of management considers the forest ecosystem in a certain defined form as "object of protection", e.g. it can be a richly structured and a close-to-nature forest ecosystem. The management practice is then focused on continuous maintenance of key structures of forest ecosystem (old-growth stands, forest edges with high diversity, etc.).

The biodiversity of floodplain forests is significantly influenced by the hierarchical level of β-diversity, i.e. by the changes in biodiversity depending on the changes in environmental gradients (micro-relief and meso-relief of the floodplain in dependence on the distance from the river channel, changes in the frequency of floods, etc.).

It is important for SFM in floodplain forest ecosystems whether the floodplain water regime and sedimentation process of alluvial deposits (loams) is or is not affected by hydraulic engineering works in the landscape. If the floodplain landscape is strongly influenced by the system of water management alterations (e.g. including river regulations and construction of dikes and flood-control reservoirs), evaporation becomes the dominating process in soil hydrology of the floodplain forest, and the floodplain forest dries up; this finally results in the loss of biodiversity with regard to the wetland and wet biotope types. A solution within the management activities is then the so-called water regime revitalizations [112].

Conversely, when the floodplain is not affected by water-engineering modifications, the landscape retains its basic ecosystem functions. In such case, the high beta diversity of the floodplain ecosystems is determined by the fluvial dynamics of the river. The mosaic of different habitats, from meandering river with sand and gravel bars, riparian islands, riversides arms and wetlands, to softwood and hardwood floodplain forests, is called the "dynamic fluvial succession series of floodplain habitats" [113]. This mosaic of floodplain habitats, varying in time and space due to river dynamics, creates the so-called environmental floodplain phenomenon [114].

We can conclude, that sustainable biodiversity conservation in dynamic floodplain forest ecosystems requires territorial protection in the form of various categories of protected areas and maintaining of ecosystem connectivity at the landscape level (ecological networks). The key target is maintaining the conditions for the functioning of the ecological floodplain phenomenon. This means that the basic principle of maintaining the floodplain forest biodiversity is the protection and undisturbed functioning of the dynamics of fluvial erosion and accumulation processes in the landscape. Floodplain forest protection is, thus, clearly based on the ecosystem approach, which provides functioning of the floodplain forest ecosystem services [115].

In the Czech Republic, the currently used management system in the Czech floodplain forests should follow the Croatian model of forest management supporting a multi-layered forest structure [116]. Focus on individual tree growth and stability with high economic value and high reproductive potential is recommended as one of the main principles of sustainable floodplain forest management [117].

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Chapter 12
Agrotechnology as Key Factor in Effective Use of Water on Arable Land

J. Bernas, P. Konvalina, J. Brom, J. Moudrý, T. Veselá, D. Bucur, M. Dirja and S. Shim

12.1 Introduction

Periods of drought, as well as torrential rain, have become more frequent in the Central Europe. Pouring rain has become more common than long-time gentle rain, which is, however, very important for the agricultural production. Distribution and frequency of precipitation are influenced by global climate change to a large extent. International articles and reports [1–3] have been drawing attention to climate change. Water retention in the agricultural land depends on water management farmers are responsible for. Generally said, the world's unfavourable water management development mostly depends on precipitation. The agricultural land has lost its water retention capacity, and it tends to get dry and too warm. People searching for ways how to retain water in the agricultural land ought to consider the landscape as a whole, not its parts [4].

J. Bernas (✉) · P. Konvalina · J. Brom · J. Moudrý · T. Veselá
Faculty of Agriculture, University of South Bohemia, Studentska 1668, 37005 Ceske Budejovice, Czech Republic
e-mail: Bernas@zf.jcu.cz

D. Bucur
Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Iasi, Mihail Sadoveanu Alley 3, 700490 Iasi, Romania

M. Dirja
University of Agricultural Sciences and Veterinary Medicine in Cluj Napoca, 3, Marasti Street, Cluj-Napoca, Romania

S. Shim
Department of Agricultural Plant Science, College of Agricultural and Life Science, Gyeongsang National University, Jinju, Korea

J. Bernas
Department of Agroecosystems, Faculty of Agriculture, University of South Bohemia, Branišovská 1457, 370 05 České Budějovice, Czech Republic

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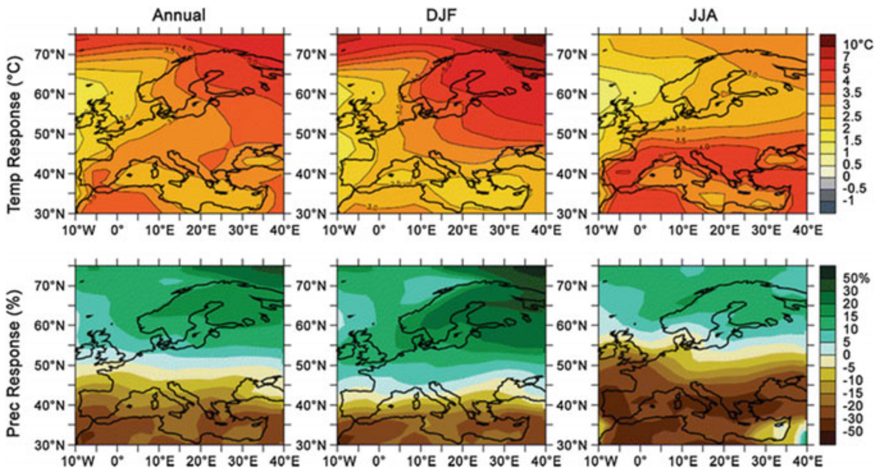
Anthropogenic activities are supposed to contribute to higher average temperature on the Earth. They are about to influence northern Europe in winter and southern Europe in summer. Moreover, such climate changes are supposed to cause water deficiency in the Mediterranean, south-western Balkan Peninsula or south European Russia [5]. It will probably have a different impact on the European agricultural ecosystems, depending on a variety (crop cultivation, forage crop growing or perennial crop cultivation), area and intensity of the climate change [6]. Concerning northern Europe, the average yield rate is supposed to increase and expand to favourable regions. As far as southern Europe is concerned, negative prediction dominates because of a lack of water and extreme climate events (higher average temperature, drought, pouring rain) [7]. The above-mentioned impacts may be strengthened by current trends of intensive farming in the northern and western Europe, or they may be opposite in the Mediterranean and south-eastern Europe. The following measures are supposed to be the most suitable ways of climate change adaptation (i.e. autonomous or planned adaptation strategies). They aim at minimizing the negative impacts of climate change and using its positive impacts: modification of crop structure, variety modification, seeding period change, modification of fertilizing management, modification of irrigation, water management and agrotechnological interventions. Choosing from all of these options, we have to consider the multifunctional role of agriculture and find a balance between economic and organic functions of agriculture in various parts of Europe.

The IPCC AR4 [8] projected that annual temperature over Europe will warm at a rate of between 0.22 °C per decade and 0.52 °C per decade (under A1B scenario—*One of the six SRES marker scenarios*; SRES = *Special Report on Emission Scenarios* [9]). The projected temperature increases are slightly higher in northern Europe. The warming in northern Europe is likely to be largest in winter and that in the Mediterranean area largest in summer. A south–north contrast in precipitation changes across Europe is indicated from A1B scenario projections, with increases in the north (up to 16%) and decreases in the south (from −4 to −24%) [5] (See Fig. 12.1).

Some other time and space scenarios [6, 9] show the land use will change significantly in Europe, as field crop yield rate and demand for agricultural commodities [11, 12] are about to change as well. For example, Schröter et al. [13] have published their predictions of the European agricultural land area reduction in 2080, varying from 28 to 47%, and a decrease in the area of European pastures in 2080, varying from 6 to 58%.

Europe is one of the world's largest and most productive suppliers of food and fibre. In 2007, it accounted for 18% of global meat production and 17% of global cereal production. About 67% of this production occurred in the EU countries. The productivity of European agriculture is generally high, in particular in western Europe, and average cereal yields in the EU countries are more than 40% higher than the world average [5, 14]. Agriculture is the world's largest consumer of water. One-third of the European water consumption is connected with agriculture. Agriculture influences the amount and quality of water. Some European regions suffer from a bad quality of water. It is caused by chemical crop protection agents, industrial and organic



*** Temperature and precipitation changes over Europe for the A1B scenario. *Top row* Annual mean, DJF and JJA temperature change between 1980 and 1999 and 2080 to 2099, averaged over 21 models. *Bottom row* same as *top*, but for fractional change in precipitation**

Fig. 12.1 Temperature and precipitation changes over Europe (from Christensen et al. [10])

fertilizers and intensity of animal production. Some regions in the Netherlands [15, 16] also faced the problem of high intensity of animal production (cattle breeding in particular) or bad quality of groundwater.

Generally said, an abundance of fresh water is not a natural thing in Europe. Predictions are not very optimistic, in spite of the fact, there is a wide network of rivers in Europe [17]. The Czech Republic is completely dependent on precipitation, and there is no water coming to the Czech Republic in rivers. Irrigation systems are necessary because of dry or semi-dry conditions in some of the South European countries, e.g. Greece, Italy, Portugal, Spain or southern France. In all of these countries, irrigation systems use more than 80% of agricultural water. Important to note that irrigated agriculture, while representing 16% of the cultivated area, is expected to produce 44% of world food by 2050 [18]. However, irrigation systems do not have to consume so much water. More efficient irrigation systems (90% more efficient) have already been developed in various parts of Europe. They are based on more efficient distribution of water and higher efficiency of irrigation [19]. A study by Pereira [12], for example, deals with the topic of irrigation and irrigation systems. Connections between irrigation, cropping system and food production are shown in Fig. 12.2. Figure 12.2 presents a scheme of the Food–Irrigation–Cropping Systems. It intends to illustrate that crop systems vary with the considered food crop and under the influence of local know-how and sociocultural conditions. Depending on local climate, soils, land conditions and water availability, irrigation may play a main role in the adopted cropping systems to support appropriate water needs of the crop. Finally, irrigation management in terms of control of water deficits and scheduling depends on food produce characteristics, the consumers and market preferences and the requirements of agro-industry. However, Food–Irrigation–Cropping Systems vary with farm size and orientation, as well as with access to technologies and capital as briefly referred above, and reflect poverty impacts.

Water is considered a strategic commodity in Central Europe as well as the Czech Republic. Applying suitable agricultural methods and adopting supportive political decisions, people may use water in a much more efficient way in the agriculture. The situation has been changing all around Europe and needs certain measures to be adopted—the measures contributing to better water management not only in the agriculture. Figure 12.3 illustrates the current situation in Europe.

12.2 Historical Development of Agriculture and Impact of Agriculture on the Landscape in the Czech Republic and Central Europe

Historians suppose the agriculture, or intended growing of crops began in the Neolithic period, i.e. 12,000–5,000 years ago [21]. The move of the agropastoral farming system from semi-arid Southwest Asia to Europe is connected with the climate and ecosystem change [22]. Agriculture, cultivation of the soil and grown crops have extended and come from the Middle East to Europe, especially to Green and

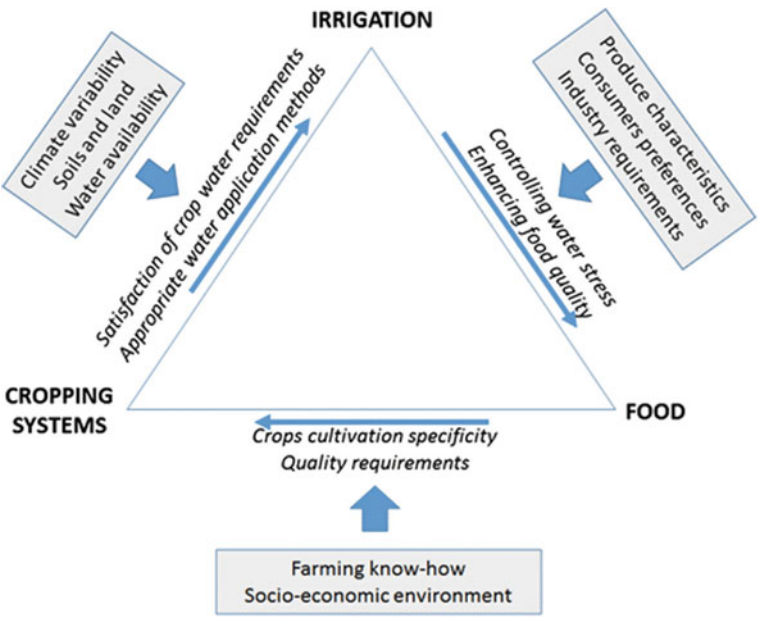


Fig. 12.2 A schematic demonstration of the Food–Irrigation–Cropping systems (from Pereira [12])

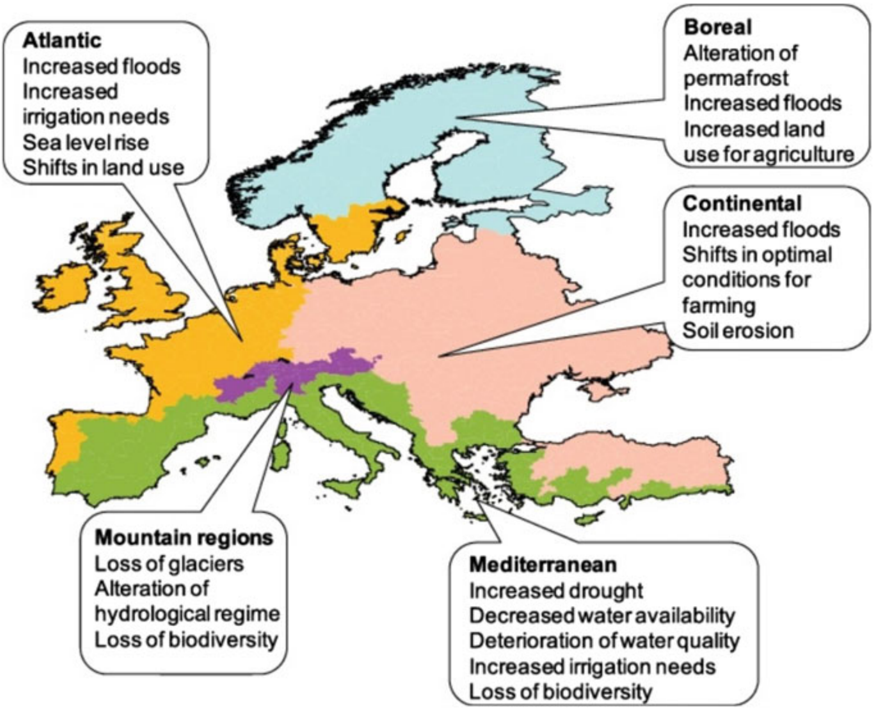


Fig. 12.3 A schematic demonstration of the current situation in Europe (acc. to Iglesias and Garrote [20])

the Balkan Peninsula. The Neolithic civilization started growing crops in the area of the Czech Republic and Central Europe in the mid-sixth millennium BC. The slash-and-burn agriculture is used to be the most common farming technique. It was based on the burning of forests and establishment of fields instead of forests [21]. As more and more forests were burnt, the two-field system of agriculture was established. The agriculture influenced the landscape, its appearance and water management in it.

Colonization caused the rural area got denser and denser and requirements for food increased. A switch to intensive agriculture was evident in Bohemia and the whole Central Europe in the second half of the first millennium. The quality of population was changing continuously—in non-agricultural production, technology and organization of farming. The fallow system of agriculture was established in the fourteenth century. The agriculture developed significantly in the eighteenth and nineteenth centuries. The three-field system of agriculture was replaced by a regular changing of crops in the cropping. Agriculture has formed the character of the landscape, and it has contributed largely to deforestation. Agriculture developed significantly in the twentieth century, and after the World War II. It was mechanized quickly, and animals were replaced by machinery (tractors and self-propelled machines). There was a wider range of tools which were aggregated in order to minimize the number of machine travel. Bigger and heavier machines have had a lot of impacts. The land is more loaded, and it gets cemented and less aerated, less water is retained, root system and edaphone have got worse conditions. There has been a trend towards the formation of larger land blocks. It was even strengthened by the end of private ownership in a lot of eastern European countries. Formation of larger land blocks was one of the tools used in that period. It has changed the structure of the landscape considerably and provoked some other consequences. Larger fields, high doses of fertilizers and pesticides have led to the deterioration of soil properties and have had a considerable impact on the landscape and environment, including water regime.

12.2.1 Agriculture and Landscape—Current Situation

The arable land represents about 11% of the total dry land area nowadays, which means about 14.7 million hectares. Grasslands and pastures are twice as large as the arable land—they represent 24% of the total dry land area. One-third of the dry land is used for the agricultural production [23]. Foley et al. [24] state similar figures (35%) in his book; he describes the agricultural land as the most extent type of ecosystem nowadays. The agricultural land area is tightly connected with the human need for food, and it copies the population growth. The population increased from 1.6 billion to 6.1 billion during the twentieth century [25]. It creates a growing need for natural resources and farming products [26]. As the population curve is growing, there is a higher pressure on new biotopes and intensification of farming on current agricultural land. There is also a higher pressure on new agricultural land to be used—parts of the virgin (untouched) nature are changed into the agricultural land, industrial buildings and houses are built on them [27]. Extension of the arable land area has slowed down recently as the most of suitable land for intensive farming had already been changed into the agricultural land. Foley et al. [24] states the world's plant production has doubled over the last forty years, but the agricultural land has only extended by 12%. Extension of the agricultural land has slowed down because of the increase in farming productivity too. As a consequence of the increase in farming productivity, there is a higher percentage of arable land (in the regions with at least 30% of arable land), the intensity of farming is higher, the area of fallow land is smaller, and the monoculture farming is changing into the multicultural one. The area of arable land has stayed the same in North America since 1950, whereas it has become smaller in Europe or China. Since 1960, the arable land area has been shrinking in the post-Soviet countries [28]. Intensification of the agricultural production has a dramatic impact on water regime—it draws water off (the agriculture consumes two-thirds of all the water consumed by humans [23]), and it pollutes water, especially with agrochemical agents. Such substances are harmful to, e.g., water animals, even in a negligible concentration below the provability level [29]. Moravcová et al. [30] also state the agriculture contributes to pollution of surface water very much. There are nitrates in water, created by the soil profile being washed out or erosion and draining of water. They cause the hydrosphere contamination and eutrophication (together with phosphorus) [31]. Basic cations (K^+, Ca^{2+}) are washed out at the same time, and an upper layer of the soil loses those nutrients and gets weaker. It leads to the acidification indirectly. Several kilograms of nitrogen are usually washed out of the soil per year [32]. It is obvious that such a high intensity of farming reduces the pressure on the conversion of natural ecosystems to agricultural ones, on the one hand, but it also increases the environmental burden, on the other hand. Such a farming system is not sustainable. Alternative farming systems have been developing in the last decades as a response to the intensive conventional farming. They aim at environmentally friendly farming, taking the quality of soil and water and the environment into consideration [33]. Such farming systems usually adhere to the agroecological principles [34].

Agroecology's position is somewhere on the boundary of several scientific disciplines. The name comes from two elementary disciplines—ecology and agronomy. Ecology focuses primarily on natural systems, whereas agronomy is based on a research and application of the research findings in the agricultural practice [35–38]. Such a connection between ecology and agronomy allows the agroecology to carry out farming activities that are environmentally friendly. Agroecological approaches are usually involved in the organic farming principles. Organic farming is a sustainable system aiming at environmentally friendly water management, water retention in the landscape and protection of surface or groundwater from the pollution [39]. Current agriculture has a major impact on the landscape and every single part of the environment as well. The environmentally friendly farming systems contribute to sustainability.

12.3 Importance of the Soil for Water Retention in the Landscape

The soil is essential for living on the Earth [40]. It allows organisms and their communities to live in and has got a lot of ecological, as well as environmental functions. From a human point of view, the soil is essential for food production and human diet. Apart from the production function, soil also fulfils non-production functions, e.g. it forms the environment and allows organisms to live in, it develops biogeochemical cycles of substances, energy exchange and formation of the climate, it fulfils a protection and stabilization function, it plays a cultural or esthetical role, etc. Water is the elementary factor connecting all the above-mentioned soil functions.

Water is a vital prerequisite for living on the Earth. It makes part of all the organisms and is the environment where all significant biochemical and biophysical processes take place. Water is very important for our lives, not just as a medium but it also creates a suitable climate for organisms on the Earth—via greenhouse effect and transformation of solar energy in the environment.

Water moves in so-called the hydrological cycle in nature. The hydrological cycle means an exchange of water between the Earth's surface and atmosphere. From a wider point of view, there is so-called great water cycle (the exchange of water between oceans and the Earth's surface). Simply assumed, water evaporates above oceans and the Earth's surfaces and consequently water condenses in the atmosphere and returns to the Earth's surface as precipitation. Then it flows away as a surface outflow and returns to oceans. From more narrow point of view, there is a regional or local water cycle called short (small) water cycle [41–43], or a water microcycle [44]. In the short water cycle, water evaporates on a local level in the evapotranspiration process and returns back in the form of vertical (rain) or horizontal precipitation (dew, hoarfrost, fog). Water stays in one place for a certain period, or it is transferred to inland (see a concept of the biotic pump; [45–47]). The short water cycle is an important mechanism stabilizing the hydrological regime and climate on the level of landscape [46, 48–51]. Not only does the short water cycle depend on water sources in a specific area (landscape, region), it also depends on the functional vegetation [47, 52, 53]. In both cases, water and vegetation are provided by the soil. Changes in the future hydrological cycle and climate adaptation in the water sector could have significant implications for adaptation and mitigation measures in agriculture [6].

Soil plays the crucial role in the natural water cycle as it can retain high amount of water. It is called retention of water in the soil. The retention of water in the soil is a significant part of the water cycle in nature, on one hand, and a capability to absorb and retain water is essential for the above-mentioned production and non-production functions of the soil. We can consider soil as the elementary and crucial part of the hydrological cycle. It deserves our attention and needs to be protected.

12.3.1 Soil Capacity to Retain Water

Soil ability to catch and retain water is a complete and complex issue. The retention capacity is influenced by a lot of factors, e.g. the soil structure, composition, physical and chemical properties. The water retention capacity is also influenced by a representation of soil elements, such as mineral elements, clay elements and organic parts. Furthermore, important is mineral composition and texture of the soil, exchange capacity, volume weight, depth of the soil, subsoil properties, etc. (for more information see Brady and Weil [40]). Number and size of the soil pores, their connectivity and properties of air–water–solid interfaces are essential for the water retention capacity of the soil.

Water in a form of the water film on soil particles can be found in the soil; it covers the soil particles as adsorption water. Water as capillary water can be found in capillary pores. Water as gravitation water can be found in soil macropores. The presence of water in films is most important in clayey soils with large surface area and is influenced by the electric double layer and the exchangeable cations present. In sandy soils, adsorption is relatively insignificant, and the capillary effect predominates [54]. Movement of capillary water is determined by adhesive and cohesive capillary forces and based on a change/gradient of the soil matric potential. Water in macropores moves by the gravitation. For more details, see, e.g., [40, 54–56].

Retention balance of the soil can be expressed by so-called water balance equation:

$$\Delta S = P - ET - D$$

where ΔS is retention of water in the soil, P is precipitation, ET is evapotranspiration and D is discharge of water. We must add that retention capacity of the soil is very variable in space and time.

Soil contains water coming from atmospheric precipitation or as an inflow from the surrounding soil. If the soil surface is covered by vegetation, some precipitation water stays on the vegetation itself. It is called the interception of water. The volume of interception water on the vegetation surface may represent several mm (see, e.g., [57, 58]). It depends on the intensity of precipitation, size of leaves and the structure of the growth. The total long-term amount of precipitation and caught precipitation water may attain up to 50% of the atmospheric precipitation amount in case of forests [59]. It depends on the vegetation cover properties and climatic conditions [60]. Interception water usually evaporates into the atmosphere, and it does not get into the soil.

Water usually flows away from the soil surface, or the soil absorbs it. Water retention capacity of the soil is called a water infiltration capacity. The water infiltration capacity depends on a lot of factors, e.g. proportion of mineral and clay elements, the proportion of organic matter, size and structure of soil aggregates, volume and quality of soil pores in the soil layer [40]. Shallow or mid-deep skeleton soil has got a high water infiltration capacity. This is sandy, loamy-sand or silty soil having a low water retention capacity (water soaks into the soil profile very fast) [61, 62]. Clay soil has got a low water infiltration capacity too [63]. On the other hand, loamy, structural soil containing a lot of organic matter has got a high water infiltration capacity and water retention capacity [64, 65]. Roughness and slope of the soil surface play an important role for water infiltration capacity. Intensity of precipitation is also crucial [66, 67].

Movement of water in the soil and retention time is essential for water retention in the soil. Generally said, water flows away very fast from sandy soil whereas very slowly from clay soil (gravitation water in particular). Capillary water moves very fast, and it can evaporate quickly from the soil surface [40]. Loamy structural soil containing a lot of organic matter is considered the optimal soil type. Such a soil type has got a good size of pores, and soil water is retained very well thanks to organic matter [56].

Hydraulic properties of the soil may be influenced by mechanical processing of the soil [68], addition of organic matter [69] or support of the vegetation cover and soil fauna [70]. Mechanical processing of the soil (skimming, tillage, etc.) changes the mechanical and physical properties of the soil, size and quality of the soil pores in particular [68]. Mechanical processing discontinues the capillary pores and macropores are formed in the soil—it may influence the amount of water evaporating from the soil surface [71, 72]. On the other hand, the mineralization of organic matter is enhanced in the soil [73] and soil aggregates get discontinued.

If organic matter is added into the soil, it has got a positive effect on water retention capacity of the soil and water infiltration capacity of the soil too [69, 74].

The vegetation cover is essential for water retention capacity of the soil. Root system penetrating through the soil profile influences the soil structure and protects the soil from erosion [75, 76]. Plants enhance new soil macropores to be created and they produce organic matter. Vegetation cover protects the soil from direct sunshine, the impact of precipitation on the soil structure and influences a percolation of water in the vertical soil profile too [40]. Root system allows water to be distributed in the soil [77].

Soil fauna is another factor increasing the retention capacity of the soil. Soil organisms create macropores, contribute to the soil structure forming and help create humus [70].

12.3.2 Problems with Water Retention Capacity of the Soil

The issue of water retention in the landscape has become more discussed because of the climate change, drought, intensification of agriculture and its impact on land, eutrophication of the environment or impact of the soil on quality of surface water, etc. On one hand, we consider land and the soil very important, and we take its hydrological importance into account. On the other hand, the soil is frequently perceived as matter of course. Human activities disrupt land that gets degraded. Some changes are irreversible and have a serious harmful impact on the soil fertility. Erosion, reduction of organic matter in the soil, unsuitable arrangements of water regime, unsuitable agrotechnology or rotation of crops, acidification, pollution, salinization, land claims, etc., are supposed to be the most serious problems nowadays. They influence the hydrological regime in the soil. Every negative intervention has got an impact on production, as well as non-production functions of the soil.

Erosion is an enormous problem for the soil worldwide. It is mostly provoked by unsuitable agrotechnological interventions, unrespect of best agricultural practice or unsuitable technological processing of the soil. Due to intensification of farming and high economic pressure crops providing high yield and having fast economic effect are preferred in the agriculture. Cropping is simplified [78–80]. Wide-row crops (e.g. corn) are preferred; however, they have minimum anti-erosion effects on the soil. Such crops are very often grown repeatedly or excessively.

Erosion causes the soil is washed away from fields, soil profile gets weaker and smaller and the soil degrades. Small and light particles (especially organic matter) are washed away [81]. Organic matter is crucial for the soil structure formation and has a crucial impact on the hydrology [65, 74]. Structural soil manages water very well, whereas unstructured soil enhances water outflow, absorbs less surface water into the soil profile and gets dry easily. Strong surface water runoff provokes more intensive water erosion [56]. Reduction of organic matter or simplification of crop rotation may have a significant impact on the soil edaphone, which influences the soil structure, forms preferential ways of outflow and influences the soil porosity [40, 82]. Reduction of organic matter in the soil (provoked by erosion or mineralization) causes increasing of the soil ions movement and their leaching from the soil. Such a reduction of organic matter in the soil and a rash or ill-considered use of mineral fertilizers may cause pollution of surface water and stronger eutrophication.

No vegetation cover also brings serious problems for the soil—soil aggregate on the soil surface is disturbed mechanically. Infiltration capacity of the soil diminishes, more surface water flows away and water or wind erosion gets stronger (for more details, see [40]).

Land claims and construction of buildings, technical buildings or roads, etc., is another acute problem concerning the hydrological function of the soil. About 217 ha of the soil have been built up in the Czech Republic every year since 2009 [83–86] (the Czech Republic has an area of 78,866 km^2). The extending built-up area has an impact on the hydrological and climatic regime in this region and bad consequences for the environment.

Technical arrangements of the soil water regime are the last issue mentioned in this chapter. It has a direct impact on water retention in the landscape. Land amelioration is a significant instrument in helping increase the production capacity of the soil. However, it may also reduce water retention capacity of the soil and disrupt its functions. There is a Czech experience as an example. Ill-conceived and rash arrangements of the soil water regime have been made in the Czech Republic; water has been unsuitably drained off from the agricultural and forest land. Water regime of agricultural land was arranged massively in two stages: in the mid-nineteenth century and the 1970s and 1980s. More than one-fourth of all the agricultural land has been dewatered until nowadays (more than 1 million ha which is about 14% of the Czech Republic's area [87]). According to [88], some hydro-amelioration interventions are supposed to be an instrument of the state and political power (to a certain extent) as a part of the collectivization of agriculture. Such unsuitable dewatering of certain fields and lands has led to a quicker outflow of precipitation, stronger erosion, and it has had a negative impact on the local climate, the chemistry of the soil and water outflow. The amelioration arrangements have not provoked any higher production of crops. Biodiversity has been significantly reduced (balks or wetlands have been removed) because of the arrangements of water regime on agricultural land and unification of fields.

The amelioration of agricultural land is also connected with arrangements of water flows; they have been straightened, banks have been fortified, etc. They have changed a natural fluctuation of groundwater level, hydrological conditions and the hydrological network [89].

The above-mentioned summary of how humans have been influencing the hydrological regime of landscape shows the greatest and most acute problems. The hydrological regime and importance of the soil that plays an important role in it have to be always taken into account.

12.4 Changes in Precipitation Distribution in the Czech Republic

The future development scenarios for the European agriculture include relocating the agricultural crop growing zones to the north as well as increasing the crop productivity in northern Europe. By contrast, we may expect a declining productivity in the south of Europe. These events may be accompanied by a limited access to water resources and by the growth of extreme rainfalls on one side and extreme droughts on the other side. These future changes may be reduced to a certain extent by appropriate water management procedures and agricultural adaptation measures [6].

Scientist and public strongly discussed the climatic changes also in the Czech Republic and their impact on the agriculture [90]. The discussion is more intense during unexpected climatic extreme like record temperatures, warm winter or the unregular distribution of rainfall. As we take the year 2018 as an example, we can see mainly unregular distribution of rainfall and the longer period with high temperatures. This trend is possible to see also from historical data [91]. As shown historical data from long-term meteorological measurements (last 200 years) from Prague Clementinum, published by Střeštík [92], there are negative trends. "The course of the annual precipitation displays no change over 200 years, only a very slow decline during the 20th century" (http://core.ac.uk/display/30239232). According to Střeštík [92], there is a strong trend in distribution rainfall. There are less rainy days with more than 5 mm rain, but total year rainfall is the same. It means an increase of irregularity in annual rainfall which is not good for agricultural crops and management. These trends indicate the possible causes of the drying of the Central European landscape [93].

The agriculture is now more than important to make everything to keep water in the landscape and also manage water in the soil efficiently. As shown some studies from the regions of the Czech Republic, one from the problems are changes in crop structure. According to Brovkina et al. [91] in the regions Třebíč and Znojmo over the period 1994–2013, there was a decrease in arable land and increase in grassland, mainly in the Less Favoured Areas (LFA) zone [94]. It could be a positive trend. However, the other results of Brovkina et al. [91] shown another negative aspect. There was an increasing trend in the annual average temperature and sum of solar radiation in both the districts, Třebíč and Znojmo. Generally, this trend confirms also other author, e.g. Eitzinger et al. [95].

Another problem of the Czech agriculture is field size, which leads to rapid water drainage. We can use the previous regions, for example, still—a change from small fields (1953) to large fields (2013), was recorded in the Třebíč and Znojmo [91]. Typical crop which can cause problems during strong irregular rainfall is corn, which is produced on more than 10% of arable land. Crop is late sown, grown in wide lines. During strong rain, the soil loses the ability to absorb rain and running water cause erosion and local floods. The proposed solution is underseeding of Phacelia tanacetifolia as protection of soil [96].

The current trend in temperature increase and irregularity in rainfall will be a real problem. As shown results of Eitzinger et al. [95], the C-3 crops in drier regions will be devastated for a significant number of seasons. According to the same authors will be difficult to use some soil fertility management as the use of crop rotations with catch crops, which may have negative impacts, exacerbating the soil water deficit for subsequent crops.

12.5 Transpiration, Evaporation, Water-Use Efficiency in Crop Production

Crop production depends on photosynthesis of leaves. Photosynthesis uses water, carbon dioxide and solar energy, among them carbon dioxide and solar energy show nearly constant level in cropping season, but moisture is very variable during crop growth, which has a significant impact on crop productivity. Water requirement and its use efficiency are to be varied depending on the type of crop and variety, as well as the cultivation method. Increasing the water-use efficiency is very important in case of water shortage [97]. The water used by the crops is mainly absorbed from the rhizosphere; consequently, the growth of crops changes depending on the water content of rhizosphere. The water present in the soil escapes into the atmosphere through transpiration and evaporation. Therefore, if the evapotranspiration is excessive, it causes the lack of moisture in the rhizosphere. Most of the water absorbed by the crops is discharged through the process of transpiration that occurred through stomata. Generally, the amount of transpiration is closely related to the amount of photosynthesis. Therefore, water discharge through proper transpiration is positive for crop growth [98, 99].

The degree of water use in crop production can be expressed as water-use efficiency (WUE). The meaning of the WUE slightly different depends on the leaf level and the crop canopy level. At the leaf level, the WUE is the ratio of leaf photosynthates to water consumption, and at the crop canopy level, the ratio of crop yield to water consumption. Therefore, reducing water consumption is a way to increase the water-use efficiency of crops. When water consumption is mainly caused by transpiration and evaporation, both transpiration and evaporation depend on the crop species, variety and cultivation method. Basically, in order to increase water productivity, it is necessary to improve the genetic trait to maximize water gain as well as to manage the crops with proper practices for efficient water use. The efficiency of evaporation in crops can be expressed as the transpiration efficiency (TE), which is the value of biomass produced for the water used for the production [100]. Reducing the evaporation to increase TE results in a decrease in CO_2 uptake, a decrease in photosynthesis and a higher water potential in the crop at which water and mineral nutrients absorption from the soil decrease [101]. Diminished uptake of nitrogen due to the reduced absorption of mineral nutrients directly affects crop yield because nitrogen is closely related to chlorophyll content and RuBisCO content that are critical to photosynthesis. Also, under high-temperature conditions, the physiological processes of the crops are decreased due to the lowered activity of enzymes [102]. Therefore, in order to alleviate the damage caused by the reduction of the yield of crops, crops with high carboxylation efficiency and high adaptation to temperature rise should be cultivated [103].

Transpiration rate is regulated by controlling the stomatal conductance relied on stomatal apertures and also influenced by the vapour pressure deficit (VPD), temperature, wind speed and sunlight. Soil water potential and soil temperature are also influencing factors. These factors growing practices can be mediated by controlling. "The stomatal aperture is regulated by a number of environmental factors in addition to soil moisture, including light, temperature, nutrition and relative humidity" [104–106].

In the field, evaporation and transpiration occur simultaneously. Therefore, it is very difficult to discriminate one from the other. Both are highly dependent on the water availability in soil and influenced each other. During crop growth leaf area and LAI increase mainly rely on photosynthates that closely related to the transpiration and affect the level of evaporation by shading the soil surface. At germination stage, nearly 100% of ET comes from evaporation, while at full canopy more than 90% of ET comes from transpiration [107]. Although evaporation partially contributes to reduce the temperature increase to improper temperature for crop growth under high-temperature condition, it is more economical to minimize the amount of evaporation for crop production with limited water resource. Soil mulch and crop residue decrease surface runoff as well as increase infiltration and soil water availability by reducing vaporization [107]. Consequently, the temperature of the soil surface increases less and the evaporation is inhibited.

At planting and during the initial stage, the evaporation is more important than the transpiration, and the evapotranspiration or crop water requirement during the initial stage is estimated less than 50% of the crop water requirement at fully developed growth stage. During the crop development, the crop water demand gradually increases. The maximum crop water requirement is reached at the end of the vegetative growth stage which is the beginning of the heading and flowering stage. It is well known that the reproductive growth is highly sensitive to water stress and water availability at this stage ranged from heading to anthesis is strongly correlated with crop yield [108, 109]. Increasing plant population density results in a rapid canopy closure that reduces evaporation from the soil surface and leads a more efficient water use in the field.

Residue on soil can conserve soil water by decreasing evaporation and rainfall runoff, and increasing rainfall infiltration [110]. To place more residue, no-tillage or conservation tillage are practical tillage system in crop fields [111]. Adequate agricultural management for the rational water use is necessary to reduce evapotranspiration to the extent that it does not affect photosynthesis [112]. These include improved irrigation such as deficit irrigation and watering depth control, and water-saving cultivation practices, pre-seeding priming, application of organic matter and modified tillage. In principle, water is stored well in the soil, and unnecessary water use is minimized by reducing the water consumption and improving the water-use efficiency [113, 114].

12.6 Agrotechnological Measures and Agrotechnological Operations Leading To Water Retention in the Landscape

Irrigation systems are not necessary for efficient water use in the agriculture in some European regions nowadays. Agrotechnological processes and approaches enhancing more efficient water use take place there. All of them are called conservation tillage. The conservation tillage is a term that, according to Hůla [115] involves various techniques of soil processing without tillage, direct seeding into the unprocessed soil, etc. Coverage of the soil with plant residues or post-harvest residues is one of the main characteristics of the conservation tillage system. Such residues should cover at least 30% of the soil surface. Such a continuous coverage of the soil surface may help reduce erosion by 50–90%. The conservation tillage is connected with some other existing systems: reduced tillage system, no-tillage system, cover crops, intercropping system, etc. Other agrotechnological interventions helping retain precipitation water in the arable land are as follows: suitable cropping, agrotechnology, mulching, tied ridging, soil processing, pre-seeding soil preparation, etc. A long-time continuous vegetation cover is the main anti-erosion cropping measure. Principles of crop rotation are anchored in the organic farming principles, or the agroecology principles [34, 116, 117]. Contour soil processing is another popular agrotechnological method [118]. It impedes fast surface outflow of water and helps absorb and retain water in the soil. Intercropping system is another solution reducing water and wind erosion and retaining water in the agricultural land. It is based on trees grown in rows on the arable land between market crops. Trees impede fast water outflow, and they bring organic matter and nutrients back to the soil and decrease a necessity and use of fertilizers [119]. Other agrotechnological measures supporting water infiltration capacity are also adopted in the Czech Republic: grass over the most vulnerable places. This measure is adopted on the arable land most susceptible to water erosion. Grass over absorption belts and furrows in the direction of contours in a similar measure. Surface outflow is converted to ground outflow on flatter fields; it slows down the surface outflow and decreases erosion risk. Windbreaks were also grown recently; it used to be a common measure against wind erosion. If a windbreak is grown in a contour direction, it transforms the surface outflow to the ground outflow, slows down the surface outflow and reduces risk of erosion. Biocentres, biocorridors and interactive components can also support water infiltration into the arable land. Herbal belts, bosks or balks are similar measures. Retaining and drainage ditches are also used in the fields susceptible to the surface outflow. Grass over the highest parts of slopes is supposed to be one of the most efficient measures supporting water infiltration into the arable land. Grass absorption belts, primary and secondary way leading across slopes, are another possible less frequent measures. Grass over space between vineyards or orchards is a measure adopted in the case of perennial cultures. Grass over concentrated outflows—horizontal furrows, or grass along small water flows are another quite frequent measures. If all the above-mentioned measures are insufficient, we may grass over the whole blocks of arable land [118].

Soil processing is a mechanical intervention helping establish favourable conditions for crop growing. It discontinues compact soil aggregates, modifies size, position and structure of pores. Processed soil may be unstable, porosity changes in time (because of the soil changing from wet to dry and vice versa, biological activities in the soil and because of machines travelling through the fields and carrying agrotechnological interventions out). Modification of physical characteristics of the soil provoked by the soil processing raises changes in water and air permeability and thermal conductivity. The system of pores makes two (or more) transportation states—pores retaining water and pores supporting water flow. There are various conditions of the soil structure which are important for water in the soil. They differ in infiltration speed, nutrient outflow and the soil erosion. Infiltration of water usually strengthens, the surface outflow reduces, and erosion risk decreases thanks to the conservation tillage [120]. On the other hand, conventional farming leads to a homogenous layer of the soil and decreases water infiltration capacity. The conservation tillage technologies may also reduce the surface outflow and enhance infiltration of water into the soil. Water flow preference is a typical feature of no-till technologies; it is because there are more macropores and vertical ruptures in the soil. The soil profile got full and aerated after tillage (as deep as the tillage goes) [115, 121]. Various methods of the soil processing lead to various water infiltration capacity. Soil-protecting technologies may support water infiltration into the soil and retain water deeper in the soil. Conventional soil processing technologies may influence water retention capacity of the soil and reduce small outflows after a thunderstorm if a certain amount of water falling down to the ground per time unit is not exceeded [121]. Water infiltration into the soil may dramatically influence soil resistance to water erosion in winter [122]. If snow is melting and rain is falling down to the frost land, water infiltration capacity of the frost land reduces a lot, the surface water outflow increases and the soil is washed out (especially on long slopes). The soil surface is usually covered with minimum plant residues, and it is not protected by winter crop either. The soil processing plays a significant role in this case. Measures reducing the surface water outflow of water have to be adopted—the soil surface is made rougher, e.g. hills are toped on the field in contours' direction [115]. It is also possible to make hills of snow mechanically, which is another agrotechnological measure supporting water retention of the soil during winter season and snowfall. Such snow hills are more resistant to wind erosion; when it gets warmer, snow is not blown away; when snow is melting, more water stays in the field. This water management technique is employed, e.g. on the flat plains of Kazakhstan.

Considerable part (16%) of the arable land is susceptible to degradation in Europe but farmers or administration respond to it slowly, and they do not take environmental consequences the soil degradation may cause into account. Conservation tillage may significantly improve the structure and overall quality of the soil. It can also help to achieve more effective water infiltration into the soil, thus securing its retention, which would prevent, to a certain extent, problems associated with weather extremes (e.g. torrential rain or drought). This improvement of the soil structure also reduces the risk and extent of surface runoff, thus reducing the pollution of surface water by sediments, pesticides and nutrients. Reduction of the intensity of soil treatment also reduces energy consumption and the quantity of carbon dioxide emissions. It also supports carbon sequestration with a growing proportion of soil organic matter (SOM) [123].

Minimization technology is a common agrotechnological tool for water retention in the soil used in the Czech Republic and Europe [115]. It is also ranked among the conservation tillage technologies. The conservation tillage technologies are supposed to make the soil conditions and the environment better. Every single change of the soil processing produces the environmental changes. How serious the environmental changes are depends on a reduction of depth and intensity of the soil processing, number of plant residues left on the soil surface or in the upper layer of the soil, and it depends on how long the technology modification lasts. Changes in the soil climate provoked by various soil processing interventions are different and depend on land and climatic conditions. The soil processing method and distribution of post-harvest residues influence a lot of physical, chemical and biological features of the soil. As far as the physical features are concerned, such changes influence the volume weight that further influences the whole complex of physical features of the soil. The volume weight correlates with the soil porosity. Representation of diverse size of pores influences water and air regime of the soil considerably. Generally said, the less intensive the soil processing, the higher volume weight of the soil and the less porous the soil. The ratio of the capillary to non-capillary pores changes, which causes the soil can retain more water and gets less aerated. Mulch made of plant residues and put on the soil surface has a positive impact on water retention on the soil; it slows down water outflowing from the soil surface and reduces non-productive evaporation and losses of water. Changes in the soil water and air permeability and heat conductivity are also provoked by changes in the physical features of the soil. Depth and intensity of the soil processing decrease; it ought to be employed in dry and warm regions and on light lands, where water regime and irrigation of plants in the growing season have to improve. By contrast, heavy land, wet and cold conditions require porous soil, especially more non-capillary pores in the soil (they determine the permeability and aeration of the soil). The various intensities of the soil processing and use of post-harvest residues change the physical properties of the soil, but they also change the soil structure. Structure of the soil is a significant condition for the soil fertility. More shallow and less intensive soil processing and plant residues left on the soil surface usually improve the soil structure (agronomically valuable structural aggregate represented more and more water is retained in the soil).

No-till techniques of the soil processing ensure better soil water management (e.g. Kern and Johnson [124]; Bescansa et al. [125]; Hůla et al. [115]). Studying humidity of the soil in certain time periods as well as randomly, we realized almost all the no-till fields contained more water than the tilled fields. This fact is, however, not general for all the no-tilled fields; it was strongly influenced by post-harvest residues left on the soil surface that helped reduce water losses. There was also a higher ratio of the capillary to non-capillary pores (more capillary ones), which raised water retention capacity of the soil too. Continuity of capillary pores leading to a seeding bed enhances germinability of seeds and emergence of a plant. Soil water savings are the biggest advantage of the minimization and protective soil processing. Plant residues we leave on the soil surface impede water evaporation and keep water in the soil. Water serves to the yield formation, and it is used more efficiently than by the conventional farming system.

Generally, higher amount of water connected with the minimization soil processing is supposed to be a positive event; it can be, however, negative in certain cases, e.g. the soil with lower absorption capacity faces a risk of fertilizers, pesticides and seeds to be washed away. By contrast, wetter less drained and less porous soil may enhance denitrification processes. Measuring how much water has evaporated from the soil, we also study distribution of nitrates as they get deeper into the soil in the no-till systems. Nitrates are washed out of the soil, which is supported by more continuous soil pores and the compact soil (it accelerates water flow and distribution of nitrates through macropores). Thanks to the no-till systems, wetter soil comprises more pores full of water, and more water travels through macropores after the rain. The minimization technologies are not recommended for heavy wetland and traditional tillage is more suitable there. The minimization and protective technologies help enhance water infiltration capacity and water retention capacity deeper in the soil. The conventional tillage technologies can influence water retention capacity and reduce small water outflows after heavy rain (e.g. after a thunderstorm) unless a certain amount of water falling down to the soil surface per time unit is exceeded [115].

Soil water management and distribution of water and nutrients to plants, root system growth and development, physical–chemical processes and biological soil activities are tightly connected with the physical characteristics of the soil. It is crucial for the soil processing system to keep the optimum balance between all characteristics of the soil; good water management is assured, and the soil fertility is regulated and stays under control.

Water capacity of the soil (absorption capacity, or capability to retain absorbed water in the capillary pores for a long time) is crucial for the distribution of soil water to plants. Some water is kept there, and it is available to plants and their root systems that draw it off. The absorption capacity is determined by the granularity of the soil. Clay which comprises a lot of capillary pores absorbs a lot of water in them. Sand absorbs little water, and it gets dry easily. Therefore, if we grow crops on sandy lands, we have to irrigate crops very much. They only use a small amount of nutrients too.

Soil must let some water in (absorption of precipitation water) and let it rise from the ground layers to the root system by the capillary pores, in order to distribute it to plants correctly. It is important if the crop stand gets dry and is in danger. There is a low capillary rise in sandy soil. Plants with deeper root system access more water; we can also plough fertilizers deep into the soil. The soil water capacity may be supported by higher amount of organic matter or hummus. Humus is a significant part of the soil;

it influences the fertility of the soil. It also controls all the necessary processes in the soil connected with plants and nutrition. Soil organic matter (or hummus) is crucial for water infiltration capacity of the soil. Soil organic matter plays an important role in the biological activity of the soil. It influences the formation of soil aggregates and water infiltration; it also influences the fertility of the soil. Soil aggregates help water infiltrate into the soil and form conditions for soil organisms; they provide roots and soil organisms with oxygen and have a positive impact on resistance of the soil to erosion. If the soil surface is not covered with plant residues and faces heavy rain, the soil aggregates get unstable, a solid firm creates, less water gets to plants and water erosion is stronger. The proportion of organic matter may indicate the soil quality as the upper organic matter protects the soil from erosion, influences water infiltration capacity and retains nutrients in the soil. Soil organic matter is distributed unequally in the soil that has not been processed for a long time. By contrast, it is distributed equally in the soil that is processed regularly. The unprocessed soil usually contains more organic carbon than the processed one; most of the carbon is in the upper soil layer ([115, 124, 125]). The different intensity and degree of the soil processing has a dramatic impact on carbon storing (as a hummus) and emission (as carbon dioxide) into the atmosphere. More carbon dioxide releases into the atmosphere, and less carbon is stored in the soil after the soil is processed intensively. Such an influence of the different soil processing intensity on the amount and composition of organic matter in the soil is measurable after a long time, as any obvious difference can be perceived in a short time. A short-time measurement of the amount of carbon dioxide released from the soil into the atmosphere may provide us with information about a mechanism of carbon circulation earlier.

Such different soil processing methods influence populations of earthworms. Earthworms play a very important role in the soil [126]. They create mesopores where infiltrated water is retained in. This space is important for infiltrated water and a preference of ways in the soil. The hydrodynamic functions are influenced by the soil processing too; ways of water flow are disturbed in the soil. Suitable agrotechnological interventions or techniques [127], and a selection of suitable crops [128] can influence the amount of edaphone and the number of earthworms in the soil profoundly. Through their activity, earthworms provide similar services as cultivation measures, make nutrients accessible for plants and support a good health condition of the vegetation, thus influencing the yields. Their effect on the soil structure, the extent of making water and nutrients accessible for plants, and the effect on the overall condition of the vegetation depend on the size and activity of the earthworm population as well as on the soil-climatic characteristics of the given location, which influence the ability of earthworms to fulfil these functions. The cultivation procedures, such as tillage and organic matter inputs, considerably influence the size of the population and the activity of earthworms [126]. Such relations are demonstrated in Fig. 12.4.

12.7 Soil and Water Conservation on Sloping Lands by Agrophytotechnical Measures

Among the important and inexpensive ways to act on the arable sloping lands inclined for framing the erosion process in admissible (tolerable) level or lower are the structure and rotation of the crops, crops emplacement on the slopes, the soil tillage and the soil fertilization.

The structure of crops or ***assortment of plants grown*** on the slope arable lands must meet several important requirements, namely:

- reducing annual soil losses below the allowable value (average 6 t ha^{-1} $year^{-1}$);
- realizing the conditions for the rational rotation of the cultivated plates;
- providing possibilities for the mechanized execution of agricultural works;
- getting high yields at a lower production price.

Depending on nature, the density, the volume of the vegetal mass during the erosive rains and the cultivated plant technology, the soil losses are much different (Table 12.1).

According to *Motoc M.*, the relative soil losses through erosion is between 0.14 and 100 (Table 12.2).

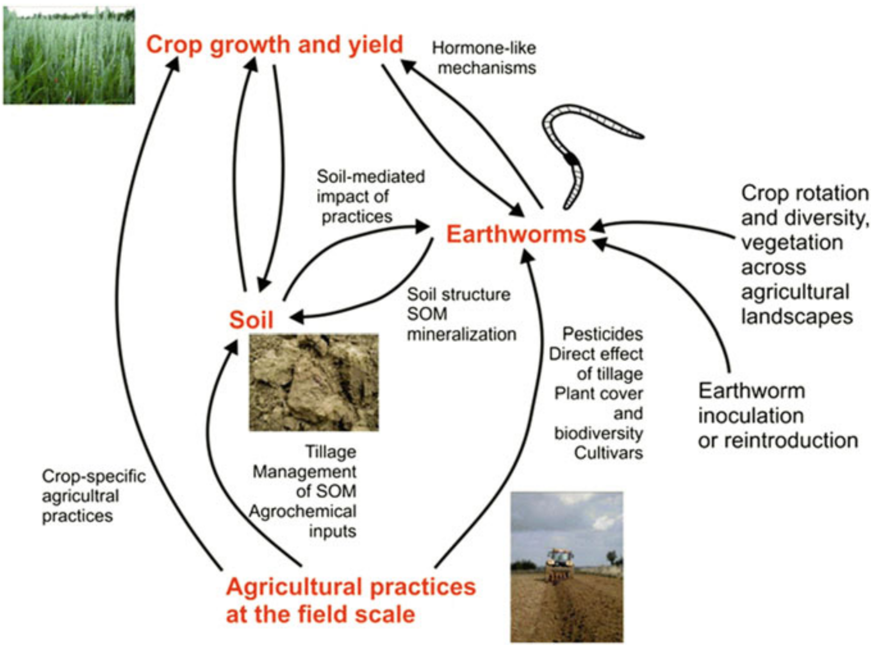


Fig. 12.4 A schematic expression of earthworm importance for the agricultural production (from Bertrand et al. [126])

It follows that on arable slope lands, different plant combinations must be grown so that erosion does not exceed the permissible limit. Researches carried out under various conditions have made it possible to determine the optimum proportion of row crops (maize, sun flower, potato …) in the crop structure in order that soil erosion losses remain acceptable. Thus, on arable land with a slope of 10–12% and the loamy-clay soil in the northern Moldavian Plain, the annual soil losses (8 years average) remained below 6 t/ha, when the row crops occupied up to 62% in the crop structure [130].

A summary of the percentage of crops participating on the slopes to provide protection against erosion, according to the slope and the runoff length, is presented in Table 12.3.

On the other hand, in the crops structure must predominate the plants that good capitalize the microclimate and edaphic conditions, specific to hilly areas. It has been found that maize, straw cereals, some legumes and others provide under medium condition of relief and erosion, superior yields relative to other plants, in the conditions

Table 12.1 Average soil losses (t ha^{-1} $year^{-1}$) in Central Moldavian Plateau to different groups of cultivated plants (Popa et al. [129])

Group of cultivated plants	Degree of land coverage (%)	Slope			
		16%		24%	
		Eroded soil	%	Eroded soil	%
Plants that protect the land very well	>75	0.5	1.5	1.2	1.5
Plants that protect the land well	50–75	4	12.3	10	13.7
Plants that provide medium protection to the land	25–50	7	27.5	14	19.3
Plants that poorly protect the land	<25	32.5	100	72.5	100

Table 12.2 Relative soil losses through erosion relative to cultivated crops (*Moţoc M.*)

Cultivated crop	The relative value of annual soil loss through erosion
Maize in monoculture	100
Maize in crop rotation	80
Potato and beet	60
Peas and beans	30
Springy straw cereals	20
Autumn straw cereals	14
Perennial herbs of the second year of cultivation	0.14

Table 12.3 Recommended crops' structure for soil erosion control, depending on slope and runoff length (Ionescu [131])

Slope (%)	Runoff length (m)	The proportion of plant participation in crop structure (%)				Restriction
		Row crops	Straw cereals	Legume	Perennial herbs	
<5	<400	100	–	–	–	No restriction
	400–600	80	20	–	–	
	>600	80	10	10	–	
5–10	<400	80	20	−10	–	Light
	400–600	70	20	10	–	
	>600	70	10	–	10	
10–15	<300	70	10	10	10	Middle
	300–500	60	20	10	10	
	>500	50	10	20	20	
15–20	<300	40	30	10	20	Great
	300–400	30	20	20	30	
	>400	20	10	30	40	
>20	<200	–	40	30	30	Very big
	200–300	–	30	30	40	
	>300	–	20	30	50	

in which production costs increased by only 8–10%, compared with the necessary costs on quasi-horizontal surfaces.

It is appreciated that the rational rotation of crop plants on the slopes determines the reduction of soil losses at least twice as compared to monoculture.

Making rational rotations is possible on land with a slope of less than 16%, using the same type of crop rotation as on the flat surfaces.

On surfaces with a slope of 16–25%, it is necessary to replace part of row crops with legume beans or technical plants.

On arable land with a slope of more than 25% and soils with high erodibility, special protection crops rotation should be applied, including straw cereal, leguminous, textile and fodder plants and a high percentage of grasses and perennial legumes for hay in order to reduce the soil and water losses (Table 12.4).

Crops emplacement on the slope lands. For soil, water and nutrient losses to be negligible, choosing the appropriate assortments of plants to be cultivated on slope arable lands and them inclusion into rational rotations should be associated with special cropping systems of crop emplacement on the slopes.

The most widely used anti-erosion cultivation systems are the *strip intercropping system* and the *contour buffer strips system*.

In fact, the cultivation of the entire surface with a small slope ($i < 5$–6%) of a sole crop, with the rows oriented on the direction of the level curves, constitutes an

Table 12.4 Soil losses in various protection crops rotation on the slopes of over 35% in condition of Barlad Plateau

Crops rotation	Eroded soil (t ha^{-1})	
	Total	Without maize
20% winter wheat, 33% perennial herbs, 17% maize, 17% pea	42.0	16.1
33% winter wheat, 67% perennial herbs	16.8	16.8
17% winter wheat, 17% maize, 66% perennial herbs	29.4	4.4
100% perennial herbs	1.2	1.2

Fig. 12.5 Strip intercropping in the Barlad Plateau (Romania) [132]

anti-erosion system, because the execution of all agrotechnical works in the same direction, causes significant reduction of water runoff and soil losses. However, the anti-erosion effectiveness diminishes as the slope increases, and it is necessary to resort to another way of orientation the crop plants.

Strip intercropping system (see Fig. 12.5) is a simple, effective and convenient means of soil erosion control on arable land with a slope greater than 5–6%. It consists in cultivating on the slope, parallel to the level curves, some land strips row crops, alternating with strips that are good protective plants (autumn cereals, annual legumes, etc.). In this way, the kinetic energy of the streams that form on the width of the row crops strips is dissipated in the downstream space, occupied with crop plants sown in close rows.

Depending on the slope land and soil erodibility, the width of the strips is shown in Table 12.5.

Table 12.5 Indicative values of the width of the cultivated strips (m) depending on the slope land and the soil resistance to erosion

Slope land (%)	Width of the strips (m) for the soil with erodibility		
	Small	Medium	High
5–10	117–83	100–71	79–56
11–15	78–59	66–50	52–40
16–25	55–30	47–25	37–20

Table 12.6 Influence of the strip intercropping cultivation system on soil erosion, mean values for 25 years in Barlad Plateau (Romania)

Slope land (%)	Rain characteristics			Number and width of strips	Crops	Eroded soil	
	Amount (mm)	Duration (min)	Intensity (mm min^{-1})			t ha^{-1}	%
5–10	41.9	15	2.0	1 × 140	maize	158	100
				2 × 70	maize + wheat	32	20
12	18.4	20	0.82	1 × 160	maize	17	100
				4 × 40	2 maize + 2 wheat	7	41
10–15	41.9	15	2.0	1 × 60	maize	76	100
				2 × 30	maize + pea	33	43
14–16	16.3	10	1.14	1 × 80	pea	17	100
				2 × 40	maize + pea	2	18
16–20	41.9	15	2.0	1 × 120	maize	280	100
				6 × 20	3 wheat + 3 maize	41	15

The use of the strip intercropping compared to the slope cultivated only with corn in the Barlad Plateau (the eastern part of Romania), regardless of the size of the slope, reduced the water runoff and eroded soil 2–7 times (Table 12.6).

In the first years of the application of the strip intercropping system, there are no significant harvest increases, but as the erosion decreases, the effects accumulate, and the increase in production increases its significance.

Keeping the site of the cultivated strips unchanged, after 10–12 years, at the boundary between the consecutive strips, there are formed uneven forms that, if seeded with perennial grasses and properly maintained, can form the slopes of future agricultural terraces (Fig. 12.6).

It is appreciated that when applying the strip intercropping, the additional labour consumption compared to the cultivation of the slope with the sole plant is about 8% (Fig. 12.7).

Fig. 12.6 Agricultural terraces formed by unchanged maintaining of the emplacement of the cultivated strips (photograph L. Niacsu 2012) [133]

Fig. 12.7 Contour buffer strips system (photograph L. Niacsu 2012) [133]

Table 12.7 Species and mixtures of perennial herbs for the sowing of buffer strips (după Popa et al. [129] şi colab.)

Annual average rainfalls (mm)	Soil erosion intensity	Herbaceous species and their proportions in the mixtures formed
<500	Moderate	*Medicago sativa* (60%) + *Dactylis glomerata*, *Arrenatherum elatius* or *Agropyrum repens* (40%)
	Strong	*Onobrychis viciifolia* (60%) + *Bromus inermis* (40%) or *Onobrychis viciifolia*, *Lotus corniculatus* (60%) + *Bromus inermis* (40%)
>500	Moderate	*Onobrychis viciifolia* (60%) + *Dactylis glomerata* (40%)
	Strong	*Onobrychis viciifolia* (60%) + *Bromus inermis* (40%)

The contour buffer strip cultivation system (photograph 12.3) is recommended for arable lands with a slope of 8–10%, especially in areas with annual precipitation greater than 500 mm, but can also be successfully applied in dry areas, choosing for the sowing of strips the appropriate range of herbs (Table 12.7).

Unlike the strip intercropping system, the contour buffer strip system consists in the alternation of the field strips on which are cultivate row crops, with narrower strips on which herbs are sown. The width of the land portions between the grass strips shall be set so that the soil losses are limited to admissible values.

In practice, it is applying, usually, buffer strips with the width of which is equal to one or two working widths of the sowers for the sowing of the herbs.

In conditions of the Barlad Plateau, irrespective of the slope land, the water runoffs and eroded soil losses was reduced 2–9 times by using the contour buffer strips system, compared to the unprotected cultivated slope (Table 12.8).

Soil tillage. Among the possibilities of reducing the erosion processes are the proper execution of the soil works.

Properly applied, tillage, harrowing and other agricultural work can help to diminish soil erosion and increase production.

The requirements of anti-erosion agrotechnics require that all soil tillage be carried out in the direction of the level curves.

In the Barlad Plateau, the traditional farming system with small plots of land, oriented and cultivated on the hill-valley directions (Fig. 12.8), continues to lead to problems related to the heavy clogging of large areas with eroded soil on the adjacent slopes.

Numerous experiences in different countries have shown that plough on the hill-valley direction causes the displacement of two to three times larger amounts of soil than plough made in the direction of the level curves (Fig. 12.9).

Table 12.8 Influence of contour buffer strips on soil erosion

Year	Eroded soil			
	Unprotected slope		Slope protected by contour buffer strips	
	t ha^{-1}	%	t ha^{-1}	%
2008	12.8	100	6.1	48
2009	20.6	100	3.9	19
2010	31.7	100	6.7	21
2011	54.0	100	8.9	16
2012	33.3	100	6.1	18
2013	18.9	100	2.2	12
2014	20.6	100	7.8	38
2015	30.0	100	5.6	19
2016	36.1	100	17.2	48
2017	41.7	100	6.1	15
Media	26.7	100	6.7	25

Fig. 12.8 Cultures in the hill-valley direction (photograph D. Bucur 2018)

Fig. 12.9 Eroded materials, transported and deposited by floods due to heavy rains since 5 September 2007 (by Ionita [134])

Table 12.9 Influence of plough direction on soil erosion in Barlad Plateau (Motoc and Mircea [136])

Slope (%)	Soil tillage			
	On level curves direction		In the hill-valley direction	
	t ha^{-1}	%	t ha^{-1}	%
9–10	11.4	100	32.3	233.3
14–15	17.2	100	45.7	265.6
18– 20	23.3	100	55.2	231.9

Also, contour plough allows reducing water runoffs by up to 75% [135].

The eroded soils on the slopes have a thin horizon of accumulation of humus, and to increase the water infiltration capacity and create better conditions for the development of the roots, they must be deeply ploughed. However, with deep plough, soil layers less fertile are brought to the surface of the land, and therefore fertilizer must be applied (Table 12.9).

By facilitating the storage of larger amounts of water in the soil, the deep plough also leads to a reduction in soil erosion.

The experiments carried out in the Barlad Plateau and the Plain of Moldavia (north-east of Romania) showed that the increase of the plough depth from 20 cm to 30 cm + 10 cm subsoiling did not increase the harvest of wheat and corn but reduced the quantity of eroded soil by 37–38%.

In the Transylvanian Plateau (central part of Romania), on an eroded argiloiluvial chernozem, the two-year alternation of plough and the soil work with the chisel increased the water reserve in the soil, reduced fuel consumption and increased the harvest to corn by 26–36%, compared to perform tillage every year [137].

Fertilization of arable sloping lands. Soil slope fertility diminishes as the erosion progresses.

Corn production obtained on moderately or heavily eroded cambic chernozem was 18 and 28% lower, respectively, compared to that obtained on the same uneroded soil. Corn and root crops have been considered the least soil-protecting crops for a long time [138]. There is a comparison of varieties and differences in the precipitation outflow—grass 12%, wheat 23%, corn 29.4% of precipitation water flows away. Mazín [139] states 85% of all the recorded and registered cases of sudden erosion occurred on the arable land sown with corn from 2012 to 2015.

Fertilizers indirectly contribute to the reduction of eroded soil quantities.

The rational application of fertilizers ensures the vigorous development of the root system and the increase of the vegetal mass at the surface of the land.

Under these conditions, water infiltration in the soil is significantly improved as the surface leakage decreases by increasing the roughness created by the increased vegetation volume.

It has been found that the anti-erosional effect of fertilization of arable land on the slope is higher for plants sown in frequent rows and with the long vegetation period.

It is appreciated that each ton of manure increases soil content by 40 kg of total carbon or 56–70 kg of humus [140].

Enhancing the soil's content in humus, manure and other organic fertilizers improves the structure and increases the permeability and speed of water intake into the soil.

Schiettecatte et al. [141] found that average soil and humus losses in spring cereals and potato were 3–4 times higher on unfertilized land compared to fertilized variants.

Research conducted in Belgium by Dautrebande and Sohier [142] on the effect of various green fertilizers on soil erosion shows that following the incorporation of a lucerne quantity of 4.7 t/ha, under the conditions of a simulated rainfall on a winter wheat, which developed a kinetic energy of 500 J m^{-2}, water runoffs decreased by 46% and soil losses by 80%.

12.8 Conclusions

Conservation agriculture is less adopted in Europe compared to other adopting regions and, reduced tillage is more common than no-tillage and cover crops. A lack of knowledge about the conservation agriculture systems and about how to implement them, an absence of dynamic and efficient innovative systems and socio-economic risks make it more difficult for European farmers to abandon tillage. It is a paradigm anchored in their cultural environment. The conservation agriculture has been enhanced and supported financially in Norway and Germany recently in order to mitigate erosion of the soil and retain water in the agricultural landscape. Farmers seem to initiate the adoption of all these technologies themselves in the other European countries; lower costs paid for machinery, fuel savings and work-force savings—these economic aspects are more important than environmental ones, and they have become crucial and propelling force. Soil and water protection issues have not been a propelling force for European farmers to decide whether the agriculture orients to the soil protection and conservation or not [143]. Changing water management regimes in Europe will also affect adaptation and mitigation in agriculture. In general, adaptation in the water sector will likely provide net benefits to agricultural production such as reduced flood risk and increased drought resilience. However, the impacts of some water management measures on agriculture are more complex and harder to predict [6]. For a future where there is enough water available to meet the needs of our ecosystems with sufficient resources left for our consumption requirements, we also need to provide the right policy packages to support efficiency measures. The EU's Water Framework Directive has contributed to this achievement through encouragement of changes to agricultural practices that can improve both water quantity and quality in Europe. Water management in agriculture would certainly benefit from a stronger focus in the Common Agricultural Policy on resource efficiency and all ecosystem services. More efficient use of our water resources in agriculture is only one of the steps we need to take in order to reduce our impact on the environment.

12.9 Recommendations

The central European agriculture, including the agriculture in the Czech Republic, faces a number of challenges associated with the water management in the landscape. In connection with the ongoing climate changes, irregular rotation of intensive rains and long periods of drought, and the growing demand for agricultural raw materials, we need to apply procedures stimulating effective retention and economic use of water. The key factors include various agrotechnical measures leading to effective water management. When considering the management procedures that lead to water retention in the landscape, we can follow several recommendations. One of the basic aspects is a good knowledge of the local soil-climatic characteristics. It is very important to set a rational cultivation plan in connection with a suitable management system. In the central European conditions, a system that is appropriate in terms of water management is conservation tillage, i.e. various methods of soil treatment without ploughing, or sowing directly in untreated soil. This should be accompanied by agrotechnical procedures connected with cover crops systems, intercropping systems, strip intercropping, strip till technology, agricultural terraces, etc. Using these agrotechnical procedures over a long term can improve the soil structure, thus making it possible to increase infiltration of water into the soil, reduce the surface runoff and reduce the risk of erosion, which constitutes one of the most significant problems connected with cultivation of arable land. Reduction of intensity of soil treatment also usually reduces the consumption of energy required throughout the cultivation cycle and also saves time. It also supports carbon sequestration with a growing proportion of soil organic matter, which originates, e.g., from left post-harvest residues. In general, these practices have significant environmental benefits.

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Part IV
Hydro-management of Water Resources

Chapter 13
Management of Drinking Water Resources in the Region of South Moravia, Czech Republic

J. Marková

13.1 Introduction

The water as an integral part of the environment is a condition of the life and the development of human civilization. Today, the company can replace a number of natural materials, but the water is still irreplaceable.

Water Resources are the most essential for life on the planet, that for our next axistence. Source quality water, especially drinking water, resources may be formerly neglected for its poor quality. Already today, we can still improve the use of water resources and of low quality. A water surface, lakes, ponds and dams, flooded quarries, but also underground water, which in the past have been contaminated by human activity.

The major pressures on the waters are pollution, scarcity (including droughts), floods and modification to water bodies. In particular, pollutants of the aquatic ecosystem have their origin in agriculture industry, municipalities and other sources [1]. Water resources management we understand as a process of comprehensive assessment of the impact of water collection, its use and the return of water to the natural environment. It includes water use and protection of water resources in the area, while respecting the water circulation patterns in ecosystems territories and safeguarding the stability of the water circulation in the country. This process promotes the coordinated development and management of water and land resources in order to maximize the resultant economic and social welfare in an equitable manner, without compromising sustainability of vital ecosystems [2–5].

In the territory of the Czech Republic, especially in the South Moravia region, the settlement has been taking place for centuries, and this also involves regulating the water regime in the area. The first was the drainage of wetlands—swamps and

J. Marková (✉)
Department of Landscape Management, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech Republic
e-mail: jana.markova@mendelu.cz

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marshes, and ponds were set up. As the human settlements expanded, there was a need for flood protection, the regulation of watercourses and the construction of flood protection tanks.

With the development of civilization, the emergence of industry and economic stability, water demand has steadily increased. Water was used in agriculture, industry, and supply of the population. The demands of not only its quantity but also its quality have increased; it has led to the search for new sources of high-quality water. People have constantly been improving in water recovery from the natural environment, as well as improving water treatment, wastewater treatment and water use as a source of energy.

The problem of water supply in sufficient quantity and quality for society has become a global problem at the end of the last century; the need for water protection has become part of a number of international documents. In 1968, the European Water Charter, which in 12 points clearly declares irreplaceability of water as a raw material that is not inexhaustible, has been proclaimed in Strasbourg on 6 May in Strasbourg, it must be maintained and cared for its preservation and expansion, where it is the duty of each of us here purposefully and economically.

In our region, by the year 1989, water management has been influenced by central management and generally underestimated economic and ecological impacts of the ill-considered use of water resources.

In recent years, the situation is finally beginning to change (perhaps not too late), water is no longer seen as a raw material but as part of the environment, which is the need to preserve for the next generation.

Today we are looking for new resources and also, as far as possible, to expand existing resources.

13.2 The Most Important Water Resources in South Moravia for Public Supply

A water source is a body of surface or groundwater that can be used to meet human needs. The inhabitants of the Czech Republic are supplied with 42% of the underground water sources, 32% receive water from surface sources and 26% are covered by mixed sources. All drinking water sources have protection zones. In these protection zones, the conditions of general protection according to the Water Act must be observed [6].

In the South Moravian region, both surface water sources (reservoirs) and underground water resources are used to supply drinking water to the public. In most of the territory, drinking water supplies to a combination of sources of surface and groundwater, with the only exception being Znojmo, where the population is supplied from the surface source of the 'Znojmo Dam' (Fig. 13.1).

Fig. 13.1 Position of South Moravian region in Czech Republic [7]

13.2.1 Water Reservoirs

Water tanks are tanks whose main priority is to accumulate water for further use as drinking water. In the Czech Republic, as 47 water reservoirs [8], of which six reservoirs participate in drinking water supply in the South Moravian Region.

The water reservoir is a water tank intended for the mass supply of potable and industrial water according to [9]. The list of water reservoirs supplying the territory of the South Moravian Region is given in Table 13.1.

The water reservoir Opatovice on the Malá Haná River is located near the village of the same name. The reservoir is a source of water for the area of Vyškov and Bučovice. The reservoir was put into operation in 1997. The water abstraction is realized by a withdrawal tower height of 43.85 m. The catchment extends into the forested part of the Drahanská highlands without significant sources of pollution. The main purpose of the reservoir is to provide water for the supply of the population. Therefore, in the year 1986, the area was declared hygienic protection zones and recreation was excluded. Approximately 2 million m^3 of water per year is taken from the storage volume in the tank for potable water treatment. Another important purpose is to ensure a minimum flow in the flow below the dam. Since 2008, this flow has been used to produce electricity in a small hydropower plant.

The Bojkovice dam on Kolelačský stream is located about 2 km north-east of the village of Bojkovice. The basin is mostly wooded and without concentrated area. The water tank was put into operation in 1966. Water collection is realized from a combined building at two levels. The main purpose of the waterworks is to provide sufficient water for the Uherský Brod group water supply and to ensure a minimum flow in the flow below the dam.

The Znojmo waterworks are located in 132.73 km of the Dyje River, put into operation in 1966. The main purpose is the supply of drinking water for the city of Znojmo and the equalization of flow on the river Dyje.

The Boskovice reservoir is situated on the river Bělá east of the town of Boskovice. The reservoir has been in permanent operation since 1994. The main purpose of the waterworks is to provide a supply to supply Blansko region with drinking water. At present, however, the water supply is suspended. The waterworks also serve to

Table 13.1 Water reservoirs supplying the South Moravian Region

Name of the reservoir	Watercourse	District
Opatovice	Malá Haná	Vyškov.
Bojkovice	Kolelačský potok	Uherské Hradiště, Zlín
Znojmo	Dyje	Znojmo
Boskovice	Bělá	Blansko
Koryčany	Kyjovka	Kroměříž
Vír I	Svratka	Žďár nad Sázavou

improve the low Bela flow under the dam, to reduce the peak flood flow and to generate electricity in a small hydropower plant.

The Koryčany reservoir is located on the Kyjovka River east of Koryčany. The reservoir has been in permanent operation since 1963. Water collection from the bay is realized by a 28-meter-high takeout tower, the collection is possible from four different height horizons.

The water work Vír I is situated on the river Svratka and was put into operation in 1958. The original purpose of the reservoir was water, but flood, recreational, energy, and mining flow in the bed under the tank. It was only after commissioning that it was decided that the reservoir would be primarily used as a water supply, eliminating its other purposes, especially recreation. The sampling object is located in the dyke and allows for collection from three levels of height. The reservoir has designated hygienic protection zones where bathing and fishing are prohibited.

The water from these tanks can only be used for drinking purposes after further treatment. The water is supplied to the potable water treatment plants and then distributed to the consumer. Today, most tanks are threatened by deterioration in water quality due to the development of cyanobacteria in the summer months. Moreover, even tanks that have a relatively good inflow or in the past due to higher altitude problems with cyanobacteria did not.

13.2.2 Water Flows

Surface flows can also be a source of water for supply as a source of potable, service water or main water for use in agriculture or industry. Water from the streams is not used in the South Moravian region for drinking purposes. The water flows are not here.

13.2.3 Underground Sources

Underground water sources are generally understood to be sources of good water. The area of the Blansko district is supplied exclusively by scattered underground sources, as is the Břeclav district. The other districts: Hodonín, Vyškov, Brno are supplied both from underground and surface sources. Underground resources in South Moravia, like all underground sources in the territory of our country, are threatened by the long-lasting dry period (last six years). Inventories of groundwater are becoming smaller and smaller due to lack of precipitation, while the sampling is still the same or even greater with the growing economic maturity of the company. An annual problem, for example, is the mass influx of swimming pools in the spring. Although there are rock sites with high groundwater accumulation capacity in the region, such as the upper Svitavy region where the groundwater source for Brno–Březová nad Svitavou or the rock of the Upper Moravian Vltava, the Quaternary of the Morava River, is located in recent years, there have been significant decreases in groundwater levels. Due to poor farmland management and an increasing share of paved areas, water does not have the potential to catch up with subsoil stocks.

One of the longest used underground sources is the source Březová nad Svitavou.

The spring field uses large reserves of cracked groundwater in the chalk layer complex near Březová nad Svitavou, supplemented mainly by the infiltration of atmospheric precipitation into the rock environment.

Of the four aquifers formed here, predominantly separate, two intermediate ones are used.

The mounds of them are collected by two sowing rows. Siphon rows of the first Březov waterworks with 14 drilling uncovered wells of profile 650 and 635 mm depths 17–21 m are placed in a 300 m long barrel with a massive brick lining.

The collecting unit water pipeline II. of the Březov waterworks consists of 28 wells to the depths of 12–18 m, the own wells of which are connected to the ascending branch of a 688 m long water pipeline located in access gallery a monolithic bottom with prefabricated walls and a ceiling.

The deeper aquifer is exploited from the II of the Březov watercourse using seven receiving boreholes of depths of 80–130 m with running submersible pumps whose discharge lines are inserted into a common collection line.

The water-permissible withdrawal from the collecting device of the I. Březová water main is 300 l/s, from the collecting device II. The actual take-off is governed by the current hydrological situation according to the status of the groundwater levels and the water demand for the supply of the consumable.

The water from the collecting units of the two Březov water pipes is brought to a common reservoir in Březová nad Svitavou with a volume of 5000 m^3. This reservoir serves both for the fixing of the hydraulic conditions in the siphons as well as for the operationally necessary accumulation for the control of the water consumption from the springs I and II with the berserker, which both divert water from this reservoir. This method of operation lasts from 1975, when it was under construction II of the Březova water supply pipeline in Březová was completed and put into operation. Originally, the I Birch water mains was operated from the collecting facility to the city of Brno without accumulation [10] (Fig. 13.2).

13.3 Water Supply Systems—Distribution of Drinking Water in the Region of South Moravia

In the South Moravian Region, drinking water is distributed to the population mainly by the Water company joint-stock company (VaS), in its divisions (in the territory of the South Moravian Region): Boskovice, Brno and Znojmo. Another company providing water transport is the Brno waterworks and sewerage system (BVaK), which operate not only in Brno but also manage watercourses and many municipalities in

Fig. 13.2 Springfield Březová nad Svitavou [10]

Table 13.2 Overview of Water company joint-stock company and their administration in the territory of the South Moravian Region

	Division Boskovice	Division Znojmo	Division Brno venkov
Water mains (km)	869	720	744
The number of municipalities supplied	90	109	119
Population supplied	86,775	81,184	117,700

the district of Brno venkov or Blansko. Also, there are spas, waterworks and sewerage Kromeriz, Waterworks and Sewerage Zlín, Waterworks and Sewerage Břeclav.

The Water Company was established in 1993. It is one of the largest water companies in the Czech Republic in the field of water supply and sewerage. The individual divisions provide water and sewerage, drinking water production and supply including substitution, maintenance and repairs of water supply and sewerage, drainage and waste water treatment (Table 13.2).

The Brno waterworks and sewerage system was established in 1992. The main activity is the operation of public water supply and sewerage systems, the production and supply of drinking water, the detection of faults on the water supply network, the layout of water supply and sewerage systems, the inspection of sewers using a television camera. Company perform drafting sewege and rainwater and cleaning in Brno—Modřice sewage treatment plant including sludge disposal. Laboratories of the company are conducting analyses of drinking and wastewater. The water supply system of the city of Brno, including the new Vír regional waterworks, which the company also operates, is also supplied with drinking water to the water mains for Šlapanice and its surroundings, Bílovice n/Svit., Adamov, Malou Lhota, Štěpánovice, Malhostovice and Drásov, Želešice, Rajhrad, Sokolnice, Těšany and other villages adjacent to the southern branch of the Vír Regional Water Supply. The insufficient capacity of the local water resources for the city of Tišnov is complemented by a new supply line from the Vír Regional Water Supply. The length of the administered water supply network is 1415 km, the number of people supplied with drinking water is 410,047.

In the Kroměříž region, the water supply network has been operating since 1993 as the joint-stock company Water supply and sewerage Kroměříž, the source of drinking water is groundwater. The length of the water network being administered is 619 km, and the number of people supplied is 105,891 persons.

In Zlín and the vicinity, there is the water supply and sewerage system Zlín, which manages and disturbs drinking water. The company was founded in 1993. The number of persons supplied with water by this company is 170,138, the length of the administered water network is 1435 km. The water distribution system is provided by the group—Zlín water mains. The advantage of this system is that both water treatment plants, in Klečůvka and the plant in Tlumacov, can represent themselves. The water treatment plant in Klečůvka is able to supply the whole large area of Otrokovice and Tlumačovska in case of emergency. This was confirmed, for example, in the devastating floods of 1997, when Otrokovice and Tlumacov were completely flooded. Should there be an outage on the contrary in Klečůvka, almost all households and businesses in Zlín and the vicinity will supply the water treatment plant.

Region Břeclav has been managed since 1994 by the Water and Sewerage Company Břeclav. The company operates water management facilities in 73 towns and municipalities, supplying them with drinking water to 110,583 inhabitants, the length of the water network in the company's management is 965 km.

Water supply and sewerage Hodonín, a company established in 1994, operates in a region comprising the district of Hodonín and parts of the districts of Břeclav, Vyškov and Kroměříž. Drinking water is drawn from three sources in total: surface water from the water reservoir in Koryčany, groundwater from the quarry of the Morava River between Bzenec and Uherský Ostroh and from underground sources near Moravská Nová Ves. The total length of the network of water mains is 340 km, and the population supplied 136,270.

Water Supply and Sewerage Vyškov is a company operating water and sewage systems with sewage treatment plants on the territory of the Vyškov district. Water comes from more sources, but three are major. Surface water comes from the water treatment plant in Lhota, the underground from the springs in Drnovice and near the Dědice. The company was founded in 1993 and currently manages 628 km of water mains.

The vast majority of inhabitants, municipalities and towns are supplied from public water supply systems, municipalities where the supply of drinking water from the

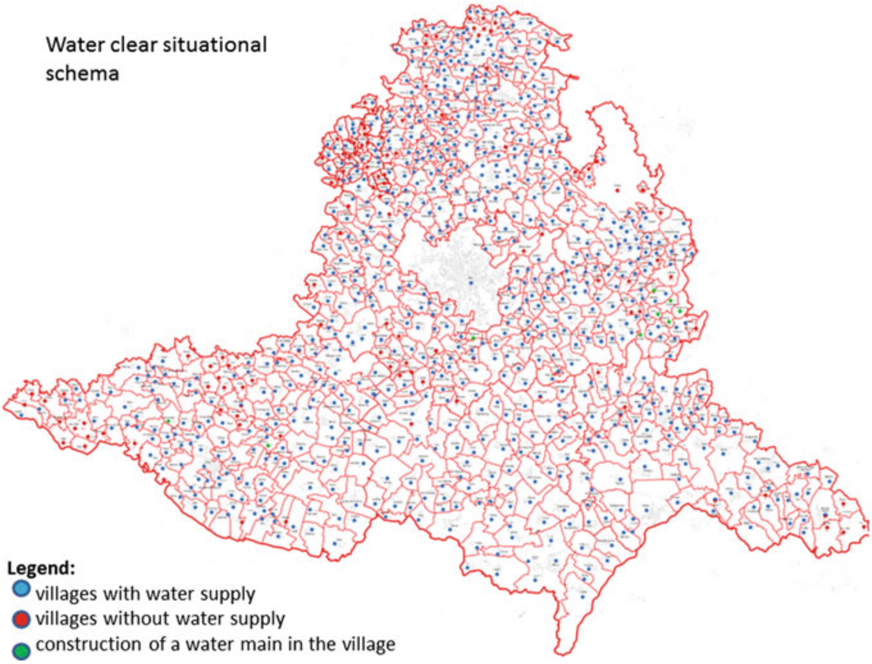

Fig. 13.3 A clear situational scheme of water mains in the South Moravian Region [7]

public network is not yet fully covered, are small municipalities in the north-west part of the region see Fig. 13.3.

South Moravian water companies produced a total of 63.6 million m^3 of drinking water in 2017; the share of quality groundwater was 86.6%. The average consumption is 93 l/person/day, which is the second highest consumption after Prague (109 l/person/day) compared to other regions.

13.3.1 Regional Water Line of Vír

Vír regional supply water systém distributes treated water from the Vírský reservoir. The water is treated in the water treatment plant Svařec. The water pipeline would be built in 1988, and the construction was completed in 2000. The water supply was put into operation in 2002, when the first phase of the Vírský vodovod, part of Švařec—Čebín, was completed, with a length of 47 km. Vodovd is in its route from the water treatment plant Svařec to the Čebín water reservoir and is made of fibreglass pipeline. It is in the reservoir near Čebín north of Brno that water is mixed from Vírský and Březovský water mains.

The water main on its route from the north of the region to the area south of Brno Fig. 13.3 supplies the surrounding villages and other municipalities are still connected. The construction of the District Vírský Vodovod is, thus, still a living building and is constantly expanding.

13.3.2 Březov Water Line

I. Březov feeder

The waterworks was put into operation in 1913. The pipeline is made of cast-iron pipes and is almost all along its length in the closed valley of the Svitavy River, along with roads and railways. In the highly articulated terrain between Blansk and Bílovice nad Svitavou, three massive stoles were pierced for laying the pipeline, the longest of which was 614 m long. The height difference between the groundwater level in the spring and the water level in the Holé Hory reservoir in the city of Brno Lesná, where the feeder ends, is 89 m and ensures a continuous flow of about 264 l/s. Directly from the feeder is water to Adamov and Letovice.

II. Březov feeder

The 55,557-meter self-propelled feeder is made of steel pipes. It was put into trial operation in 1975. The conveyor is led from the reservoir from Březová nad Svitavou and ends in a water reservoir on Palacký hill in Brno. The height difference of the water reservoir levels at both ends of the feeder is 66.50 m and provides a maximum flow of 1140 l/s. Pipeline route is 6× railway, several times Svitavy River and many small streams and streams all along the route.

In 1997, in connection with the construction of the Vír Regional Water Supply, the II the birch duct and the feeder of the Vír Regional Water Supply in the Čebín node. This build allows the mixing of water from the two different water sources in the Čebín water reservoir built within the Vír Regional Water Supply and thus the possibility of qualitative homogenization of the harder waters of the birch and soft water of the Vortice. Furthermore, water is hygienically provided with chlorine dioxide. A part of the mixed water from the Čebín water reservoir is fed back into the piping of the feeder II. water supply system and through the Palackého hill water reservoir to the Brno water supply network. The Čebín pumping station still remains an important node of the system in which the inflow of drinking water from both feeders to the Čebín water reservoir is measured and the outflow to the continuing II. Březov water supply.

Inclusion II of the Březov Water Supply, along with the I Březov Water Supply, a significant complex of quality water resources was created, providing sufficient water for the dynamic development of the whole Brno region and the wider area for many years to come [10] (Fig. 13.4).

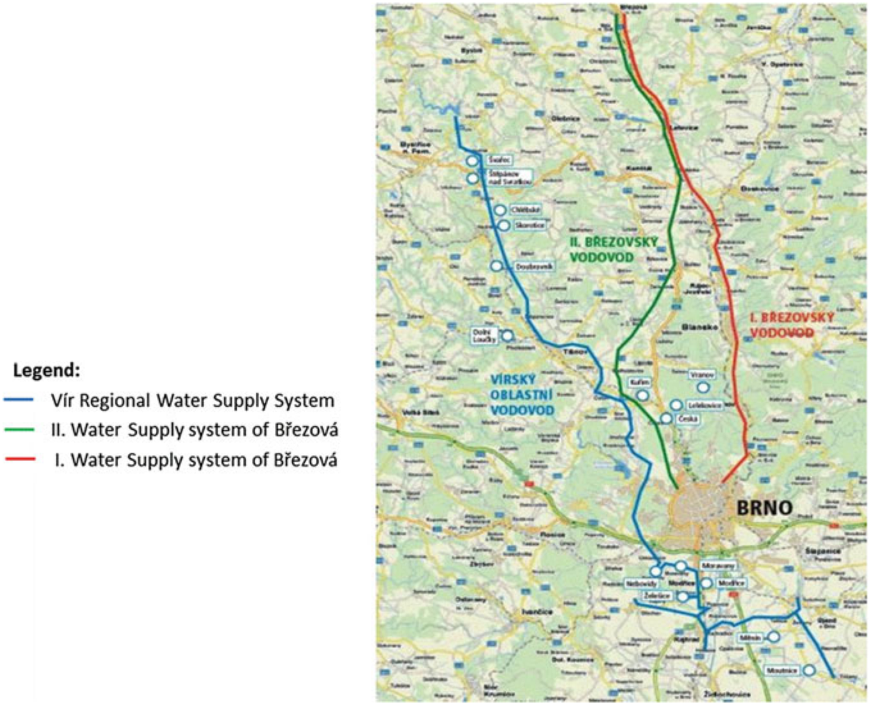

Fig. 13.4 Waterway routes for Brno and surroundings [10]

13.4 Drinking Water Quality

Chemically pure water does not occur naturally, as well as drinking water is a mixture of various substances, minerals, and compounds dissolved in water. The amount of these substances depends on the origin of the water—the groundwater dissolves these substances in the passage through the rocks. Therefore, their content is usually higher than the surface water where the higher proportion of the rainwater with the minimum content of dissolved substances is represented. New research addresses how to protect underground sources from barrier contamination [11].

13.4.1 Springfield Březová nad Svitavou

The quality of the water from the Březová spring is very balanced and meets the requirements of the standard [12]. Which sets out the hygiene requirements for drinking water and hot water and the frequency and scope of drinking water control, as amended) drinking water without modification. The water has a balanced mineral content, a stable temperature of 9–10 °C and is one of the most valuable drinking water for human consumption. Water quality has not changed much since the beginning of the use of resources. However, the influence of anthropogenic activities in the vicinity of the sources has been manifested by unfavourable development of ox disability and, in particular, the concentration of nitrates, when nitrate levels increased to a level of 40–45 mg/l from around 20 mg/l in the 1970s. However, water quality has always been ensured with the abovementioned Decree on Drinking Water.

To maintain the current state of water quality, protection zones of the water source are declared.

13.4.2 Water from Reservoir Vír I

Another important source of drinking water in the region is the Water Reservoir Vír I Water from this reservoir is supplied gravitationally to about 5 km away from the Švařec water treatment plant. The water is free of impurities and undesirable dissolved substances in the treatment plant. The water is filtered on sand filters and charcoal filters, adjusted by pH liming, ozone disinfection and chlorine dioxide (ClO_2) hygiene. The water from the tank is worse in recent years due to the poor water quality of the inflow. Among the most polluted profiles in the basin of the reservoir are the long profiles of the White Creek, which is the tributary of Svratka from the town of Polička above the water reservoir Vír. The stream is extremely polluted, especially municipal sewage, which comes from the sewerage network directly into the flow, is blamed here. Another factor that degrades the water quality in the tank is the overgrowth of cyanobacteria, especially in the summer. Despite these problems, the water from the Vír reservoir is suitable for drinking purposes according to the relevant legislation (Table 13.3).

Raw water in the reservoir has deteriorated in recent years, mainly due to strong eutrophication.

Table 13.3 Selected parameters of raw water quality of the water reservoir Vír I

Parameter	Measured value
pH	7,07
Nitrates (mg/l)	12,63
Total nitrogen (mg/l)	2,75
Phosphates (mg/l)	0,1
Manganese (mg/l)	0,128

Table 13.4 Selected parameters of water quality from some underground sources in Vyškov

	Dědice	Drnovice	Rašovice	Olšany	Kobeřice	Milešovice	Limit according [6]
pH	7,5	7,46	7,29	6,9	7,37	7,49	6,5–9,5
Hardness (mmol/l)	4,73	3,94	4,09	1,64	5,82	2,67	2–3,5
Nitrites (mg/l)	<0,0005	<0,005	0,014	0,006	0,012	0,06	0,5
Nitrates (mg/l)	26,8	5,8	11,5	4,83	1	13,4	50

Table 13.5 Selected parameters of water quality in the Opatovice reservoir

pH	8,1
Hardness (mmol/l)	1,58
Nitrites (mg/l)	0,003
Nitrates (mg/l)	2,4

13.4.3 Vyškov Region

Vyškov region supplies mainly underground sources, the water of which meets the limits given by the Decree on the Quality of Drinking Water. Some parameters of selected underground sources are in Table 13.4. Generally, the water from these springs is harder, contains higher concentrations of calcium and magnesium, but these never exceed the allowed limits.

The only surface source of water in Vyskov region is the water reservoir Opatovice. Parameters of some quality indicators are in Table 13.5.

13.4.4 Kroměříž Region

In this area, groundwater, which is conditioned by ozonisation, is collected, which ensures sufficient quality for drinking purposes. The quality of water supplied to the city of Kroměříž is shown in Table 13.6.

Table 13.6 Selected parameters of water quality in Kroměříž

Parameter	Measured value	Limit according [6]
pH	7,33	6,5–9,5
Hardness (mmol/l)	3,1	2–3,5
Nitrites (mg/l)	<0,02	0,5
Nitrates (mg/l)	5,0	50

Table 13.7 Water hardness scale

Very soft (mmol/l)	0–0,7
Soft (mmol/l)	0,7–1,4
Medium hard (mmol/l)	1,4–2,1
Hard (mmol/l)	2,1–3,2
Extremely hard (mmol/l)	3,2–5,3
Very hard (mmol/l)	>5,3

13.4.5 Blansko Region–Boskovice Region

In the northern region of the South Moravian Region, there is a large number of predominantly smaller underground sources, the quality of which is satisfactory after ensuring health. Since it is groundwater, it is medium to hard to very hard water, for water hardness assessment see Table 13.7.

13.4.6 Zlín Region

Drinking water in the Zlín region flows from the Klečůvka and Tlumačov water treatment plants. The water has to be treated in the form of a chemical–technological process in a water treatment plant. Drinking water in Zlín is usually medium–hard, which is ideal for everyday consumption. In Zlín and around it, every year they drink and consume millions of cubes of water, which come from two main sources of drinking water.

The water for the eastern part of Zlín, surroundings of Vizovice, Slušovice, Kostelec and Fryšták is pumped from Slušovice reservoir and undergoing subsequent treatment in a water treatment plant in Klečůvka. For the western part of Zlín and around Otrokovice and Napajedla, underground water from wells and hydrogeological wells is collected in two areas: Tlumačov forest and Kvasice–Štěrkoviště. This water passes through the treatment water in Tlumačov. As already mentioned, the quality of the raw water collected is reflected in the quality of the reservoir and its catchment area. It is not surprising that the parameters of raw water taken from Karolina, followed by collection from Slušovice, are by far the best.

Other tanks have their specific problems, for example, the Bojkovice reservoir has high levels of manganese in the raw water, which is released during the summer months in the absence of oxygen at the bottom. Iron and manganese cause the taste of drinking water. In terms of these indicators, Karolinka and Slušovice are the best.

13.4.7 Znojmo Region

In Znojmo, where the Znojmo water reservoir is the main source of water, the quality of the drinking water is ensured at Znojmo water treatment plant. The plant has recently been renovated, and water quality is currently secured by filtering through activated carbon, chlorination and the use of UV lamps. Water is roughly as hard to medium as hard to extremely hard see Table 13.7.

13.4.8 Břeclav Region

Three water treatment plants are in operation for the production and supply of drinking water: Břeclav–Kančí obora, Lednice and Zaječí (Table 13.8).

In the South Moravian Region, water for drinking purposes is treated in 157 water treatment plants in total. Overall, the Břeclav and Blansko districts show a satisfactory state of supply to the public with water from public water supply systems. The most unsatisfactory situation is in the districts of Znojmo and Brno–venkov.

Own water supply is done overwhelmingly by group waterworks, connected to significant water sources and, in some cases, interconnected into integrated district supply systems. As there is a large number of inhabitants in the Czech Republic supplied with drinking water from public water supply systems that are connected to sufficient capacity water supply sources, there has not been a more serious problem with the supply of drinking water in towns and larger municipalities during the last two years. On the contrary, problematic problems were in municipalities using local groundwater resources and individual sources (wells). These resources are not able (by way of exception) to bridge the prolonged drought. Quality control of these local resources is also striking, and in the case of household wells, it is almost zero.

For the further development of water management in the region, it is a priority to ensure the qualitative parameters of drinking water and to reduce losses in water mains.

South Moravian water companies generated 63.6 million m^3 of water in 2017 (62.5 million m^3 in 2015), of which water from groundwater accounted for 86.6%.

Table 13.8 Selected parameters of water quality in Břeclav

Parameter	Measured value	Limit according [6]
pH	8,1	6,5–9,5
Hardness (mmol/l)	3,2	2–3,5
Nitrites (mg/l)	<0006	0,5
Nitrates (mg/l)	2,82	50

13.5 Drinking Water Consumption

Drinking water consumption in the Czech Republic has started to fall sharply since 1990, and the consumption of drinking water for households in the last three years increased to about 89 litres per person per day. The development of water consumption in the Czech Republic is shown in Fig. 13.5. The many-year decline was due to a radical increase in water prices. A slight increase in recent years can be attributed to the growing economic strength of society as well as to the increasing share of connected inhabitants in public water supply systems, which is connected to almost 95% of the population. Current consumption also places us in a group of states with lower water consumption.

South Moravian households have the second largest consumption of drinking water after Prague. The development of water consumption for the regional city of Brno is presented in Fig. 13.6. Consumption in brine is higher than the average water consumption in the whole region. In 2016, a person living permanently in the household in the South Moravian Region, which was supplied with water from the water supply, daily consumed 92.9 litres of water a day, Praguers drank another 15 litres of water from the tap. The lowest average consumption in the Zlín Region is 75 litres per person per day [13] (Fig. 13.7).

The area of South Moravia is one of the driest in the Czech Republic, especially in recent years; the precipitation deficit in this area is deepening. This is related to the decrease in water levels in tanks, where water levels in the river cannot be maintained, as the reservoirs provide the missing flow of water in the water, to preserve life in riverbeds and streams. Very significant is also the decrease in groundwater, which is not subsidized by the absorbing water. Another problem is the constantly increasing share of paved areas due to new construction. Areas of arable land, where the water has naturally plummeted, are now converted into impermeable surfaces, and the

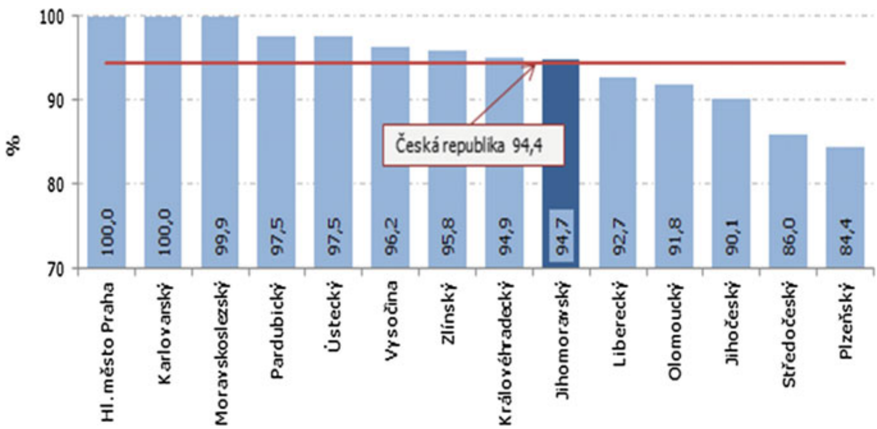

Fig. 13.5 Residents connected to a public water supply

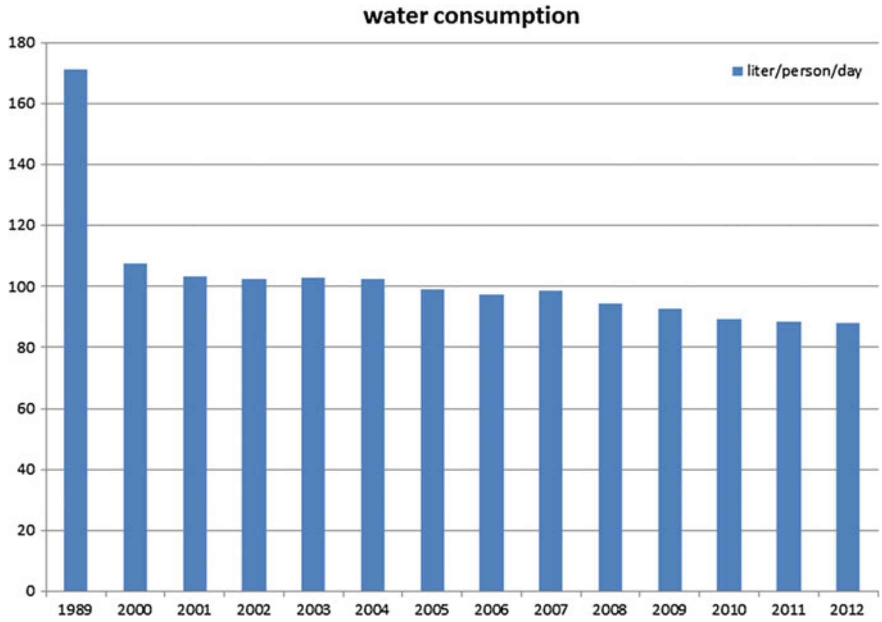

Fig. 13.6 Process of water consumption in the Czech Republic

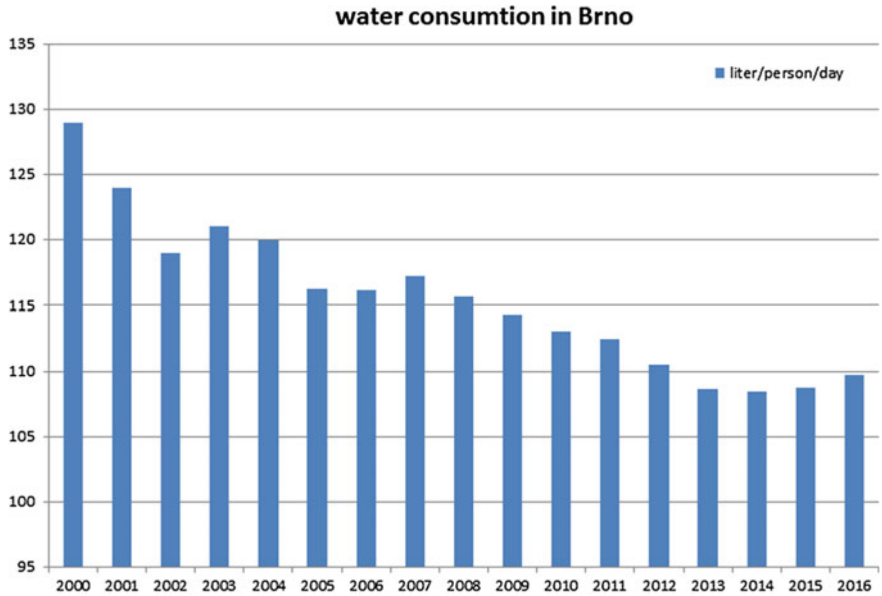

Fig. 13.7 The process of water consumption in Brno City

water is drained through the sewer system directly into the flow channels. Which means that the water does not bounce into the underground. But it is very quickly taken to the waterways where it increases the flows during the rainy season and thus increasing the demands for flood protection. This situation first occurs in shallow underground sources, but it is only a matter of time when water supplies fall in deeper horizons.

Water distribution in South Moravia does not always respect the administrative division, so the parts of some neighbouring regions are included in the text.

13.6 Strategies for Sustaining the Water Supply

The main objectives to ensure the required level of drinking water supply in accordance with the requirements of the European Union are:

- Expansion of the public water supply network, especially in locations where local sources of suitable quality cannot be used. This problem concerns mainly the districts of Znojmo, Brno–venkov and Blansko. These are predominantly smaller municipalities with less than 500 inhabitants.
- Reconstruction and renewal of water mains, which are often in an unsatisfactory condition. The reason is the use of inappropriate material or the age of the water supply. It is necessary to reconstruct the relevant water management objects and to extend the water reservoirs accumulation.
- Enhancement of technological processes to ensure the required level of drinking water to meet the relevant legislative requirements [14].

These measures are already being implemented. In municipalities around large cities, water mains are spreading mainly due to the dynamic development of housing construction.

This implies both the requirements for the construction of the distribution network, but also the increase of the existing network capacities and the increase of the accumulations in the water reservoirs.

In major cities and in the centre, attention has been focused on the renovation and reconstruction of the water mains.

Installations for potable water treatment plants are also being continuously modernized.

Another important strategic measure is the interconnection of water systems. Ensure substitution of individual sources and ensure continuity in water supply even when disconnecting or closing some water management parts and objects on the network.

13.7 Conclusions

With water resources, we have to constantly learn to handle very gently, trying to continually improve this skill. Come with new solutions to reduce water consumption and use it efficiently, expand opportunities and strategies for rebuilding water supplies and increasing both quality and quantity. In recent years, climate change has also been reflected in legislative measures in the Czech Republic. Measures for water retention in the countryside and for the management of rainwater are supported, in the form of subsidy titles. Therefore, these tendencies should be supported, extended and legislatively enforced. It is also necessary to map the existing resources in detail and, if possible, to seek ways of recovering both surface and underground resources. One possibility is detailed monitoring of underground aquifers and sustainable management of their use [15].

The problems faced by South Moravia in recent years are not just a local problem, it is a worldwide problem of the twenty-first century.

Lack of water has undue consequences for human society; one of the consequences is also the limitation of agricultural production. Lack of water will affect what we eat, how we adjust our food, who has enough food and even the ultimate taste of food. Our behaviour and our approach to water resources to use water and its consumption will need to be radically changed.

The South Moravian Region has so far reliable supplies of drinking water, both surface water and groundwater. However, it is evident that the influence of drought is slowly reflected both on the quantity and quality of water. Undertakings that have water and water resources management apply a strategy of interconnection and duplication of individual supply systems, trying to ensure water distribution in the event of a failure of individual regional sources. Such a water-related water supply solution for drinking water supply is far from obvious in the Czech Republic.

Quite often, it seems to be an effective tool to get an advanced company to water, but also to discuss water consumption, to raise prices for water. However, companies that are involved in water distribution, management and production of drinking water are often foreign corporations, which make a significant profit. Then, it is very speculative if the money that is spent is back spent on sustainable water management. According to the World Resources Institute's analysis, a total of 37 countries in the world are currently facing an extremely high level of water stress. For many, it could certainly be an interesting opportunity to invest in the life-giving fluid. Investments in flood-traded funds that are built on the water do not mean that the value of the fund depends on the actual price of water, but it depends on the price of the shares of companies dealing, for example, with the saving or treatment of water and, last but not least, delivering new technologies to the water industry.

13.8 Recommendations

In the past, the Czech Republic, in the face of extreme floods, was preparing to protect itself from increased flows and the occurrence of drought was greatly underestimated. Scientists have warned that floods and drought are two sides of the same coin. There is finally a public debate on the need for water management in the countryside and water resources. It is necessary to prevent the rapid flow of water from the landscape, by appropriate measures, such as the revitalization of watercourses, the construction of reservoirs, pools and wetlands. Last but not least, the change in farming, both on agricultural land and forests. Particularly in the catchments of drinking water supply systems, it is necessary to strictly observe the measures for improving the water absorption into the subsurface layers, by keeping the water in the landscape. A possible tool for improving the situation is artificial water infiltration [16]. Scientists have been inspired by Israeli experts in this context. In the Middle East, water is captured in this way for a long time. South Moravia is the most affected area in the Czech Republic, so the implementation of this measure is about to be done in the South Moravia region and in Břeclav.

In places where the construction of a new building is underway, rainwater management is already required according to the legislation. Rainwater is not discharged through a pipeline into water courses or wastewater treatment plants. Capture tanks and trenches are built to catch it or use it for further use.

These measures, and in particular the building of nature-friendly measures, should be administratively and mainly financially supported by state subsidies.

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Chapter 14
Ecosystem Services and Disservices of Watercourses and Water Areas

J. Schneider, Ž. Kalasová and J. Fialová

Abstract Ecosystem services and disservices of the watercourse network in the Czech Republic are not systemized in detail yet. It is a pity for the Czech Republic operates long-term monitoring of physical, chemical and biological characteristics of watercourses of all orders. A large part of these data is publicly accessible and serves as the basis for water management planning and management measures. These data are also used for the work of numerous major governmental institutions—the catchment area management establishments, the Czech Hydro-Meteorological Institute, the T. G. Masaryk Water Research Institute, the Academy of Science of the Czech Republic and academic research sites. Tow complex and general assessments of ecosystem services on the national level have already been made by Seják et al. and Vačkář et al. However, a complex system already developing on the international scene allowing for practical applicability of the approach is missing in our country. This chapter, therefore, offers a brief cross-sectional view of the application of ecosystem services in water management and options of application of this system in the Czech Republic.

Keywords Ecosystem function · Ecosystem services · Ecosystem disservices · Blue infrastructure

J. Schneider (✉) · Ž. Kalasová
Department of Environmentalistics and Natural Resources,
Faculty of Regional Development and International Studies,
Mendel University in Brno, Třída Generála Píky 2005/7, 613 00 Brno, Czech Republic
e-mail: jiri.schneider@mendelu.cz

J. Fialová
Department of Landscape Management, Faculty of Forestry and Wood Technology,
Mendel University in Brno, Brno, Czech Republic

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14.1 Introduction and Overview

14.1.1 Ecosystem Services Versus Ecosystem Functions

Ecosystem services are a dynamically developing concept, and one of the main concepts of currently applied ecology, environment protection, environmental management and accounting and the concept of sustainable development. The term ecosystem service connotes benefits provided by nature to human society. They are biophysical processes intentionally or spontaneously used and influenced by mankind. Ecosystem services represent an interconnecting element between biodiversity and human society. Biodiversity may be a determining element of resilience or survival of ecosystem services.

Ecosystem services are usually divided into four categories: supply service, support service, regulating service and cultural service.

- Supply services can be imagined as material or production aspects of the environment, in particular, agricultural crops, farm animal produce, fish, wood, water etc.;
- Support services provide support to the provision of and production by individual ecosystem services, i.e. soil genesis, photosynthesis, primary production, nutrient (element) circulation and water circulation;
- Regulating services represent the results of ecosystem processes leading to direct use or consumption. They include effects on the quality of the atmosphere, climate, regulation/effects on the hydrological regime, erosion regulation, self-cleaning water quality and waste elimination, disease regulation, effect of past occurrence or regulation of natural disasters;
- Cultural services are understood as intangible benefits of the ecosystem existence, i.e. spiritual and religious values of ecosystems, cultural diversity, value for education and upbringing, aesthetic values, cultural heritage or assets for recreation and ecotourism.

The concept of ecosystem services is sometimes confused with the notion of ecosystem functions. The latter, however, denotes biophysical relations in the nature existing regardless their benefits for the human society. On the other hand, ecosystem services are ecosystem functions with a positive impact on human society (Fig. 14.1).

14.1.2 Ecosystem Disservices

Ecosystem services are opposed by ecosystem disservices (from now on also EdS). They do not have their established Czech equivalent yet. They can be understood as ecosystem services with a negative effect on human health or services creating loss and damage. A typical example may be trees planted along the riverbank in the city as a source of allergens.

Fig. 14.1 Dams and their lakes are a typical example that final environmental benefits of water ecosystems for human society are not the only result of positive impacts, but also ecosystem disservices—e.g. interruption of migration corridors or water pollution by cyanobacterias. Brněnská přehrada Dam. Photograph: Jiří Schneider

Ecosystem disservices must always be viewed from the angle of the negative impact on human society they represent. These are the functional effects of ecosystems negatively affecting human society values. These values include material as well as immaterial values, such as impacts on assets, services, spiritual values, use and natural elements with relevance for people.

The anthropocentric aspect is also very important. When we talk about the negative effects of some ecosystems or components on others, it is the man that gives them value, without which they are not more but ecosystem functions forming natural parts of nature processes.

To distinguish ecosystem services from EdS may sometimes be problematic, depending on the perspective from which you view them. See, for example, the tree planting in cities. The trees as ecosystem service increase biodiversity and provide shadow in hot summer days and increase the aesthetic value of the urban landscape. From the negative point of view, they are a source of allergens, their fallen leaves may represent obstacles to rainwater draining, or their immediate environment may represent a night shed for violent attackers. Thus, they may increase the risk for passers-by etc.

Ecosystem burdens are understood as ecosystem processes and functions with a negative effect on human wellbeing or causes of loss and damage to humans [1, 2].

Another significant step is the setting of indicators of the transformation of functional effects to EdS. Their identification requires fulfilment of the following condition—they represent an impact of functional effects viewed by people as negative. There are several aspects to this condition:

(1) Different social groups can hold different opinions on the same thing. A good example may be rotten wood in the forest—a positive element if viewed from the angle of environmental stability, but an element reducing economic production of the forest from the viewpoint of a producing forester;
(2) The number of affected individuals making the EdS significant;
(3) The current level of knowledge may not be sufficient to recognize an EdS;
(4) The financial value of EdS is often given by the value of the human property (potentially) affected by the EdS. A good example may be house building in inundation areas;
(5) Is the environmental burden represented by the potential risk or by the actually suffered damage? See, for example, toxic mushrooms—people do not have to pick them. An opposite example may be represented by big predators, such as bears, that can represent a risk for forest visitors. Even this may differ according to the level of effect of man on the bear and its environment. For example, in virgin forests versus city forests where the bears are less wild and are, for example, used to pick waste food from waste bins. Another good example may be the already mentioned trees in cities as a source of allergens. This EdS and its value depend on the (potential) size of the population allergic to the given tree. Moreover, please note that, at the same time, city greenery contributes to improved air in the city, i.e. reduced stress on human organism as a source of allergy development;
(6) Sources of EdS can but need not be present. For example, dig excrements in parks are not their natural component and depend on several conditions: (a) presence of dogs; (b) irresponsible conduct of their owners; (c) absence of park care. One thing is clear, dog excrement presence in parks (albeit not caused by the ecosystem but by man) is an EdS;
(7) Additionally, there is the measure. Some EdS follow from the very essence of the ecosystem existence, and their impact (or their potential risk) is broad and more or less permanent. On the other hand, the above-mentioned dog excrements may be short term and confined to, for example, a couple of square metres and dependent on human (non)activity.

Shackleton [3] mentions a couple of attributes typical of EdS.

1. EdS spatial measure varies;
2. EdS temporal horizon varies;
3. EdS may be interactive through direct or indirect feedback;
4. Many EdS include threshold phenomena and nonlinearity;
5. EdS impacts are not equal across socio-economic groups;
6. EdS perception differs by context;
7. EdS interfere with human well-being;
8. EdS impact may be long term;

9. Frequency and occurrence may vary widely;
10. EdS impact may be extremely unexpected.

A lack of attention to ecosystem burdens and their addressing is not sustainable in the long run. Their existence must be considered in the ecosystem service management for they are real and their non-consideration may lead to incomplete results, mainly in the case of efforts for enumeration of ES and EdS value. Another aspect is their clear negative impact on human health. A good example may be a study by Ango et al. [4] describing harvest loss caused by wild animals or direct threat for humans represented by the occurrence of a certain type of large carnivorous predators [5], etc. Non-consideration of environmental burdens might cause inaccuracy of presentation of direct positive relations between ecosystem services, biodiversity and human health [3].

14.2 Evaluation of Ecosystem Services in the Czech Republic

To classify ecosystem quality, a list of 192 biotope types was compiled and called 'Natura 2000 + BVM'. The classification is based on biodiversity evaluation by biotope valuation method (BVM) pursuant to Seják, Dejmal et al. [6]. The evaluation used landscape cover mapping by Corine–LC (scale 1:100,000). Thanks to the accurate representations of the Natura 2000 + BVM categories in the Corine-LC classes the evaluation was possible for natural, close-to-nature as well as anthropogenic biotopes for the whole territory of the Czech Republic. The classification was followed by calculation of percentages of incidence of Natura 2000 + BVM biotopes in the individual Corine-LC classes [7]. Ratings for the 192 biotopes were subsequently calculated by the biotope valuation method (BVM) [6].

For example, the class of Corine-LC 'Watercourses and waterways' received scoring 23.14/m^2 and monetary value of 286/m^2. The class called 'Water areas' was rated 18.67/m^2, with the monetary value calculated as 230.8/m^2 [6].

The main purpose was to quantify obvious ecosystem functions and related services. Table 14.1 shows the selected research results (Table 14.2).

Another method proposed for ecosystem service evaluation is the methodological framework of integrated evaluation of ecosystem services in the Czech Republic pursuant to Vačkář et al. [9]. This concept of ecosystem service evaluation assumes that one ecosystem provides more services in synergy or in other cases, the services may be competitive, i.e. mutually exclusive [9]. The methodology is based on ecosystem classification pursuant to the consolidated layer of ecosystems (CLES) of the Czech Republic. The method is based on a couple of principal research methods, including value transfer, biophysical evaluation of ecosystem services, economic evaluation of ecosystem services and expression of the social value of ecosystems. This methodology was developed on the basis of the 2020 EU Strategy for Biodiversity, asking the

Table 14.1 Calculation of monetary values of selected ecosystem services [7]

Function group	Area	Ecosystem services (CZK/m^2/year)				Summary of ecosystem services	
		Climate service	Small water cycle support	Production of 0_2	Biodiversity support	Relative sum (CZK/m^2/year)	Total sum (billion CZK/year)
Water areas	675	1680	1425	623	12	3740	2524
Marshland	23	2240	1853	74	36	4202	98
Other wetlands	364	2240	1853	760	26	4878	1775

Table 14.2 Survey of economical values of ecosystem services relevant to the Czech Republic (EUR/ha) [8]

Service category	Ecosystem service	Mean value (EUR/ha)
Supply	Biomass production	421.39
	Fish production	107.54
	Game production	9.91
	Non-forest products	57.23
	Wood mass production	6912.09
	Water production	32.43
Regulating	Air quality regulation	266.33
	Climate regulation	4015.78
	Disaster regulation	8456.19
	Erosion regulation	5766.57
	Nutrient regulation	200.1
	Pest control	7.31
	Pollination	1378.76
	Water draining regulation	1373.14
	Water quality regulation	1210.67
Cultural	Aesthetic value	5971.94
	Recreation	2190.52

member states to map and assess the status of ecosystems and their services within their territories.

With regard to the classification of cultural services of ecosystems, there is the method of evaluation of recreational effect of watercourse adaptations [10]. The method synthesizes the following existing methods:

- Evaluation of revitalization measures by Langhammer [10], method of evaluation of implemented revitalization projects—selected rivers and small water reservoirs by Vrána, Dostál and Vokurka [10], methods of riverbank condition assessment—the quality of riverbank index QBR and the method of evaluation of the current status of vegetation around watercourses by Šlezingr and Úradníček [10];
- Assessment of the effect of designed building, activity or change of land use on the landscape by Vorel et al. [10];
- Evaluation of the recreational potential of the landscape and tourism—TERPLAN method, methodology pursuant to Vepřek [10] and methods pursuant to Bína [10].

These syntheses are summarized in an evaluation table where the rows represent the individual elements of the river and the riverside growth (natural and manmade) and the columns the individual recreational activities which may be implemented in the area. The classification includes effects of the individual elements on the possible implementation of the individual recreational activities with the overall assessment. The method was applied in the context of the project of RaFa—Increase of awareness and promotion of the role of forest in the landscape and close-to-nature river basins in urban areas as part of ecosystem services of catchment areas, evaluating 30 cities and a hundred of river sections across the Czech Republic.

14.3 Ecosystem Services and Disservices of Watercourses and Water Areas

Ecosystem services and disservices of water courses are not confined to the river basin but also include riverbank and accompanying growth, the related valley or even the whole catchment area.

Watercourses are a significant natural component. The landscape and its rivers represent an inseparable part of the environment. Moreover, that is even though the river network in the Czech Republic does not include any large-stream rivers, but rather small rivers, springs and streams. Even they are, however, of great environmental relevance for their support of specific hydrological, chemical and biological processes. Freshwater ecosystems are by nature directly interconnected with dryland ecosystems within their catchment areas, including wetlands, and consequently, coastal and sea waters.

Nearly 80% of the European watercourse network is represented by small streams and springs. Even they are, however, of great environmental relevance for their support of specific hydrological, chemical and biological processes [11]. Freshwater ecosystems are by nature directly interconnected with dryland ecosystems within their catchment areas, including wetlands, and consequently coastal and sea waters.

A positive aspect is the slow but continuous understanding of the river process and the natural functions of river valleys.

According to Martin-Ortega [12], the aquatic environment creates a unique context from regulation to cultural service provision, thanks to which it is possible to express the status of the natural capital and flows between the various ecosystems and effects on human health. Costanza [13] says that the relative value of ecosystem services expressed in hectare/year is very high in the case of river valleys. The author mentions $8498 per ha/year. When comparing global biomes, the river valley ranks third after river deltas and mangrove growths.

Ecosystems are connected to the hydrological cycle in the catchment area, such as water cleaning, water retention in the landscape or climate regulation [14]. Most of these ecosystems are directly valued and quantified but some of them, especially with regard to the regulating and support services, are hard to express in terms of financial value. The instrument of the environmental policy of the European Union, the Mapping and Assessment of Ecosystems and their Services (MAES), is developed on the basis of cooperation of the European Commission, the European Agency for the Environment and the EU member states (hereinafter together just the EU). The project has mapped ten EU cities with regard to ecosystem services.

The main aspects affecting the quality of freshwater ecosystems include water pollution, excessive water consumption and changes in basins affecting water morphology and flow rates [15]. Rivers and lakes are often adapted to reflect requirements of agriculture and urbanism. Also, the climate change reflects in the hydromorphological condition of rivers—in winter, the flow rates show a short-term increase while in summer, they are generally reduced. The consequences include long-term droughts, increasing water temperatures in rivers and lakes and reduced ice crust [16]. These manifestations show a clear impact on the ecosystem services of the river environment. Water quality is affected by the reduced dilution of pollutants and the increased temperature stimulates algae growth in eutrophication affected areas.

Some authors maintain that there is still incomplete understanding of how exactly biodiversity affects ecosystem functions and services of water systems [17–20]. The result is a broad range of expert literature references on the effects of biodiversity on selected which not always call them ecosystem services or functions.

Table 14.3 depicts the individual categories of ecosystem services connected with the river basin area.

Table 14.3 The main water-related services provided by ecosystems in a typical watershed [21]

Provisioning services	Regulating services
• Freshwater supply • Crop and fruit production • Livestock production • Fish production • Timber and building materials supply • Medicines • Hydroelectric power	• Regulation of hydrological flows (buffer runoff, soil water infiltration, groundwater recharge and maintenance of base flows) • Natural hazard mitigation (e.g. flood prevention, peak flow reduction and landslide reduction) • Soil protection and control of erosion and sedimentation • Control of surface and groundwater quality
Supporting services	**Cultural and amenity services**
• Wildlife habitat • Flow regime required to maintain downstream habitat and uses	• Aquatic recreation • Landscape aesthetics • Cultural heritage and identity • Artistic and spiritual inspiration

14.3.1 Ecosystem Services of Blue Infrastructure, River Landscape and Water Areas

Water elements in the landscape and urban areas represent a significant source of ecosystem services, but often also burdens. These elements also include watercourses and related surroundings in urban areas. The river area definition draws from the definition of the river landscape. The river area can be defined from this point of view as the space of the river basin, the river sediments (the alluvia) and the riverbank (riparial) zone as the transition zone between the dryland and the water component of the river landscape. An example of ecosystem services of the river area may be the provision of drinking and service water, water retention in the landscape, fishing, flood protection, water quality maintenance, water draining regulation, etc.

The aquatic environment forms a unique basis for the process from regulation to cultural service provision thanks to which the natural capital status can be expressed by comparison between various ecosystems. The relative value of river ecosystem services expressed per hectare/year is very high. When comparing global biomes, the river valley ranks third after river deltas and mangrove growths.

Ecosystem services of the river landscape include:

- Plant and animal production, i.e. wood and fodder increment;
- Fish and game production;
- Landscape retention able to attenuate flow rate extremes;
- Retention of nutrients and sediments;
- Recreation by the river;
- Carbon stabilization and sequestration;
- Climate cooling and wetting;
- Increase of biodiversity.

Water areas include ponds, lakes, water reservoirs, dam lakes, wetlands, marshlands, etc.

Ecosystem services of rivers and other water areas are very similar with only a few different aspects. Although lakes and wetlands in the Czech Republic are small in their surface area, their significance is unrivalled. There are many ponds and small water reservoirs in the territory of the Czech Republic.

As already mentioned, wetlands represent a specific ecosystem dependent on landscape processes. The proposed methods of evaluation of wetland ecosystem services thus include not only cultural characteristics but also environmental function attributes. Significant aspects include hydrology (periodicity of flooding, water depth and water saturation), water physical and chemical parameters (such as oxygen level, accumulation of organic substances, pH, toxic substances, the redox potential and the nitrogen cycle) and plant populations and assessment of plant adaptation to the flooded environment. There is a methodology based on similar parameters, the wetland evaluation technique (WET) [22]. Another method of wetland ecosystem service evaluation [23] includes also soil classification (organic substance levels, biotope for invertebrates, total nitrogen level, water in pores and nutrient levels). In the case of plants, the classification criteria include vegetative cover density, plant height, biomass and numbers of varieties. The same method also classifies animals, invertebrates, fish population and bird incidence.

Ecosystem services provided by wetlands include:

- Flood control;
- Groundwater stock replenishment;
- Bank stabilization and storm protection;
- Sediment and nutrient retention and transfer;
- Water cleaning;
- Reservoir for biodiversity;
- Cultural value;
- Recreation and tourism;
- Climate change mitigation and adaptation to it.

Of course, not all ponds, lakes and wetlands provide the same ecosystem services. All depends on their type, size and location. Ecosystem services with allocable economic value are easier to identify. In the case of water areas, these include commercial and recreational fishing, existence of hydropower plants, etc. The ecosystem services with spiritual, historic, aesthetic and other similar values are hard to express in terms of financial value (Fig. 14.2; Table 14.4).

14.3.2 Sociological Approach to Ecosystem Services and Functions of Hydrological Network

Water has been part of human life since times immemorial. Urban settlements were intentionally established near watercourses. The main reason was to have a source

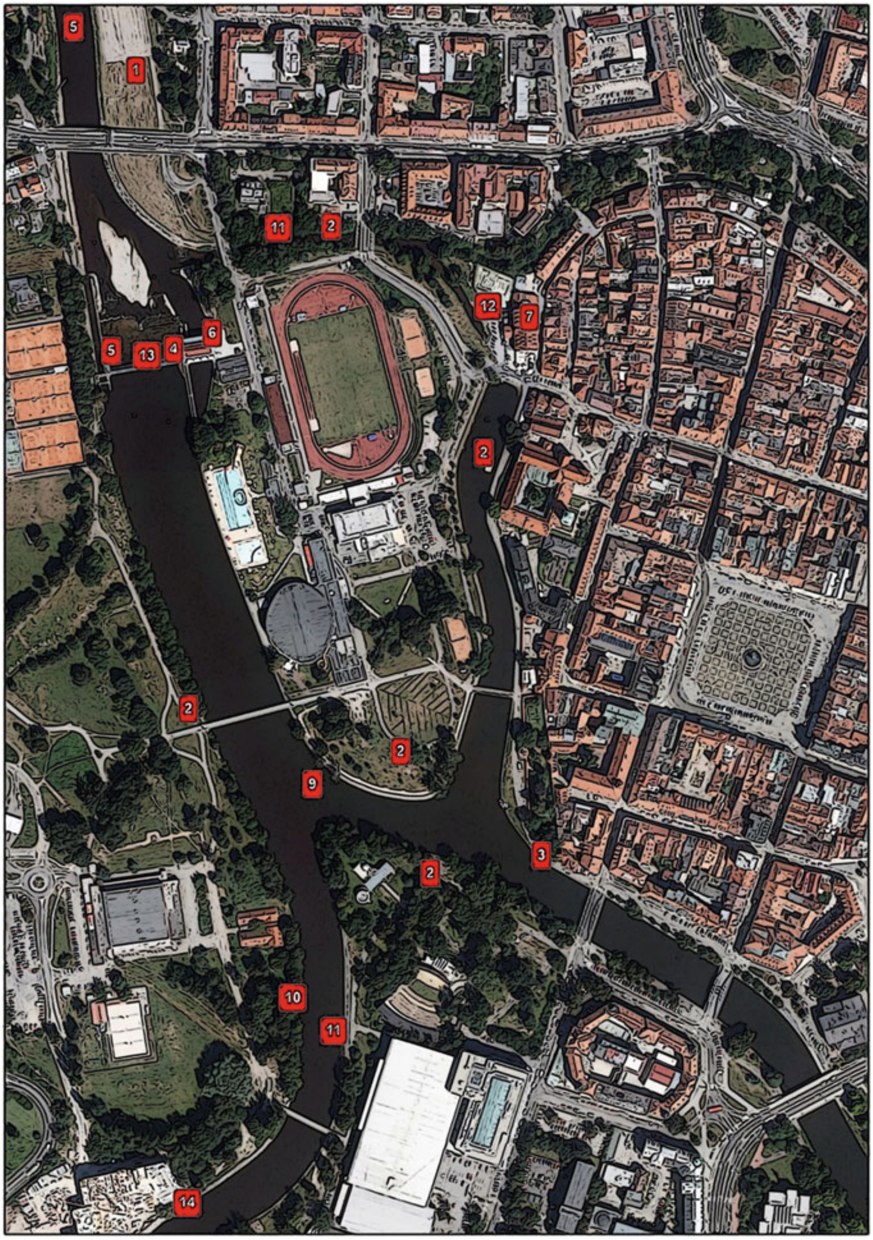

Fig. 14.2 The main functions and services of an urban river space. Legend: 1—flood control; 2—recreation opportunities; 3—fishery (food supply); 4—stream (water flow) control; 5—navigation; 6—hydroenergy; 7—culture and history (water mill); 8—modification of urban space; 9—(micro) climate regulation; 10—biodiversity; 11—biocorridor; 12—water supply; 13—erosion control; 14—water purification

Table 14.4 Watershed services and examples of indicators of the state of services and sustainable use levels [21]

Watershed services	Service attributes	State indicator	Sustainable use indicator
Provisioning services			
Water supply	Precipitation, infiltration, soil water, retention, percolation, streamflow and groundwater flow	Water storage capacity (m^3/m^2)	Discharge (m^3/year)
	Biotic and abiotic effect on water quality	Pollutant concentrations	
Food provision	Crop, fruit and livestock production	Agricultural water use (m^3/ha)	Maximum sustainable water use for irrigation (m^3/year)
	Edible plants and animals (e.g. fish, algae and invertebrates)	Fish stock (kg/m^3)	Net productivity (kg/ha/year)
Non-food goods	Production of raw materials (e.g. timber and reeds)	Amounts available (kg/ha/year)	Maximum sustainable harvest (kg/ha/year)
	Production of medicines		
Hydroeletric power	Flow for energy	Storage capacity of riverbeds and lakes (m^3/km^2)	Maximum sustainable energy production (kWh/year)
		Slope (deg), elevation (m)	
Regulating services			
Regulation of water flows	Retention of rainfall and release (especially by forests and wetlands)	Infiltration capacity (mm/h)	Baseflow volume (m^3/year)
	Water storage by rivers, lakes and wetlands	Water storage capacity of soils (m^3/m^2)	

(continued)

Table 14.4 (continued)

Watershed services	Service attributes	State indicator	Sustainable use indicator
	Groundwater recharge and discharge		
Hazard mitigation	Reduced flood peaks and storm damage	Maximum natural water storage capacity (m^3/m^2)	Size (km^2) and economic value (US$/$km^2$/year) area protected from flooding
	Coastal protection		
	Slope stability		
Control of soil erosion and sedimentation	Protection of soil by vegetation and soil biota	Infiltration capacity (mm/h)	Soil loss (kg/ha/year)
		Slope length (m)	Sediment storage (kg/ha/year)
		Barren land (%)	
Water purification	Reduced siltation of streams and lakes	Nitrogen amount (kg/ha)	Denitrification (kg/ha/year)
	Nutrient uptake and release by ecosystems	Total dissolved solids (kg/m^3)	
	Removal or breakdown of organic matter, salts and pollutants	Electric conductivity (μS/cm)	
Supporting services			
Wildlife habitat	Wildlife and nursery habitats	Resident and endemic species (number)	Increase or decline in species population size (number)
		Surface area per ecosystem type (ha)	
Environmental Flows	Maintenance of river flow regime	Area of critical habitats (ha)	Fish species and population
		Discharge for each season (m^3/day)	Total fish catch (t/year)
Cultural and amenity services			
Aesthetic and recreational services	Landscape quality and features	Stated appreciation	Houses on lakeshore (number/km)

(continued)

Table 14.4 (continued)

Watershed services	Service attributes	State indicator	Sustainable use indicator
		Recreational value (e.g. Entrance fees (US$/visit)	Visitors (number/year)
Heritage and identity	Landscape features or species	Cultural significance and sense of belonging	Visitors (number/year)
			Pilgrims (number/year)
Spiritual and artistic inspiration	Inspirational value of landscape features and species	Books and paintings using watershed as inspiration	

Fig. 14.3 Landscaped embankment of the Ostravice River in Frýdek-Místek as a space for recreation and social interactions. Photograph: Ivana Lampartová

of drinking water, but the watercourse was also used as the source of energy for mills, wood transport, etc. Water also created space for architectural developments in terms of bridges and embankments. Rivers were and continued to be a major element of urban area composition. A river passing through the city centre creates an ideal opportunity for recreation and social interactions of the citizens (see, for example, the Ostravice River in Frýdek-Místek) (Fig. 14.3).

14.3.3 Ecosystem Disservices

Unlike ecosystem services, ecosystem disservices do not have any clearly defined classification. One of the few classification attempts is represented by the categories defined by Escobedo [24], Von Döhren and Haase [25]:

(1) Health area;
(2) Economic area;
(3) Environmental area.

An example of watercourse ecosystem disservices may be river basin regulation to obtain water flow generated energy. The regulation bears negative consequences on the natural hydrological regime and freely flowing water. This in effect changes the natural river environment and biota. Another consequence may be the occurrence of animals which may carry various diseases (for example, gnats in the case of water areas), or water plants initiating allergic reactions or potentially toxic. Wild green areas are non-aesthetical and may hide violent attackers [3]. A similar example may be represented by renewed wetlands, which in the terms of EdS support occurrence of diseases in some parts of the world, such as malaria or schistosomiasis [26]. Also, physical manifestations of animal presence are often perceived as ecosystem burdens, see, for example, animal excrements, intense bird twittering, frog quacking, etc. [27]. Another example may be intensive agriculture, especially the use of fertilisers and the impact on groundwater quality.

What needs to be emphasized is that most ecosystem disservices are seen as such by human perception. While some see overgrown riverbanks as a source of biodiversity and a refuge for animals, others see these areas as non-aesthetical. They are also rejected as an environment for gnat reproduction or habitats of other animals which may be perceived negatively.

The main examples of watercourse and water area ecosystem disservices may include

(1) Flood damage;
(2) Erosion of banks;
(3) Transport of solid materials and sediments;
(4) Human fear and phobias of various animals (e.g. snakes);
(5) Unpleasant plant vegetation, e.g. nettles and dense scrub;
(6) Dangerous and unpleasant bottom covers—stones and mud;
(7) Obstacle to landscape and urban area negotiability;
(8) Water pollution as a source of an unpleasant odour;
(9) Water pollution as an aesthetic issue;
(10) Chemical pollution of water as a health risk;
(11) Biological pollution of water as a health risk;
(12) Bio-corridor and environment for harmful organism spread in general;
(13) Risk of drowning;
(14) Waterlogging of adjacent soil profile;
(15) Mechanical damage caused by icebergs;

Fig. 14.4 The wetland nature of water areas—positive with regard to biodiversity and environmental stability—is a significant producer of ecosystem disservices as a source of gnats and other unpleasant organisms, as an obstacle to the landscape negotiability and forest management, as a non-aesthetical element for the general public, as a source of unpleasant odour from rotting residues and polluted water and as a source of disturbing noises such as frog quacking. Photograph: Jiří Schneider

(16) Maintained or unmaintained (adapted versus natural) river basin as an aesthetic issue;
(17) Source of disturbing animal noises (Figs. 14.4, 14.5 and 14.6).

Fig. 14.5 The regulated Labe in the city of Hradec Králové—as an example of subjective perception and the paradox of ecosystem disservices. The river binding between firm walls is part of flood protection and the reinforced silting permits recreational enjoyment close to the water surface. On the other hand, the straightened and monotonous river basin is aesthetically dull and makes the Labe a canal more than a river. Ecosystem disservice (the non-aesthetic nature) of the watercourse is, therefore, a consequence of anthropological activity—river basin adaptation—done to suppress another ecosystem disservice (erosion and floods). Photograph: Jiří Schneider

14.4 Conclusions and Recommendations

A complex (and detailed) evaluation of ecosystem services and burdens provided by watercourses has not yet been performed in the Czech Republic. And yet there is a number of sources for the evaluation provided by research institutions. For example, the TGM Water Management Research Institute, the catchment area management establishment, universities (Mendel University in Brno, South Bohemian University in České Budějovice, University of J. E. Purkyně in Ústí nad Labem) as well as interest groups (the Czech Fishermen´s union, the Czech Ornithological Union etc.).

At the same time, there are ready-to-use general methodologies for evaluation of ecosystem services [6, 9], so far dealing with complex but only general evaluation of ecosystem services of all types of ecosystems existing in the Czech Republic.

Czech legislation and administration also knows a number of documents for water management and territorial planning where ecosystem services of the blue–green infrastructure might be applied—catchment area plans, regional forest development plans, regional development principles, zoning plans, territorial analysis document, etc. Another large potential application area is the EIA process where the value of ecosystem services can be used for initial investigation as well as for the actual documentation preparation.

Fig. 14.6 Another risk factor is represented by iceberg formation in spring thaw of frost-bound rivers. The ice may clog the basin and cause flooding of the surrounding area. The ice may also be washed off into the environment and cause mechanical damage of for example riverbank growth. Photograph: Jiří Schneider

The above-mentioned suggests the need for further enlightenment and above all cooperation along the following two axes:

(1) Between basic research in the area of monitoring of ecosystem elements and processes (biological, climatologic and hydrologic) and applied research focused on support for the decision-making processes, zoning planning, environmental management and environmental accounting by means of ecosystem services;
(2) Between applier ecosystem service research (within the scope of point 1) above and public administration for practical applications of the mechanisms of assessment of ecosystem services in state administration and the decision-making process

For the implementation and further use of stakeholders, it is necessary to use the full range of tools:

(1) Awareness raising and popularization—focused on the professional and general public;
(2) Processing of clear and understandable, scientifically published and accepted methodologies, applicable in the conditions of the Czech Republic;
(3) Incorporation into legislation;

(4) Incorporation into conceptual residential documents, as a river basin plans, regional development plans, spatial development principles, zoning plans and territorial analysis;
(5) Financial support for measures to optimize and support ecosystem services based on their knowledge and assessments;
(6) Continuation of research and case studies. Implement the results of major international projects, as OpenNESS, Opera, Esmeralda and others. The participation of stakeholders in projects and research activities is also very important.

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Chapter 15
Water Resources Management Planning in the Czech Republic

J. Schneider, M. Blahová, H. Lorencová and I. Lampartová

Abstract Administration of the basins and watercourses in the Czech Republic is defined by Act No. 254/2001 Coll., on waters (the Water Act). It includes the state administration, administration of the river basins and administration of minor watercourses. It defines the rights and responsibilities of the administrators as well as obligations of the owners of the land on which the watercourse is located and the neighbouring land, and obligations of the owners of the water management works and structures on these plots. Planning in the water sector performed within the hydrological basins is a systematic conceptual activity undertaken by the government. Its purpose is to determine and mutually harmonize public interests of water protection as a component of the environment, to reduce adverse effects of floods and drought, and to ensure sustainable use of the water resources. The chapter briefly summarizes the development of planning in the water sector and presents plans of individual river basins and sub-basins as the basic conceptual documents. Protection against floods also includes the Flood protection strategy and the Flood risk management plans.

Keywords Watershed management · Watershed planning · Watercourse administration · Spatial planning

15.1 Introduction

Water resource systems planning and management is a multidisciplinary activity. Reducing the frequency and/or severity of the adverse consequences of droughts, floods and excessive pollution are common goals of many planning and management exercises [1]. Water management is a purposeful activity with multiple and partly conflicting goals to maintain and improve the state of water resources. Water as

J. Schneider (✉) · M. Blahová · H. Lorencová · I. Lampartová
Department of Environmentalistics and Natural Resources,
Faculty of Regional Development and International Studies,
Mendel University in Brno, Třída Generála Píky 2005/7, 613 00 Brno, Czech Republic
e-mail: jiri.schneider@mendelu.cz

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a resource must be allocated among competing uses. In many areas, the available water is polluted and hence cannot be used for many purposes or requires expensive treatment. An uncontrolled urbanization and fast industrialization in developing and threshold countries contribute to exacerbate the pressure on the water resource [2, 3]. Water management planning seems to be more successful where there is a balance between expectations and resources/funding, effective leadership and management, interpersonal trust, committed participants, and a flexible and informal structure [4, 5]. Short-term economic criteria are not able to guarantee ecological stability [6] and multi-functionality. The complex nature of groundwater and the diversity of uses and environmental interactions call for emerging groundwater problems to be addressed through integrated management and planning approaches. Planning requires different levels of integration dealing with: the hydrologic cycle (the physical process) including the temporal dimension; river basins and aquifers (spatial integration); socioeconomic considerations at regional, national and international levels; and scientific knowledge [7].

15.1.1 International Trends in Water Resources Management

Lund [5] distinguishes six major approaches for water planning: (1) Requirement-based planning; (2) Benefit-Cost-based planning; (3) Multi-objective planning; (4) Conflict resolution planning; (5) Market-based planning and (6) Muddling through multi-objective planning is most comprehensive, but it still typically lacks a formal institutional mechanism to establish the trade-offs needed to identify a most desirable alternative [5].

Current water management and planning (WMP) trends respond to the specifics and nature of the river basin and its parts (urban water, arable land, groundwater etc.). Sustainability in urban water management is prominent to arid or remote regions, as well as to big industrial cities. The distribution of water should depend not only on the availability of this valuable natural resource but also on its efficient use [8].

However, WMP also reflects urgent problems and their impacts, especially global climate change. Sustainable water resources planning and management under climate change are solved by many authors [9].

Last but not least, WMP refined by new scientific and management knowledge.

Adaptive management represents an iterative cycle of critical processes beginning with data and information collection, analysis, plan development, implementation and then monitoring and evaluation [10].

The objective of smart water management is to achieve water security at all levels (building, city and regional) in a sustainability and self-sufficiency manner, through the use of information technology, monitoring and control technology and the implementation of holistic system of all the processes in water cycle [11].

Main barriers to the development and adoption of smart water management solutions are related to difficulties in collecting precise monitoring data, lack of interoperability standards and use of simple data mining and data visualization techniques that do not fully exploit the data value [12].

Biswas summarizes the global view of integrated water management in [13, 14].

Ecosystem services are a progressive and rapidly evolving decision-making tool and planning, including water management. Value identification is a step towards implementing ecosystem services in water management planning. For example, Mostert [15] distinguishes six types of values: (1) Harmony—unity with nature, environmental protection, beauty, peace; (2) Embeddedness—order, obedience, tradition, security, politeness; (3) Hierarchy—authority, humbleness, wealth, power; (4) Mastery—ambition, daring, influence, success, recognition, setting own goals; (5) Affective autonomy—pleasure, excitement, variety; (6) Intellectual autonomy—broadmindedness, curiosity, creativity, freedom; (7) Egalitarianism—justice, equality, honesty, loyalty, responsibility, accept portion in life [15]. Lampartová, Schneider et al. [16] assess the recreational value of watercourses in cities as part of cultural ecosystem services.

The water resource management challenge of the future is not only a question of water allocation among irrigation, industry and municipalities but involves difficult decisions for balancing green and blue infrastructure for food, nature and society [17].

15.1.2 Framework of the Planning in the Water Sector in the Czech Republic

The hydrological network of the Czech Republic, consisting of the three main hydrological river basins—the Labe, the Odra and the Morava (Danube) basic. These are further divided—for purpose of planning in the water sector—into eight hydrological river basins (the Upper and the Middle Labe, the Upper Vltava, Berounka, Ohře and the Lower Labe, Odra, Morava and Dyje); the Annex No. 1 to Decree No. 178/2012 Coll. [18] then lists 819 significant watercourses. It is then branched into minor watercourse of lower orders. Administration of the basins and watercourses in the Czech Republic is defined by Act No. 254/2001 Coll., on waters (the Water Act) [19]. It includes the state administration, administration of the river basins and administration of minor watercourses. It defines the rights and responsibilities of the administrators as well as obligations of the owners of the land on which the watercourse is located and the neighbouring land, and obligations of the owners of the water management works and structures on these plots.

Planning in the water sector performed within the hydrological basins is a systematic conceptual activity undertaken by the government. Its purpose is to determine and mutually harmonize public interests of water protection as a component of the environment. It includes reducing adverse effects of floods and drought, and ensuring sustainable use of the water resources, mainly for the purpose of potable water supply. The chapter summarizes the development of planning in the water sector in the Czech Republic and presents plans of individual river basins and sub-basins as the basic conceptual documents. Protection against floods also includes the Flood Protection Strategy and the Flood Risk Management Plans.

15.2 Administration of Watercourses

Administration of watercourses is understood the set of obligations, authorizations and ensuring normal watercourse functioning. They are defined in detail by the Act No. 254/2001 Coll., on waters (the Water Act) [19].

Administration of watercourses in practice incorporates four groups of measures and actions:

- Administrative actions and the duty to report towards the water management authority
- Organizational steps and cooperation
- Monitoring
- Realization of care, new modifications, repairs and maintenance of the existing ones (Fig. 15.1).

According to the Water Act [19], under the administration of watercourses, the following obligations and duties are understood

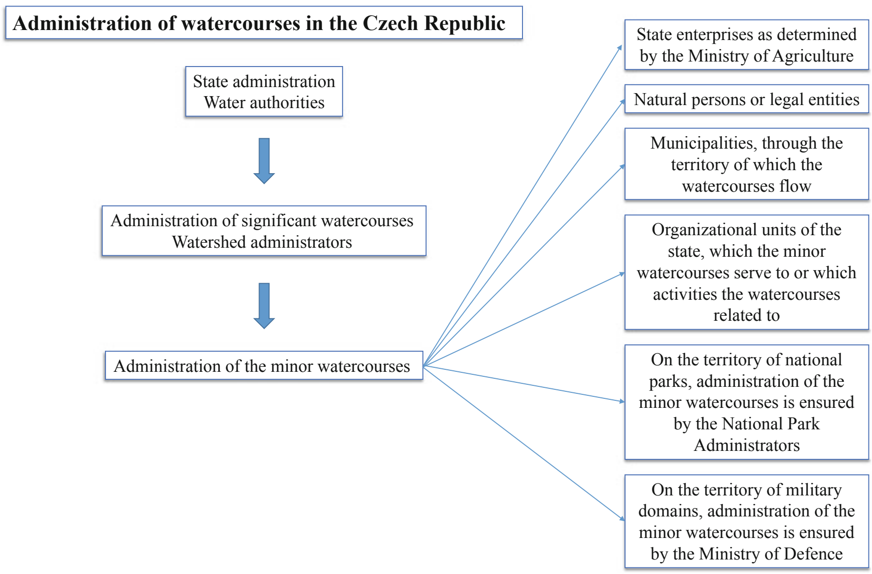

Fig. 15.1 Scheme of watercourses administration in the Czech Republic

(a) to monitor the condition of watercourse channels and adjacent coastal land in terms of the watercourse functions,
(b) to care for watercourse channels, to maintain bank side vegetation on the watercourse channel land or on adjacent land from becoming an obstacle to smooth water flow during floods,
(c) to operate and maintain in proper state those water management structures in the watercourse channels that are necessary for ensuring normal watercourse functions,
(d) to prepare and ensure modifications of the watercourse channels, provided that they serve for ensuring normal watercourse functions,
(e) to create conditions allowing for justified water handling related to the watercourse,
(f) to inform the respective water authority of serious defects detected in the watercourse and its channel caused by natural or other impacts; at the same time, to propose corrective actions, to renew natural watercourse channels,
(g) to cooperate in ameliorating accidents on the watercourses,
(h) to propose the actions remedying human interventions and leading to restoration of the natural watercourse channels.

Administration of significant watercourses also includes the following obligations [20]:

(a) to operate and maintain in good condition the water management structures on significant watercourses, ensuring justified surface water use and handling,
(b) to maintain the navigability of the frequently used significant waterways, including the destruction of ice sheets in public ports,
(c) to maintain in a good state and operate the third-party water management structures on watercourses,
(d) to manage and influence water management in the water reservoir system in conformity with the complex rules of operation,
(e) to submit suggestions for processing, modifications and coordination of the rules of operation of the water management structures owned by third parties,
(f) to cooperate in amelioration of accidents in the river basin, provided that they may endanger water quality in significant watercourses,
(g) if asked so by the competent water authority, to submit the draft complex rules of operation, coordinating rules of operation of individual water management structures creating the system of mutually affecting water management structures, to the water authority for approval,
(h) to cooperate with the administrators of minor watercourses in solving the tasks relating to watercourses within the whole basin area (Fig. 15.2).

Fig. 15.2 **a** Bilingual (Czech and English) Information about the danger of weird and instructions of First Aid—Mlýnský potok stream in Olomouc. Water Administrator: Morava River Board, s. e. (Photograph: Jiří Schneider). **b** Bilingual (Czech and English) Information about the danger of weird and instructions of First Aid—Svitava river in Brno. Water Administrator: Morava River Board, s. e. (Photograph: Ivana Lampartová)

15.2.1 Watercourse Administrators

Administration of significant watercourses is ensured by the legal entities designated as the 'river basin administrators'. The following state enterprises are the river basin administrators: Labe Basin, Vltava Basin, Ohře Basin, Odra Basin and Morava Basin. The river basin administrators perform, among other things, supervision over administration and management of minor watercourses.

According to the Water Act [19], administration of the minor watercourses or their complete sections may be performed by

- municipalities, through the territory of which the watercourses flow,
- natural persons or legal entities,
- organizational units of the state, which the minor watercourses serve to or which activities the watercourses related to,
- state enterprises as determined by the Ministry of Agriculture,
- on the territory of military domains, administration of the minor watercourses is ensured by the Ministry of Defence.

– on the territory of national parks, administration of the minor watercourses is ensured by the National Park Administrators.

On the minor watercourses, for which no administrator has been appointed, the administration is undertaken by the administrator of the watercourse, to which the minor watercourse is a tributary.

Exercise of watercourse administration is connected with a number of authorizations:

– to enter another person's land or structures within the necessary extent, provided no permission is requested pursuant to special legal regulations,
– with respect to care for the watercourse channel and upon negotiations with landowners, to remove or plant new trees and bushes on the land closes to the watercourse,
– to request submission of an approval or a permission by the competent water authority concerning the watercourse and to determine whether or not such permissions are observed,
– to give orders for the operation of the water management structures to their users in compliance with the overall rules of operation of the system water reservoirs on the watercourse, if required so in an extraordinary situation,
– to use the land adjacent to the watercourse channel (if inevitable and upon the prior consultation with the landowners) (Fig. 15.3).

15.2.2 River Basin Administration

River basin administration means administration of significant watercourses, some activities connected with monitoring and assessment of the state of surface water and groundwater in the given river basin. River basins are administered by the river basin administrators; these are summarized in Table 15.1. The river basin administrators cooperate with the minor watercourse administrators and authorized technical authorities in solving the tasks concerning whole river basin. The river basin administrators record, within the relevant river basin area, reduction of the retention capacity of the floodplains due to changes in the area, in particular, due to the implementation of the flood protection structures.

15.2.3 State Administration

The state administration under the Water Act [19] is exercised by the water authorities and by the Czech Environmental Inspectorate.

The water authorities are as follows:

– municipal authorities,

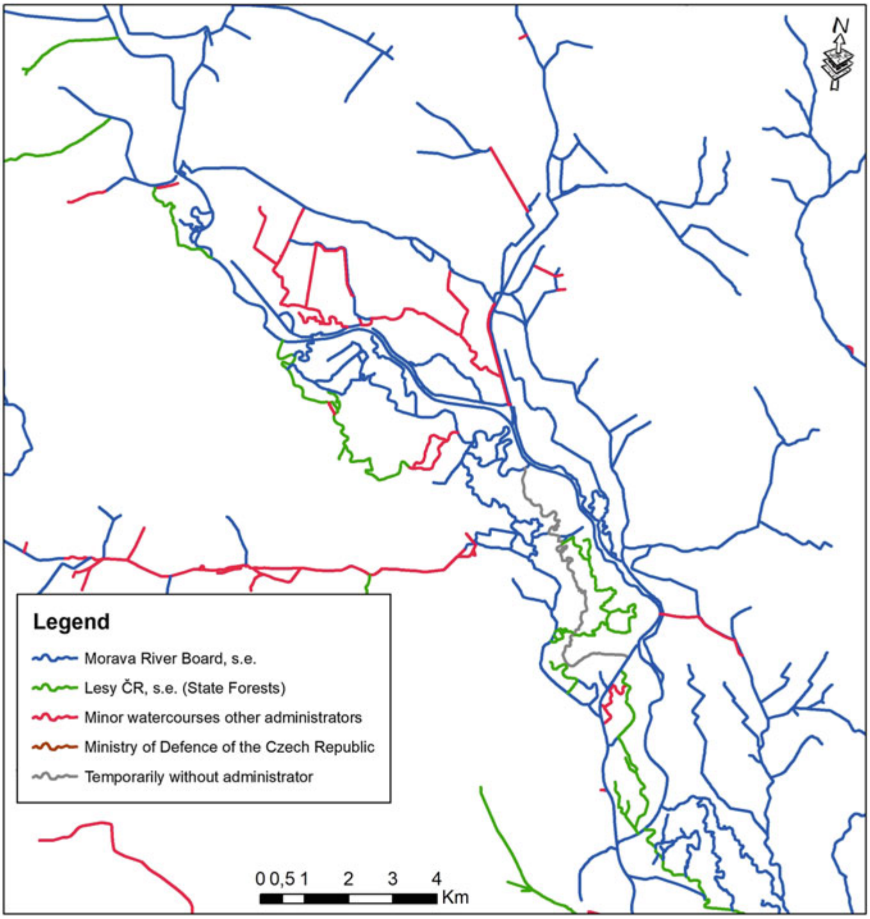

Fig. 15.3 Hydrological network within Morava river partial watershed—an example of watercourse administrators

– military zone authorities in the military zones,
– municipal authorities with extended jurisdiction,
– regional authorities,
– ministries, as the central water authority.

Watercourse administrators under the competence of the Ministry of Agriculture ensure administration of more than 94.5% of the length of all watercourses in the Czech Republic. Approximately, 5.5% of the watercourses are administered by the Ministry of Defence, National Park Administrations and/or natural persons and legal entities. Watercourses in the Czech Republic are divided into significant (major) watercourses and minor watercourses.

Table 15.1 Specialized watercourse management in the Czech Republic [21]

Category	Administrator	Length of watercourses in km	
		2014	2015
Significant watercourses	Labe River Board, s. e.	3667	3667
	Vltava River Board, s. e.	5493	5503
	Ohře River Board, s. e.	2377	2377
	Odra River Board, s. e.	1111	1111
	Morava River Board, s. e.	3768	3755
	Total	16,396	16,413
Minor watercourses	Forests of the Czech Republic, s. e.	38,491	38,495
	River Boards, s. e. in total	39,657	40,928
	Other administrators[a]	5857	4962
	Other[b]	5	3
	Total	84,010	84,388
Watercourses in total		100,406	100,801

[a]Administrations of National Parks, Ministry of Defence
[b]Administrator has not yet been designated

Administration of minor watercourses is performed pursuant to provisions of sec. 48 of the Water Act [19]. The major part of the minor watercourses is administered and managed by the state enterprise Lesy/Forests of the Czech Republic (38,495 km) (see Figs. 15.4 and 15.5).

15.2.4 Obligations of Owners of the Land Connected with Watercourses

Obligations of owners of the land on which the watercourse channels are located
Owners of the land, on which the watercourse channels are located, have a number of responsibilities:

- to tolerate coastal vegetation on their land as well as general water management in the watercourse,
- to maintain the banks of the watercourse channel in the condition and state necessary to ensure smooth water flow, to remove obstacles and foreign objects in the watercourse, except for sediments,
- to tolerate the water management structures in the watercourse channel located on their land,
- to report evident defects in the watercourse channel to the watercourse administrator,

Fig. 15.4 State Forests Enterprise Lesy České Republiky, s.e. is an important water administrator of minor watercourses not only in the forests but also in open landscape. Floodplain forest in Natural Reserve Kolébky near Morava River. (Photograph: Jiří Schneider)

Fig. 15.5 Maintaining migration corridor on the river Ohře—under Ohře River Board, s. e. administration. (Photograph: Jiří Schneider)

- to tolerate (on their land without any compensation) installation of the equipment serving for monitoring state of the surface water and groundwater and ecological functions of the watercourse, e.g. the navigation marks, etc.,
- to allow the water authority, the Czech Environmental Inspectorate, and the watercourse administrator to exercise their authorizations,
- to tolerate passage of the persons along the watercourses,
- to tolerate a natural watercourse channel on their land.

Obligations of owners of the land adjacent to watercourse channels
Owners of the land adjacent to watercourse channels have similar obligations:

- to allow watercourse administrator to exercise his authorizations,
- to tolerate (on their land without any compensation) installation of the equipment serving for monitoring state of the surface water and groundwater and ecological functions of the watercourse, e.g. the navigation marks, etc.,
- to tolerate, upon the prior negotiations with them, the passage of persons on them; this is not applicable to the land in a developed territory and on the fenced plots,
- to tolerate a natural watercourse channel on their land.

Obligations of owners of structures and equipment installed in watercourse channels or adjacent to it
Owners of structures and equipment in the watercourse channels are obliged to remove the objects caught or stuck on such structures or equipment. Owners of structures, which are not considered the water management structures or equipment installed in watercourse channels or adjacent to them, must in public interest maintain their static safety and general maintenance so that they may not threaten continuous surface water flow, and to protect them from the damage caused by water and ice.

Obligations of owners of water management structures
The water authority may ask the owner of the water management structure to process and submit the rules of operation of the water management structure for approval. The owner of the water management structure is obliged to observe the conditions and obligations, under which the water management structure was permitted and put into operation, in particular, to observe the approved rules of operation and service. In addition to it, he is obliged

- to maintain the water management structure in good condition in such a way not to endanger the safety of persons, property and other protected interests,
- to perform technical and safety supervision of the water management structure at his costs,
- to adopt the measures and actions to eliminate the defects revealed in the water management structure,
- to observe instructions of the water management structure administrator in case of emergencies,
- to remove objects and masses caught or stuck on the water management structures
- to place water gauge, watermark or flow gauge on the water management structure, to ensure continuous data transfer concerning the watercourse flow rate,

Fig. 15.6 Concrete base for mobile flood protection wall. Vltava river bank. Obligations of owners of the land adjacent to watercourse channels to tolerate this tool of flood protection. (Photograph: Jiří Schneider)

– to install navigation marks on the water management structure,
– in case of the water management structure intended for impounding water in the watercourse, maintain, at his own expense, the river bottom and banks in the impounding area in a proper condition, care for smooth water flow there, and create conditions for the migration of aquatic fauna unless the structures are involved,
– to remove self-seeded wood species from the dams used as protection from floods, for water impounding or water accumulation,
– to perform technical revisions of the water management structure once in two years (Fig. 15.6).

15.3 Planning in the Water Sector

Planning in the water sector performed within the hydrological basins is a systematic conceptual activity undertaken by the government. Its purpose is to determine and mutually harmonize public interests of water protection as a component of the environment, to reduce adverse effects of floods and drought, and to ensure sustainable use of the water resources, mainly for the purpose of potable water supply [21].

It is based on water management planning, which has a long tradition in the Czech Republic. As early as in the nineteenth century and the first half of the twentieth century, comprehensive documents were elaborated within the regional scope; they addressed both the problems of protection against floods, utilization of water power or navigation and other water management issues related to water drainage or water supply. The State Water Management Plan of the Czechoslovak Republic of 1953 and its second edition of 1975 was the basic and first nation-wide conceptual water management document [21].

Planning in the water sector, compared with the original water management planning system, does not cover only requirements for utilization of water resources and requirements for protection against harmful effects, but also considers the solution of environmental objectives and requirements for protection of water resources and related ecosystems. In this sense, planning in the water sector implements requirements of the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (hereinafter referred to as the 'Water Framework Directive'). By this Directive, Europe has commenced a complex process of unified approaches in the field of protection of water and aquatic ecosystems, while promoting sustainable water use and mitigating consequences of floods and droughts [21].

The general objective of the state policy in the water sector is to create conditions for sustainable management of the limited water resources of the Czech Republic. This allows to harmonize requirements for all forms of utilization of the water resources with the requirements for protection of water and aquatic ecosystems, while considering the measures and actions focused on the reduction of the harmful impacts of water. The very purpose of planning in the water sector is to define and mutually harmonize the public interests [22]:

– water protection as a component of the environment,
– protection against floods and other harmful effects of water,
– sustainable use of water resources and water management to meet the requirements for water management services, in particular for the purposes of potable water supply.

15.3.1 History of Planning in the Water Sector

The process of planning in the water sector is divided into three six-year stages in the Czech Republic in accordance with the Water Framework Directive [23].

The first planning period was running in 2009–2015. During that period the river basin plans have been elaborated and accepted at the following levels:

- Plan of main river basins of the Czech Republic
- River basin district plans.

Plans of the Main River Basins in the Czech Republic

Plans of main river basins of the Czech Republic have set out the general objectives for surface water and groundwater management, for protection and improvement of the state of surface water, groundwater and aquatic ecosystems. Programs of measures are the main tool to achieve the targets identified in the Plan of main river basins of the Czech Republic and in the river basin district plans. They have been processed and approved as their integral part. They have set the schedule for their implementation and a strategy for their funding. The measures adopted to achieve the water protection objectives in the Programs of measures had to be implemented within three years after approval of the Plan of main river basins of the Czech Republic and of the river basin district plans.

River Basin District Plans

The river basin district plans have stipulated specific objectives for the given river basin districts, based on the general programs of measures of the Plan of main river basins of the Czech Republic as above, on the needs and ensuring state of surface water and groundwater and on the needs of use of these waters in the given territory.

The river basin district plans have been drawn up by river basin administrators according to their competences in cooperation with relevant regional authorities and central water authorities for the eight river basin districts.

The process of planning cannot be managed without effective coordination of a wide range of stakeholders. For this purpose, in 2003, the Ministry of Agriculture has established the Water Planning Committee and its Proposal Group, and thus de facto commenced the process of planning in the water sector in the Czech Republic.

The Water Planning Committee (WPC) coordinates planning activities at the national level. The Committee shall assist the institutions involved in the process of planning. The Committee discusses and approves procedures, methodologies and documents of the planning process which are then utilized for specific plan preparation activities. Members of the Committee are nominated both by the institutions responsible for drawing up the plans and by other stakeholders.

The task of the Proposal Group of the Water Planning Committee is to prepare documents and suggestions for WPC meetings. The Group proposes and discusses procedures, methodologies and documents before they are submitted to WPC. Its function is only supportive; the decision is adopted by WPC.

The second planning period is running in the period 2015 and 2021. In response to the comments of the European Commission (the so-called infringement) on the implementation of the Water Framework Directive, a new structure for processing of the water basin plans has been determined for the second planning period by modification of the legislation (amendment to the Water Act [19]). Updating the river basin plans has been running since 2015 at three levels:

- *International river basin plan*
  For the international river basin districts (Labe, Odra, Dunaj).
- *National river basin plan*
  For parts of international river basin districts in the territory of the Czech Republic. National river basin plans are prepared by the Ministry of Agriculture and the Ministry of the Environment, in cooperation with the relevant river basin administrators and competent regional authorities. They are approved by the Government.

- *Plans of sub-basins*
  For the sub-basins (Upper and Middle Labe; Upper Vltava; Berounka; Lower Vltava; Ohře, Lower Labe and other Elbe tributaries; Upper Odra; Lužická Nisa and other Odra tributaries; Morava and Váh tributaries; Dyje; other Dunaj tributaries). Plans for sub-basins are elaborated by the river basin administrators according to their competence in cooperation with the relevant regional authorities and cooperation with the central water authorities. According to their territorial competence, they are approved by the regions.

Updating the river basin plans from the first planning period was performed between 2013 and 2015. In the plans for sub-basins, the river basin administrators have reviewed and updated—in cooperation with regional authorities—individual measures, based on which the measures in the national river basin plans have been compiled and incorporated into the programs for their realization. Measures in the national river basin and sub-basin plans adopted to achieve the water protection objectives of the Programs of measures have to be implemented within three years after approval of the river basin plans.

In parallel, the Flood risk management plans have been compiled and approved in coordination; they implement requirements of Directive 2007/60/EC on the assessment and management of flood risks (from now on the 'Floods Directive'). The flood risk management plans are drawn up by the Ministry of the Environment and the Ministry of Agriculture in cooperation with the relevant river basin administrators and competent regional authorities. They are approved by the Government.

The third planning period will be running in the period 2021–2027. Within the framework of preparation for this planning period, a second update of the river basin plans and the first update of the flood risk management plans will be performed.

15.3.2 Water Management Planning Documents

River basin plans
Contents of the river basin plans are set out in the Annex No. 3 to the Decree 24/2011 Coll., on river basin plans and flood risk management plans [24].

National river basin plans
The national river basin plans contain

1. General description of characteristics of the part of the international river basin district in the territory of the Czech Republic. For instance maps of eco-regions, drainage basin and types of surface water bodies, reference conditions for types of surface water bodies or list of groundwater bodies and related surface water bodies, aquatic and directly dependent terrestrial ecosystems, including summarized information about mutual relationship.
2. Overview of significant influences and impacts of human activities on the status of surface water and groundwater.

3. Identification and mapping of protected areas.
4. Results of determination and assessment of the status of waters, incorporating, for example, maps of monitoring networks created for the purpose of identifying and assessing the status of waters and status of protected areas, maps of the results of monitoring programs for the ecological and chemical status in case of surface waters and chemical and quantitative status of groundwater.
5. List of objectives for surface water, groundwater and protected areas, e.g.

   – Objectives for protection and improvement of the status of surface waters, groundwater and aquatic ecosystems
   – Objectives for reduction of adverse impacts of floods
   – Objectives for flood risks management
   – Objectives for surface water and groundwater management and sustainable use of these waters to ensure water management services
   – Objectives for improvement of water conditions and for protection of ecological stability, in particular, rehabilitation of the water regime, increase of water retention in the countryside, principles of creation of new biotopes, increase of quality and stability of water and water-bound ecosystems, and improvement of hydro-morphological indicators in watercourse channels and river plains
   – Achievement of a good chemical status of surface waters in selected chemicals

6. Summary of results of economic water use analysis.
7. Summary of the Program(s) of measures through which the objectives set out in Sec. 5 shall be achieved.
8. Records of other more detailed programs and plans for the relevant part of the international river basin district in the territory of the Czech Republic concerning in particular sub-basins, branches, issues or water types, together, including summary of their contents.
9. Summary of the adopted measures for public awareness and consultations, their results and changes that have been made in the river basin plan as a consequence.
10. List of competent authorities and description of the administrative coordination of the works on the elaboration of the river basin plan.
11. Contact points and procedures for obtaining the basic documentation and information, and in particular details of the water management permits, and the latest results of the water status determination and assessment.

The National Labe river basin plan has been extended by five plans of sub-basins:

– Upper and Middle Labe
– Upper Vltava
– Berounka
– Lower Vltava
– Ohře, Lower Labe and other Labe tributaries

The National Dunaj river basin plan has been extended by three plans of sub-basins:

– Morava and Váh tributaries
– Dyje
– Other Dunaj tributaries.

The National Odra river basin plan has been extended by two plans of sub-basins:

– Upper Odra
– Lužická Nisa and other Odra tributaries.

Plans of sub-basins

The plans of sub-basins extend the National river basin plan by the detailed data and proposals of measures. They include in particular:

(1) General description of characteristics of the sub-basin, including the map(s) of locations and boundaries of surface water and groundwater bodies, maps of types of surface water bodies or information about risk groundwater bodies
(2) Overview of significant influences and impacts of human activities on the status of surface water and groundwater including, among other things, information about local and diffuse sources of pollution or information about emissions, discharges and leaks
(3) Identification and mapping of protected areas
(4) Results of determination and assessment of the status of waters, incorporating, for example, information about monitoring networks created for the purpose of identifying and assessing the status of waters and status of protected areas, information about the results of monitoring programs of the status
(5) List of objectives for surface water, groundwater and protected areas, supplemented by detailed information about the application of partial provisions of the Water Act
(6) Information about revenues from various uses of water to cover the cost of water services
(7) Proposals of measures, including the procedures through which the objectives set out in Sec. 5 shall be achieved, such as the proposal of the measures for the waters used by or intended for human consumption, including an estimate of the relevant cost or draft measures for reduction of water abstraction and impoundment
(8) A list of other more detailed programs and plans in a sub-basin, incl. summary of their contents
(9) Summary of adopted measures to inform the public
(10) List of competent authorities and description of the administrative coordination of the works on the elaboration of the river basin plan
(11) Contact points and procedures for obtaining the information about the water management permits, and the latest results of the water status determination and assessment

(12) Conclusions of preliminary flood risk assessment and results of analyses of the areas with a significant flood risk.

Rules of operation and service of the water management structure
The rules of service (handling) are understood a set of principles and instructions for water handling for the purpose of its efficient and cost-effective use under the permit for surface water or groundwater management and handling. The rules of operation of the water management structure are understood as a set of principles, instructions and documentation for operation and maintenance of the water management structures and equipment

The rules of operation and service of the water management structure are defined in the Decree No. 216/2011 Coll., on the requisites applicable to the rules of operation and service of the water management structures [25].

Contents of the rules of service (handling) can be divided into three parts:

(1) Identification data about the owner (user) of the water management structure, about the watercourse administrator, the water authority having local competence, authorized persons, competent flood authorities
(2) Technical data about the water management structure, among other things, location and description of the water management structure, the purpose of the water management structure, permission to handle the surface water or groundwater
(3) Basic requirements, principles and instruction for handling water in the water management structure
(4) Instructions for water handling in case of emergencies
(5) Requirements for type, method, scope and frequency of measurements and monitoring of the water management structure necessary for water handling
(6) Lists of important addresses and communication links
(7) Principles of cooperation in water handling between owners or users of related water management structures
(8) Other provisions and annexes.

15.3.3 Planning in the Field of Flood Protection

In the Czech Republic, the so-called *Flood protection strategy* is the basic document that provides a framework for defining specific procedures and preventive measures to increase systemic flood protection. This document defines the scope of responsibilities of the flood protection system at the level of the line-forming entities: the state—the self-government bodies—the civil and business public. It defines the predictive and reporting service, influencing the course and extent of floods, notifying potential damage, protection of property, and implementation of the Strategy and related links. This document has a long-lasting validity and is open for complementing proposals that will respond to development and also to the implementation of the proposed measures [26]. The document focused on flood protection measures at the

Fig. 15.7 Building of flood protection wetland near Slavkov u Brna. (Photograph: Jiří Schneider)

level of the Czech Republic, is the Concept of solution of flood protection issues in the Czech Republic with the utilization of technical and nature-friendly measures.

Proposal of protection of the model cities from floods in terms of their impact on the territory, on the settlements, on their urban structure, building funds and the urban environment is incorporated in the land planning acts. Specifically, in the Building Act (Act No. 183/2006 Coll.) and the Water Act (Act No. 254/2001 Coll.), as the requirement for dealing with flood protection of the territory in all land-use plans. Through the regulations, the land-use plan limits, restricts, sets the rules and/or removes those possible activities from the territory that might—in case of floods—pose a threat to people, destruction of buildings, environmental impairment, etc. (Fig. 15.7)

Contents of the Flood Risk Management Plan

1. Conclusions of preliminary flood risk assessment and determination of the areas with significant flood risks, which the plan applies to, including mapping.
2. Description of the relevant flood risk management objectives.
3. Flood hazard maps and flood risk maps and the conclusions that can be deduced from these maps.
4. Summary of measures and their effectiveness, economic efficiency and priorities, including the flood-related measures adopted under other legal regulations.

Fig. 15.8 Information for the general public—water flow, temperature of water and level of flood activity. Orlice River in Hradec Králové, 800 m far from confluence with Labe river. Administrator: Labe River Board, s. e. (Photograph: Jiří Schneider)

5. Description of the methodology used in the international river basins for the cost-benefit analysis in order to assess the measures with transnational effects, if available.
6. Description of prioritization and how the progress the plan implementation will be monitored.
7. Summary of adopted measures or actions to inform and consult the public.
8. List of competent authorities and a description of the coordination procedure within the international river basin districts and sub-basins.
9. Description of the coordination procedure with river basin plans.

The updated Flood risk management plan also contains

1. Summary of all changes or updates since the publication of the previous plan.
2. Assessment of progress in achieving the flood protection objectives.
3. Description and explanation of all measures from the previous plan that were planned but have not been implemented yet.
4. Description of all other measures from the publication of the previous plan.
5. Information about the likely impacts of climate change on the occurrence of floods (Fig. 15.8).

15.4 Conclusions and Recommendations

Management, administration and planning in the water sector have been designed and implemented logically and effectively in the Czech Republic. The current situation is complemented by planning and implementation of flood protection. Despite this fact, the Czech Republic sometimes has problems with floods, but recently, drought is a problem. This is caused on the one side by the intensity of both phenomena and on the other side by the state of the long-term intensively utilized landscape. All measures proposed and implemented in the field of water management, administration and planning are unable to save everything. It is necessary to continue in a close link with other forms of the planning of landscape utilization and management, which include, in particular, land-use planning, forest management planning, regional development, agricultural activities and, to a lesser extent, reclamation plans, for example.

Further development of water management and planning in the Czech Republic can be supported:

- implementation of new sectoral knowledge and practical results of agricultural, forestry, urban and other research into river basin management plans
- implementing progressive decision-making principles
- reflecting the complex of ecosystem services and disservices and their implementation in water planning
- reflecting the participative approach, where appropriate
- developing a comprehensive approach to the state of the river basin
- improvement of expert arguments in the EIA process, especially for the purpose of clearly damaging structures, such as the planned Danube-Odra-Elbe channel.

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Chapter 16
Technical and Economic Evaluation of River Navigation

J. Korytárová, V. Hromádka, Z. Dufek and E. Vítková

16.1 Introduction

The issue of the public investment projects preparation is very broad and complicated. There exists a big interest of the public only the most efficient investment projects, respecting the 3E approach to be carried out. This is the reason, why it is necessary to analyse public investment projects from the financial and economic point of view before their realization starts. The special interest is given to the transport infrastructure projects because of their big expected impacts in the society. This part is oriented mainly on the trafficly significant waterways.

The issue of the trafficly significant waterways and their economic evaluation is solved in many countries from many reasons. The broader economic consequences of transport infrastructure investments are solved in [1]. Economic analysis of benefits connected with the intermodal transport including water transport is carried out in [2], intermodal freight transport is in detail analysed in [3]. The revitalization of watercourses for the needs of transport is the subject of [4].

From mentioned publications, it is evident that issue of the efficiency of waterways is important topic in the investment area. This paper is focused on the economic efficiency of projects on waterways oriented on the freight transport in conditions of the Czech Republic.

Evaluating economic efficiency of transport infrastructure projects, including water transport projects, is in the Czech Republic governed by an implementing methodological guideline issued by the Ministry of Transport of the Czech Republic. This implementation guideline is based on the document issued by the European Commission—Guide to Cost-Benefit Analysis of Investment Projects (Economic Appraisal Tool for Cohesion Policy 2014–2020) [5]. Technical and economic eval-

J. Korytárová (✉) · V. Hromádka · Z. Dufek · E. Vítková
Faculty of Civil Engineering, Institute of Structural Economics and Management,
Brno University of Technology, Veveří 331/95, 602 00 Brno, Czech Republic
e-mail: korytarova.j@fce.vutbr.cz

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uation of the projects of important water transport structures, carried out in the form of CBA, consists of four basic parts:

- Transport prognoses,
- Financial analyses,
- Economic analyses,
- Sensitivity and risk analyses.

In the following text, individual parts are further analysed in detail, basic methodological approaches to their determination and other recommendations of the authors are described making use of the experience in the evaluation of projects at the national level.

16.2 Analysis of the Current State

16.2.1 History of Water Transport

Water transport has been evolving over the centuries; it essentially represents the oldest way of transporting goods over long distances. Freight transport as a whole is significantly affected by two fundamental trends. On the one hand, it has been growing in the long-time perspective, and there is also a noticeable trend for transport of consignment in standardized containers. Container transport is a relatively new phenomenon. It has been in use since 1956. The first regular container lines have only begun its operation in the year 1966. Then, in the year 1980, only 11 million tonnes of goods were transported in containers. However, in the year 2016, 244 million tonnes of goods were transported using containers for ocean transport.

The overall trend in the growth of the amount of water transport is illustrated by Figs. 16.1 and 16.2, which show the total volume of goods transported in the ports of Hamburg [6] a Constantza [7]. These ports play the key role in transporting goods across Central European inland waterways as they are final destinations for transport along the Elbe and the Danube rivers.

In the case of Constanta port, there is a noticeable decrease in the volume of goods transported in connection with the fall of the so-called eastern bloc after 1989. Both ports recorded a decrease in the volume of goods transported in connection with the economic crisis after 2008. However, in the long-time perspective, the growing trend in the volume of transported goods is noticeable. A different situation can be seen on another important Central European river, the Odra River. Before the year 1989, the port of Szczecin was the preferred port within the Council for Mutual Economic Assistance, where ocean transport for the so-called Eastern Bloc was primarily directed. Therefore, after the political changes in the year 1989, the volume of transported goods fell to one third. At the same time, water flow maintenance was neglected, and investments in river infrastructure were not sufficient. The current volume of water transport on the Odra River is therefore marginal.

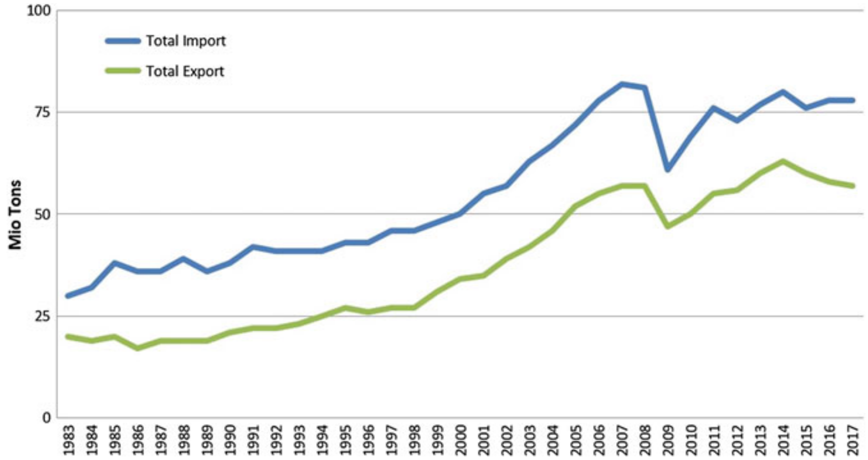

Fig. 16.1 Hamburg—historical development of transported goods (mil. Tonnes). *Source* In-house processing using data from Hafen Hamburg [6]

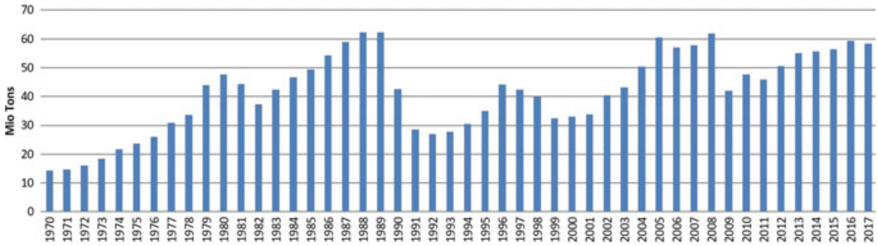

Fig. 16.2 Constanta—historical development of transported goods (mil. Tonnes). *Source* In-house processing using data from Constanta Port [7]

While from an all-European point of view the share of inland water transport on the total transport is about 4% with its gradually growing share, the trend in the Czech Republic is reversed. The share of water transport on the total transport in the Czech Republic currently represents only around 1% [8].

16.2.2 Potential of Water Transport in the Czech Republic

Decreasing trend in the use of inland waterways for freight transport within the Czech Republic can be clearly explained by the unreliability of the waterway. Especially due to the missing Děčín navigation stage, navigation is regularly stopped for several months a year. Because of the unreliability of the waterway, transport clients do not use this form of transport, causing the decline in the transport capacity, stop of investments in the port infrastructure and loss of overall economic viability of the sector. Ready prepared conceptual materials for the development of inland water transport area in the Czech Republic have been made, which estimate that, in the case of adequate investments in the development of waterways, the volume of transported goods on waterways could increase from 3.2 to 6.4 million tonnes per year [9]. This increase has been predicted only in relation to the current the Elbe—the Vltava (the Labe—the Vltava) waterway. It does not concern any possible increase after the construction of the Danube–the Oder–the Elbe (the Dunaj–the Odra–the Labe) water corridor project. Planned construction and technical measures are included in the water transport concept, approved by the Government of the Czech Republic at its session on 17 January 2018.

Concerning transport trends, the intensity of road and rail transport has been expected to grow in the long-time horizon. This growth will result in depletion of the capacity of transport routes and growth of congestions. This phenomenon will stimulate the interest of the ordering parties in alternative transport routes, which will positively influence the demand for waterway use. The demand-boosting trend will be positively affected by the planned infrastructure investments which will increase the capacity and reliability of the waterway.

In addition to the increase in transport volumes, the following trends can be expected in the area of river transport:

- Reduction in exhaust emissions from ship engines and reduction in noise,
- Increase in the tonnage of vessels towards Class Vb (3200–3700 tonnes),
- Introduction of the full day navigation (24/24 h),
- Acceleration of the passage through the navigable structures,
- Increase in the container transport.

16.2.3 Classification of Waterways

European Agreement on Main Inland Waterways of International Importance (AGN) is the key document in Europe in terms of the classification of waterways designed both for passenger and for freight transport. This international treaty was concluded on 19 January 1996 in Geneva. It entered into force in the Czech Republic on 26 July 1999. The official Czech text of the agreement was published in the Collection of Laws No. 163/1999 Coll. [10]. The contracting parties of the agreement adopted a coordinated plan for the development and construction of an inland waterway network. Annex I sets out a uniform system of numbering of the waterways of international importance and their list, Annex II establishes a uniform system of numbering the inland ports of international importance and their list and Annex III determines characteristics of waterways of international importance.

In the list of waterways, waterway E20, the river Elbe from the North Sea through Hamburg, Magdeburg, Ústí nad Labem, Mělník, and Pardubice—(the Elbe–the Danube link) and E 20-06 the river Vltava: Mělník—Prague-Slappy are relevant waterways for the Czech Republic.

In the lists of inland ports, the relevant ports for the Czech Republic are P 20-15 Děčín (the Elbe, 98.2 and 94.2 km), P 20-16 Ústí nad Labem (the Elbe, 75.3 and 72.5 km), P 20-17 Mělník (the Elbe, 3.0 km), P 20-06-01 Prague (the Vltava, 46.5 and 55.5 km) [10].

The AGN Agreement defines waterway classes as IV, Va, Vb, VIa, VIb, VIc, and VII when setting the minimum ship size requirements for the conditions of safe and fluent operation on the waterways. However, it does not include a definition of the minimum parameters of the navigable fairway and waterway structures. Definition of these parameters is left to national legislation. In the Czech Republic, these issues are dealt with by Decree of the Ministry of Transport of the Czech Republic No. 222/1995 Coll., On Waterways, Shipping Traffic in Ports, Common Accident and Transportation of Dangerous Goods as amended [11]. This degree in its § 5 defines the minimum parameters of the navigation fairway and in § 6 the minimum dimensions of the lock chambers for the water classes occurring in the Czech Republic, i.e. regional classes 0, I, and international classes IV, Va and Vb. Such defined parameters are mandatory for newly constructed or reconstructed waterways. Actual parameters of the already existing Czech waterways are determined by a Decree of the Ministry of Transport No. 344/1991 Coll., which has issued the Navigation Safety Order [12].

To ensure reliable international transport on European waterways, these routes must conform to the required operating parameters according to AGN. The waterway European network includes a system of inland ports of international importance that must comply with the relevant technical and operational criteria.

16.2.4 Commodities Suitable for River Transport

Inland waterway transport is suitable for commodities that are bulky, heavy, non-perishable and irrelevant to delivery speed or are relatively inexpensive due to their volume. Typically, these are the following commodities:

- Agricultural products—grain, mash feed,
- Metallurgical material—sheets, coils, concrete steel, shaped and rod steel,
- Oversized engineering products,
- Fertilizers,
- Bauxite, andalusite, clay, iron ore, magnesite,
- Coke and coal,
- Kaolin,
- Road salt,
- Fluorite, aluminium hydrate, apatite,
- Slime,
- Building materials—gravel, sands, large construction components, excavated soil,
- Wood,
- Waste—scrap iron, communal waste, sludge from WWTPs, plastics for recycling, rubble.

This may concern a national short-distance transport but also transport from domestic ports to seaports and vice versa. Use of water transport for shorter distances may be disadvantaged by the need of transfer and transport by other means of transport from the initial to the final location and vice versa. The necessity of transfer always increases the cost of transport, the risk of damage to the cargo, and in the case of loose, substrates each transfer carries a loss of about 1–2% of the weight of the cargo.

Transport of agricultural products, chemicals and metals prevails in the Czech Republic. In the area of the German Mitteland Canal, transport of minerals and building materials together with agricultural products and food followed by transport of solid mineral fuels dominates.

16.2.5 Theoretical Approaches to Economic Evaluation

Investment activities related to the transport infrastructure in the Czech Republic are funded by the State Fund for Transport Infrastructure (SFTI). SFTI funds provide for:

(a) Construction and modernization of the transit sections of roads and motorways,
(b) Exploratory and designing work, studies and expert activities focused on the construction, modernization, and repair of roads and motorways, important transport waterways and national and regional rail constructions,
(c) Implementation of programmes aimed at enhancing transport safety and making it accessible to persons with limited mobility and orientation,
(d) Construction and maintenance of cycling paths.

At the beginning of the approval procedure, there is an application for funds, which is submitted by the investor of the construction project to the State Fund for Transport Infrastructure (SFTI) in the form of a Project Intent. According to the subject matter of the infrastructure project, the investor is as following:

- Road and Motorway Directorate,
- Rail Infrastructure Administration,
- Waterways Directorate.

Waterways Directorate of the Czech Republic was established by the Ministry of Transport and Communications of the Czech Republic on 1 April 1998 and forms an organizational unit of the State established by the Ministry of Transport, pursuant to § 51, paragraph 1, Act. No 219/2000 Coll. The main activities provided by the Waterway Directorate are mainly the following agendas:

- Ensuring preparation and implementation of construction and modernization of the important transport waterways parts and other structures necessary for the operation on the waterways as well as for their management, maintenance and acquisition of other property necessary for the management and maintenance of the waterways,

- Ensuring management, maintenance and repair of newly established parts of waterways and other property necessary for their operation and their management and maintenance,
- Exercising the state ownership rights to property forming newly established parts of waterways,
- Providing background information for establishing concepts in the field of waterways and their components,
- Coordination of major repairs of the reconstruction and modernization of waterway components.

The evaluation of the economic efficiency of the transport infrastructure construction on waterways has undergone significant development in recent years. Since 2014, the economic evaluation of the significant water transport infrastructure has been carried out in accordance with the "Implementation Guidelines for Investment Evaluation on Waterways", which determined the obligation to use the "Methodology for Evaluating the Effectiveness of Investments in Waterways" [13] issued by the Ministry of Transport. In the course of 2016, the "Implementation Guidelines for the Methodology for Evaluating Economic Efficiency and Ex-Post Assessing of the Costs and Benefits of Rail Infrastructure, Roads and Transport Infrastructure and Significant Waterways" [14] and the Methodology itself (the "Transition Methodology") [15] were issued. Guidelines and methodology are complementary to the existing methodology in line with the requirements defined in the Guide to Cost-Benefit Analysis of Investment Projects issued by the European Commission at the end of 2014 [5]. The last change is coming into force of the "Sectoral Methodology for Evaluation of the Economic Efficiency of Transport Projects" [16], which, on the basis of the "Implementation Guidelines for Evaluation of the Effectiveness of Water Transport Infrastructure Projects" [17], replaces all up-to-now existing methodologies not only for the economic evaluation of the significant water transport structures, but also methodologies for the evaluation of road and motorway as well as rail structures.

16.3 Methodology

Methodology is based on the following steps. Firstly, the detailed analysis of particular methodologies intended for the evaluation of the economic efficiency and risks of projects on trafficly important waterways and their development was done. Then the synthesis of acquired information and determination of topics for possible research was carried out. Consequently, the suggestion of the process of the solution of determined topics was presented and finally recommendations were formulated and results were verified on case studies.

16.4 Results

This chapter aims at defining basic specifics of economic evaluation of important transport water structures while respecting the changes given by the development of methodological materials.

16.4.1 Evaluation of the Economic Efficiency of the Waterway Transport Infrastructure Construction

Compared to road and rail transport modes, river transport is characterized by the lower amount of exhaust emissions, lower noise and accident rates. River vessels can transport considerably higher freight volumes than trucks or freight trains. They thus show lower specific energy consumption per unit of cargo transported.

In addition to transport benefits, construction of transport infrastructure on the waterway can have other benefits such as:

- Flood prevention,
- Improving water supply,
- Revitalization measures—habitats,
- Saving costs for maintaining road or rail infrastructure for transport of oversized cargo,
- Hydropower plants.

Construction of transport infrastructure on the waterway may also bring negative environmental impacts. Therefore, each intention should be evaluated in accordance with corresponding legislation and possible compensatory measures should be addressed. However, it should be noted that construction of infrastructure for competing for transport modes also means interference with the environment.

In terms of water transport disadvantages, the most important issue is the transport speed. This is both the slowest mode of transport and the most exposed one to the risk of restriction due to climatic conditions (drought, frost). The decision of the authorizing officer concerning the choice of the transport route is always determined by the optimal choice between costs, time of transport and risk rate. The parameter of the cost of capital bound in the goods also enters in the decision-making process when selecting the mode of transport and the transport route. The basic idea is as follows—the later the goods are delivered to the customer, the later the customer pays and the longer the seller has his finances bound in finished products. Analogously, this consideration applies to input raw material. The longer the company has it on the way to the factory, the larger the stock and the bound capital are. The capital for financing the stock of material or finished products, either in the form of own funds or in the form of foreign capital, carries costs in the form of interest or cost of reciprocated opportunity. Entrepreneurs are thus motivated to have a little stock of raw material or finished products as possible.

In fact, the situation is even more complicated as the agreed delivery parity or the issue of the minimum or maximum possible delivery quantity enters the decision-making process. For example, if a customer buys raw material that the seller is willing to deliver only in the form of full cargo delivery, the buyer's interest in minimizing the financial costs associated with financing the stock is suppressed by the impossibility of dividing the delivery. There may also be a situation where it is advantageous for the customer, on the contrary, to take advantage of relatively slow transport speed to use the vessel as a floating storehouse. The reason for this decision may be, for example, the high cost of storing goods in a seaport or the limited storage capacity in the production factory at the final consumption point of the raw material.

The density of the inland waterway network is limited compared to the rail or road network. Therefore, it is not necessary to process the transport model when determining the prognosis. Making prognoses should take into account generators of demand for freight transport, determining possibilities of their decline or growth in the outlook and identifying commodity groups specific for water transport. An important element in the demand estimate is the prognosis of the amount of cargo transferred from the competitive transport modes. Another input that serves for making the estimate more accurate is surveyed among authorizing officers, carriers or freight forwarders.

A specific area is represented by the use of waterways for passenger transport. In the Czech Republic, passenger transport is solely used for recreational purposes. Estimation of demand is usually done through marketing analysis. The result of the analysis should be the anticipated development of the demand and subsequent evaluation of the benefits from tourism in the area concerned. Segments of recreational and passenger transport are defined by different types of vessels corresponding to different types of recreation activities and socio-economic groups.

CBA (cost-benefit analysis) based on the evaluation of all significant benefits and costs associated with the project and their subsequent use for determining standard efficiency indicators (NPV, IRR, BCR) is the basic method for economic assessment of significant water transport structures. In exceptional cases, use of multi-criteria analysis or qualitative and quantitative analysis is methodologically acceptable; however, these cases are specified in detail in the methodologies [5, 16].

Basic areas determined in the framework of the economic evaluation of projects of significant water transport structures are as follows [16]:

- Analytical part, which analyses the problem being solved, the demand for the corresponding infrastructure, the connection to the related infrastructure and defines the project goal,
- Design part, which mainly deals with the solution proposal or its variants, which should lead to the achievement of the goal defined in the analytical part,
- Evaluation part, which contains an economic evaluation of the corresponding investment project itself.

The subject of this chapter is, in particular, the evaluation part. However, it is very important to state that the correct implementation of economic evaluation depends on the correctly and responsibly prepared first two parts.

16.4.2 Financial Analysis of Significant Water Transport Construction Projects

In accordance with the Sectoral Methodology [16], the purpose of the financial analysis is to assess all relevant financial impacts of the project under assessment, and it is carried out primarily from the perspective of the investor. The following aspects are mainly assessed as a part of the financial analysis [16]:

- Consolidated profitability of the project,
- Project profitability for the project owner,
- Financial sustainability of the project is verified,
- Cash flows that form the basis for calculating the socio-economic costs and benefits are described.

Financial analysis, similarly to the entire CBA, is based on the analysis of incremental cash flows, which are determined as the difference between cash flows within a project variant and a non-project variant. The main cash flows entering the financial analysis generally include:

- Investment costs,
- Operating costs,
- Operating income,
- Residual value.

Financial analysis also includes assessing and evaluating funding sources and possible self-financing of the investment.

Investment costs
Investment costs represent, according to the Sectoral Methodology [10], the sum of all capital costs that will be incurred as part of the investment project. In accordance with the currently applicable methodology, the framework structure is as follows:

- Project documentation,
- Land occupation and purchase,
- Building and construction (separate part—building costs),
- Machinery and equipment,
- Technical assistance, promotion,
- Technical supervision.

Operating costs
Operating costs are considered to be all the costs incurred during the operational

Table 16.1 Water transport infrastructure operating costs [16]

Item		Measure unit	Operation	Repairs and maintenance
Waterway	The Elbe—waterway including navigation canals	CZK/km/year	84,863	42,445
	The Vltava—waterway including navigation canals	CZK/km/year	84,524	206,710
	The Baťa Canal—canal sections including the locks	CZK/km/year	185,672	172,705
	The Baťa Canal—river sections including the locks	CZK/km/year	92,412	150,835
Locks (lock chambers, weirs)	The Central Elbe	CZK/km/year	2,230,635	1,537,057
	The Lower Elbe	CZK/km/year	5,860,882	3,316,408
	The Vltava	CZK/km/year	2,621,684	879,101
	The Vltava dams	CZK/km/year	5,103,459	1,671,700

phase of the project being evaluated to ensure operation and maintenance of the corresponding infrastructure.

Determination of the infrastructure operating costs is methodically determined in the case of significant water transport structures. In its data section, the Sectoral Methodology [16] defines unit costs for typical water structures. If the unit cost is not defined for the corresponding project, it must be determined individually. Table 16.1 shows an example of operating cost unit prices.

In the section of the water transport infrastructure operating costs, some changes have been made in comparison with previous methodologies (2014 Methodology [13] and 2016 Transition Methodology [15]). In the first place, the original two items for repair and maintenance were merged into one, which is a rather formal matter. In the framework of the Sectoral Methodology [16], unit costs for the harbour walls maintenance were left out, lock chambers and weirs were combined under one item—locks to determine the costs of operation, maintenance and repair. On the contrary, the determination of the costs of operation, repair and maintenance for individual waterways (the Elbe, the Vltava, and the Baťa Canal) have been made more precise compared to the former uniform rate for all waterways.

Traffic management operating costs are inconsistent with the Sectoral Methodology [16] for economic assessment and due to the marginal differences in these costs between the project variant and the variant without the project, are not relevant. In terms of vessel operating costs, these include in particular vessel repair and maintenance costs, fuel, lubricants and oil consumption, insurance and crew costs for passenger and freight transport. In the data part of the methodology, only the costs associated with the operation of vessels are outlined, other costs must be determined individually. Finally, it is important to note that assessing vessel operating costs is only relevant if the assessed project contributes to making transport on the waterway more efficient, either speeding up the traffic or reducing the operational demands for the vessels.

Operating income

Operating income is a general item used in all modes of transport, but it is necessary to state that, according to the Act No. 254/2001 Coll. On Water and Amending Certain Acts (the Water Act), free access to the waterway is guaranteed. Thus, the use of the waterway by any entity does not generate any income for the watercourse administrator.

Sources of financing

In the framework of the financial analysis and in compliance with the Sectoral Methodology [16], it is also necessary to identify sources of financing of an investment project to cover investment or operational costs and assess the financial feasibility of the project.

Residual value

Following the Sectoral Methodology [16], the residual value represents the potential of the infrastructure realized within the evaluated project after the expiration of the evaluation period until its economic life has been exhausted. The residual value is calculated by determining the Net Present Value of all cash flows realized within the project until the end of its economic life.

Indicators of financial analysis

The cash flows identified within the previous section serve as basic inputs for determining financial analysis indicators. Other inputs are the financial discount rate and the length of the evaluated period. Both indicators are based on the Guide to Cost-Benefits Analysis of Investment Projects issued in 2014 by the European Commission [5]. The financial discount rate is set at 4%; the evaluated period is 30 years from the first year of the investment. Compared to the original 2014 Methodology [13], there was a certain shift, as this methodology used a discount rate of 5% and the evaluated period covered included the whole project implementation period and the next 30 years of operation.

Indicators of financial analysis intended for the purpose of economic evaluation of projects in the field of the significant water transport structures are represented by the Financial Net Present Value (FNPV) and Financial Internal Rate of Return (IRR) which take into account only the cash income and expenses, i.e. the actual cash flows expected within the project.

16.4.3 Economic Analysis of Significant Water Structure Projects

Economic analysis is a key part of the economic evaluation of any public investment project. The objective of the economic analysis is to assess the extent to which will support the implementation of the project contributes to increasing the economic well-being of the society. The economic analysis is based on the materials for financial analysis, which is subsequently supplemented by all-society welfare (benefits) and costs (losses) which do not primarily have a financial dimension and therefore do not enter the financial analysis. Input data taken from the financial analysis must be transformed from market prices to shadow (conversion) prices using conversion factors. This will remove the disturbing impact of an imperfect market. Before using conversion factors, it is also necessary to make a so-called fiscal correction, in which the corresponding prices are reduced by VAT or other added taxes. More detailed information on market price correction is provided in the corresponding methodologies [5, 16].

Evaluation of the project economic efficiency is carried out based on the results of the cash flow balance in the form of Net Economic Returns, modelled ex-ante for the economic life period of the investment. On the revenue side, increases in socio-economic returns compared to the present, or decreases in socio-economic costs, are reported. On the expenditure side, increases in socio-economic costs or decreases in socio-economic returns are reported. The calculation formula is as follows:

$$NB_{(m-n)} = CI_{(m-n)} + BC_{(m-n)} + BE_{(m-n)} + BP_{(m-n)} + BEm_{(m-n)} + BO_{(m-n)} \tag{16.1}$$

where

$NB_{(m-n)}$ = Net economic yield of the project state (m) to the initial state (n)
$CI_{(m-n)}$ = Cost of the waterway in the project state (m) to the initial state (n)
$BC_{(m-n)}$ = Direct socio-economic return of freight water transport in the project state (m) to the initial state (n)
$BE_{(m-n)}$ = Saving from external freight water transport cost in the project state (m) to the initial state (n)
$BP_{(m-n})$ = Effects of personal and recreational water transport in the project state (m) to the initial state (n)
$BEm_{(m-n)}$ = Benefits of direct employment in the project state (m) to the initial state (n)
$BO_{(m-n)}$= Other benefits of the project state (m) to the initial state (n)

Indicators of economic analysis
Key outputs of the economic analysis are the following indicators:

- Economic Net Present Value,
- Economic Internal Rate of Return,

- Cost-effectiveness.

The critical inputs for the determination of these indicators are the economic cash flows after the corresponding fiscal adjustments and application of the corresponding conversion factors, the discount rate is, in compliance with the Sectoral Methodology [16], considered at 5% when compared to the original 2014 Methodology [13], it decreased by half of a percentage point.

Benefits and costs entering the economic analysis A key activity in the framework of the economic analysis is the evaluation of the all-society benefits and costs associated with the implementation, operation and liquidation of the investment project. Sectoral Methodology [16] presents the general structure of general effects (applies to all transport modes):

- Investment and operating costs of the infrastructure including reinvestment,
- Change in the general cost of transporting goods or persons, i.e.
  - Savings in vehicle operation costs,
  - Time savings,
- Changing external transport costs in areas
  - Reduction in accident rate,
  - Reduction in noise emissions,
  - Reduction in greenhouse gases emissions,
  - Reduction in emissions of non-greenhouse gases including dust particles,
  - Other, previously undefined, impacts.

Investment and operating costs are analysed in detail in the chapter on financial analysis. Other impacts are then dealt with separately for partial modes of transport in the Sectoral Methodology [16].

In the case of cost savings for vessel operation, the decrease in the cost of transport operators who subsequently provide services for the end users (passengers in the case of passenger transport, cargo in the case of freight transport) is considered to be beneficial in the case of projects of significant water transport structures. However, these savings have to be calculated individually, the Sectoral Methodology [16] does not specify any specific unit prices for the costs associated with the operation of vessels.

Time savings are another significant benefit which is a standard part of the economic evaluation of investment projects in transport infrastructure. Time savings can arise as:

- Savings in the frame of already existing transport where savings occur within the appropriate mode of transport,
- Savings due to transferred transport, where the transfer of transport (e.g. from rail to water or from road to rail) can cause time savings in one or more transport modes.

A large group of benefits consists of changes (in particular reduction) in costs in the areas of traffic accidents, noise emissions or harmful or greenhouse gas emissions. The change in the number of traffic accidents can be determined by reference to the processed traffic model and statistical information on the accident rate at particular traffic sections or the average accident rate on the roads of the respective classes. Unit costs associated with traffic accidents are based on the actual costs associated with an accident of particular severity. In the case of evaluation of accident-related impact a simplified evaluation can also be used to. This evaluation works with the unit costs associated with traffic accidents per passenger/km in the case of passenger transport and tonne/km in the case of freight transport.

Other benefits associated with changes in external costs include changes in noise emissions, greenhouse gases emissions and pollutants. Similarly, to the case of savings associated with traffic accidents, according to the Sectoral Methodology [16], it is possible to use a more detailed calculation or a simplified calculation in the case of noise. The detailed calculation works with quantifying the cost per person exposed to noise of certain intensity per year. The simplified approach works with unit costs per passenger/km for passenger transport and tonne/km for freight transport.

The social costs associated with pollutants and greenhouse gases emissions are determined in two steps. In the first step, the quantity of emissions in grams per transport/km for a specific means of transport is determined. In the second step, the resulting costs are determined by multiplying the determined emissions by unit costs.

Compared to the original 2014 Methodology [13], the Sectoral Methodology [16] made the calculation more detailed. According to the previous methodology, all external impacts (accidents, noise, greenhouse gases and pollutants) were determined simply based on the saved passenger/km or tonne/km and the unit costs of those externalities.

In contrast to the above-mentioned benefits, which are given the appropriate attention, Sectoral Methodology [16] does not pay much attention to the benefit in the form of savings in transport costs resulting from the transfer of traffic to the waterway, which is, crucial however, especially in the case of freight transport on the significant transport waterways. In the original 2014 Methodology [13], this benefit belonged to the direct socio-economic benefits of freight transport and represented a reduction in freight costs for goods owners in the case of the transfer of traffic from road and rail to a waterway which seems to be the cheapest in this respect. Quantification and evaluation of this benefit consist of the following successive steps:

- Identification of goods suitable for transfer from road and rail transport to water transport,
- Definition of the relations under which the goods are assumed to be transported, as well as the relations within which the goods were transported within the original transport,
- Determination of unit costs in Czech crowns per tonne/km for individual transport modes,
- Determination of the costs of transporting goods respecting the anticipated distribution of freight transport among individual transport modes in the zero variant

Table 16.2 Average freight transport rates (CZK/tonne/km excluding VAT, 2014) [9]

Transport	CZK/tkm
Road transport	2.14
Rail transport	0.96
Water transport—Inland	0.68
Water transport—cross-border	0.68

(without the project) and the investment variant (with the project) and determination of their differences,
- The inclusion of the results into the economic analysis.

Determination of this benefit requires a thorough marketing analysis and verification of the willingness of the goods owners to use the waterway instead of the existing road or rail transport in the case of the implementation of the corresponding project (the project can ensure the possibility of transport itself and increase its reliability or safety). Based on the marketing analysis, it is subsequently determined what goods and in what quantities will be transferred to the new mode in the case of the variant with the project. This is usually done using the tonne/km of the transferred transport. Another important element in determining this benefit is the definition of unit transport prices per tonne/km of transported goods. The original 2014 Methodology [13] used the average values of these costs. However, the economic analysts have the opportunity to determine these costs individually according to the currently available transport data and its prices. The unit transport costs determined to process the study of making the Elbe navigable [9] at 2014 prices are shown in Table 16.2.

On the basis of the simplified transport model, information about the amount of the transferred transport and the unit transport prices in the form of the average transport rates, the costs associated with the transport both within the variant without the project and the variant with the project can be determined. The difference between these variants then represents the impact of the transferred traffic and, if the cost of the variant with the project is lower than the cost of the variant without the project, it represents a societal benefit. This part of the economic analysis subsequently becomes the subject of the case study.

The authors of this part of the monograph propose to supplement the last part of the calculation formula, the $BO_{(m-n)}$ value_other benefits or harm of the project state (m) against the initial state (n) by two quantities that can be appropriately valued if the methodical material is used correctly. They are the following:

- Impact of the project on landscape character,
- Impact of the project on historical monuments.

Another significant impact of waterway projects is their influence on landscape character. Especially if the investment project of a significant waterway is located in parts of a predominantly unbuilt and agriculturally used landscape, whose axis is formed by the river with the remains of, e.g. formerly abundant floodplain ecosystems, in the area. The value of the landscape character can then be changed or deteriorated. In the projects, therefore, it is also necessary to evaluate their expected impact on the landscape character, i.e. to what extent they will interfere with the so-called legal criteria for the protection of landscape character, i.e. natural and aesthetic values, significant landscape elements (SLE), special protection areas (SPA), cultural dominants, harmonic scale and harmonic relations in the landscape [18].

Each area can be assessed in these terms from the point of view of ecological damage to the populations of significant plants and animals and their habitats within the area of interest (i.e. occupy the land for the waterway structure) and minimization and compensatory measures should be proposed for this occupation. Basic inputs for evaluation are significant plant and animal species and their habitats. The influence of the project is reflected in the negative impact on particular species. Species populations require ensuring functionality of the whole habitat for their sustainable preservation. To minimize or compensate for the impact on species, it is necessary to ensure functionality of the habitats which host the plant and animal community, allowing for the existence of a stable population of particular significant species. Compensatory measures are based on the creation of new biotopes. However, a new biotope or newly management controlled location will result in hosting a wider range of species than the basic representation of the relevant habitat is therefore each new habitat must be uniquely assessed.

Economic evaluation of the project impact can be carried out according to the NCA CR Habitat Assessment Method [19], which is based on the so-called Hessian Habitat Assessment Method.

Procedure for evaluating the area regarding habitat types consists in assigning habitats of the assessed area to specific types of habitat. By using the point values of the relevant types (representatives) of habitats expressed on 1 m^2 and multiplying it by their specific area, the summary point value of the surveyed area can be determined.

Point value for the entire monitored area of occupation at a particular time can be determined based on the following relation [19]:

$$BHC = \sum_{i=1}^{n} HB_i \tag{16.2}$$

where

BHC = point value of the whole monitored area (occupied habitats in the corresponding project) [points]
HB = point value of the ith biotope in the monitored area (occupied habitats in the corresponding project) [points]
i = habitats $1 - n$.

With regard to the fact that projects of significant waterways represent a permanent impact on the countryside with a time limit of 30 years according to the methodological materials, permanent environmental damage (or ecological benefit) is calculated according to the following formula:

$$TU = |BHC2 - BHC1| \tag{16.2}$$

TU = permanent ecological damage on a particular area [points]
BHC1 = point value of the area before the intervention [points]
BHC2 = point value of the area after the intervention [points].

Permanent environmental damage is paid by Department of Landscape Care as a lump sum in the amount of full point difference. According to the Act No. 17/1992 Coll., a permanent environmental damage is compensated by substitution measures at the site or other parts of the area in the vicinity of the damage caused, or, if this is not possible or effective, is paid in cash. Point value for the year 2016 is CZK 15.94/point [18]. Another important element in the evaluation of waterway projects is their possible impact on historical monuments, which occur very often on the waterways in the Czech Republic. As an example can serve the water structure Lock Přelouč. It is a monumental system of a weir, a lock, a bridge and a hydroelectric power plant on the Elbe River, which was built according to the project by architect František Roith, by the Prague Company Kapsa and Müller. This structure shows the strong rejection of the Art Nouveau aesthetic form by supporters of modern neoclassicism. The structure was created in the years 1921–1928. It is a part of many trips and hiking trails in the Pardubice Region and the Chrudim district. Within the consideration of the variants of the technical solution to the navigation section, among other things, it was necessary to include in the evaluation the price of the historical structure—national technical monument so that the all-society damage can be assessed from the economic point of view if it was totally or partially destroyed [18]. The amount of all-society damage was determined by the calculation of the historical price of the lock, where the price of the property determined according to the price regulation was adjusted by the coefficients representing the category of the cultural monument and its historical age, plus the price of art and craft work.

16.4.4 Risk Analysis

Structure of the risk analysis has not undergone significant changes in recent years as a result of the changes to the methodologies. Risk analysis can be formally divided into the following parts:

- Sensitivity analysis,
- Qualitative analysis,
- Quantitative analysis.

Sensitivity analysis focuses on assessing the sensitivity of evaluation criteria to the change in key input factors.

The qualitative analysis addresses identification of the key risk factors which are then assessed from the point of view of possible negative impacts on the project and its results and their intensity and from the point of view of probability with which the risk factors actually occur.

Quantitative analysis is then focused on probability risk analysis using simulation, e.g. using the Monte-Carlo method.

16.5 Case Study

The case study focuses on calculating the benefit in the form of transport cost savings resulting from the transfer of traffic to the waterway. This corresponds to the realization of the navigation stage in Děčín and other subsequent projects leading to the stabilization of the navigation conditions in the territory of the Czech Republic [9].

Socio-economic benefits in the form of import costs and other transport costs create cost savings for the transporters. The company benefit from implementing the project lies in reducing transport costs for goods owners, which leads to lower prices of imported raw materials and goods and on the other hand to higher profit from exported goods.

The first step of the economic evaluation is traffic analysis and prognosis; respectively a marketing analysis that quantifies the anticipated change in traffic flows after the evaluated project is completed. In this study, a marketing analysis was carried out to measure the amount of freight transport in tonne/km transferred from road and rail to water transport. Marketing analysis is based on the assumption of increased interest in water transport as a result of the implemented corresponding measures and ensuring reliable navigability of the Vltava and the Elbe rivers. Economic analysis in a simplified version presumes a step shift in transport volume since 2020 onwards, and the possible development of transport volumes in time, is not taken into account. However, calculations take into account the differences in the distances for the road, rail and water transport. Determination of the amount of transferred traffic is based on a detailed marketing analysis for defined relations. Partial relations consider the number of tonne/km transferred from rail and road to water transport, and the length of relations for individual modes of transport are given for both inland and cross-border relations in the study. Redistribution of the amount of traffic among individual transport modes for the presumed first year of the project operation (2020) is shown in Table 16.3 for both inland and cross-border transport.

In order to determine the direct socio-economic returns of freight transport, unit transport rates were used for partial transport modes. The rate for water freight transport is based on actual market prices for the individual transport relations predicted for 2020. The calculation of the rate is divided into two parts. The first part calculates the rate for inland transport; the second part calculates a rate for cross-border transport. Both partial rates are calculated using the same principle as the weighted arithmetic average of the rates in Czech crowns per tonne/km for the individual relations considered. Weights are the amount of transport in thousands of tonnes. The overall rate for water transport is set as the weighted arithmetic average of the partial

Table 16.3 Redistribution of freight transport (thousands of tonne/km) [9]

Inland transport	2020	Cross-border transport	2020
Total from road	78,064	Total from road	304,148
Total from rail	123,406	Total from rail	413,095
Total to water transport	219,775	Total to water transport	717,243

Note Values since 2021 are considered at the level of the 2020 values

Table 16.4 Cost savings of transporters (thousands of CZK, CO 2014) [9]

Inland transport	2020	Cross-border transport	2020
Total from road	166,886	Total from road	650,207
Total from rail	118,943	Total from rail	398,158
Total	285,829	Total	1,048,364

Note Values since 2021 are considered at the level of the 2020 values

rates for both inland and cross-border transport where the weights are the volumes of transport in thousands of tonnes. The overall rate for water transport was set at CZK 0.68/tkm and is in the price level of 2014 for which the analysis was carried out [9].

The value of the transport rate for rail transport is based on the analysis of the freight transport operated by ČD Cargo Company, which provides up to 76% [20] of rail freight transport in the Czech Republic. The calculation is based on the assumption that the average rate for rail freight transport corresponds to the share of revenues from CR Cargo own transport (CZK 10.2 billion in 2013, see the source [21]) and the number of transport volumes in tkm performed by CR Cargo company [20]. The amount of realized transport performance is based on the total realized transport performance for the Czech Republic in 2013 (13,965 million tkm, see source [22]) multiplied by the share of CR Cargo company for 2013 on the total transport performance (76.33% see source [20]). The final rate for the rail transport was set at 0.96 CZK/tkm in the 2013 price level.

The value of the freight transport rate on the road was taken from the Methodology [13], as it, according to the expert assessment of the processors, corresponds to the real values of the market prices of freight transport on the road. The rate is presented in the price level of 2012.

The used average transport rates were converted to a single price level of 2014 and are shown in Table 16.2.

Table 16.4 shows cost savings of transporters when transferring goods from road and rail to water transport.

However, the transfer of road and rail transport to the water transport does not only mean the decrease in road and rail freight costs for transporters but also increase

Table 16.5 Increase in the cost of transporters (Thousands CZK, CO 2014) [18]

Inland transport	2020	Cross-border transport	2020
To water transport	149,447	To water transport	550,338
Total	149,447	Total	550,338

Note Values since 2021 are considered at the level of the 2020 values

in the cost of transport on the waterway associated with the newly transferred traffic. Table 16.5 lists the costs associated with the transport of goods on the waterway.

16.6 Conclusions

Potential of water transport in the Czech Republic has not been currently fully exploited, especially due to the unreliability of the waterway. For several months a year, navigation is usually interrupted especially due to the missing Děčín navigation stage. Conceptual materials for the development of water transport in the Czech Republic include the realization of adequate investments in the development of the waterway, which will allow an increase in the volume of transported goods from 3.2 to 6.4 million tonnes per year since 2020. Transport trends indicate a continuous increase in the intensity of road and rail transport with the assumption of congestion growth due to their limited capacity. This phenomenon seems to positively affect the demand for waterway use in the future. Each of the intended partial investment projects has to prove economic efficiency. It is clear from both the methodological material and the international research that CBA method seems to be the appropriate methodical approach. The basic technical prerequisite of its use is, besides its own technical solution to the researched water infrastructure segment, a transport forecasting model. For this reason, the total volume of goods transported in the ports of Hamburg and Constanta have been presented in the text, as they play a key role in the transport of goods on the Central European inland waterways because they are final destinations for transport along the Elbe and the Danube rivers.

Two important components of economic evaluation, financial and economic analyses have been discussed in the test. The basis for the financial analysis is the creation of standard cash flows including investment costs, operating costs, operating income and residual value. Cash flow for economic analysis includes, in addition to adjusted values of the financial cash flow also benefits and damages related to water transport. At the end of the chapter, the authors demonstrate certain parts of the methodological procedures of the case study of Děčín water stage realization.

16.7 Recommendations

Methodological documents of the Czech Republic define a certain list of basic benefits and damage and further enable to include other specific items in the evaluation. Based on results of the research, authors recommend to supplement a methodology with determining of the impact of investment projects on landscape character in the form of evaluation of permanent ecological damage, if the investment action leads to the occupation of habitats. Another influence that should be included in the methodological procedures according to the authors is possible impact of waterway projects on historical monuments by determining their historical value.

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Chapter 17
Water Balance and Phase of Hydrocycle Dynamics

J. Rožnovský

17.1 Introduction

Climate dynamics in the Czech Republic has been increasing during the past 20 years and even before it was already characterized by high variability. The number of weather extremes increases, there is a statistically significant increase in air temperature, but not of precipitation. These changes manifest themselves also by the more frequent occurrence of drought and floods, which in general occur at irregular intervals. It is argued that climate change is the cause of high precipitation amounts, which cause major floods, such as the ones in 1997 and 2002 and that due to the quick melting of snow cover also in 2006. In 2010, high precipitation amount and many local floods occurred as a result of torrential rains. However, the number of drought events has been increasing in the last 20 years, caused by insufficient precipitation amount in particular during the warm half-year (April–September), with dry periods lasting several weeks or even months. Unusually, dry years in the entire Czech Republic were in 2000, 2003, 2012, 2015 and 2017. In South Moravia also in 2007. It is important to note that drought in the region of the Czech Republic is a random event, and it is therefore very difficult to predict. Due to the fact it is unexpectable and occurs in different seasons, also the negative impacts are more profound.

Precipitation deficit during vegetation period is often associated with high temperatures and occurrence of tropical days (maximum day air temperature equal to or above 30 °C), lower relative air humidity, lower cloudiness, and a higher number of sunshine hours. Precipitation is the only source of water in the Czech Republic. Even though precipitation amount is the only parameter used to assess drought and its occurrence, it is not the best characteristic to use.

J. Rožnovský (✉)
Czech Hydrometeorological Institute, Kroftova 2578/43,
616 67 Brno, Czech Republic
e-mail: jaroslav.roznovsky@mendelu.cz

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17.2 Precipitation

The only source of water in the region of the Czech Republic is atmospheric precipitation. Studies of climate change estimate that unlike air temperature, there will be a slight decrease in precipitation amount. Kożuchowski and Marciniak [1] presented a study, based on which precipitation amount in the Western and Northern Europe increased in recent years and will do so in the future as well. In contrast, in Southern and Eastern Europe, the precipitation amount decreases and will keep on decreasing. The region of the Czech Republic lies in the area with expected precipitation decrease. This trend has also been proven by other, more recent, studies [2].

Average annual rainfall for the entire Czech Republic for the whole period is 695.5 mm. However, the individual annual values are often quite variable. In the driest the year 2003 only 513 mm was measured, in 1983 it was 551 mm. The wettest year observed was 1966 with 860 mm, followed by 2002 (856 mm) and 1981 (852 mm). The trend during the 1961–2010 period shows a slight increase in precipitation amount, but this increase is almost negligible given the large variation from year to year. Regression line shows an increase of approximately 50 mm, while the difference between the driest and the wettest year is about 350 mm. Approximation using a parabola shows that the rate of increase is getting higher in recent years. There is no obvious periodicity in annual or even decadal values (i.e., wet years are not followed by dry years). Decadal averages in the 50-year period, or even 20- or 30-year averages show similar trends as the average over the entire 50-year period. These are given in Table 17.1.

The course of precipitation amounts for the individual stations or regions is similar to the course in the entire country. Individual maximums and minimums show a similar pattern. A dry year is dry in all regions and at all stations and similarly, a wet year is wet everywhere. This is because the total area of the Czech Republic is not very large. There are, however, large differences in the individual absolute values. Highest precipitation amounts are observed at mountain stations, especially in the northern parts close to the borders. On average, the station with the highest annual precipitation amount during the entire period was Vítkovice in Krkonoše mountains (1447 mm) and Lysá hora in Beskydy (1422 mm). The absolute highest observed annual precipitation was 2127 at the station Lysá hora in 2010. Lowest precipitation amounts are observed in lowlands, at stations Tušimice in Podkrušnohoří (437 mm) and in Prague-Karlov (440 mm). Absolute lowest observed annual precipitation amount in

Table 17.1 Average precipitation amount in the individual decades and 20- and 30-year periods for the entire Czech Republic

1961–1970	1971–1980	1981–1990	1991–2000	2001–2010
702	673	673	693	736
1961–1980	1971–1990	1981–2000	1991–2010	
687	673	683	715	
1961–1990	1971–2000	1981–2010		
683	680	701		

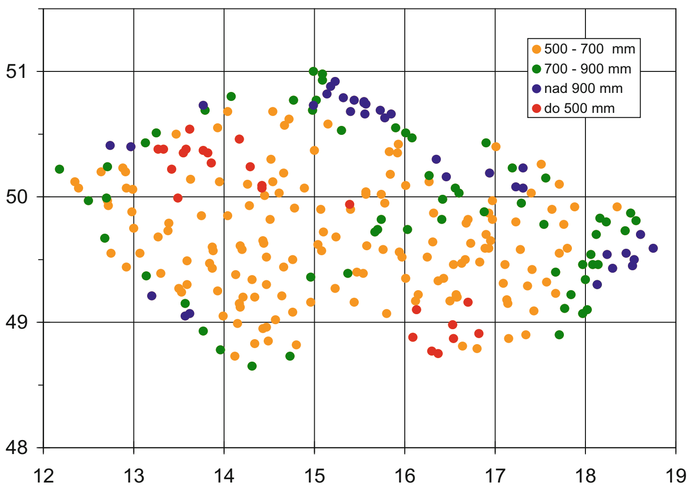

Fig. 17.1 Distribution of annual precipitation amount in the period between 1961 and 2012 in the Czech Republic

the entire period was 238 mm in 2008 in České Budějovice. The wettest region is eastern Bohemia (average of 892 mm) and northern Moravia (average of 827 mm). Driest region is central Bohemia (average of 556 mm) and southern Moravia (average of 593 mm). The distribution of average annual precipitation amount in the Czech Republic is depicted in Fig. 17.1. In general, the precipitation amounts show a significant positive correlation with elevation (coefficient of 0.72), to a certain extent also with latitude (coefficient of 0.31). However, this is because higher mountains are located mostly in the northern part of the country.

Change in precipitation amount in the individual regions is different. The highest rate of increase is observed in Podkrušnohoří (an increase of 13.2%) and southern and western Bohemia (an increase of 10.2%). In contrast, a slight decrease was observed in southern Moravia (−0.3%) and in northern Moravia, the increase is relatively small (2.8%). The distribution of the rate of increase or decrease at the individual stations is shown in Fig. 17.2. One can see that the differences, in this case, are more significant. A significant increase was observed at the station Bohdanovice in Jeseníky (32.4%), the largest decrease at the station Nedvědice in Vysočina (−20.4%). Despite the relatively small total area of the Czech Republic, one can also see some pattern with regard to geographical longitude. The western half of the country shows mostly increase (except Polabí and its vicinity), whereas eastern half of the country shows either only very minor increase or, more frequently, a decrease in precipitation amount, except high-elevation regions of Jeseníky and Beskydy. This means there is a significant negative correlation between precipitation amount and longitude (coefficient of −0.43). There is no significant correlation between absolute average annual precipitation amount and the trend (increase or decrease) (coefficient of just 0.14).

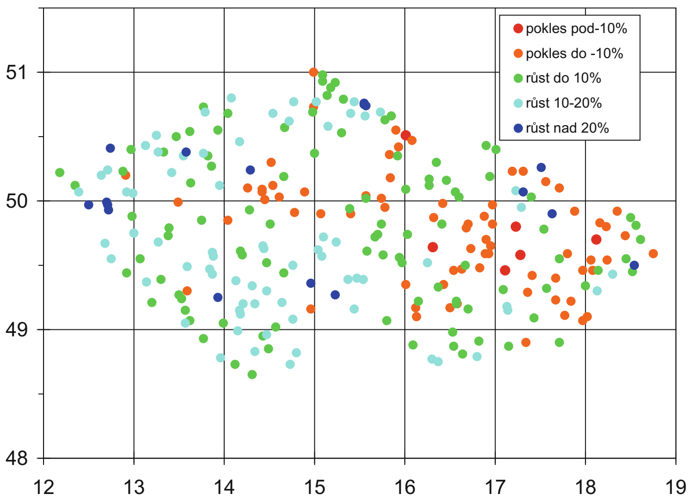

Fig. 17.2 Distribution of increase and decrease of annual precipitation amounts in the Czech Republic for the period 1961–2012

The season with the highest precipitation amount is summer (Jun–Aug), on average 36.8% of the annual total. This value differs only very slightly in the individual regions. Relatively wettest summers are in central Bohemia (39.3%), relatively driest in Podkrušnohoří (33%). The differences for the individual stations, however, are much more profound. Highest ratio of precipitation in summer is observed in Žatec (44.9%), absolute highest was the summer of 1997 in Vítkov in Oderské hills (63.3%). In contrast, the long-term lowest ratio of summer precipitation is at the station Vrbatova bouda in Krkonoše (20.3%), record low was the summer of 1983 at the station Rychorská bouda (8.6%). Percentage of summer precipitation amount also fluctuates from year to year (Fig. 17.3). Overall, driest summer was the one in 1962, when only 23.9% of the annual total precipitation amount was observed. On average, the highest summer precipitation ratio was in 1966 and 2011 (47.0%). Long-term change is negligible, based on the regression line the ratio of summer precipitation increased from 36.1 to 37.5%. There is also no periodicity (Fig. 17.4).

In spring (Mar–May), the average precipitation amount ratio is 23.5% of the annual total, highest value observed in central Bohemia and lowest in east Bohemia. In fall (Sep–Nov), the average for the entire country is 21.9%, the highest percentage being in east Bohemia and lowest in central Bohemia. Winter (Dec–Feb) is on average the season with least precipitation, average ratio for the Czech Republic as a whole being just 17.8%. Relatively most rainy winters are in east Bohemia, least in southwest Bohemia. The differences, however, are small, at most 1–2% more or less than the country average. Distribution of precipitation amount in the individual seasons for the Czech Republic as a whole and the individual regions are given in Table 17.2.

Change in seasonal precipitation amount in 1961–2012 is quite different from the course of annual precipitation amount (Fig. 17.2). The individual maximums and

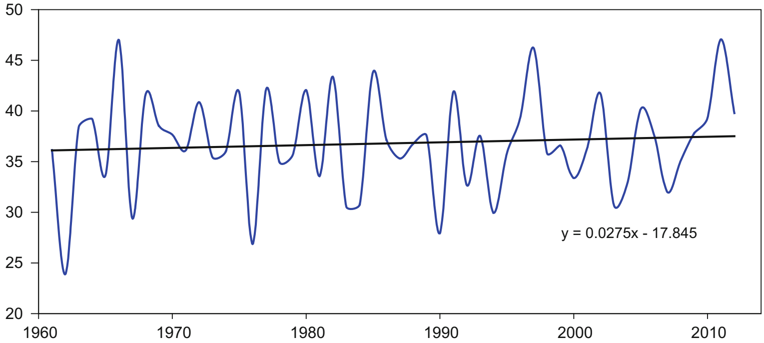

Fig. 17.3 Percentage of precipitation amount in summer from the annual total in the years 1961–2012 for the entire Czech Republic

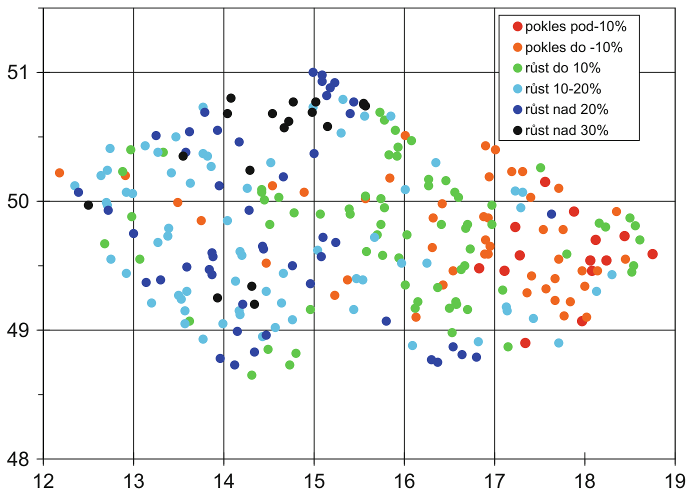

Fig. 17.4 Distribution of increase and decrease of precipitation amounts in summer for the Czech Republic between 1961 and 2012

Table 17.2 Ratio of precipitation amount in the individual seasons and regions

Region	Spring	Summer	Fall	Winter
Czech Republic	23.5	36.8	21.9	17.8
Podkrušnohoří	22.8	33.4	23.0	20.8
Western and southern Bohemia	24.1	38.7	21.0	16.2
Central Bohemia	24.2	29.0	21.0	15.8
Eastern Bohemia	22.2	33.5	22.7	21.6
Vysočina	23.5	36.5	21.3	18.7
Southern Moravia	23.9	37.6	22.4	16.1
Northern Moravia	23.8	37.5	21.9	16.8

minimums do not match, i.e., when a particular season in a year is quite dry or wet, this does not have to be true for each month of that particular year. A dry spring can be (but does not have to) compensated by higher value in the summer or fall. Even, many weather sayings suggest that extremes more often compensate each other rather than observing several similarly extreme months in a row. Also, the long-term trend in precipitation amount for the individual seasons is different. Highest increase is observed in the summer, mostly due to thunderstorms. This means that the number of heavy rain events and torrential rains in the summer increases. Given the fact these are limited to just a relatively small area, the change is not as apparent in the overall total as one could expect. In contrast, there is a decreasing trend in spring, which if significant can have negative impacts on agriculture. Other seasons show an increasing trend, but smaller than the annual average. Differences between regions for seasonal precipitation amounts show a similar pattern as in the case of the annual ones. The larger increase is observed in the western part of the country, and smaller increase or even decrease is observed in the eastern half of the country. This also holds for the individual stations. In summer, when the overall country increase is higher, there are more stations in western Bohemia with a more significant increase, while there are less stations with a decrease, and these are concentrated in Moravian lowlands. In spring, when the overall country trend is decreasing, there is an increase at only very small number of stations in mountain areas near borders and this increase is very small. Number of stations with a decrease is quite large, especially in Moravia. Distribution of increase or decrease in fall and winter is not much different from the annual distribution, just that in winter the number of stations with an increase or decrease is more evenly distributed and decrease is again more common in Moravia. The highest increase was observed at the station Jindřichov in Salesia (35.2% in spring, 52.8% in fall and 46.7% in winter) and Labská bouda in Krkonoše (44.7% in summer). Record decrease was observed for spring at the station Tuhan near Mělník (−44.7%), for summer in Olomouc (−16.7%), for fall in Lečtina near Zábřeh (−26%) and for winter in Nedvězí near Polička in Vysočina (−49.0%).

Just like the course of precipitation in the individual seasons differs, also the course in the individual months is different, even within the same season, given the average for the three months. Trying to show all months in one figure would be unclear. Instead one can focus on the change in annual variation (course of precipitation during the year) for the 50-year period of interest. Change in fall and winter months is very small. A decrease can be seen in the spring months, compensated by unusual increase in Match, so the overall spring decrease is relatively small. It is also worth noting that there is a gradual shift of the summer maximum. At the beginning of the period of interest, there was a significant maximum in June, over time this shifted to July. Annual variation for the entire period of interest shows flat maximum from June to August, with a slight increase in July. Differences between regions are small: June maximum compared to July maximum is more profound in southern regions (south Moravia, south and west Bohemia).

Annual precipitation amount for the entire Czech Republic slightly increases. However, this trend is not statistically significant and is not true for all the individual regions. In general, the regions in the western part of the country observe an increase slightly more significant than the country as a whole; in contrast, the eastern parts of the country have either only slight increase or even decrease. The precipitation trend is therefore in accordance with the European trend described earlier [1–3].

17.3 Water Balance

Drought occurrence is also related to the rate of evaporation [4]. Evaporation is a complex physical process, and it is, therefore, unlike many other meteorological parameters, very difficult to quantify [5]. Evaporation data, but only from the water surface, are available from the network of stations of the Czech Hydrometeorological Institute. Regular evaporation measurements from water surface using the GGI-3000 device began already in 1968, similarly in Slovakia [6]. By 2011, all the GGI-3000 devices were replaced with EWM automatic [7]. Evaluation of the data shows that evaporation totals and their temporal variability are quite different in different regions, which is due to the variability of other meteorological parameters [8]. Average daily evaporation in the Czech Republic as a whole in the period between 1971 and 2000 was 2.6 mm and the average for vegetation period (May–Sep) was 393.7 mm. Average daily evaporation in South Moravia between 1981 and 2010 was 3.0 mm, and average vegetation season total was 462.3 m [9].

Given the complexity and high costs associated with measuring evaporation, several equations for evaporation estimation are being used globally [10]. Evapotranspiration, which also takes into account evaporation from vegetation, is a better representation of the total evaporation from landscape [11]. It is also included in equations for calculating watering requirements [12]. To evaluate the occurrence and intensity of drought, we use a simplified, in fact, meteorological water balance, expressed by the difference between precipitation amount and potential evapotranspiration. This is referred to as basic (potential) water balance for grass cover (from now on referred to as ZVB_TP) and this value allows one to evaluate drought in the landscape [13]. Difference between potential evapotranspiration and precipitation is an indicator for the evaluation of particular regions within the agroclimate zoning [14]. It is also part of crop yield models [15].

It is obvious that water balance significantly affects the amount of water in the soil. The amount of water in the soil in landscape is primarily affected by the course of the weather, but also the soil type and characteristics, especially retention capacity [16].

ZVB_TP is a simple expression of water status in landscape for a particular time interval. It is calculated as the arithmetic difference between precipitation and evapotranspiration (potential, current, reference) for a particular time period, where both parameters are expressed in mm for better comparison. To make things simpler, no outflow components are taken into account, also for evaporation calculation from basic water equation homogeneous evaporating surface is assumed, which is very similar to a standard grass cover in terms of its physiological properties. If such an assumption was not made, the issue of water balance in real conditions would be extremely complex and from the perspective of landscape as a whole practically impossible to solve [17].

It is necessary to emphasize that the occurrence, course, and intensity of drought in the Czech Republic are different in individual years. Drought in the Czech Republic is a random event with an irregular occurrence. For drought description, the year 2015 was selected, where it is possible also to show that the standard approach in climatology to express values for individual months is inappropriate for drought evaluation. Its course is also affected by the course of the weather in winter. The winter of 2014/2015 as a whole was above average in terms of air temperature by 1.5–3.5 °C. Precipitation deficit was up to 50% (in some parts of south Moravia and a large part of Bohemia). Only parts of northern and eastern Moravia were slightly above average. Between April and June, the precipitation amount in most regions in the country was below average, so by the end of May, the stretch from Karlovy Vary, central Bohemia down to České Budějovice only measured 50–75% of normal precipitation amount. A similar situation was found in central and southern Moravia. In June, the situation in Podkrušnohoří improved and the precipitation reached normal values. In contrast, in Moravian region, the area with deficit between 25 and 50% got larger values. Exceptionally, low precipitation amount in July caused that large part of the country had a deficit between 25 and 50%. In some places, especially in south Moravia, the precipitation deficit was even larger than 50%. However, thanks to several thunderstorms, the deficit decreased in some places. The constant increase of the deficit was stopped by more intense rains on August 16. However, the deficit was not evened out so overall the annual precipitation total was only 50–75% of normal values in some parts of the south, central, and northern Moravia and 75–90% in rest of the country.

Given such conditions, the values of basic water balance were average in March, which was therefore also true for ZVVP in the soil profile. The course of the air temperature in April led to higher values of evapotranspiration at approximately 50% of Bohemian region by 20 but in some places even 40%. As can be seen in Fig. 17.5, by the end of May, practically all agricultural regions had ZVB-TP deficit, in South Moravia and a few other places the deficit was larger than 200 mm.

The occurrence of tropical days increased the deficit so much that by July 12, 2015, there were places, where the basic water balance had a value of less than -150 mm. This remained for the entire July and the non-homogeneity of this field caused local thunderstorms, which, however, were scarce so did not affect the water balance. In mid-August, approximately 25% of the country observed a deficit of 200 mm. Despite some precipitation later, the effects of agricultural drought in most of the country were apparent even as late as October. The values of ZVB_TP on October 4, after the end of vegetation period (Fig. 17.6) are highly deficient. This occurs not just Northern Moravia, but also part of Southern Bohemia. On the other hand, the eastern part of Central Bohemia and up to the Krkonoše mountains had a deficit of more than 250 mm.

The more and more dynamic weather in the last two decades is undeniable evidence of changes of the Czech climate. When evaluating the amount of water in the landscape, where soil moisture and other hydropedological characteristics play

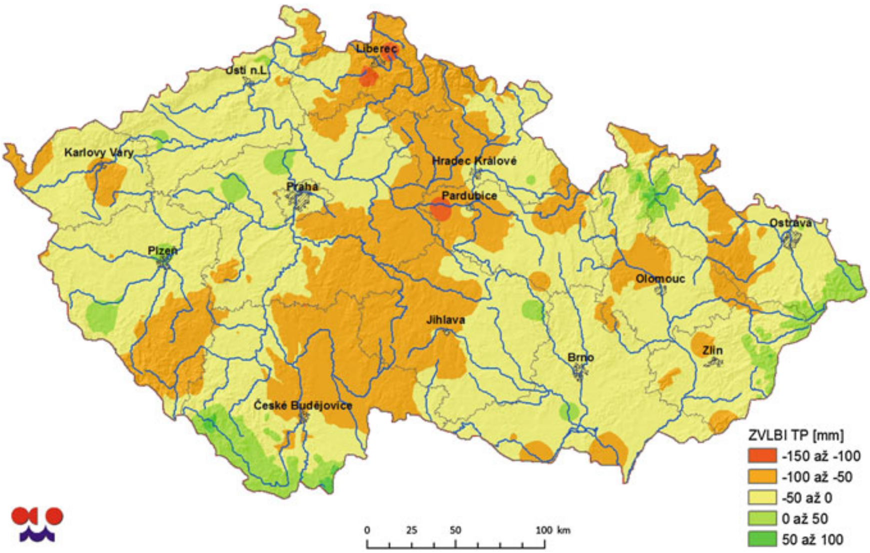

Fig. 17.5 Basic water balance of grass cover in the region of the Czech Republic (%), comparison between March 1 to May 31, 2015, with long-term average (1961–2010) (http://portal.chmi.cz/aktualni-situace/sucho#)

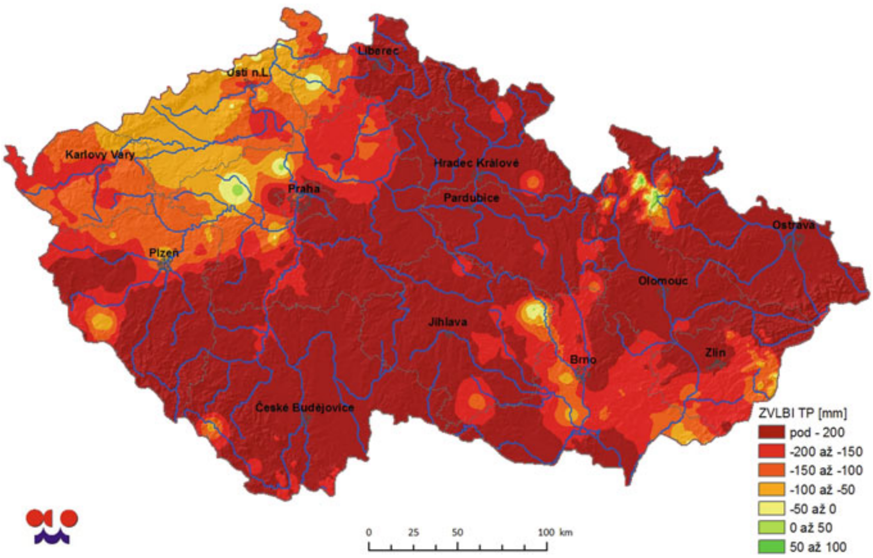

Fig. 17.6 Basic water balance of grassland in the Czech Republic (%), comparison between March 1 to October 4, 2015, and long-term average (1961–2010) (http://portal.chmi.cz/aktualni-situace/sucho#)

an important role, one must take into account that extremes in precipitation are a major cause of drought—but not the only cause. There is a significant increase in air temperature between 1961 and 2010 and statistically constant annual precipitation amount. This means that the course of drought is affected by the increasing potential evapotranspiration due to increased air temperatures. A useful indicator of drought intensity and occurrence is the so-called basic water balance, which is expressed as the difference between precipitation amount and potential evapotranspiration from grassland. The calculations are performed at the Brno branch office of the Czech Hydrometeorological Institute (CHMI) as part of the AVISO model in daily step and weekly published at the official CHMI website as part of drought monitoring.

17.4 Conclusions

In Western and Northern Europe, precipitation increases; in Eastern and Southern, precipitation decreases. In European context, the Czech Republic lies eastwards, but the western part of the country still observes a slight increase. Even though the extent of increase or decrease does not correlate with the annual amount, in Moravian lowlands there is both low average annual precipitation amount and a decrease. It is also likely that this decrease in these regions will continue in the future as well.

It is, however, different when it comes to seasonal amounts. In summer, the precipitation amount increases significantly more than the annual average. Given that summer precipitation is usually associated with intense thunderstorms, it is likely that the number of these will also increase in the future. However, even though this means an overall increase in summer precipitation amount because a lot of water reaches the ground in a short period, most of it flows away and is not maintained in the landscape. Such higher precipitation amount, therefore, does not lead to a larger water reserve in the soil. In contrast, there is an obvious decreasing trend in precipitation in spring. It is, therefore, possible that there is a lack of water at the beginning of the vegetation period, especially in regions, where the overall precipitation amount is low. Precipitation amount in fall and winter is of less importance in terms of vegetation period. There is a slightly increasing trend, but less than the overall annual trend. The same holds for seasonal precipitation in regions, as for the precipitation trend in the entire country—there is an increase in the western part of the country, a decrease in the eastern part, and this decrease is more significant in lowlands.

Looking at the basic water balance values during dry years in the Czech Republic, it can be seen that it is a good indicator of drought and useful for evaluating its intensity. The results proved that the region of the Czech Republic is in terms of water balance quite a variable environment. This is due to an uneven distribution of precipitation as well as average air temperature, which is, in particular during dry years, exceptionally high. The drought has a certain cumulative nature, and during unfavorable conditions, its intensity and impacts increase every day. These impacts can then last long after the drought is over. During the mentioned dry years, the values of ZVB_TP deficit reached even more than 250 mm by the end of the vegetation period. This is approximately half of the precipitation amount in these regions.

17.5 Recommendation

It should, however, be emphasized that the onset of drought, as well as places affected, are variable depending on precipitation. In general, drought is most common in the warmer regions with the lowest average annual precipitation. Results also prove that the extent of drought in a certain year is affected by the conditions during the previous year, especially by the conditions at the end of vegetation period, fall and winter. If it is dry even during fall and the water deficit is not compensated during winter, the drought will be apparent in soils in spring of the next year. Also, as recent studies show, the air temperature increases even in winter and the amount of snow decreases; this leads to a decrease in soil water content in spring.

Soil properties (both agricultural and forest) are very important from the perspective of retaining precipitation water in the landscape, where most of the absorption takes place. It is therefore important to take measures that will lead to better infiltration abilities and increased soil retention capacity to its original level. This includes measures aiming to decrease soil erosion because the topsoil horizon has a significantly higher capacity than eroded soils. Increasing the variability of the landscape will contribute to lower water outflow, also because of decreased airflow and subsequent lower evapotranspiration.

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Part V
Conclusions

Chapter 18
Update, Conclusions, Recommendations for Assessment and Protection of Water Resources in the Czech Republic

M. Zelenakova, J. Fialová and A. M. Negm

Abstract This chapter presents an update regarding the assessment and protection of water resources in the Czech Republic. The conclusions and recommendations of the chapters presented in this book are generalized and summarized. The chapter presents a summary of the most important findings presented by the contributors to the book. Topics which are covered include water resources in the Czech Republic, including groundwater, small water reservoirs, ponds, wetlands, small bodies of water, rivers and the importance of water for different ecosystems (fauna, flora and for human with no exception). Important topics are the protection of the water resources, the role of the water in the landscape in general and with some specifics in the arable lands, hydrological reclamations in the landscape. Also, a set of recommendations for future research work is pointed out to direct future research towards and development of water resources in the Czech Republic.

18.1 Introduction

Water is an essential medium regarding the transport, decomposition and accumulation of pollutants, whether of natural or anthropogenic origin, which in excessive amounts represent considerable risks for all kinds of living organisms, thus also for human beings. The step towards adequate protection of water resources

M. Zelenakova
Department of Environmental Engineering, Faculty of Civil Engineering,
Technical University in Košice, Košice, Slovakia
e-mail: martina.zelenakova@tuke.sk

J. Fialová (✉)
Department of Landscape Management, Faculty of Forestry and Wood Technology,
Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech Republic
e-mail: jitka.fialova@mendelu.cz

A. M. Negm
Water and Water Structures Engineering Department, Faculty of Engineering,
Zagazig University, Zagazig 44519, Egypt
e-mail: amnegm85@yahoo.com; amnegm@zu.edu.eg

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is to know their quality. Systematic investigation and evaluation of the occurrence of surface water and groundwater within the country is a fundamental responsibility of the state, as an indispensable requirement for ensuring the preconditions for permanently sustainable development as well as for maintaining standards of public administration and information. The primary requirement in this context is to optimize the water use especially with the consequences with the long-term drought.

The chapter presents a brief of the essential findings of the studies on the assessment and development of water resources in the Czech Republic, then the main conclusions and recommendations of the volume chapters in addition to few recommendations for researchers and decision-makers.

18.2 Update

In the following, the national studies regarding the water resources, assessment and development in the Czech Republic are presented. The brief results of the studies are introduced.

Paseka et al. [1] studied the new approach to decision-making methods for the design of new reservoir due in times decreasing water resources. The methods have been selected primarily to analyse different design parameters of a new dam, mainly dam heights leading to different reservoir volumes. A simulation model has been coupled with a cost model and a Non-dominated Sorting Genetic Algorithm II multi-objective optimization algorithm to quantify resilience and robustness under a range of uncertain future climate supply scenarios and one possible demand scenario.

Sekáč et al. [2] mentioned the conversion of farmland to non-farm uses that significantly influences the spatial variability of farmland prices. They tested 12 factors of land prices that experience real estate brokers indicated to be the most important determinants for the conversion of farmland to non-agricultural use. Five factors can be described as landscape, four as geographic and three as climatic explanatory variables influencing farmland prices. Their results indicate that the two most important factors in explaining the sales price per square metre were proximity to a river and proximity to a lake. In both cases, the price of land diminished significantly with the increasing distance from the edge of water bodies. The fact that the two most powerful factors indicate the distance to a river, brook, lake or pond shows how important are these freshwater features as determinants of farmland prices in a landlocked country such as the Czech Republic, where this study was performed. The consequences of this finding for water resources planning and management are discussed.

The water demand management was analysed in the study by Slavíková et al. [3]. Water demand management stresses the crucial roles of water user motivations in balancing actual water availability and competing human needs. The study shows how the absence of such motivations influences artificial water scarcity, even in resource-abundant countries, and how slight modifications to economic instruments (surface water charges in particular) might solve the problem. By constructing a simple and relatively static model based on Czech historical data, they were able to illustrate the impacts of surface water payment modifications, particularly the introduction of the capacity (reserved volume) payment into the existing system. The ultimate goal of the modification was to solve the detected problem of artificial water scarcity that has social/political rather than environmental/ecological causes. They found that the modification results in the following outcomes:

– it does not cause a major increase in the average surface water price (when considering the proportional decrease of the initial actual use payment and maintaining the appropriate ratios of both types of payments);
– it slightly increases annual revenues of state water administrators while respecting the user pays principle better;
– it effectively reduces redundant surface water claims (solely based on the individual decisions of water users rather than through non-flexible administrative decision-making).

Moravcová et al. [4] conducted a study of land consolidation project and their impact on land use changes. The case study covers 19 cadastral areas in the western part of the Czech Republic that were affected by the land consolidation process during 2000–2006. The main task of this study was to document how land consolidation processes could affect the change in land use and landscape structure and whether the land consolidation planners take into account the protection of natural resources. The increased acreage of grasslands was the most important change which has occurred in the land use in the 19 analysed cadastral areas, before and after land consolidations. In the studied area, the changes in land use involved 6.8% of the total land consolidation area. This area of grassland significantly increased the protection of agricultural land from water erosion. Regarding changes in the landscape structure, the construction of new field road networks is the most important result. The results confirm the importance of land consolidation processes not only for the organization and recovery of ownership and cadastral records but also for the improvement of agricultural use of landscape and protection of natural resources such as soil, water and plant and animal communities. The main results of this study are that grasslands also significantly increased the protection of agricultural lands from erosion, and significantly increased water resources protection.

Xuan [5] with her colleagues from the Czech Republic focused their study on the intensive forest management and modelling of the long-term water yield effects. Intensive forest management is one of the main land cover changes over the last century in Central Europe, resulting in forest monoculture. It has been proposed that these monoculture stand impact hydrological processes, water yield, water quality and ecosystem services. At the Lysina Critical Zone Observatory, a forest catchment in the western Czech Republic, a distributed physics-based hydrologic model, Penn State Integrated Hydrologic Model (PIHM), was used to simulate long-term hydrological change under different forest management practices, and to evaluate the comparative scenarios of the hydrological consequences of changing the land cover. Stand-age-adjusted leaf area index (LAI) curves were generated from an empirical relationship to represent changes in seasonal tree growth. By consideration of age-adjusted LAI, the spatially distributed model was able to successfully simulate the integrated hydrological response from snowmelt, recharge, evapotranspiration, groundwater levels, soil moisture and streamflow, as well as spatial patterns of each state and flux. Simulation scenarios of forest management (historical management, unmanaged and clear cutting to cropland) were compared. One of the critical findings of the study indicates that selective (patch) forest cutting results in a modest increase in runoff (water yield) as compared to the simulated unmanaged (no cutting) scenario over a 29-year period at Lysina, suggesting the model is sensitive to selective cutting practices. A simulation scenario of cropland or complete forest cutting leads to extreme increases in annual water yield and peak flow. The model sensitivity to forest management practices examined here suggests the utility of models and scenario development to future management strategies for assessing sustainable water resources and ecosystem services.

18.3 Conclusions

The following part of the conclusions have been mainly extracted from the generally known states and the materials prepared by the Ministry of Agriculture of the Czech Republic [6, 7]

The Czech Republic, sometimes called ‘the roof of Europe’, is a landlocked country in the heart of Central Europe, which predetermines its relation to the European river network. Czech rivers drain away all meteoric and spring water from our mountainous springy drainage area to the surrounding lowlands. The main European watershed (drainage divide) runs through the territory of the Czech Republic and meets with the drainage divide between the Baltic Sea and the North Sea. The triple divide point is located at the Czech-Polish border on Mt. Klepý in the Králický Sněžník Mts.

The territory of the Czech Republic is drained into three seas—the drainage area of the North Sea covers 66.2% of the country´s territory, the Black Sea drainage area covers 24%, and the Baltic Sea drainage area covers 9.8% of the territory. The long-term average annual precipitation on the Czech Republic territory is approx. 670 mm, i.e. 53 milliard m^3 of water, of which approx. 29% (15 milliard m^3) are drained by rivers.

The main hydrographic network comprises nearly 108 thousand km of watercourses with both natural and artificially channelled beds. The Water Act classifies the watercourses of the Czech Republic as significant and minor, and their administration is performed in accordance with the provisions of the Water Act. The main administrators of watercourses within the scope of the Ministry of Agriculture are the River Basin Administrations, state enterprises, and the Forests of the Czech Republic, state enterprise; as of 2016, they provide administration of 94.4% of the total length of watercourses within the Czech Republic. Other subjects that may administer the remaining 5.6% of minor watercourses include the Ministry of Defence, the National Park Administrations and other natural persons or legal entities.

In total, there are 819 significant watercourses on the territory of the Czech Republic with the total length of 16,350 km, managed by the individual River Basin Administrations (RBA), state enterprises: the Elbe RBA, the Morava RBA, the Oder RBA, the Ohře RBA and the Vltava RBA. The backbone watercourses are the Elbe River (370 km) with 'the Vltava River (431 km) and the Ohře River (254 km) in Bohemia, the Morava River (269 km) and the Dyje River (194 km) in the south of Moravia and the Oder River (135 km) with the Opava River (131 km) in the north of Moravia and in Silesia' (http://eagri.cz/public/web/file/10537/Professional_management_of_watercourses_20).

All the other watercourses are in the category of minor watercourses, and their administration is carried out on the basis of the respective appointment by the Ministry of Agriculture of the Czech Republic. 'The administration of minor watercourses may be carried out by the municipalities through the territory of which they flow' (http://eagri.cz/public/web/file/10537/Professional_management_of_watercourses_20), by natural persons, legal entities or by the organizational units of the state using them or performing activities with which these minor watercourses are connected. The total length of minor watercourses (as of 2016) according to the Central Register of Watercourses is 83,200 km.

As of 2013, there are 165 significant water reservoirs and 523 minor water reservoirs in the Czech Republic. The total length of the Czech Republic´s waterways is 522.2 km.

The country is extremely poor in lakes; the small number of lakes is due to the long-term development of the territory and to the fact that it was not affected by significant climatic changes during the Quaternary. Our lakes are located in the areas affected by the Quaternary glaciation. Numerous lakes were found in the Ostrava region and in the North-Bohemian hooks some 200,000 years ago; however, during the last glacial periods, they eroded through and thus were naturally drained. The main region of our lakes is the Šumava Mts. with a total of eight cirque lakes, five of which are on the Czech side and three on the Bavarian side. The lakes are open (exorheic), supplied by precipitation and streams. The Bavarian lakes and the Čertovo jezero lake drain to the Danube River Basin, and the remaining Bohemian lakes to the Elbe River Basin. Their cessation is slow as the rock erosion is held back by forests; the lakes are oligotrophic with bottoms formed of sand and sludge. In 1831, our largest lake (5, 21 km^2 including the swamps at its periphery) by Komořany u Mostu was artificially drained to give way to agricultural land. It had probably been a residuum of a large Tertiary lake in the Most basin. Some of the lakes in the Czech Republic developed as oxbow lakes along larger watercourses. Oxbow lakes are river meanders that had been cut off from the main stem and can be found in the central Polabí region (between the towns of Pardubice and Lovosice) and along the lower stretches of the Morava and the Dyje rivers. Karst lakes developed in cavities formed by cave corrosion and at the bottoms of abysses. In the Czech Republic, such type of lake is represented by the upper and the lower lake of the Macocha Abyss or by the lake at the bottom of the Hranice Abyss. The bodies of water accumulated in the peat bogs may also be viewed as lakes; the largest of them is the lake in the Chalupská slať peat bog (1 ha) by the upper stretch of the Vltava river. Similar lakes are found in the Hrubý Jeseník Mts. (the lake near the Rejvíz municipality) or in the Krušné hory Mts. (the Velké Jeřábí Jezero and the Malé Jeřábí Jezero lakes).

Peat bogs cover an area of 23.000 ha in the Czech Republic with half of this area belonging to mountain bogs and a half to fens or transitional types between bogs and fens. A mountain bog filling a depression (basin), receiving water exclusively from precipitation and with an elevation in the centre of the basin resulting from the massive accumulation of peat moss layers is called a raised bog. Raised bogs are found mainly in the Šumava Mts. where they cover an area of 5.000 ha with the centre of their occurrence in the Šumava Plains, i.e. an area between the upper stretches of the Vltava, the Otava and the Řezná Rivers. Bogs can be found in the mountains with the occurrence of old flattened surfaces, for example, at the horst of the Krušné Hory Mts., in the Jizerské Hory Mts. or at the north of the Hrubý Jeseník Mts. Larger areas of bogs are also present in the Slavkovský Les upland by the town of Mariánské lázně. The wetlands of the lower altitudes are called fens and are eutrophic (as compared to the oligotrophic bogs). The fens are found in lower or basin elevations, such as in the Třeboň basin between the towns of Soběslav and Suchdol nad Lužnicí or in the Litovelské Pomoraví area. Temporary swamps occur in the northern part of the Ralská pahorkatina Hills or in the region of the Žďárské vrchy Hills in the form of bogs in lower altitudes on subsoils poor in minerals.

In order to reduce the threat of soil erosion and the consequences of drought as well as to increase protection against the negative effects of surface runoff, it is necessary to propose and to implement appropriate measures, preferably in a complex system. A combination of organizational, agro-technical and technical measures is most recommended. The most effective tool for the implementation of such measures in a landscape is the process of land consolidation. To the present (as of 2016), simple and complex land consolidation has been performed at more than 31% of the agricultural land area and at nearly 7.1% of the area it is currently in progress. Within the realization of common facilities, anti-erosion and water management measures had been performed at 705.1 and 461.25 ha, respectively, by the end of 2016. The costs of the anti-erosion measures realized within the land consolidation process in 2016 exceeded 13 million CZK and the costs of the realized water management measures exceeded 67 million CZK.

In 2016, 9.972 million inhabitants (i.e. 94.4% of the total population) of the Czech Republic were supplied with tap water. The waterworks altogether produced the total of 593.3 million m^3 of drinking water. The volume of drinking water supplied against payment (invoiced) was 478.9 million m^3, of which 322.3 million m^3 were supplied to households. The length of the water supply network was 77,681 km in 2016. New construction and completion of the existing water supply network segments increased the number of the inhabitants supplied with tap water by 42,806. The length of the water supply system per capita (of the inhabitants supplied with tap water) is, therefore, 7.79 m.

In 2016, 8.944 million inhabitants of the Czech Republic lived in houses connected to the sewage system, which represents 84.7% of the total population. The total of 446.9 million m^3 of wastewater was drained away by the sewage system, of which 97.3% went through wastewater purification. In 2016, the total length of the sewage system reached 47,141 km, and the total number of wastewater treatment plants was 2554.

There are currently approx. 24 thousand fish ponds and water reservoirs on our territory with the total area of about 52,000 ha, of which more than 41,000 ha are used for fish farming. They are managed by 70 major fisheries, each with annual production over 5 tons, and a several hundred minor fish farmers. Over 2.000 fishing grounds have been designated in the Czech Republic with a total area of 42.000 ha, and there are approx. 350,000 registered recreational fishermen.

International cooperation of the Czech Republic in the field of water protection is based on the principles set by the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes, signed by the Czech Republic in 1992.

Second part of the book with the title '**Surface and Ground Water Bodies**' consists of 6 Chapters and here are the main conclusions of them.

The chapter '**Rivers in the Czech Republic**' provides basic information about rivers in the Czech Republic which is a small landlocked country located in Central Europe between Poland, Germany, Austria and Slovakia. Being an inland country in Central Europe with rugged relief and located on the Main European Divide of three seas, the Czech Republic has no other source of water than precipitation. Of the 76,000 km of natural watercourses, 28.4% are altered. Although there has been a significant improvement in water quality since 1990, particularly a decrease in saprobic pollution, other significant pressures have emerged such as eutrophication, morphological alterations of the channels, disruption of sediment transport or fish migration that degrade aquatic ecosystem functions and restrict the structure of their biological communities. Moreover, many streams and rivers in the Czech Republic have experienced extreme climate fluctuations leading to unexpected floods and long periods of drought in recent years. Regardless of what degree these extreme fluctuations are a consequence of ongoing climate change or the result of improper landscape management, flooding and drought are expected to adversely affect instream life as well as people. Therefore, future management of streams and rivers should consider the needs of water supply, wastewater dilution, hydropower generation or navigation on the one hand; and on the other hand, the good ecological status of watercourses supports sustainable water balance of the landscape. Thus, while diffuse pollution from arable lands may be reduced by improved agricultural practices, hydro-morphological alterations could also be considerably improved through stream restoration efforts (e.g. [8, 9]), reopening and creation of side channels and by the construction of effective fish ladders at weirs [10–12].

The next chapter '**The Role of Water in the Landscape**' pays attention to the important aspect that in recent years, the Czech Republic has experienced extreme weather fluctuations leading to unexpected floods and long periods of drought. The current situation is a result of the long-term use of our landscape which is no longer able to retain and accumulate water, mainly due to technical alterations of watercourses, changes in land use and deforestation. The principles outlined in this chapter call for alternative approaches to land use and land management. Widespread agricultural practices in Czech Republic that reduce the soil's capacity to retain water (e.g.

through soil compaction, reduced organic matter, etc.) should be replaced with strategies that work within the confines of the hydrological cycle. In particular, the European Commission's Climate-ADAPT programme suggests checking and rebuilding old drainage systems; establishing variable water flow regimes; rehabilitating and reconstructing/adapting morphological structures in rivers; adopting crop rotation, minimal or no-tillage systems and improved soil cover management practices; in addition to other recommendations [13]. Unchecked growth of urban areas, often coinciding with increased area of impervious surface, should be put in check and/or developed in a manner allowing maximum water retention in the landscape. Riverine elements within or adjacent to the stream (floodplains, wetlands and alluvial ecosystems) have a disproportionately large impact on water storage capacity relative to their small surface area as compared to uplands, and should, therefore, be granted special protection where they existed and prioritized as areas for restoration where they have been degraded.

The chapter '**Small Water Reservoirs, Ponds and Wetlands' Restoration at the Abandoned Pond Areas**' addresses the small water reservoirs that are one of the basic elements of the agricultural landscape in the Central European space. They are one of the most valuable nature-loving elements of the cultural landscape. In the Czech Republic, they have a long historical tradition. The abandoned pond areas often have soils which are not very suitable for intensive agricultural production (e.g. the area near Dolní Bojanovice). The options include a transformation to permanent grasslands (the area near Popovice) or plantations of energy species (fast-growing woody species). However, it is necessary to consider the suitability of plantation of non-indigenous species in watercourse plains where most of these areas are located. Grasslands may also be included in the anti-erosion measures; they can also serve as bumper zones preventing soil entry into watercourse beds. On the contrary, plantations of woody species may cause problems during floods: spillage regulation, creation of barriers, etc. In some cases, the reservoirs can fulfil flood protection and retention functions. However, this function may be restricted by field modifications and adaptations, as in the case of the area near Kopřivnice. Recreation represents another function. This function, however, is dependent on the water environment quality, level of contamination, which is, unfortunately, high in the Czech river network in terms of eutrophication. Eutrophication represents a considerable risk for the recreational function.

On the contrary, for the utilization as fish ponds, it is relatively marginal. Because intensive fish farming may imply higher contamination by nutrients [14], it is not possible to apply this utilization for all the renewed reservoirs. Besides the functions mentioned above, the main function will probably be the creation of water supply in the landscape and support of the creation of water-related biotopes. Virtually, all the three examined areas may fulfil both functions in case of change of their utilization, including the retention of contamination transport, and may also be complemented with the function of sports, fishing or breeding of regulated and targeted fish quantities.

The chapter '**Small Bodies of Water which have Disappeared from the Czech Landscape and the Possibility of Restoring them**' deals with pond management that is a historical and landscape-forming phenomenon in the Czech lands. The ponds, whose traditional role is linked mainly with the economically lucrative fish farming, did, however, play a wider role within the historical landscape, where they fulfilled the requirements of society for water, they formed a potential supply of energy to power production facilities or they were part of the fortification of noble estates. The chapter describes the development and decline of pond management in the Czech Republic. There has been an intensive discussion in recent years on close-to-nature measures in both catchment areas and watercourses themselves, as such measures contribute to a reduction in flood risk and loss of soil, and they also support infiltration and accumulation of water in the landscape, thus slowing down surface runoff. A sophisticated approach to the issue of water retention, i.e. combining all suitable and mutually compatible measures, will be an optimum solution for the landscape as a whole. Such measures should be set in successive order with regard to the current state of a particular area. ‘Soft’ measures must be preferred on farm and forest land, such as establishing wetland areas. The construction and renewal of reservoirs, as a technical measure, should only be a subsequent step in a complex system of solutions. Among these measures in individual catchment areas within the Czech Republic, ponds have a fundamental role, their main benefit being their ability to retain and accumulate water for use in periods of drought. As is apparent from the preceding text, many of these water bodies have disappeared from the Czech landscape, and it is vital to consider their renewal in many areas.

The chapter ‘**Protection of Water Resources**’ is oriented to water protection in the Czech Republic, in accordance with EU requirements, helping to improve the state of water resources, aquatic ecosystems, promote sustainable water use and mitigate the adverse effects of floods and droughts. In many catchment areas, the agriculture is the most important polluter for surface and underground water, because of that we have to find a way with the proper target to provide people with enough quality drinking water.

The chapter ‘**Groundwater Flow Problems and Their Modelling**’ presents groundwater flow and methods how it can be solved. It also presents groundwater flow modelling. Groundwater is an inseparable component of the hydrological cycle and water resource systems. For practical calculations, it is crucial to choose and provide appropriate existing groundwater modelling software. There are numerous computer codes on the market [15–19] solving groundwater flow and contaminant transport using numerical methods like finite difference, finite volumes or finite element methods. Solving practical problems needs, except for theoretical background [20], skill and familiarity with the software used. Before using commercial codes, it is advisable to search for relevant professional reviews [21].

The third part of the book titled “**Water in the Landscape**” consists of 4 Chapters. Conclusions are as followed.

The chapter ‘**Hydrological Mine Reclamations in the Anthropogenically Affected Landscape of North Bohemia**’ deals with the surface mining of brown coal that has long burdened the landscape of the northern part of the Czech Republic. The chapter presents the case study results obtained by numerical experiment. The area is disturbed by surface quarries, external spoil tips and related anthropogenic interventions in the territory and its vegetation. Most of these interventions resulted in the removal of vegetation and were connected with the distortion of the natural dynamics of surface water and groundwater. Transforming residual mining pit into an artificial lake within the process of hydrological reclamations is the most logical and effective way how to integrate it into the surrounding landscape. Several aspects need to be taken into consideration to ensure the stable development of the lake. Essential is to provide a quality source of the filling water and to secure geotechnical stability of the lake's slopes. It is recommended to choose revitalization of the slopes by planting stabilizing tree species, and not to turn to natural succession. Natural succession is a much slower process, and the slopes are often endangered by erosion. As to the planning process, professional and non-professional public should be included in the decision-making process since the beginning. Participation of citizens and civic initiatives is important for the creation of recreationally attractive area. All decisions on reclamations and revitalizations should always be guided by the principle of sustainable development.

The chapter "**Modelling of the Water Retention Capacity of the Landscape**" provides basic information about the procedure for calculation of spatial specification surface runoff is based on a combination of specific functions of geographic information system which is enabled by runoff curve number method. The formulated LOREP model represents an application of a solution using a methodical approach for the identification and localization of areas with low flood storage capability. The modelling of the water retention function is currently subjected to new challenges.

The chapter '**Floodplain Forests—Key Forest Ecosystems for Maintaining and Sustainable Management of Water Resources in Alluvial Landscape**' represents the floodplain forests as key forest ecosystems in lowland regions of the European temperate zone. Ecosystem services of floodplain forests are essential for maintaining and sustainable management of water resources. The biodiversity of floodplain forests is significantly influenced by the hierarchical level of β-diversity (beta-diversity), i.e. by the changes in biodiversity depending on the changes in environmental gradients (in this case, these are changes in micro-relief and meso-relief of the floodplain in dependence on the distance from the river channel, changes in the frequency of floods, etc.).

The chapter '**Agrotechnology as Key Factor in Effective Use of Water on Arable Land**' describes the necessity of water for food production. Demand for good-quality food puts pressure on agricultural production. Agriculture influences the amount of water available, and the quality of water is tightly connected with the intensity of farming and the use of crop protection agents and fertilizers. The Central European agriculture, including agriculture in the Czech Republic, faces a number of challenges associated with water management in the landscape. In connection with the ongoing climate changes, irregular rotation of intensive rains and long periods of drought, and the growing demand for agricultural raw materials, we need to apply procedures stimulating effective retention and economic use of water. The key factors include various agro-technical measures leading to effective water management.

The fourth part of the book is titled "**Hydro-management of Water Resources**" and consists of 5 Chapters.

The chapter titled '**Management of Drinking Water Resources in The Region Of South Moravia, Czech Republic**' presents and discusses the supplies of good-quality water for supply in the region of South Moravia that to residents is sufficient. However, it is necessary, these sources maintain, where appropriate, restore, monitor their quality and quantity and ensure their adequate protection from spoilage. In the past, the Czech Republic, in the face of extreme floods, was preparing to protect itself from increased flows and the occurrence of drought was greatly underestimated. Scientists have warned that floods and drought are two sides of the same coin. There is finally a public debate on the need for water management in the countryside and water resources. It is necessary to prevent the rapid flow of water from the landscape, by appropriate measures, such as the revitalization of watercourses, the construction of reservoirs, pools and wetlands.

Last but not least, the change in farming, both on agricultural land and forests. Particularly in the catchments of drinking water supply systems, it is necessary to strictly observe the measures for improving the water absorption into the subsurface layers, by keeping the water in the landscape. A possible tool for improving the situation is artificial water infiltration [22]. Scientists have been inspired by Israeli experts in this context. In the Middle East, water is captured in this way for a long time. South Moravia is the most affected area in the Czech Republic, so the implementation of this measure is about to be done in the South Moravia region and Břeclav. In places where the construction of a new building is underway, rainwater management is already required according to the legislation. Rainwater is not discharged through a pipeline into water courses or wastewater treatment plants. Capture tanks and trenches are built to catch it or use it for further use. These measures, and in particular the building of nature-friendly measures, should be administratively and mainly financially supported by state subsidies.

In the chapter titled '**Ecosystem Services and Disservices of Watercourses and Water Areas**', the authors discuss ecosystem services and disservices of the watercourse network in the Czech Republic. Ecosystem services and disservices are not systemized in detail yet. A complex system already developing on the international scene allowing for practical applicability of the approach is missing in The Czech Republic. A complex (and detailed) evaluation of ecosystem services and burdens provided by watercourses has not yet been performed in the Czech Republic. Moreover, yet there is a number of sources for the evaluation provided by research institutions—for example, the TGM Water Management Research Institute, the catchment area management establishment, universities (Mendel University in Brno, South Bohemian University in České Budějovice, University of J. E. Purkyně in Ústí nad Labem) as well as interest groups (the Czech Fishermen´s union, the Czech Ornithological Union, etc.). At the same time, there are ready-to-use general methodologies for evaluation of ecosystem services [23, 24], so far dealing with complex but only general evaluation of ecosystem services of all types of ecosystems existing in the Czech Republic.

The chapter '**Water Resources Management Planning in the Czech Republic**' deals with the planning in the water sector that performed within the hydrological basins and is a systematic conceptual activity undertaken by the government. Its purpose is to determine and mutually harmonize public interests of water protection as a component of the environment, to reduce adverse effects of floods and drought and to ensure sustainable use of water resources. Management, administration and planning in the water sector have been designed and implemented logically and effectively in the Czech Republic. The current situation is complemented by planning and implementation of flood protection. Despite this fact, the Czech Republic sometimes has problems with floods, but recently, drought is a problem. This is caused on the one side by the intensity of both phenomena and on the other side by the state of the long-term intensively utilized landscape. All measures proposed and implemented in the field of water management, administration and planning are unable to save everything. It is necessary to continue in a close link with other forms of the planning of landscape utilization and management, which include, in particular, land use planning, forest management planning, regional development, agricultural activities and, to a lesser extent, reclamation plans, for example.

The chapter '**Technical and Economic Evaluation of River Navigation**' is devoted to a possible solution to water freight transport in the Czech Republic. One part discusses possibilities of evaluation of the economic efficiency of waterway projects by CBA method as well. Methodological documents of the Czech Republic define a certain list of basic benefits and damage and further enable to include other specific items in the evaluation. Based on results of the research, authors recommend supplementing a methodology with determining of the impact of investment projects on landscape character in the form of evaluation of permanent ecological damage, if the investment action leads to the occupation of habitats. Another influence that should be included in the methodological procedures according to the authors is possible to impact of waterway projects on historical monuments by determining their historical value.

The chapter '**Water Balance and Phase of Hydrocycle Dynamics**' is about the climate dynamics in the Czech Republic that has been increasing during the past 20 years and even before it was already characterized by high variability. The number of weather extremes increases, there is a statistically significant increase in air temperature, but not of precipitation. It should, however, be emphasized that the onset of drought, as well as places affected, are variable depending on precipitation. In general, drought is most common in the warmer regions with the lowest average annual precipitation. Results also prove that the extent of drought in a certain year is affected by the conditions during the previous year, especially by the conditions at the end of vegetation period, fall and winter. If it is dry even during fall and the water deficit is not compensated during winter, the drought will be apparent in soils in spring of the next year. Also, as recent studies show, the air temperature increases even in winter and the amount of snow decreases—this leads to a decrease in soil water content in spring. Soil properties (both agricultural and forest) are very important from the perspective of retaining precipitation water in the landscape, where most of the absorption takes place. It is therefore important to take measures that will lead to better infiltration abilities and increased soil retention capacity to its original level. This includes measures aiming to decrease soil erosion because the topsoil horizon has a significantly higher capacity than eroded soils. Increasing the variability of the landscape will contribute to lower water outflow, also because of decreased airflow and subsequent lower evapotranspiration.

18.4 Recommendations

The part of the book with the title '**Surface and Ground Water Bodies**' consists of the recommendations as followed.

There is still a gap between the findings of scientists and water management [25]. Coordination of activities among individual sectors is unsatisfactory, and standards are not clearly defined (e.g. among the watercourse administrators, fishing organizations and private owners). It is also clear that employing purely technical solutions in water management, such as construction of new dams, will not provide sufficient water for our streams and rivers [26]. Natural river beds with a rich structure of benthic sediments and frequent overbank flows can be used as an effective and relatively inexpensive means of solving numerous problems in water and landscape management [25, 26]. To avoid disturbances caused by extreme water fluctuations, we need to systematically change the way our landscapes are managed to support water retention.

Future research should strive to elucidate a better understanding of how water functions at both global and local scales. Many controversies about the most basic functions of rivers still exist; for example, whether restoration of wetlands adjacent to small streams and subsequently increased water retention translates directly into increased late-summer streamflow and reduced water temperature, both vital to aquatic life (see [27] and [28] for differing viewpoints). Increased understanding of aquatic–terrestrial linkages would help provide the knowledge basis for difficult decisions about managing uplands, floodplains, wetlands and river ecosystems in general. Studying the connections among wetlands, floodplains and small water bodies to climate change—for example, their complex role in acting as carbon and methane sources and/or sinks—would further aid managers and policy makers in balancing the needs of (and benefits from) ecosystems with a growing human population.

Finally, we recommend engaging stakeholders and professionals from diverse disciplines in discussions about how to manage water on the landscape in a manner that is beneficial to all parties, including humans but also wildlife and ecosystems. Author of this chapter outlines recommendations for coordination among natural scientists, land and water users, water managers, planners and policymakers with the desired outcome of better water management practices too. These various disciplines, having disparate objectives, will need to find common ground if productive dialogue will ensue about scarce water resources in Czech Republic and elsewhere, especially in the face of a rapidly changing climate.

To conclude, it may be said that small water reservoirs, including a specific category of ponds, i.e. fish ponds, are currently one of the basic elements of the agricultural landscape. They are one of the most valuable near-natural elements of the cultural landscape. Many locations currently belong to protected areas, some of them within Natura 2000. One of the possibilities to increase or preserve the ecological stability of the landscape, and, at the same time, to improve its aesthetic, urbanistic, water management and agricultural activities, is to restore roles and functions of small water reservoirs and ponds, together with landscape revitalization (projects of complex field adaptations and elements of territorial systems of ecological stability). The cases of three pilot locations document a process of selection of the best utilization of abandoned pond areas. This process, when applied in planning and state and local administration, as well as by the plot owners, will facilitate the selection of right functions of the planned small water reservoirs and their construction and technical project. It may also help to eliminate the negative phenomena potentially occurring after the reservoir (pond) realization unless previous in-depth surveys and right assessment of input conditions (climatic, hydropedological, hydrogeological, hydrological and qualitative) were performed. Particular attention in the aim of a pond or small water reservoir restoration should be paid to water environment contamination and quality. Since this factor is difficult to connect with general tools and indicators of abandoned pond area assessment, it is necessary to provide local monitoring of pollution sources and water quality of the water network. A detailed observation, with comparable results of the survey of fish ponds [29, 30], has brought important data for projects of renewal or construction of small water reservoirs in the landscape so that they do not become a source of contamination within their drainage basin, as it often happens nowadays.

The greatest proportion of defunct pond land is now used for agricultural purposes, and it seems that the current use is far from optimum in a number of these localities. This is why a more detailed evaluation of soil conditions in former pond areas will be important in the future, as well as considering the possibilities for changes in the use of some of these areas towards the restoration of water bodies, with respect for natural conditions and socio-economic criteria. Soil conditions will be fundamental in the decision-making process, and available data shows that the soil in many of these areas is heavy, not highly productive, with low infiltration ability, etc. making such areas more suitable for the renewal of bodies of water. Regarding the renewal of some ponds within forests, their benefit is mainly in improved water management in upper parts of catchment areas. This can have a positive effect in dry periods and also reduce flood damage. Forest owners and companies managing forests would welcome better access to water supplies in the case of forest fires, and nature conservationists can appreciate the creation of suitable conditions for the development of communities bound to a water environment or wetland.

Protection zones, like preventive protection, are necessary. Due to their importance, we have to support with conducting education. However, there is needed legislation and political wish and support. As far as legislation is concerned, it is primarily necessary to solve the raised problem with the Decree No. 137/1999 Coll. which is ineffective, and some of the provisions of this Decree are inconsistent with valid Water Act. In this way, it is necessary for the Central Water Protection Authority to add activity and novelize or at least abolish that Decree. In relation to climate change and the effects of drought, we recommend specifying in more detail the protection of water resources for season droughts—i.e., to solve in more details the protection of water resource efficiency.

The valid legislation needs to be elaborated, supplemented, updated and in practice adapted to a wide variety of natural and economic conditions (depending on the location, soil conditions, hydrology, hydrogeology and the way water is used).

The goal is not to recreate unified methodology, according to which should be proposed the protection zones of water sources. The suggestion of protection zones in counter should be processed in a form which shows attitudes in the landscape above the source of drinking water. The proposal of regime and scope of the protection zones should always be solved individually according to specific conditions.

However, it would be advisable to devote more attention towards the problem of financial compensation in protection zones, and the development of a methodical approach could be beneficial. This issue needs to be elaborated. The failure to solve the current situation is not a starting point for farmers operating in the protection zones, and for water companies, it is not for improving the quality of drinking water.

The practical journey is clearly based on cooperation and understanding between water-farmers and farmers, as well as the involvement of researchers from universities who are independent experts.

One of the possible tools for the protection and rational use of land in the protection zones are land consolidation, which offers the potential for the creation of a flexible, ecological and sustainable agriculture. Combined with the protection zones optimization, this could be an effective tool for solving conflicts between agriculture and water management in the protection zones of water sources.

It is necessary to emphasize that the groundwater management and seepage modelling is a multidisciplinary issue at which significant role is played by geologists and hydrogeologists, water managers, hydraulic and civil engineers, for the development and adjustment of computer codes the cooperation with mathematicians and programmers is necessary.

Practical experience shows that many times the role of computers and numerical modelling is overestimated and traditional engineering feeling is frequently abandoned. It must be remembered that one of the most important activities at the modelling is the definition of objectives, conceptual formulation of the problem and relevant interpretation and rational explanation of results achieved. Based on the final decisions and technical proposals are carried out. All these items need experienced staff with good knowledge about the necessary data for the solution and a clear vision about the results and their application.

The part titled '**Water in the Landscape**' consists of the recommendations as you can see bellow.

In the context with the ongoing climate change, with irregular alternation of flash abundant rainfall and long periods of drought, it is essential to well describe the current and future state of the landscape. The following recommendations should be followed when modelling a water retention function:

(i) work with a model that best simulates real water behaviour in the landscape, (it means that the model works with an advanced multiflow algorithm to simulate real water movement in the landscape),
(ii) use a model with an advanced iteration algorithm to calculate infiltration, which can estimate at each step whether retention capacity is already achieved or not and
(iii) use the appropriate drain equation according to the evaluation of this state. Static (GIS) data describing the state of the landscape should be integrated with sensor data (e.g. snow supply, soil moisture) to update hydrological/hydropedological conditions.

Digital representations of all landscape components (terrain, land use, soil) should be current and at the same scale and for the same period. The scale should be detailed enough to capture the small line elements in the landscape and their orientation towards the direction of the surface runoff. For the conditions of the Czech Republic, it is appropriate to scale 1:10,000. To identify the problem areas, it is necessary to work with the model in a raster environment in order to divide the studied area into sub-watersheds, not exceeding 25 m^2. This tool is really useful in the situation when almost all plots of concentrated surface runoff should by identified and multidirectional runoff, including runoff along small line elements, should be assessed.

We can conclude that sustainable biodiversity conservation in dynamic floodplain forest ecosystems require territorial protection in the form of various categories of protected areas and maintaining of ecosystem connectivity at the landscape level (ecological networks). The key target is the maintaining the conditions for the functioning of the ecological floodplain phenomenon. This means that the basic principle of maintaining the floodplain forest biodiversity is the protection and undisturbed functioning of the dynamics of fluvial erosion and accumulation processes in the landscape. Floodplain forest protection is, thus, clearly based on the ecosystem approach, which providing a functioning of the floodplain forest ecosystem services [31].

In the Czech Republic, the currently used management system in the Czech floodplain forests should follow the Croatian model of forest management supporting a multi-layered forest structure [32]. Focus on individual tree growth and stability with high economic value and high reproductive potential is recommended as one of the main principles of sustainable floodplain forest management [33].

When considering the management procedures in the arable land that lead to water retention in the landscape, we can follow several recommendations. One of the basic aspects is a good knowledge of the local soil–climatic characteristics. It is very important to set a rational cultivation plan in connection with a suitable management system. In the Central European conditions, a system that is appropriate in terms of water management is conservation tillage, i.e. various methods of soil treatment without ploughing, or sowing directly in untreated soil. This should be accompanied by agro-technical procedures connected with cover crops systems, intercropping systems, strip intercropping, strip till technology, agricultural terraces, etc. Using these agro-technical procedures over a long-term can improve the soil structure, thus making it possible to increase infiltration of water into the soil, reduce the surface runoff and reduce the risk of erosion, which constitutes one of the most significant problems connected with the cultivation of arable land. Reduction of intensity of soil treatment also usually reduces the consumption of energy required throughout the cultivation cycle and also saves time. It also supports carbon sequestration with a growing proportion of soil organic matter, which originates, e.g. from left post-harvest residues. In general, these practices have significant environmental benefits.

In the part called '**Hydro-management of Water Resources**' can you find recommendations as follows in the text.

Czech legislation and administration developed a number of documents for water management and territorial planning where ecosystem services of the blue–green infrastructure might be applied—Catchment area plans, regional forest development plans, regional development principles, zoning plans, territorial analysis document, etc. Another large potential application area is the EIA process where the value of ecosystem services can be used for initial investigation as well as for the actual documentation preparation.

The above-mentioned suggests the need for further enlightenment and above all cooperation along the following two axes:

(1) Between basic research in the area of monitoring of ecosystem elements and processes (biological, climatologic, hydrologic) and applied research focused on support for the decision-making processes, zoning planning, environmental management and environmental accounting using ecosystem services;
(2) Between applier ecosystem service research (within the scope of point (1) above) and public administration for practical applications of the mechanisms of assessment of ecosystem services in state administration and the decision-making process.

For the implementation and further use of stakeholders, it is necessary to use the full range of tools:

- Awareness raising and popularization—focused on the professional and the general public;
- Processing of clear and understandable, scientifically published and accepted methodologies, applicable in the conditions of the Czech Republic;
- Incorporation into legislation;
- Incorporation into conceptual residential documents, as a river basin plans, regional development plans, spatial development principles, zoning plans and territorial Analysis;
- Financial support for measures to optimize and support ecosystem services based on their knowledge and assessments;
- Continuation of research and case studies. Implement the results of major international projects, as an OpenNESS, Opera, Esmeralda and others. The participation of stakeholders in projects and research activities is also very important.

Further development of water management and planning in the Czech Republic can be supported:

– implementation of new sectoral knowledge and practical results of agricultural, forestry, urban and other research into river basin management plans.
– implementing progressive decision-making principles.
– reflecting the complex of ecosystem services and disservices and their implementation in water planning.
– reflecting the participative approach, where appropriate.
– developing a comprehensive approach to the state of the river basin.
– improvement of expert arguments in the EIA process, especially for clearly damaging structures, such as the planned Danube–Odra–Elbe channel.

Sustainable catchment management requires integration among natural and social scientists, land and water users, land and water managers, planners and policymakers across spatial scales [34]. The principle of managing rivers, their floodplains and entire watersheds for balanced human and ecological goals is being embraced globally by scientists, NGOs, water managers and various policy and government institutions [35]. River managers still lack appropriate science-based tools to realize the integration of human and environmental water needs; however, natural scientists will be required to consider the socio-economic setting and implications of their research [35]. All groups, including scientists, engineers, environmental managers and stakeholders faced with hydro-ecological problems need to converge upon a common vision and a unified approach. We believe that coordination between these groups is possible and will provide numerous benefits. However, it will be necessary to overcome many barriers in thinking established between both professional branches during the nineteenth century through the present [36].

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