HUNGARIAN WATER RESEARCH PROGRAMME CHALLENGES AND RESEARCH TASKS

Centre for Ecological Research, Hungary

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PREFACE

Water is fundamental and indispensable element of life and its strategic importance is intensively growing due to diverse global processes such as climate change and population growth. This is reflected by a number of international agreements as the Sustainable Development Goals adopted by the UN's General Assembly in September 2015 which dedicates a stand-alone goal to water among the 17 to be accomplished by 2030. The Goal 6 „Clean water and sanitation" covers the whole hydrological cycle including the right to drinking water and sanitary services, sustainable water use and the protection of aquatic ecosystems. More adaptive and operational water management is also a prerequisite for the fulfilment of other goals from ending of hunger to the development of sustainable cities. The integrated, cross-cutting and multidisciplinary investigation of the changes related to the entire hydrological cycle is crucial for the accomplishment of these goals.

Unfortunately, scientific areas and research institutes related to water science are mostly working separately in Hungary and the efficient scientific support of operational water management tasks is not solved. There is an increasing demand for closer cooperation of researchers working in diverse scientific areas, institutions and countries on a number of fields. One of the outstanding examples is water science. Therefore, it is indispensable to eliminate fragmentation and begin a new chapter in the Hungarian water research. The establishment of a cooperative framework and the organization of joint activities is a global challenge for both scientific institutions and research funding agencies.

The Hungarian Academy of Sciences, as the coordinator of water research institutions, shall play an integrative role in cooperation with governmental organizations of water management and in accordance with international trends. The ongoing activities in the academic research network are in line and constitute the scientific basis for the Kvassay Jenő Plan, the key document of National Water Strategy and are also compliant with the European Union Water Framework Directive (WFD).

The Carpathian Basin was always an undivided water management unit during history, independently from the number of the countries situated in its territory. Cooperation in water management with other Danubian countries and with those situated in the Carpathian Basin is fundamental as the watershed of Hungary's rivers extend beyond the borders. Strengthening these relationships deserves special attention not only for water event management but also in fundamental research. The inclusion of the highest possible number of renowned international experts into the collaborative work and the cooperation with the academies along the Danube basin and the EU scientific bodies are fundamental goals to achieve.

An old debt was settled to the scientific community when the decision was taken by the MTA about the initiation of the National Water Programme in 2016, after one year of preparatory work. The launch of the Hungarian Water Research Programme as part of the National Water Programme coordinated by the MTA was proposed to provide the scientific basis for the National Water Strategy (Kvassay Jenő Plan) and elevate the level of national water research to the highest international standards. The priority objective is the elaboration of a comprehensive and multidisciplinary, national scientific research programme to determine the priorities of the national water science and the creation of a multidisciplinary network ranging from engineering sciences and ecology to social sciences to initiate harmonized research activities in the major national scientific institutes.

The Water Research Coordination Group was established by the MTA within the Centre for Ecological Research on 1st October 2016 to elaborate the Hungarian Water Research Programme and promote the establishment of a water science network. The work of this group was supported by the Governing Body, the MTA Presidental Water Science Committee at the level of strategic decisions and a committee of internationally renowned international experts.

The current document compiled during this work is unique with regard to the applied methodology and the coverage of a variety of scientific areas. The compiled research programme is relying on the results of previous national strategic documents, several international examples, the status report of a national expert team with multidisciplinary background and the findings of a questionnaire aimed at thorough and systematic evaluation of the knowledge gaps in water management practice.

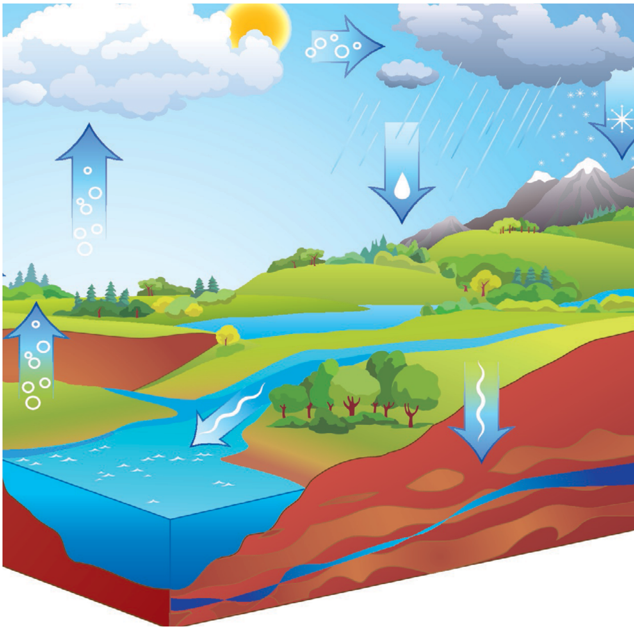
Budapest, March 22, 2018

László Lovász
President of the Hungarian Academy of Sciences

Objectives

Water is the basis of life, a public good universally accessible for the society, both an economic resource and a threat. Its strategic importance is increasing from several different perspectives as a result of global processes.

The continuously increasing water scarcity might endanger two thirds of the global population in the coming years and climate change is expected to intensify quantitative limitations. Simultaneous increase in the frequency of extreme meteorological events (droughts, floods and flash floods) is also anticipated in most parts of the world. Spatial inequity in the water demand and in pressures on water will be aggravated by the expansion of urbanization. Intensifying chemical pollution of the environment directly endangers both wildlife and human health. To date, more than 800 million people lack access to safe drinking water and 2.5 billion people do not have access to basic sanitary services which are fundamental pillars of both human health and economic and social development. International cooperation in the management of transboundary water resources is frequently lacking or unsatisfactory. These proceedings lead to the deterioration of aquatic ecosystems, increase the risk of infectious diseases, impair economic development and might contribute to social processes as external or internal migration and growing social discontent.



Surface water and groundwater resources of Hungary are exceptionally rich in international comparison and their conservation is an imperative responsibility for the society. This recognition lead to the development of the National Water Strategy (Kvassay Jenő Plan), the strategic framework and mid-term action plan of water management to avoid the world-threatening water crisis in Hungary and to preserve water for future generations by integrated and sustainable water management.

The implementation of the National Water Strategy requires – among other factors – the establishment of the scientific background and the optimization of scientific support for sustainable water management. The two levels of water-related research needs and both contribute to the realization of the National Water Strategy. Strategic research is necessary to understand the water-related processes and the hydrological cycle more accurately and to support operational activities. Research, development and innovation directly influencing the efficiency of operational water management complement fundamental research.

The Hungarian Academy of Sciences (MTA), as the coordinator of water science research institutions shall play an integrative role in cooperation with governmental bodies responsible for water management in line with international trends. Therefore, MTA launched the National Water Programme outlining objectives which are also included in the government decree on the National Water Strategy.

The historical excellence of the national water science research is currently difficult to sustain as it is running separately in more than 100 institutions (research institutes, universities, governmental and non-governmental organizations). Under the actual circumstances, it is necessary to establish a network of all relevant national water science institutions (institutes, university departments) to conduct strategic water management research effectively and coherently and explore all the possibilities for international scientific cooperation. The identification of a roadmap to harmonize the national scientific activities is a key objective of the National Water Programme. Another formulated proposal is the development of an open access and integrated database including all elements of the hydrological cycle (climate, weather, rivers, lakes, groundwater, springs, etc.) by connecting the currently available disintegrated hydrological databases.

One of the pillars of the National Water Programme is the elaboration of a comprehensive Hungarian Water Research Programme (HWRP) to summarize the most important water-related national challenges and research tasks. It shall also be the basis for integrated and multidisciplinary research supporting the accomplishment of the goals of the National Water Strategy and increasing the level of national water science research to meet the highest international standards. This research programme shall focus to short-term national research tasks while taking into account the ongoing global processes which affect the future of water resources.

Introduction

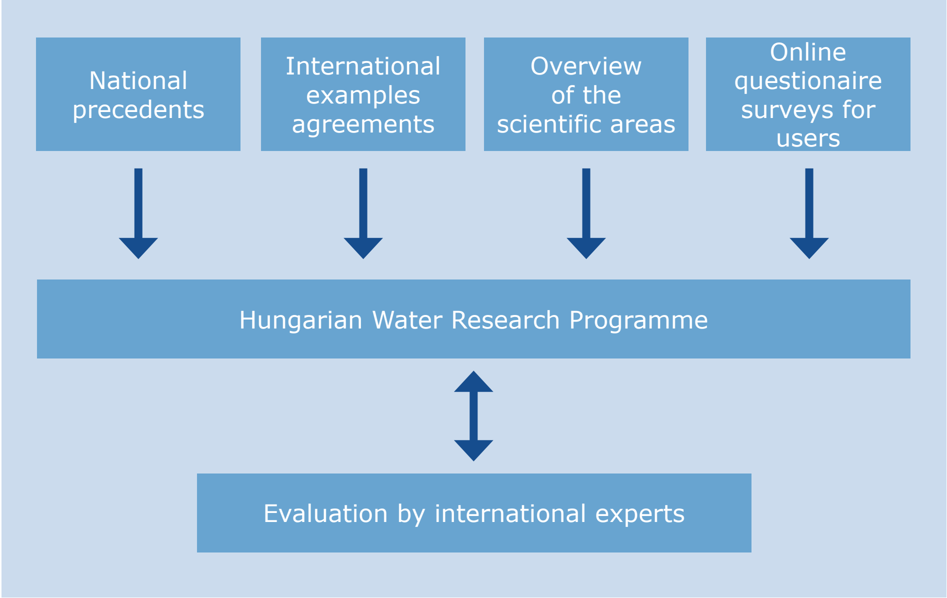
Development of the Hungarian Water Science Research Programme – Challenges and research tasks

The current document was developed by the MTA Water Research Coordination Group under the guidance of the Governing Body.

The key resources used for this work were: (i) relevant national strategies and other key studies; (ii) international policies, agreements and examples of national water research programmes from other countries and regions; (iii) status reports and trend analyses of scientific fields written by delegated experts; (iv) extensive survey research (Figure 1).

The draft programme compiled based upon the source documents was evaluated by internationally renowned experts and their proposals were incorporated into the document.

Figure 1. Source documents of the Hungarian Water Research Programme



(i) National precedents: strategies and studies

The identification of the problems and challenges which call for multidisciplinary water research, in line with the tasks of the Hungarian Water Research Programme, was based primarily on the National Water Strategy (Kvassay Jenő Plan, see its overview below) which is a key national source document. Other relevant national strategic documents used are: Second National Climate Change Strategy (2014–2025, with an outlook to 2050); National Biodiversity Strategy (National Strategy for the Conservation of Biodiversity in 2015–2020); Hungarian National Landscape Strategy and National Strategy for Rural Development. Other key source documents used as starting point in the compilation were: National River Basin Management Plan 2015, Water Management in Hungary: Status and Strategic tasks – Public Body's Strategic Programmes of the HAS, 2011, and National Water Technology Platform Strategic Research Plan, 2010.

National Water Strategy (Kvassay Jenő Plan)
The National Water Strategy or Kvassay Jenő Plan was approved in March 2017, formulating the strategic framework of the Hungarian water management until 2030 and defining the medium-term action plan until 2020. (http://www.kormany.hu/download/6/55/01000/Nemzeti%20V%C3%ADzstrat%C3%A9gia.pdf).

The key cornerstones are protecting Hungary against the emerging global water crisis, safeguarding the country's water resources for future generations, utilizing the water-related economical and social possibilities while ensuring protection against the threats associated with water.

The strategic challenges of the Plan are formulated in the context of water-related global, sustainable development objectives and the regional water policy. The action plan is defined in compliance with the framework of the strategic national development policies. The Plan comprehensively summarizes the current structure of the national institutional system for water management and defines the directions of further developments with regard to professional education and institutional structure.

Key priorities of the National Water Strategy:

1. Water retention and redistribution for optimizing the exploitation of water resources and water management supporting the economy
2. Risk-based water damage prevention
3. Continuous improvement of water quality to achieve sustainable good status
4. High quality and affordable water utility service and precipitation management
5. Improvement of the relationship of water and the society (private, economic and decision-maker level)
6. Revision of planning and governance
7. Reorganization of the economic regulation system of water management

(ii) International examples and experiences

The compilation of this document was preceded by reviewing the strategic research document of the European Union (Strategic Research and Innovation Agenda of the Water Joint Programming Initiative of the European Union) and four other national research programmes (USA, Ireland, Germany and New-Zealand). The development process, scope and structure of the national programmes is different but the objectives are highly overlapping with those of the programme initiated by the MTA. The objective of the Hungarian Water Programme Research Strategy of the United States Environmental Protection Agency (US EPA) is the identification of the research, scientific and technological needs of the Water Programme in a comprehensive plan to support harmonized research cooperation. The Irish water science research plan (Water Research Pillar – Research Priorities 2014–2016 of Irish EPA's 2014–2020 Research Programme) identifies the relevant research tasks and reviews the Irish and international research funding programmes. The summary of the German research priorities (White Paper – Priority Research Fields of the German Water Science Alliance) describes the research network and identifies the key areas for research by briefly overviewing the relevant issues and listing specific scientific questions. The water science strategy of New Zealand (Water Research Strategy of New Zealand) identifies the research tasks related to water management and dedicates an entire section to modelling, data processing and the exploitation of the results. The strategy of the European Union (Water Joint Programme Initiative) focuses on the economical aspects and the definition of the research needs is followed by listing the social, economical, technological, environmental and policy impacts. The allocation of research tasks and the resulting specific scientific questions to several (4–7) comprehensive priority areas is similar in all strategic documents. The priority areas described in the documents are significantly overlapping (listed in Annex 1). For example, all of them emphasize drinking water safety and the protection of aquatic ecosystems.

The harmonization with international obligations (for example, the EU Water Framework Directive, Floods Directive, Drinking Water Directive, Urban Waste Water Treatment Directive) and global objectives (for example, the Sustainable Development Goals adopted by the UN) was a key consideration in defining the research tasks.

(iii) Overview of scientific areas

The contributing experts represented the fields of hydrology, hydraulics, ecology, microbiology, water quality, water chemistry, geography, soil science, hydrogeology, engineering geology, hydrobiology, law, economics and water hygiene. The compilation of the overviews was supported by the identification of the priority areas and key themes based upon national and international experiences.

(iv) Online questionnaire survey

The involvement of water professionals contributing to the implementation of water-related tasks in the identification of research tasks and knowledge gaps related to the everyday practice was accomplished by a questionnaire survey. Apart from asking for general background information, the questionnaire formulated questions in connection with the research tasks and knowledge gaps belonging to the six priority areas and also supported the identification of other related problems (Annex 2).

The online survey was sent to the head of more than 350 institutions identified as stakeholders in water-related practice or research and they were asked to distribute the survey among a wide range of co-workers. The recipients included government organizations (authorities and public administration), research institutions (universities, research institutes and groups, private companies engaged in research), scientific associations, non-profit organizations and enterprises. Organizations belonging to areas indirectly related to water management (human rights, community development) were also addressed (Annex 3).

Respondents were mostly graduated professionals in their active years (26–65), working in employee status with drinking water, surface water and groundwater or in the agriculture. Those who indicated the type of their institution were working mainly in state administration or higher education. On the other hand, the proportion of those who answered privately or without indicating the type of their institution was very significant (Annex 4).

Close to 1500 research questions and proposals arrived belonging to the diverse themes in a balanced proportion. The answers showed variability in extent and depth, ranging from the formulation of targeted research needs to the indication of difficulties of a wider spectrum (Annex 5).

Structure of the document

Challenges and research tasks of the HWRP are listed in six priority areas reflecting the water-related target areas of the Sustainable Development Goals which are also central elements of the National Water Strategy

1. Safe drinking water
2. Water quality
3. Sustainable water use
4. Water management
5. Protection and restoration of aquatic ecosystems
6. Water-related social conflicts

The six chapters of the document, defined by these priority areas, describe and group the problems for further research. Each chapter starts with listing the most important keywords related to the priority area and ends with defining the key research tasks which result from the indicated challenges. The priority areas cannot be unambiguously separated and several challenges and tasks are discussed in more than one chapter (Figure 2).

The identified research tasks shall not only constitute the basis for the multidisciplinary research corresponding to the priority areas but shall also be used for the elaboration of diverse integrated water science research plans at regional or water body level based upon the different chapters.

The themes listed in the six priority areas – in line with the main objective of the HWRP – include all key areas defined by the National Water Strategy, focusing on the areas which require further research. Moreover, the document defines several other multidisciplinary research topics such as emerging pollutants (xenobiotics, plastic microparticles and antibiotics resistance), evaporation research or the expansion of invasive foreign species endangering aquatic habitats. Interrelationships of the priority areas of the HWRP and the key tasks of the National Water Strategy are illustrated in Figure 3.

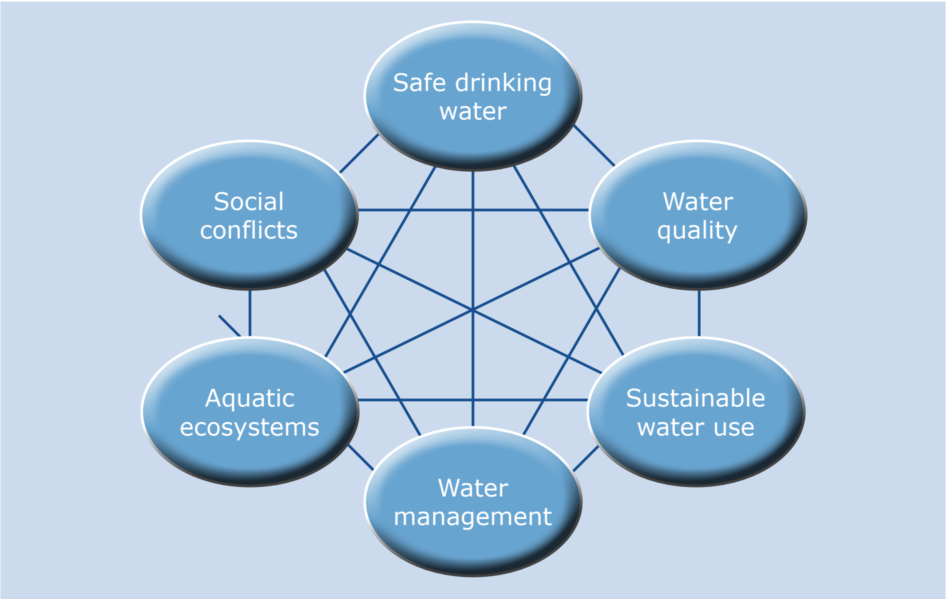


Figure 2. Priority areas of the Hungarian Water Research Programme

Future tasks

In line with other pillars of the NWP and based on the challenges and research tasks relevant for practice, which are described in the following chapters, water science faces the following tasks:

- Provision of resources for the comprehensive research projects targeting the key knowledge gaps, integrating scientific areas and having direct social benefit.
- Improvement of networking, information exchange and cooperation activities among national water research institutions beyond active projects.
- Identification of international resources, funding possibilities and partners in parallel with national funding, networking and improvement of the efficiency of existing cooperation. This is an indispensable need for the optimal and coordinated management of transboundary river basins.
- The National Water Programme, as an academic programme, shall not ignore the objective of strengthening scientific excellence and, consequently, the appropriate recognition of significant research results is crucial.

Key tasks of the National Water Strategy	Priority areas of the Hungarian Water Research Programme					
	Safe drinking water	Water quality	Sustainable water use	Water management	Protection and restoration of aquatic ecosystems	Water related social conflicts
Water retention and redistribution for optimizing the exploitation of water resources and water management supporting the economy			+	++	+	+
Risk-based water damage prevention	+	+		+++	+	+
Continuous improvement of water quality to achieve sustainable good status	+	+++				
High quality and affordable water utility service and precipitation management	++			+++		+
Improvement of the relationship of water and the society (private, economic and decision-maker level)	+		+		+	+++
Revision of planning and governance			+	+		++
Reorganization of the economic regulatory system of water management			+	+		++

Figure 3. Interrelationship of the priority areas of the Academy's Hungarian Water Research Programme and key tasks of the National Water Strategy

- Building on future research projects, feedback mechanism should be established to the government and other decision-makers in connection with the NWP, supporting the development of the professional background needed for executing the objectives of the National Water Strategy by the scientific community.
- Provision of feedback is necessary to the operational level to support direct exploitation of scientific results

1. Safe drinking water

Keywords

- drinking water safety: drinking water quality, water source protection, riverbank filtration, resource overuse
- drinking water treatment, micropollutants, emerging water pollutants, drinking water borne diseases, new generation water treatment technologies, disinfection by-products
- safe infrastructure, water quality deterioration in distribution systems, water loss, opportunistic pathogens
- risk-based approach, benchmarking, best practices
- private wells, innovative technologies, decentralized infrastructure, precipitation and grey water reuse, public health risks
- access to drinking water: physical access, equity, affordability, cost recovery

Challenges

Status of drinking water supply and protection of water sources

Drinking water supply in Hungary is currently considered good both qualitatively and quantitatively, in spite of the risks detailed below. Centrally provided piped water is available in all municipalities of the country supplying 95% of the population and water quality meets the regulatory requirements in increasing proportion due to the development of the water supply systems and the improvement of operational practices. Existing and newly recognized challenges (such as emerging pollutants, climate change, condition of distribution system, more stringent quality standards, deliberate water contamination) call for the overview of qualitative and quantitative risks of drinking water production and distribution from the water source to the consumer.

Water resource quantity and quality and protection of water sources are fundamental factors in drinking water safety. As higher quality of raw water decreases the technological demand for water treatment, the load on operational and prospective drinking water sources should be determined, reduced and the effectiveness of the national water resource protection programme should be evaluated.

Further issues related to quantity and quality of surface water and groundwater which are closely related to sustainable water abstraction and drinking water quality are also discussed in Chapters 2 and 3.

Factors threatening water resources

More than 90% of the country's drinking water supply originates from groundwater, mainly from deep groundwater aquifers and riverbank filtration. Riverbank filtration wells are connected directly to the riverbed gravel and abstract mainly surface water. Bank filtration systems constitute 30% of the volume of current drinking water supply and two-thirds of prospective drinking water resources. Budapest and its suburbs use almost exclusively riverbank filtrated water for supplying close to two million inhabitants. The riverbed material (colmation layer) and the biofilm formed on its surface plays crucial role in the process of riverbank filtration. Long term alteration of the sediment composition of the riverbed is expected as a consequence of climate change and/or riverbed management interventions which in turn might influence the filtration process both qualitatively and quantitatively. Changes in water level and temperature may also affect filtration. Characterization of the processes determining the quality of the produced water is crucial for the preservation of the water resources of strategic importance.

Deep groundwater aquifer sources constituting 45% of drinking water supply have the highest geographical coverage and play predominant role in the supply of lowlands. The quality of deep groundwater aquifers is determined primarily by the geological status and the flow conditions. Arsenic is the most important currently known pollutant posing risk to human health in Hungary. The considerable ammonium, iron, manganese and organic matter content of groundwater entails the application of water treatment technologies in many areas. The presence of several previously unidentified organic and inorganic micropollutants (uranium, vanadium, iodide, etc.) need to be considered beyond those currently monitored. Other problems related to groundwater quality are discussed in Chapter 2. Thermal drinking water sources (warmer than 20 °C and of unique composition) deserve special attention. Possible hydrogeological and water management solutions (water transfer, changing water resource) which do not rely on very expensive water treatment technologies, should be considered during drinking water quality improvement in the mitigation of water source-derived pollutants.

Karst water sources play a crucial role in drinking water abstraction in the Transdanubian Mountains (Dunántúl) and Bükk region. Open karst water sources are the most vulnerable to environmental and anthropogenic effects. Major recent drinking water epidemics were linked to karst water contamination as a result of extreme precipitation and the risk of such events is increasing in connection with the climate change. The rising level of karst water in the Transdanubian Mountains (Dunántúl) after the cessation of mining poses a potential contamination pathway due to the insufficient technical protection of the positive wells.

In some parts of the country the water content of fractured and fissured aquifers is also a relevant source for local drinking water production. While the majority of the shallow groundwater resources is not suitable for drinking water purposes and the sources currently in use constitute only 5% of the public drinking water production, the role of shallow groundwater is vital in decentralized supply. Approximately 8% of Hungary’s drinking water originates from surface water sources. The specific risks associated with surface water quality deserve further attention (with a focus on toxin-producing cyanobacteria, organic micropollutants and pharmaceutical residues). The current drinking water abstraction does not amount to one-third of the total potential capacity at country level but there is considerable geographical variation in the degree of exploitation of the water production capacity. There are water resources which

are already overused, especially on the Great Plain (Alföld). The capacity of prospective water resources is comparable to the current water abstraction level. The impact of drinking water abstraction on water resource management and vulnerability of water resources to extreme meteorological events also shows regional differences. Characterization of the extent of spatial variation and fitting them to climate change models is a mid-term research task in the whole Carpathian Basin.

Challenges of drinking water treatment

Drinking water production faces new challenges as expectations on drinking water quality are increasing. Parametric values became more stringent for many traditional pollutants, placing an increasing technological and economic burden on the water service providers. Emerging or newly recognized pollutants posing potential risk to human health (e.g. organic micro- and nano-pollutants, endocrine disrupting substances, protozoic pathogens, viruses, antibiotic-resistant organisms) receive increasing attention. Currently applied water treatment technologies may result in the emergence of technology-related pollution during the elimination of raw water pollutants. Chlorine-based disinfection is applied predominantly to reduce microbiological risk frequently leading to the formation of disinfection by-products which are harmful to health and the primary source of citizen complaints. New generation water treatment technologies replacing old procedures should enable the elimination of emerging pollutants and the more effective removal of traditional ones. Production of non-corrosive, biologically stable water with low organic matter and nutrient content is necessary to prevent water quality deterioration in the distribution system. Disinfection by-product formation can be reduced by replacing chlorine-based disinfection by alternative methods. The expectations towards the new technologies are high: beyond effective water purification and minimization of technology-related by-products the conservation of the valuable mineral content of drinking water and the cost-effective operation by efficient water and energy use are also indispensable.

Emerging pollutants of diverse origin and strict limit values are also a challenge for water analytics. Beyond the characterization of the presence of pollutants and the concomitant method development it is crucial to assess the risk and the actual health impact of individual pollutants under the national circumstances.

The most complex technological requirements in drinking water production are linked to reclaimed water treatment systems which convert treated wastewater to drinking water quality. This type of new technologies currently receive limited attention in Hungary due to the relative abundance of other water sources. On the other hand, considering sustainability aspects the need to separate water for consumption and other household uses is growing, since only 3% of the produced drinking water is finally consumed. Water for household use may originate from diverse sources: the same raw water as drinking water but undergoing lower level of purification, rainwater, groundwater wells or greywater (domestic wastewater not containing faecal pollutants). The public health risk associated with dominant types of use (washing, irrigation, toilet flushing) is still considerable although smaller than in case of consumption. Therefore it is indispensable to establish specific water quality limit values for different types of use and to elaborate other public health constraints.

The growing use of decentralized systems (see below), the increasing awareness of consumers and the preventive approach to drinking water supply with higher focus on in-process control call for the development of novel on-site analytical methods – complementary to instrumental water analysis techniques – which enable basic water quality assessment without laboratory background and with minimal instrumentation and expertise.

Risks of distribution systems: water loss and secondary water quality deterioration

Drinking water consumption decreased continuously in the last 30 years (it halved to an average of 110 l/capita/day). Introduction of water tariff was the major reason of shift in the consumer habits. The change is even more significant in small rural municipalities where the daily consumption is only 60-80 l/capita, partly as a result of urbanisation and partly because of the use of private wells. The distribution systems are typically deteriorated and over-sized for the current level of water consumption and. The water loss resulting from the leakage from the aged distribution systems is considerable (20–30%) and it requires the development of modern methods for distribution system-related water leakage detection. These also support the optimized planning and schedule of reconstruction programmes. Reconstruction of the pipelines is a public health as well as an economic concern because the failure of pipe integrity is one of the primary causes of microbiological contamination in drinking water. The quality of materials in contact with drinking water and adequate sizing of the pipeline for the current water use are crucial to ensure the long-term effectiveness of the reconstruction work. However, sufficient water pressure for fire hydrants limits the potential to decrease system capacity.

The decreasing consumption corresponds to higher stagnation time in the distribution system. A plausible consequence is the initiation of unfavourable processes (deposition of inorganic material, leaching, biofilm formation). The risk of water quality deterioration in the distribution system is expected to grow in connection with the climate change resulting in increasing mean summer temperature. Plumbing systems located inside buildings are especially exposed to ambient temperature. Asbestos cement pipes comprise more than half of the mains pipes in Hungary. The health impacts of fibres released during the abrasion of asbestos pipes is unclear. The lifecycle and potential problems related to plastic pipes used to replace asbestos should also be clarified.

The contamination caused by substances (especially lead but also copper, chromium, nickel and cadmium) leaching from pipes and fittings and microbial regrowth are predominantly present in the internal distribution system of buildings. Although most microbes which colonize distribution systems and form biofilms on the surface are harmless environmental organisms, biofilms may also harbour opportunistic pathogens which do not threaten healthy people but cause disease in the immunocompromised.

Their impact is currently observed mainly in healthcare facilities but the risk of domestic environments is also increasing in aging societies. The formation of biofilms in the distribution system contributes to spontaneous nitrification and the resulting nitrite concentrations pose a threat to newborn and infant health. Though water quality deterioration in the pipelines is primarily a public health risk, a joint action in multiple sectors is necessary such as developments in water treatment, materials science (e.g. pipe materials not supporting bacterial growth) and building engineering.

Risk-based approach in drinking water supply operation

Good operational practice is just as indispensable in securing high quality treated water as technological development. New technologies – based upon traditional principles – were established in the Drinking Water Quality Improvement Programme using European Union Cohesion Funds. Optimization of economic and public health aspects of the treatment technologies represents a further task. Several processes support the expansion of best operational practice at country level. The Water Utility Act of 2011 reduced the number of service providers nearly to one-tenth by merging utilities. This resulted in more harmonized operation at higher standards. Benchmarking as an increasingly important element in the management of non-competing public services was initiated by the national water supply regulator in line with international trends. A country-level benchmarking procedure might support the establishment of a new platform for regional cooperation among researchers and service providers. The implementation of a risk-based approach (drinking water safety planning) into the operational practice is a significant progress towards increasing drinking water safety.

Intentional water contamination or other intentional hazardous events (terror attacks) threatening drinking water supply are scarcely investigated areas. Preparedness (risk assessment, development of early monitoring systems) is a key task for the water service providers and the authorities in disaster management.

Risks and tasks related to decentralized drinking water supply

Statistical data indicate that approximately 5% of the population does not have access to drinking water from centralized water supply. This group includes people living in non-supplied zones (secluded rural areas, farms, recreational or holiday home neighbourhoods) and those who are reluctant to use it for social reasons (e.g. unable to finance the connection to the centralized system, consumers excluded from the service due to non-payment or relying partly or completely on other sources because of the high water tariffs). Individual (institutional, commercial, or community-based) supply systems provide drinking water to approximately 3% of the population. In addition, 200 000 people consume water from private wells, boreholes using mostly shallow groundwater and this number is increasing. There is no comprehensive country-level survey on the basic drinking water supply (and wastewater management) solutions of vulnerable and marginalized groups lacking centralized piped water supply. Both insufficient drinking water quality (contamination of the accessible water) and inadequate quantity (due to limited capacity for personal hygiene) increases the risk of infection in case of households without access to piped water or excluded from the supply.

While the quality of drinking water from the public water supply systems and most of the individual small scale systems are monitored regularly, the obligation to monitor private wells (once in every 3 years) came into force only in June 2016. There is only accidental information on their water quality. The available evidence indicates that infectious and non-infectious diseases are more likely to be associated with private wells than the centralized water supply, though the number of cases corresponding to a specific event is higher in case of the latter. Water from private wells has been the only cause of recent cases of drinking water-related methemoglobinaemia due to their high nitrite and nitrate content. Increasing incidence of hepatitis-A virus infections was also linked to non-adequate drinking water supply. Consumption of natural spring waters of uncontrolled quality as primary source for drinking water poses comparable public health risks, but typically for other social groups.

The requirements and tasks of drinking water treatment appear both centrally and locally due to the increasing popularity of decentralized supply, mostly from private wells (although there are examples of systems based on rainwater collection as well). Household water treatment devices and technologies might also have an important role. Currently there is no information on the composition of raw waters (private wells or rainwater) used as drinking water and on the effectiveness of home water treatment devices in case of different raw water quality. The application of home water treatment devices for point-of-use treatment of tap water to solve (mostly hypothetic) quality problems is gaining popularity among the consumers. The possible health gains of device use and the health risks resulting from their (frequently incorrect) application are awaiting evaluation.

Equity aspects of drinking water supply

Drinking water is indispensable for human health and also for human dignity from a social perspective. The UN's General Assembly recognized the right to water which is also reflected in Hungary's Fundamental Law and implemented by several key regulations. However, experience shows that the provision of universal and sustainable right to water for certain vulnerable and marginalized groups is difficult in the Hungarian society. The re-evaluation of the National River Basin Management Plans revealed increasing difficulties in affordability. Half of the consumers pay water tariff above 3% of their income which is the acceptability threshold according to international and national documents. In the lowest income decile, this ratio can exceed 8%. The solution would be the separation of the tariff and compensation systems for the average users and the poorest, vulnerable and marginalized consumers. Although the regulatory background is theoretically adequate, in practice this issue is currently unresolved. The situation of slums in the city outskirts is difficult as the local governments have limited obligation to secure drinking water in these areas. The exclusion of consumers due to non-payment might cause multiple level problems. Not only the right to water is violated but the economic operation of the water supply system is also threatened without the re-integration of these consumers. Those who are excluded from the consumption or not connected to the centralized system frequently use publicly accessible wells as their only drinking water source. The elimination or capacity limitation of these public wells further restricts their access to drinking water. The provision of universal and equitable access is challenging for the society as the availability of water sources is decreasing in some areas, due to climate change or overuse.

Key research tasks

Factors threatening water resources

- Risk assessment of uncharacterized chemical, microbiological and radiological drinking water pollutants from surface waters and groundwaters, and determination of necessary limit values
- Evaluation of environmental factors and processes (water level, water temperature, sediment transport, colmatation) influencing the effectiveness of riverbank filtration and examination of the impact of hydromorphological interventions (e.g. water dams) on drinking water quality
- Evaluation of the effectiveness of riverbank filtration in the removal of organic micropollutants (e.g. pharmaceutical residues)
- Characterization of the microbiological communities influencing water quality in water abstraction plants, riverbank filtration wells and distribution systems
- Analysis of changes in the spatial distribution of drinking water sources as a function of utilization level and climate change to prevent drinking water scarcity

Challenges of drinking water treatment

- Development of innovative water treatment technologies: production of biologically stable water, elimination of emerging pollutants while preserving the mineral content of the water, possibilities of technology-related microbiological risk management
- Development of biological methods to remove micropollutants
- Investigation of the production dynamics of disinfection by-products correlating with raw water composition and the applied water treatment methods, development of chemical analytical procedures and protocols for their identification
- Assessment of health impacts of emerging disinfection by-products (haloacetic acids, haloacetonitriles)

Risks of distribution systems: water loss and secondary water quality deterioration

- Development of innovative diagnostic methods for leakage detection in the distribution system
- Monitoring water quality deterioration in the distribution system: opportunistic pathogens, microbial processes posing health risk, risks associated with pipe materials

Risk-based approach in drinking water supply operation

- Modelling of the effects of extreme meteorological events on vulnerable drinking water resources and implementing adaptation in the operation of water utility services
- Implementing protection against emerging safety risks (e.g. terrorism) in the operation of water utility services
- Development of risk-based, cost-effective and energy/water-efficient drinking water supply
- Development of a surveillance system for detecting drinking water-related diseases and epidemics

Risks and tasks of non-centralized drinking water supply

- Elaboration of public health, financial, technical and legal conditions for the use of alternative water sources (e.g. precipitation, greywater) and evaluation of the need for establishing a separate water system for other household uses
- Characterization of rainwater composition as a function of weather and contamination sources, identification of risk factors
- Development of innovative and cost-effective water analysis methods for risk-based operational control, water quality assessment of private wells and other small-scale individual water supply systems, in-situ measurements
- Development of modular water treatment technologies suitable for the treatment of private wells, rainwater-based and other small-scale individual water supply systems

Equity aspects of drinking water supply

- Elaboration of solutions for total cost recovery while preserving affordability of drinking water
- Provision of universal, long-term and sustainable access to drinking water for all people, including the vulnerable and marginalized groups, identification of legal, technical and financial solutions
- Identification of legal, technical and financial solutions for drinking water supply systems of special legal status (transboundary drinking water supply, supply of informal (illegal) settlements, systems operating on a courtesy basis)

2. Water quality

Keywords:

- surface water and groundwater, physical, chemical, biological and ecological water quality
- analytics, automated online measurements, remote sensing, emission inventories, ecotoxicology, isotope hydrology, modelling at river basin level
- classification methods, emission and immission limit values
- traditional and emerging pollutants, diffuse and point source water pollution, saline and thermal load, nutrient load, eutrophication, pharmaceutical residues, pathogens, xenobiotics
- extreme meteorological events, transport processes, mixing
- load reduction, remediation, wastewater treatment, natural technologies

Challenges

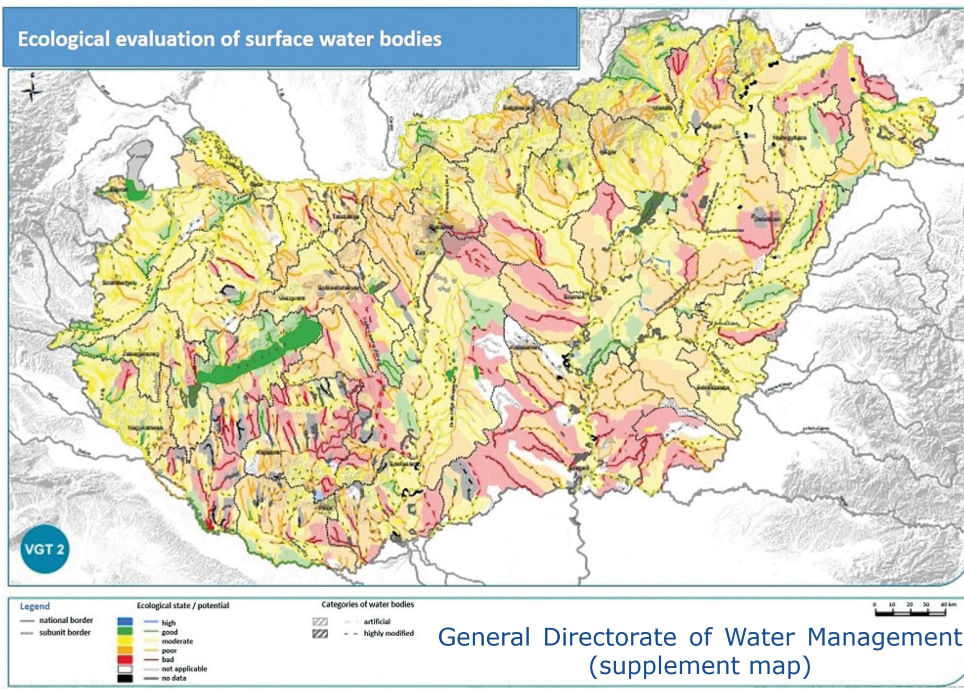
Definition of water quality

Surface water and groundwater quality is determined by a wide range of physical, chemical and biological parameters and influenced by all environmental and anthropogenic processes. In consequence, the evaluation of water quality is always related to a specific set of criteria (e.g. ecological or human). The measured water quality parameters (exposure) shall be evaluated together with their human health or ecological impacts. The quality status of water should usually meet the demands for human water use and ecological objectives (drinking water supply, irrigation, thermal water use, fisheries, recreation, etc.). A further challenge of evaluation is that human health or ecological impacts are not always unambiguously predictable from water quality parameters. Some stressors might act synergistically, others antagonistically. Ecological aspects of water quality are discussed in Chapter 5.

Measurement and modelling of water quality parameters

Traditionally, characterization of surface water and groundwater quality is based upon large-scale temporal and spatial monitoring, in accordance with the Water Framework Directive (WFD). The key objective of the WFD is to achieve "good ecological and chemical status of water". However, limit values set for water quality mostly adhere to human goals (e.g. drinking water quality). The assessment of specific physical, chemical and (in case of surface water) biological parameters is performed by periodical sampling at designated monitoring points of the water bodies. There is currently a lack of data for a large number of water bodies and thus their qualitative classification is not reliable. Sometimes even the hydromorphological data are not fully available for the categorization of water bodies. The ecological classification system based upon specific groups of organisms requires continuous development and fine-tuning. The detection of several components (e.g. organic micropollutants) by the presently applied chemical monitoring methodology is not sufficiently reliable. The expansion of the parameter range required to be monitored, the establishment of more stringent limit values and the appearance of emerging pollutants call for the development of analytical methods (and accompanying separation techniques), mainly in the field of instrumental analytics.

(Supplement map) kell ez a szöveg?? Én törölném!



General Directorate of Water Management (supplement map)

The expanding use of methods with large-scale temporal and spatial resolution and the tremendous increase of the calculation capacity enable novel approach for traditional problems. Automated methods becoming available in the last decade support the significant increase of monitoring frequency and remote sensing contributes to the expansion of spatial coverage. Therefore, dynamic changes and transient events influencing water quality are detectable. Drone technology development supports the application of field tests similar to laboratory assays. These methods have not yet been integrated into the national practice and the long-term storage of data generated by automated monitoring is not solved.

Although online measurements open new horizons for data collection, current technologies have methodological and economic limitations (e.g. analysis of micropollutants). Risk-based monitoring focusing to the potential pollution sources is a more cost-effective direction of development. This calls for the revision of the available emission inventories and the overview of the baseline environmental limit values with respect to the components defined by the EU legislation and those specific to river basins. The ecotoxicological methods suitable for the characterization of synergistic effects require stronger focus. Nevertheless, the range of available analytical methods should also be extended (e.g. for endocrine disrupting substances).

The increasing volume of data supports and requires the application of complex models. River basin level models can be used to characterize the source and transport of pollution and to define the actions of substance-specific programmes for reducing pollution. Hydrological measurements, together with chemical and isotope hydrological assays, support the characterization of dynamics at the river basin scale. Access to monitoring data of the entire river basin is necessary for the simultaneous evaluation of multiple measurement points. The high number of transboundary groundwater and surface water bodies hinders the availability of data at river basin level.

Classification of surface water and groundwater, harmonization of emission and immission limit values

One third of the 185 groundwater bodies in Hungary have poor or deteriorating chemical water quality according to the evaluation performed as part of the revision of the National River Basin Management Plan. The source of the problem is mostly diffuse (nitrogen) load. (Quantitative evaluation is discussed in Chapter 3.) Classification of the current status, determination of vulnerability limit values and actualization of the risk classification of groundwater resources should also receive attention. This is a strategic task in case of drinking water resources (see Chapter 1).

Looking at surface waters, only 7% of rivers and 12% of lakes are in good status based on their ecological classification. Most water flows received “moderate” ranking on the applied scale of five categories (excellent, good, moderate, poor, bad), mostly due to biological classification results. Half of them had “good” chemical status. Analyses of specific pol-

lutants identified mainly metals as a cause of contamination, though the coverage of the investigation was limited. Among standing waters, the ecological status of large Hungarian lakes (Balaton, Fertő, Velencei) and saline lakes is good. In case of backwaters and other modified water bodies, nutrient load and sediment deposition are the major obstacles to achieve good status. Status evaluation of several water bodies is not possible due to the lack of data.

The classification of surface waters used for bathing is based upon additional water quality monitoring which is harmonized with recreational requirements. More than 95% of the country's designated bathing waters are of good or excellent quality (though the lack of data is a problem for bathing waters as well). Nevertheless, the applied classification scheme does not cover risks related to special pathogens (enteroviruses, protozoa) or cyanobacterial toxins. The classification of bathing waters increasingly relies on predictive methods identifying events which lead to water quality deterioration and defining control points for intervention (e.g. a specific precipitation quantity or water level) indicating possible risk for bathing.

The impact of different load sources – mainly emerging pollutants, see later – on the ecological status is not sufficiently clarified (see also Chapter 6). Harmonization of limit values of specific emission sources (emission thresholds) with the tolerable load of the water body (immission thresholds) is necessary to reduce the cumulative effect of pollutants. This issue is especially important in case of small streams which are highly vulnerable to pollution.

Water quality hazards: Traditional pollutants

Organic matter, nutrients, heat, ions and heavy metals are traditional pollutants with prolonged presence. The type and extent of the resulting problems are already known and although the possible solutions are mostly identified as well, they are not expected to be achieved in the near future.

Treatment plants for communal wastewater are a major source of the organic matter load affecting most water bodies. The environmental impact of the non-watertight municipal liquid waste reservoirs (septic tanks) is not sufficiently clarified. Agricultural activities are another fundamental source of organic matter and plant nutrient load. Nitrate and ammonium levels limit the human use of most shallow groundwater bodies. Surface water quality is strongly influenced by the upward movement of polluted groundwater (mainly in dry periods) and the water runoff related to the soil erosion from (steep sloped) arable lands. The agricultural load in running water on the plains is heavily potentiated by excess water drainage. Beyond the washout of nitrate from intensive artificial fertilization, phosphorus load might also be significant though the regional differences are great. Eutrophication is a primary consequence of nutrient load in surface waters (see Chapter 5), but organic matter shall also influence the biological and chemical status of water by oxygen depletion. The pollutants accumulating in groundwater gradually reach deep aquifers of longer transit time through natural recharge and drilling to deeper layers.

In addition to the organic matter, the soluble metal content of the fertilizers washed from the soil also has a negative impact. There are other, partially identified sources of metal load, such as sludge composts (see above), unprofessionally deposited spoil tips from metallurgy or power plants, water residing inside abandoned coal and mineral mines and red mud (a by-product of alumina production). Deposition from the atmosphere and municipal rainwater runoff are quantitatively important, but not adequately characterized pathways of metal load and therefore their investigation is crucially important.

Active ingredients, residues and metabolites of agricultural pesticides are diffuse pollutants of nationwide importance which might migrate across the root zone and accumulate in deep groundwater aquifers. The already banned persistent pollutants (mainly triazine derivatives) are detected most frequently. Chlorinated hydrocarbones (e.g. trichloroethylene, chloro-benzene derivatives) used for industrial degreasing and dry-cleaning are also hazardous soil pollutants which are present in deep aquifer groundwater. Large-scale groundwater and soil contamination in previous industrial zones, army bases and abandoned waste dumping sites all pose risk to groundwater (partly managed in the National Environmental Remediation Programme).

Thermal pollution of surface waters originates primarily from industrial cooling waters and used thermal waters. In case of thermal waters, concomitant saline and organic matter pollution is frequent. Thermal load does not typically have direct impact on human use but its influence on the aquatic ecosystems might be considerable and needs to be further clarified (especially in combination with other pollutants).

Thermal water injection well in Tura

Water quality hazards: Emerging pollutants

Emerging pollutants are diverse chemicals such as pharmaceuticals, new pesticides, anti-corrosive substances and industrial additives. The molecule families are quickly expanding due to the development of research and production in the pharmaceutical and chemical industries. The prevalence, concentration, environmental transport and degradation of emerging pollutants and their impact on human health and aquatic ecosystems is not yet sufficiently characterized. For these compounds, parallel development of detection methods and research targeting the mechanism of action are necessary.

Currently the major public concern relates to the pharmaceutical residues and hormones which are released mostly through wastewater and thus are present in surface waters. Moreover, there are other chemicals (e.g. biocides, pesticides, heavy metals) which also act as endocrine disruptors. The impact of these emerging pollutants on living organisms is poorly understood but might be very significant due to high exposure. Phtalates used as industrial plasticisers are of crucial importance and they are detected in nearly all waters, including drinking water. Illegal plastic waste deposits are a possible source of phtalates in groundwater but they can also leach from plastic products during their dedicated use (even from drinking water pipes and mineral water bottles). Nanomaterials, such as carbon nano-tubes, with expanding technological applications or microplastic particles from plastic waste fragmentation are examples of emerging pollutants with unknown bioactivity. The release of antibiotics resistant microbes and the transfer of resistance genes in aquatic environments are also emerging risks of increasing concern. In addition to municipal (especially hospital) wastewater, organic fertilizers and agricultural wastewater exacerbate this process due to the intensive use of antibiotics in animal husbandry.

Impact of meteorological and transport processes on water quality

A number of natural processes influence the impact of the above detailed pollutants on water quality: for example, meteorological events, hydrodynamical or aquatic ecosystem processes (the latter is discussed in Chapter 5). Chemical and biological processes can be modified by the expected increase of water temperature during summer months. Low flow periods with decreased discharge contribute to the concentration of pollution from wastewater. Flash floods emerging after intensive rainfalls result in combined sewage overflow and increased load as well. The aspects of water quality in connection with other water uses (e.g. irrigation, fisheries, thermal water use) are discussed in Chapter 3.

Natural processes intensifying due to the climate change have influence on soil infiltration, mixing, sediment transport and on the resulting hydrodynamical and pollution events. These processes and their impacts need to be evaluated by comprehensive monitoring and modelling programmes and development of integrated models. Modelling can also facilitate the optimization of competing, area-specific water demands (e.g. irrigation, drinking water or water abstraction for energetic purposes).

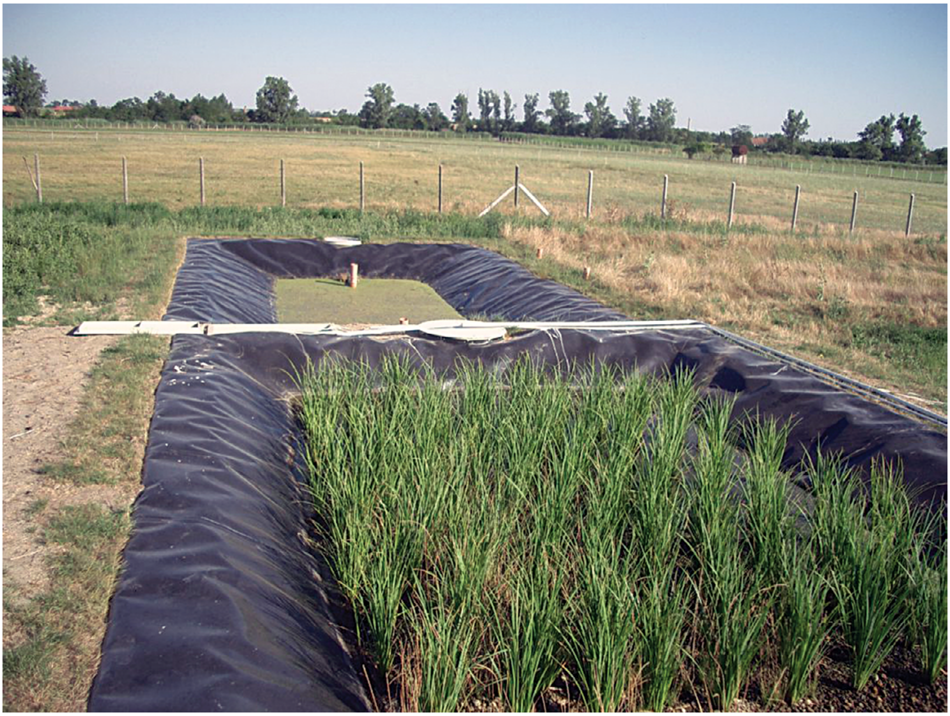
Better characterization (and forecasting) of the impact of extreme meteorological events are equally important for water management, prevention of hazardous events (see Chapter 4) and water quality. For instance, sudden, extensive precipitation does not only have a quantitative effect but may also influence the quality of water by dilution or through its chemical composition. The water droplets contributing to cloud and fog formation play an important role in the chemical processes of the atmosphere and the washout of environmental and anthropogenic atmospheric gases thus may modify the chemical composition of the precipitation as well. Increasing the accuracy of the information to predict extreme meteorological events and development of computational modelling are necessary for forecasting the processes leading to the formation of precipitation in the clouds. The best tracers are natural isotopes which are continuously present in rainwater and in surface water bodies. Therefore, the natural isotopes are suitable for monitoring the local impact of global changes and generating basic data for water research and other scientific areas.

Detailed theoretical knowledge is available about the mixing processes (advection, turbulent diffusion and dispersion) in rivers. However, simplifications of theoretical descriptions cannot be applied to complex currents (e.g. 3D flow structures, meanders, confluences, multiphasic currents) requiring, therefore, the further development of field assays and computational models. The assessment of river turbulence conditions and the modelling of 3D currents have not yet been solved.

Modelling of wind-related dynamic load and long-term analysis of morphological, water quality-related and ecological processes is crucially important to clarify the flow and turbulence conditions of lakes. The integration of high-resolution meteorological forecasts, water quality monitoring data and sediment transport processes relying on continuous on-site measurements and remote sensing is challenging. The characterization and quantification of pollutant mobilization from mixing sediments and those of water-sediment-bed relationships requires extensive data collection and modelling.

Load reduction and efficient removal of current pollution

Beyond reduction of diffuse wastewater load (through the development of the sewerage system and reconstruction of the aged infrastructure), it is a priority to apply state-of-the-art, energy-efficient wastewater treatment technologies, adapted to the composition of wastewater. Natural technologies (e.g. tree plantations, constructed wetlands, combined systems, living machines) are development trends supporting cost-effective



and sustainable water management. Quaternary treatment is widely applied to remove micropollutants in the international practice and expected to have a more pronounced role at national level as well. Decentralized wastewater treatment technologies are becoming more valuable, especially where connection to centralized sewerage is not economically feasible. Local treatment (and exploitation) can reduce wastewater volume and the impact on aquatic ecosystems. The comparative evaluation of the environmental impacts of different treatment methods is needed for other alternative solutions (e.g. drainage) applied in the management of treated wastewater. The current direction of national development is the expansion of the agricultural use of wastewater sludge. However, quality issues or inadequate treatment of sludge compost might contribute to nutrient, heavy metal and sometimes organic micropollutant load and facilitate the transport of pathogens and antimicrobial resistance. The leading international trend – recognizing these difficulties – is the increasing use of wastewater sludge for energy (incineration), especially in urban environments.

Basic research needs emerge mostly in the fields of novel remediation technologies and diagnostic and analytical methods. These developments are expensive but contribute to the improved reliability of status reports and the increasing efficiency of technical interventions for stakeholders responsible for remediation. There is also growing need to develop technical solutions for passive remediation and risk-mitigation.

The prevention and management of traditional pollution is primarily a regulatory task. Classic soil and groundwater remediation technologies for extensive and diffuse contamination are extremely expensive. Distribution of resources between the contaminated sites should be determined by the severity of their ecological and/or social impact. Besides the development of novel remediation methods, the optimization of the currently applied technologies is also crucial for maintaining cost-effectiveness while reaching the defined objectives. Significant load reduction might be accomplished by introducing locally optimized good agricultural practices, given the high spatial variability of erosion and transport processes. Several other methods (adjacent plant defense zones along running waters, establishment of constructed aquatic habitats, etc.) might also support the improvement of water quality. Similar objectives can only be achieved at much higher cost without the application of these methods, even in smaller river basins.

Nitrate and ammonium, both traditional pollutants, are detected in most of shallow groundwater bodies and there is currently no available technology for their removal. Further technical and technological developments (e.g. artificial recharge, water treatment) are necessary for the reduction of saline and thermal load from thermal waters (see Chapter 3). The exposure to pharmaceutical residues and hormones can be reduced mainly by further development of wastewater treatment (e.g. application of oxidation or membrane technology-based quaternary treatment procedures). Risk management of endocrine disrupting chemicals of diverse sources (e.g. biocides, pesticides, heavy metals) is a complex task.

The environmental impact of xenobiotics should be minimized through the development of new chemicals with more favourable persistence and bioaccumulation profile and follow-up treatments. The environmental damage and the remediation costs can be reduced by introducing regional restrictions with regard to certain chemicals or supporting the use of less persistent molecules with the same mechanism of action. High investment costs entail the need for environmental economy assessment prior to the introduction of targeted local wastewater treatment technologies.

Key research tasks

Characterization of water quality (measurement, classification, modelling)

- Determination of vulnerability limit values for groundwater resources
- Assessment of temporal changes in mineral and therapeutical water composition
- Analysis of organic and inorganic micropollutants, their transport and degradation as a function of environmental factors at national level
- Assessment of human health and ecological impacts of emerging pollutants (nano-substances, plastic microparticles, antibiotics resistant microorganisms)
- Identification of microbiological processes influencing water quality in thermal waters, sewerage and rainwater drainage systems
- Improvement of the classification of natural bathing waters (modelling, site-specific systems for the prediction of water quality, harmonization with ecological water classification, real-time detection of pathogens)

Water quality hazards: pollutants and interventions

- Monitoring the changes in groundwater quality due to soil contamination (at national, regional, and river-basin level)
- Assessment of the impact of waters from operating and abandoned mines on surface water and groundwater quality
- Assessment of water quality and human health effects of the pollutants (pathogens, organic micropollutants, heavy metals) from industrial and communal wastewater sludge compost used in the agriculture
- Investigation of the pressure from waste dumping sites effluents on surface water and groundwater
- Identification of pollutants posing risk to human health or the environment in waters used for irrigation (groundwater, deep aquifers, greywater, treated wastewater, stored waters, thermal water, etc.)
- Assessing the impact of increasing karst water levels on the quality of connected surface water, groundwater and drinking water resources in the Transdanubian Central Range (Dunántúl)

- Assessment of the effect of thermal load from used waters (cooling water, thermal water) on water quality
- Impact assessment of urban rainwater runoff on water quality
- Investigation of the effect of changes in connectivity (fragmentation, reconnection) on water quality
- Assessment of the impact of legally or illegally discharged, treated and untreated industrial, agricultural and communal wastewater on recipient water quality with a special focus on temporary or very low flow volume streams
- Evaluation of the impact of the load from fisheries on the recipient surface water quality, identification of the possibilities for impact mitigation in the operational practice

Impact of natural processes on water quality

- Model development to describe turbulence and complex flow conditions of rivers and the establishment of monitoring system for data collection
- Development of interconnected 3D hydrodynamical and water quality models to describe the impacts of wind in lakes, independently of their size
- Assessment of the impact of extreme meteorological events, summer mean temperature increase and extreme precipitation on wastewater treatment plants and systems (efficiency rate, by-product formation, hydraulic load)
- Investigation of water body contamination from atmospheric deposition, transport and washout
- Development of the models for hydrological and transport processes influencing surface water and groundwater quality, introduction of case-based models, evaluation of the data requirement and the temporal and spatial resolution of the models

Technology and innovation (load reduction and efficient removal of existing pollution)

- Assessment of the impact of novel agricultural practices (soil use systems, precision agriculture) on soil characteristics (including hydrological parameters), the transport of pollutants and the quality of sur-

face water and groundwater sources; possibilities to decrease diffuse agricultural pollution
- Evaluation of alternative (biological) treatment possibilities of agricultural, industrial and communal wastewaters, development of quaternary wastewater treatment technologies (for micropollutant removal) and decentralized technologies, optimization of microbiological processes in wastewater treatment
- Development and adaptation of effective pool water treatment technologies minimizing the production of disinfection by-products

Social, economical, legal aspects

- Development of economic tools for the reduction of diffuse pollution of groundwater, establishment of the legal background to promote the implementation
- Evaluation of the data requirement of implementing the EU Nitrate Directive and harmonization to meet the current obligations for data provision
- Identification of economic drivers to involve agricultural stakeholders in the reduction of diffuse pollution

3. SUSTAINABLE WATER USE

Keywords

- limited water sources, uneven spatial distribution, temporal changes, surface runoff, infiltration, recharge
- water demand, conflicts, economic water use, overuse
- sustainable water use and abstraction
- industrial water use, reuse, efficient technologies, hydropower sources: use for energy purposes, technological development
- agricultural water use, irrigation, water-saving irrigation technology, irrigation water demand, illegal water abstraction
- thermal water use, sustainable use, energetics, exploitable quantity, artificial recharge, thermal and saline load, disposal of used water
- water use for touristic and recreational purposes, water use for therapeutical purposes, water treatment technologies, water transport

Challenges

Uneven spatial distribution and temporal changes of water resources and demands

Sustainable water use should consider both quantitative limitations and the minimization of qualitative impacts. Water uses generating emission and their impact on water quality are discussed in Chapter 2. Meeting all types of water demand while distributing already limited resources is challenging. The experienced spatial and temporal shifts in the quantity of available water due to climate change and the varying needs of the users might aggravate emerging social conflicts.

Hungary has significant surface water and groundwater resources but their spatial distribution is inhomogeneous. The use of surface waters is limited quantitatively by low flows, often aggravated by quality deterioration, especially in case of small streams receiving wastewater load. Exploitation of water sources approaches or exceeds the level of sustainable environmental recharge in several groundwater bodies, especially in the Great Plain (Alföld).

Soil, as the highest capacity natural water reservoir, deserves particular attention. Soil stores a significant proportion of accessible water in the form of soil humidity.

Climate change is expected to result in reduced surface flows in national and transboundary river basins and decreased soil infiltration recharging groundwater tables. Consequently, the volume of accessible water resources is anticipated to decline. In addition, the water demand of several different uses might increase in correlation with climate change (e.g. irrigation, cooling, public water use, mineral water production), especially in the summer period. For tracking changes of water resources and user demands, development of quantitative indicator and monitoring systems is indispensable. More accurate forecasts can support the elaboration of climate adaptation plans.

State-of-the-art instrumentation and measurement programmes are necessary to collect more precise data on the extent and trends of infiltration influencing groundwater resources. The role of hydrogeological modelling should also be upscaled.

Conflicts of interest among the users of water sources

Most conflicts among different water abstractions from the same groundwater source originate from the absence of quantitative limit values and the typically missing consumer awareness with respect to the real value of the service (e.g. in case of agricultural and some types of industrial water uses). These factors lead to the negligent use of resources, lack of interest in efficient technologies and overuse of the infrastructure. Very high proportion of groundwater abstractions is illegal (only 10% of the wells are officially authorized according to the estimations of National River Basin Management Plan) what also influences the sustainability of water use.

Conflicts with respect to surface water are mostly related to water quality and emerge among diverse types of human water uses (e.g. bathing and fishing) and the demands of the society and the ecosystem. (The achievement and maintenance of good ecological status is a key objective of the WFD and it is discussed in more details in Chapter 2). The real costs of surface water abstractions are not always perceivable to the consumers and the distribution mechanisms do not enforce economical use (e.g. in the agriculture).

Major water uses: drinking water

Drinking water supply has highest priority of all water uses. Drinking water scarcity leads to severe local and regional social problems such as migration due to the lack of water. The aspect of supply sustainability, both quantitative and qualitative, also needs special attention. (Chapter 1 discusses several aspects: economic, water- and energy-efficient water production, water treatment, consumer habits, leakage reduction in the distribution system.) The economic and environmental sustainability of in-situ treatment possibilities and connection to regional drinking water supply systems (water transfer) should be considered during developments aiming at improving drinking water quality. Both quantitative and qualitative protection of drinking water resources from diverse, but predictable negative effects (climate change, groundwater overuse, emerging pollutants, riverbed deepening), has crucial importance.

Major water uses: industrial water use, hydropower use

Industrial water abstraction comprises approximately 80% of total water use and cooling water amounts to 90-95% of industrial use. The used cooling water is returned to the hydrological cycle very rapidly, but it still has considerable impact on water quality (thermal load). Beyond their water demand, other types of industrial water use influence the status of water by wastewater discharge of diverse composition. This load can be reduced by using manufacturing technologies optimized to minimize emissions and developing locally applicable, end-of-pipe treatment technologies especially in case of industries with high water demand (such as paper and pharmaceutical industries). The establishment of the adequate

technological framework might enable water reuse for meeting industrial water demand.

Energy use of surface waters currently accounts for only a small portion of the Hungarian electricity mix: only 1% of the technically exploitable hydropower potential (Tisza, Rába, Hernád rivers) is used. While the ratio and quantity of the electric power generated from renewable sources might be increased by developing hydropower use, there are ecological impacts and social conflicts which should be considered. Targeted research is needed to identify the environmental impact of hydropower plants, for instance, hydraulic changes caused by water dams, changes in water quality and sediment transport, erosion, habitat fragmentation and the impacts related to the construction work.

Major water uses: agricultural water use, irrigation

Irrigation requires the highest quantity of water in agriculture and it is aimed at different objectives (e.g. frost protection, flowering time control, soil protection) beyond water replenishment. Crop cultivation is significantly affected by the adversities of the climate and the resulting extreme water flow regimes. Optimization of the adaptation to the changing conditions requires consciousness and the synthesis of knowledge in hydrogeology, soil science, agricultural and irrigation technology. The expansion of irrigated fields, intensification of irrigation or crop rotation and increasing the weight of ecological considerations are all possible directions of irrigation development. The costs and impacts should be evaluated from economic, water management and ecological perspectives.

The development of low-volume, water-saving and innovative micro-irrigation techniques (e.g. surface or subsurface drip irrigation, irrigation mulch) is an important element of sustainability but has special limitations (e.g. related to water quality). The specificities of the water-soil-plant system should be considered to determine the most adequate solution.

Optimization of water abstraction for irrigation is indispensable for the sustainability of water use. Negligent (and mostly illegal) water abstraction from groundwater resources (typically from shallow groundwater) results in lowering groundwater table and has subsequent negative impact on the water management in the affected regions.

The quality of water from groundwater wells is generally suitable for irrigation, though pathogens and organic or inorganic micropollutants might pose food safety risk. The chemical composition (total mineral content or the presence of some chemical pollutants) of deep groundwater aquifers might limit possibilities of application as well. Considering surface water resources, irrigation in most parts of the country could be theoretically based completely on the larger rivers. However, the cost efficiency rapidly decreases as the distance from the rivers is increasing. Reclaimed waters (treated wastewater, greywater, used thermal waters) might be alternative sources. However, robust analysis of water quality (focusing on pathogens, emerging pollutants and factors influencing soil quality) and the elaboration of technical, food safety and public health requirements are necessary prior to their application.

The comprehensive and integrated management of excess water and droughts is indispensable in arable land cultivation. In addition to the reconstruction and extension of the existing infrastructure (e.g. excess water drainage network), it is necessary to regulate both its ownership and operation. The quality of retained water should be monitored, and its optimal distribution needs to be defined (see Chapters 4 and 6).

Increasing the exploitation of the soil's water storage potential might reduce irrigation water demand. This calls for more accurate description of the soil hydro-physical characteristics (water absorption, permeability and retention capacity) by targeted data collection and the development of methods for estimation from easily measured soil parameters. The demand for irrigation can be predicted using information on the amount of precipitation, soil humidity, soil evaporation, the water quantity accessible for plants and evapotranspiration. The agrotechnological procedures supporting infiltration to the soil might also contribute to water-efficient cultivation. The application of plant varieties capable of adapting to the local environmental conditions (e.g. low water demand, efficient water use or resistance to water coverage) shall be a feasible solution. However, the ecophysiological investigation of plant responses to the environmental factors (e.g. water supply, temperature, atmospheric CO2) is indispensable for their successful introduction.

Major water uses: energy use of thermal waters

Hungary is in an outstanding situation for thermal water utilization: the average heat flow is approximately 90 mW/m2 and the geothermal gradient is between 30 and 50 °C/km. Thermal water sources are hydraulically related to drinking water resources and mineral water abstraction sites in many places of the Carpathian Basin. Competing drinking water, mineral water, therapeutical and energy demands can only be sustainably fulfilled in certain areas by applying a targeted water management strategy. Similar to other groundwater types, quantitative limits should be determined for thermal water abstraction. Although there are available technologies for the use of waters with different temperatures, further development is necessary for better exploitation of the geothermal energy potential.

Electric energy production and the use of excess thermal energy generated during this process is the dominant method for the utilization of waters warmer than 100 °C. Such systems are currently missing although there are several areas in the country which would be appropriate for this purpose.

The first geothermic power-plant in Hungary, Tura

Alluvial fans of rivers are the best locations for the installation of open loop (water production- and absorption-based) geothermal heat pumps and thermal probes for waters cooler than 30 °C. The installation of closed loop heat pumps (with a geothermal probe or collector) is possible in many regions of the country, with the exception of karst hills. These systems enable the use of thermal water sources which are stored and recharged in the upper surface layers at 80–100 m (maximum 250 m) depth. Their use might influence shallow groundwater sources.

Waters with temperatures between 30–100 °C are utilized in communal systems organized in a cascade for heating, public and industrial hot water supply, wellness centres, spas and agricultural facilities.

Abstraction of thermal waters exceeds the sustainable volumes at many places thus the water table is continuously decreasing. The best currently available preventive measure is artificial recharge of the abstracted water, however, it is applied only in less than 10% of thermal water abstractions. Used thermal waters which are still over ambient temperature and often have very high salt concentration are transferred to surface reservoirs in the absence of artificial recharge resulting in significant environmental load. The technology of artificial recharge should be developed to reduce the costs and achieve full scale technical feasibility, taking into account the quality of used waters. Thermal waters abstracted for energy purposes are usually also chemically treated (e.g. phosphate is added to reduce salt precipitation). Optimization of thermal energy use in ongoing water abstractions, planning and implementation of cascade-type use and increasing efficiency should be in focus to secure sustainable use.

Major water uses: recreation, therapy, transport

Surface waters are used for a wide range of recreational purposes including bathing, aquatic sports, sport fishing and (eco)tourism. Perspectives and demands related to these activities should be harmonized and also adjusted to the needs of navigation and agricultural use. There are about 280 designated and authorized bathing sites in the country's natural waters, half of which are situated at Lake Balaton. (The number of beaches used for bathing without authorization or control is much higher.) There are frequent conflicts between the designation of a site for bathing and other water or land uses (e.g. environmental protection, navigation, fishing, pasture or cultivation in the protection zone).

Recreational and therapeutic use of thermal waters have long-standing tradition in Hungary. The development of pools and spas (not exclusively relying on thermal waters) was a strategically important objective of tourism in the last decades. Thermal waters are mostly classified as therapeutic waters. The medicinal pools typically operate in a fill-and-drain system (the entire pool is drained once or twice daily) and without disinfection. This practice is not sustainable neither from water management nor from public health aspect. In spite of the extravagant water use, microbiological pollution is frequent in therapeutic pools implying health risk and also impairing artificial recharge. The used water from thermal pools reaching freshwater reservoirs is a source of considerable saline and thermal load.

The pools not using therapeutic water operate by water circulation and use water more economically. Chlorine-containing disinfectants are typically applied to ensure microbiological safety but overdosing may lead to the formation of by-products which have adverse health effects. Both sustainability and public health aspects call for the improvement of pool water treatment technologies. Scientific investigation of the biologically active components responsible for therapeutic effects is necessary to create the basis for the development of treatment technologies for therapeutic waters. More conscious and responsible bather behaviour would also support the safety of bathing sites with pools.

River transport is the most eco-friendly type of transport according to the majority of calculations. However, most comparisons only take into account the direct costs of fuel in relation to the transported goods but neglect the costs of the development and maintenance of transport waterways, the reduction of water quality deterioration caused by water transport and the damages to the aquatic ecosystems. In order to sustainably maintain the navigation on the Danube, modelling of the location of shallows and the flow of goods, information technology development of forecasting and the organization of transport need international harmonization. Sustainable navigation on the country's major rivers should also be evaluated by balancing the effective level for transport use and other water uses (especially ecological aspects).

Nevertheless, navigation is only one aspect of sustainable river management and the problems awaiting solution (e.g. sediment migration, riverbed deepening, conservation/improvement of the status of side

streams) cannot be separated from other water uses (e.g. drinking water abstraction, recreation, aquatic habitats). The technical questions of river regulation shall be handled together with the issues related to the ecological impact of interventions, recreation, effects on drinking and other water resources and economic aspects. Harmonized measurement and modelling procedures should be created via the cooperation of diverse scientific areas.

Key research tasks

Spatial and temporal distribution and changes of water sources and demands

- Development of quantitative indicator and monitoring system to assess the current level of water use and the consequences of climate change affecting the water flow regime and water management; forecasting of quantitative changes of surface water and groundwater sources using meteorological and hydrogeological models
- Establishment of quantitative limit values for groundwater sources, investigation of infiltration and the changes of current subsurface transport pathways in order to secure sustainable water abstraction
- Assessment of the water demand of diverse production areas to introduce strategic planning of water use; specification of water balance calculations considering all water demands, illegal water abstractions and natural water recharge
- Establishment of the scientific background to maintain the ecologically important water level fluctuations at Lake Balaton without threatening human water use and the populated shorelines
- Development of methods to estimate water balance characteristics of the soil, identification of the impacts of human interventions on water retention and permeability (soil cultivation systems, drainage, closure of soil surface by pavement)
- Establishment of the scientific background to halt the decrease of the groundwater level in Duna–Tisza közi Homokhátság
- Investigations supporting the introduction of fishery and forest management practices which contribute to the qualitative and quantitative protection of surface waters and groundwaters with special focus on water retention

Human water uses

- Development of innovative, water- and cost-efficient irrigation methods, adaptation of irrigation to the water-soil-plant systems, increasing the accuracy of spatial and temporal prediction of irrigation water demand
- Setting the foundations of the economic and ecological development of Danube navigability and examination of the possibilities for navigation of other waters

- Establishment of the scientific background for the optimization of thermal water use (cascade-type use, efficiency increase, boring and yield improvement techniques, artificial recharge, inclusion of non-operational oil and gas wells)
- Ecological, economic and technical optimization of the regulation and revitalization of certain rivers (opening of closed side streams, increasing connectivity of zones close to shorelines)
- Development of local and regional thermal transport models to support efficient thermal water management

Technology and innovation

- Development of agrotechnology procedures to increase soil water retention capacity
- Technological developments for agricultural, industrial and communal wastewater reuse; development of end-of-pipe wastewater treatment technologies
- Development of water treatment technologies for medicinal waters without compromising the therapeutic effect

Social, economic and legal aspects

- Identification of the needs and possibilities in the development of the regulation of the Hungarian water utility services and water resource protection
- Overview of the legal background of used thermal water disposal to protect surface water and groundwater resources
- Establishment of the legal, technical, public health and water quality framework of artificial recharge related to geothermal energy use
- Establishment of the legal, technical and public health background to support household greywater use
- Intensification of the cooperation among designers, builders, bath service providers, controlling authorities and bathers to preserve the quality of water in pools and spas
- Development of a framework supporting cooperation of bathing and recreation with other water uses instead of competition
- Introduction of sustainable and fair distribution of limited water resources using economic and legal drivers

4. WATER MANAGEMENT

Keywords

- water resource management: transboundary waters
- water damages: flood, low flow, ice damage, excess water, drought prevention and prediction, protection against water damage, recovery from water damage, hydrodynamical modelling
- drought monitoring, assessment of soil humidity and evaporation
- water retention, water storage, bed regulation, bed management
- sediment management
- community development: integrated municipal water management, precipitation management, smart cities

Challenges

Management of transboundary water resources: tasks and constraints

The fundamental tasks of water management are the optimization of the natural water balance and the water demands of the society, the establishment of the framework for appropriate water use and exploitation, and the elimination of water damages caused by a number of environmental and anthropogenic factors. (The topics of water use and sustainability are discussed in Chapter 3.) Water management includes scientific, technical, economic and governance activities. The increasing frequency of extreme meteorological events resulting from the climate change and the emerging changes in public demand require the revision of water management practices.

Hungary's surface waters and groundwaters are typically downstream, 96% of surface waters arrive from neighbouring countries and more than half of groundwater bodies are transboundary waters. Therefore, water management is strongly exposed to transboundary effects. The major part of the catchments of Hungarian rivers is situated in the upstream coun-

tries, thus the flood water primarily derives from these areas. This geographical circumstance hinders the implementation of flood prevention measures. Low flows and the associated water scarcity limits the provision of water for agriculture, which can only be secured by adequate water governance. Transboundary processes may not only lead to quantitative problems, but the quality of water is also affected. For instance, development of sewerage system in upstream regions without the simultaneous increase of the wastewater treatment capacity leads to water quality deterioration in Hungary. Integrated river basin management would facilitate the solution of transboundary problems but international cooperation and conflict management is presently lacking in practice in case of smaller local issues (see Chapter 6). Internationally harmonized measures such as the integrated flood risk assessment formulated in the EU's Flood Directive which economically quantifies river basin-level adaptation processes open new possibilities for complex water management. The national implementation might support the establishment of integrated water management practice.

Adaptation to extreme hydrological regimes

Climate models predict longer and more intensive low flow periods, droughts and – due to the temporal concentration of precipitation – floods of growing intensity in the Danube basin. Altogether, increasing frequency and intensification of extreme hydrological situations is expected. According to the calculations, the average water quantity which caused the extensive floods of the last decade is also expected to be present in the future, however, the temporal concentration might be higher.

Hydrodynamical modelling, including the identification of the relevant flood water levels, flood risk mitigation and riverbed management in case of high flows, receives central role in the methodology of novel national water management plans. The relevant flood water levels are defined by 1D hydrodynamical modelling while the identification of the barriers to water runoff and the impact analysis of alternative recovery plans are supported by 2D models. Flood risk mitigation is aimed at the long-term economic management of flood risk instead of simply reducing flood water level. The determination of the optimum model parameters was already started in Tisza valley and this direction of development is expected to be successful for other running waters as well. Flood predictions relying on hydrodynamical data contribute to the assessment of the impact of interventions (e.g. the opening of an emergency reservoir). Therefore, further development of predictive methods shall have a key role in flood protection.

The preparation for droughts and sustainable use of water resources needs to be supported by improved forecast accuracy of low flow periods. To achieve this objective, areas with slow or non-existent runoff should be included; however, the methods developed for the steeper upstream-like segments are partly or not applicable in their investigation.

The determination of the extent, frequency and duration of low flows and floods is crucially important for the different water uses (e.g. the prediction of navigable periods or the planning of cooling water demand in the process of the capacity extension of the nuclear power plant in Paks). Adequate forecasting is required for the management of emerging flash floods – which are still considered a novel phenomenon in Hungary – and the calculations of ice phenomena (start of freezing, ice drift, complete ice coverage, break-up and complete melting) under operative conditions based upon hydrological and meteorological data. The development of predictive models and their validation by in-situ measurements are necessary not only for the management of extreme flow situations but also for the description of the transport of pollution waves and the removal of pollution from water.

Complex management of excess water and droughts, large scale investigation of evaporation

Excess water is a result of topographic, geological, meteorological, and also anthropogenic factors (e.g. land use, soil cultivation, irrigation) and threatens more than 45% of the country's territory. Excess water affects mostly agricultural lands or areas at the outskirts of municipalities where the drainage systems are not adequately operating. The most important element of protection against excess water is prevention, supported by targeted land use, application of state-of-the-art agricultural techniques and the development and maintenance of the infrastructure for water drainage. Beyond preventive measures, novel research-based solutions (e.g. hydrological and geoinformatics-based evaluation of excess water coverage, development of in-situ excess water utilization possibilities) might also support cultivation in areas frequently covered by excess water. Changing the cultivation method or supporting ecological land use are alternative solutions. Emerging costs might be reduced by more differentiated land use (adapted to temporary changes of water coverage or infiltration) (see Chapter 6).

Droughts are frequently returning events of the Hungarian climate mainly affecting the agriculture but they also have possible hydrological consequences due to increased water abstraction. Prolonged droughts contribute to the sinking of groundwater table and limit the availability of surface water and groundwater resources. Hungary will become more exposed to the impact of recurrent droughts according to the climate change scenarios. Therefore, further extension and development of the drought monitoring system is necessary to support the decision-making process of water use. It is necessary to create a drought prediction system supported by short and mid-term weather forecast models and using wide range of satellite-derived and other type of remote sensing-based information (data on soil humidity, vegetation status and coverage). Simultaneous application of local measurements and large scale data from models will contribute to the improved accuracy of drought monitoring and support the prediction of irrigation water demand as well.

Together with the analysis of water runoff, large scale evaporation research is another important field of rapid international development. The main directions of international research are based on satellite-based determination (e.g. MODIS) of vegetation type and coverage, vegetation status characterized by different indexes, surface temperature and radiation balance. Evaporation is estimated from a number of physical and often empirical functions. The other trend in large scale evaporation research uses the physical variables of the atmosphere (atmospheric temperature, humidity, wind speed, global or net radiation). The advantage of these methods is the substitution of the extensive data requirement of satellite-based assessments and the elimination of water balance calculations which typically contain significant bias. These methods might also support the calibration and verification of surface heat exchange calculations based on water balance and – indirectly – the improvement of the accuracy and reliability of models describing climate change and the related hydrological processes. The dynamics of precipitation formation is examined through precipitation recycling, a related novel research field.

Efficient water retention and distribution: requirements and tasks

Water retention, one of the tools for the simultaneous management of floods, excess water and droughts, has growing importance as extreme weather events, water flow regimes and riverbed deepening are becoming more frequent. The spatial distribution of water sources and reservoirs is not homogeneous and this might lead to further social conflicts. Therefore, both the identification of accessible water sources and the investigation of possible solutions for water retention have crucial importance.
Water retention in riverbeds and the full utilization and capacity expansion of existing reservoirs and lakes – while considering nature protection aspects – contribute to continuous use of water sources and the development of complex water management systems. In order to achieve higher efficiency in local water retention, the re-introduction of the elements of traditional floodplain management shall be considered in suitable areas.

The water retention of a certain area is closely correlated with land use: successful retention of temporarily available excess water might be supported by adequate cultivation type and method. Sustainable water management relies also on different forest functions supporting local water retention and reduction of diffuse water pollution and consequently results in naturally functioning aquatic ecosystems. Establishment of plant protection zones along running waters, artificial sedimentation areas and aquatic habitats, installation of dikes, increase of green roofs and zones in urban areas are further solutions to modify water flow characteristics and slow down water flow. Fishery lakes, especially in case of small water streams in hilly areas, might play a role in water storage and local water retention, but significantly modify the quality and ecological status of the water body (see Chapters 2 and 5).

Subsurface storage is more favourable than open storage in terms of evaporation and water quality. Artificial infiltration (groundwater recharge), which is newly introduced in the national practice might be applied for this purpose if the infiltrated water does not cause deterioration of groundwater quality.

The utilization of the soil storage capacity might be a preferred solution for agriculture. Its use requires information on the hydrological characteristics and water balance of the soil and the description and estimation of the changes in the soil hydrological functions (see Chapter 3). Country-level hydrophysical databases integrated to modern geographical information systems, containing reliable data on deeper soil layers and fitted to the spatial and temporal resolution and data requirement of water management maps and models are necessary to predict extreme hydrological regimes and recovery from the resulting damages.

Sediment management

Sediment management is a novel sub-area of water management which is gaining importance. The transported sediment affects the hydromorphological and ecological status of the water body, influences navigability (e.g. fords and contractions in case of low flows), correlates with flood risk (deposition of fine sediment on the riverbank) and might have direct economic impact (e.g. decreased efficiency of energy production due to sediment deposition in the reservoirs of hydropower plants).The sediment migration parameters of the country's rivers need to be clarified by initiating the sediment monitoring in the water body, thus supporting sediment management. Traditional procedures relying on physical sampling can be replaced by indirect optical or acoustic methods. The hypotheses on riverbed deepening might be tested by collecting adequate riverbed- and sediment-related data and clarifying the interactions among flow characteristics, sediment migration and changes of the riverbed. Sediment quantity and quality, especially in case of small streams in hilly areas, is extensively influenced by soil erosion which also affects surface water and groundwater quality (see Chapter 2).

Integrated municipal water management: requirements and tasks

The water management of municipalities consists basically of drinking water supply, wastewater drainage and rainwater management. Harmonized and simultaneous action in these fields is difficult. While drinking water supply and wastewater collection are legal obligation of the municipality, precipitation management is voluntary (and costs are currently not recovered). Therefore, the development of the infrastructure for rainwater drainage is generally slower, though the frequency of intensive rainfalls and the resulting damages will probably increase as a consequence of climate change. Rainwater runoff from paved surfaces can represent considerable pollutant load (heavy metals, oil derivatives, PAH compounds) for surface waters. Moreover, unexpected but intensive rainfalls might lead to combined sewage overflow (from non-separated wastewater and precipitation collection systems). Effective, scientifically based programmes are required for the development of methods for rainwater drainage, treatment and utilization (e.g. rainwater storage in tanks and stormwater retention ponds, support of drainage by changing the surface coverage, rainwater treatment technologies) and the regulation at the municipality level. Integration of precipitation management in the central and peripheral areas of the municipalities is indispensable.

Water management in small municipalities has specific challenges. The coverage of the public utility systems is mostly moderate and the relative cost is higher due to the lower population density. Concentrated pollution of the groundwater below municipalities (the so-called wastewater lentils) is typical in the absence of piped sewerage. Small streams flowing through the municipalities are frequently used for wastewater drainage. The development of innovative and decentralised wastewater treatment systems is crucially important in these zones.

Urbanization leads to different type of problems. Urban pollution emission is much higher than in rural areas and urban wastewater is a major source of different emerging pollutants (e.g. pharmaceutical residues, household chemicals, personal care products, antibiotic resistant microorganisms). While sewerage reduces diffuse pollution from wastewater, the impact of other diffuse pollution sources is not adequately clarified. The site where treated wastewater reaches the recipient reservoir is characterized by concentrated pollutant emission (see Chapter 2). Aging water distribution and sewerage systems are a nation-wide problem. The development of diagnostics, in situ repair methods and the application of new generation pipe materials support reconstruction. Experience shows that urban construction work might also modify groundwater flow.

Comprehensive problem management calls for an integrated and science-based water management system at the level of municipalities, optimized to the whole hydrological cycle and including drinking water supply, wastewater collection and treatment (and the related sewage sludge management) and rainwater management. Current research directions are aimed at the concept of smart city: relying on innovative technical solutions and adapting continuously. One of the key conceptual elements is the "closure" of matter flux cycles by the local retention and (re)use of rainwater and the produced wastewater (separated to grey, yellow and black water) and the establishment of the technical, public health and legal framework. Sludge becomes energy source and a secondary raw material in this context (e.g. phosphorus retrieval, chemical industry). Innovations for the improvement of energy efficiency and the use of renewable energy are also important elements of this concept. The development of an adaptive and possibly decentralized infrastructure decreases the pressure on natural resources but extensive research is needed in order to provide fully safe services. The barrier to the expansion of novel technologies (e.g. waterless, composting toilets) is often the lack of social acceptance.

Establishment of the coordination of water management and municipal development is a crucial, short term task in line with emerging developments. The harmonized approach and the adequate institutional and regulatory background are currently missing.

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Key research tasks

Adaptation to extreme hydrological regimes

- Development of a monitoring system to track and predict quantitative and qualitative changes of surface waters and groundwaters
- Development of innovative methods for the reliable determination of natural and temporally fluctuating groundwater recharge
- Identification of matter and energy fluxes at river basin level for water management purposes
- Identification of the possible role of traditional floodplain management in reducing the impacts of water damage and supporting sustainable, local economy harmonized with landscape
- Evaluation of long-term storage possibilities of excess volumes of water by regional water management
- Establishment of the scientific basis of large temporal scale sediment management methods and monitoring while considering economic and ecological aspects
- Evaluation risks related to the installation and operation of dams from the aspect of flooding
- Development of models and data collection methods to predict extreme hydrological events (floods, low flows, ice phenomena)

Complex management of excess water and droughts, large scale examination of evaporation

- Establishment of the national soil humidity monitoring system to model and forecast weather, water flow regime and crop cultivation
- Investigation of precipitation recycling by using new research areas and programmes and re-evaluation of archived research data
- Further development of excess water prediction systems to improve adaptation
- Investigation of the relationships between the duration of water coverage and the regeneration capacity of the soil structure in areas with excess water, examination of excess water retention as a possibility for alternative use
- Large scale forecasting of the evaporation rate based upon atmospheric physical variables
- Further development of drought forecast systems and drought monitoring

Efficient water retention

- Complex assessment of water retention methods applicable on rivers (hydropower dams, damming by weirs, reservoirs, traditional floodplain management, etc.) to slow down water flow and increase retention under altered climatic conditions
- Complex investigation of the impacts of retention on water bodies receiving effluent waters

Integrated municipal water management

- Identification of the impacts of sewerage on groundwater (elimination of wastewater lentils, decrease of groundwater level) in the proximity of municipalities
- Possibilities for sludge use as secondary raw material (phosphorus retrieval, raw material for the chemical industry) or for energetic purposes
- Clarification of the impact of water surfaces on urban microclimate
- Evaluation of the possibilities of water and matter retention in urban environment

Technology and innovation

- Developments supporting reconstruction of sewerage systems (diagnostics, in situ repair, pipe materials)
- Development of innovative, energy-saving methods in integrated municipal water management (wastewater separation, local treatment, use and reuse, rainwater use, etc.)

Social, economic and legal aspects

- Assessment of changing the cultivation regime or the introduction of innovative tillage methods as possible solutions for water management
- Assessment and (if needed) development of international and EU-level regulations and institutional systems to support transboundary water management and strengthen the implementation of international agreements for integrating water management at river basin level
- Establishment of the legal, technical and economic framework for the utilization of excess water
- Elaboration of the technical, economic, legal and public health requirements for rainwater retention and use

5. PROTECTION AND RESTORATION OF AQUATIC ECOSYSTEMS

Keywords

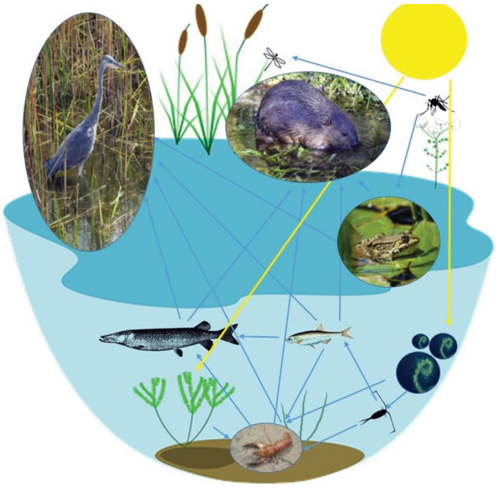
- sustainable aquatic ecosystems, ecosystem services
- unique habitats, unity of water body – littoral – terrestrial zone
- biodiversity, monitoring, ecological status
- stressors and their impact, ecological water demand, changes in water discharge, flow conditions, water temperature, eutrophication, emerging pollutants
- invasive species
- global processes, climate change
- rehabilitation and reconstruction, water recharge, connectivity, recultivation, buffer zones, tourism

Challenges

Need for the characterization and protection of natural aquatic ecosystems, ecosystem services

Optimally functioning and self-regulating ecosystems are indispensable for the preservation of the adequate water quality and for meeting different public demands sustainably. Ecosystem services are the beneficial effects of aquatic ecosystems, for example, the production of atmospheric oxygen by aquatic organisms, the provision of fresh (including drinking) water as a result of the biological cleaning capacity, the mitigation of the impacts of floods and extreme rainfalls, the beneficial influence on microclimate, reducing erosion and nutrient washout, providing food and environment for recreation.

Detailed scientific characterization of the aquatic ecosystems is necessary for their appropriate protection and the long-term and sustainable utilization of the beneficial effects. The application of multidisciplinary tools is indispensable for the characterization of the complex structure and functioning of ecosystems. The identification of the multilevel inter-



actions among the elements of these systems (a variety of living organisms and their physical, chemical and biological environment) calls for the application of methodologies from nearly all scientific fields and the development and application of adequate methods for measurement, data analysis and modelling. The integration of ecosystem services to cost-benefit analyses, impact assessments and regulation is another crucial and unavoidable step.

During the protection and restoration of aquatic habitats particular attention should be paid to the habitats unique at European or global level. The shallow saline lakes of Hungary are an example of such unique habitats, which are highly susceptible to extreme meteorological events and changes of the groundwater table. Temporary water bodies and small streams have similar importance and will probably be increasingly affected by the growing water scarcity due to climate change and the shifts in human water use. Limited knowledge is available about the functioning of the ecosystems in other special habitats (e.g. caves, thermal springs and thermal waters) and the hazards threatening them. Collection of detailed and accurate data on these special communities is an indispensable research task, as well as their continuous ecological monitoring, focusing on the impacts of changing environmental processes.

Investigation of the aquatic ecosystems should also take into account that their status and functionality are strongly influenced by the characteristics of the adjacent terrestrial zones, such as the soil composition, vegetation coverage and land use. Research should be therefore extended to the water body – littoral – terrestrial zone complex.

Monitoring of biodiversity and characterization of ecological status

Diversity of living organisms, i.e. biodiversity, is one of the fundamental characteristics of ecosystems and has crucial role in resilience, the adaptation to environmental changes. One of the earliest indicators of quality deterioration is the reduction of biodiversity and the consequent limited functionality of ecological relationships. Therefore, continuous monitoring of the biodiversity of aquatic habitats is a fundamental task which also supports the ecological classification of water quality.

The WFD requires the simultaneous monitoring of biotic and abiotic elements of water bodies. Comprehensive characterization of the status of aquatic ecosystems requires the detection of the cumulative impact of several factors and pollutants. The analytical methods applied for the description of chemical quality are in themselves insufficient for the characterization of the cumulative impact of various pollutants.

The WFD uses stressor-specific indicators for the characterization of the ecological status, which allows for the detection of deviations from natural status and as well as the identification of their origin. However, further methodical development is necessary for biological indicators relying on specific organism groups. Achieving and sustaining good ecological status of water bodies, which is the fundamental objective of the WFD, was accomplished only for 9% of the surface waters in Hungary.

Stressors and interventions threatening aquatic ecosystems

Aquatic ecosystems might be threatened by a wide range of global or local, focused or diffuse stressors, of natural or (directly and indirectly) anthropogenic origin. The anthropogenic stressors with the highest impact are the industrial, agricultural or communal pressures (see Chapter 2), pollution from land or water transport, water overuse and hydrological interventions (e.g. dams, drainage, inflows of poor quality water). These stressors result in habitat degradation and invasion processes. While most pollutions also hinder human use, some of them threaten the ecological status without having harmful effects on humans (e.g. thermal or saline load of used thermal waters, targeted mosquito control in aquatic habitats). The stressors influence the physical (e.g. temperature, hydrological

and light conditions), chemical (e.g. nutrients, micropollutants, toxins) and biological (e.g. invasive species) environment of aquatic communities simultaneously.

The consequences of these diverse and mostly interrelated processes are only partially and in several cases, scarcely or not at all known. Further research is needed to identify the specific impacts of harmful effects on the ecosystems and to understand the stressor-effect relationships, especially in case of partially characterized pollution pathways (runoff and infiltration from paved roads or railways, deposition from the atmosphere). The identification of the causes is fundamental for pollutants which originate from unknown sources but have perceivable ecological impacts.

Water demand of aquatic ecosystems, impact of changes in water discharge

The availability of water in adequate quantities is indispensable for aquatic ecosystems. The provision of ecological water demand is a prerequisite for sustainable water use (see Chapter 3) requiring the collection of accurate data about the water demand of each specific ecosystem. Any deviation from the optimal level (to positive and negative directions as well) might have severe consequences on aquatic communities.

Inadequate water quantity might result from various processes: water abstractions for agricultural, industrial or drinking water use, agrotechnology and bed morphology interventions or hydrological changes (lowering water level and decreasing flow velocity) caused by extreme mete-

The Szigetköz (Little Rye Island) Cikola, during the diversion of the river Danube orological events becoming more frequent due to climate change. These processes might lead to the transformation and temporary or permanent disappearance of aquatic habitats. Temporary, astatic water bodies, small streams, river branches separated from the main channel are particularly endangered. The harmful consequences of decreasing water surface appear first in the littoral zone.

Excessive water quantities or even inadequate water dynamics – either too frequent fluctuation of high and low flows or its absence – might be potentially dangerous as well. High water level which is maintained artificially of prolonged periods (already demonstrated in Lake Balaton) has significant effect on the planktonic organisms or those living in biofilms or on the sediment surface, as well as the quantitative composition of aquatic plants (extensive reed decay might arise in the littoral zone) and the whole food network. Therefore, the impact of water level regulations should be comprehensively investigated at ecosystem level.

Changes in water discharge influence the concentration of water-soluble substances and sediment and underwater light conditions and these directly affect aquatic primary production. Energetically, aquatic ecosystems rely on primary producers (aquatic plants) therefore their changes have long-term impact on the entire aquatic ecological system. Altered water flow velocity affects the colonization of planktonic organisms (phytoplankton, zooplankton) and the spread of aquatic plants and biofilm-dwelling animals. Furthermore, some fish species need special flow conditions for reproduction. Changes in flow conditions (e.g. river regulation, damming, dredging) interfere with the hydrological processes of the riverbed and the floodplain (for instance, sediment deposition in riverbed zones and lake segments due to the formation and reposition of stagnant zones is frequent). Their impact on aquatic ecosystems should be identified by thorough multidisciplinary investigations.

The ecological consequences inundation for the purpose of flood control and the subsequent remediation process received less attention so far than direct flood damages or preventive measures to avoid flooding of an area. Nevertheless, short- or long-term flood periods also constitute a complex problem affecting groundwater level, nutrient availability, agricultural production, transport of chemical and biological pollution and changes in the aquatic ecosystems. Social, economical and ecological aspects should therefore be assessed simultaneously.

Impact of changes in water temperature

Water temperature, as a physical parameter, has predominant impact on the composition and functioning of aquatic communities, it influences the oxygen balance and the solubility of nutrients and toxic substances. The temperature tolerance of organisms is variable. Further research is necessary to characterize the ecological answers to the thermal load from global and local factors (climate change, discharge of industrial cooling water or used thermal water).

Impact of nutrient load (eutrophication)

Eutrophication is one of the best characterized problems related to water quality. It is linked mainly to the nitrogen and phophorus load from agricultural and communal wastewaters or often from other, poorly characterized pollution pathways (e.g. runoff from urban areas, roads, or washout from the atmosphere) (see Chapter 2). In this process, pollutants support the rapid proliferation of plant biomass as nutrients, leading to decreasing light availability in the water body which is often followed by plant biomass decay and oxygen depletion due to the decomposition processes and, finally, may result in the death of animals. Another harmful consequence is the excessive toxin production caused by the over-proliferation of cyanobacteria which also poses a threat to the human use (drinking water abstraction, recreation) of these waters. Human use is further limited by the unpleasant smell of the water body and its reduced aesthetic value. All of the above effects are influenced by the riverbed morphology and the hydrological conditions (e.g. water flow rate).

Harmful effects of emerging pollutants

The ecological impact of chemical substances from various sources and of diverse chemical properties (implying extremely complex impact) such as heavy metals, pesticides, or emerging pollutants (pharmaceutical residues, endocrine disrupting substances, plastic microparticles, nano-substances) is scarcely or not identified (see Chapter 2). Some of these might have immediate influence on living organisms even in very small quantities. For others, the long-term impacts should be studied.

Pharmaceutical residues might affect animal behaviour, influencing feeding, reproductive success or even protection against predators. Hormones and endocrine disrupting substances might interfere with the growth, reproduction or development of animals. Though their impact is partially characterized on specific organism groups such as zooplankton and fish (for instance, decreased ovule numbers are described for zooplankton and modified genitals, delayed maturation and lower egg number for fish species), but there is no information on the changes of the complex interrelationships within the ecosystem. For several compounds, even the chemical composition of their intermediate degradation products is unknown, therefore, their effect on the aquatic ecosystems is hard to identify.

Microplastics absorb micropollutants on their surface and consequently might have concentrated toxic effect. Due to their small size, microplastics are easily ingested and get into the digestive system of aquatic animals, finally reaching humans through the aquatic food web.

Invasive species: spreading and threats

Spread of non-native species is a biological threat impairing the ecosystems at several levels. Although this might be a natural process, it has recently been accelerating, partly due to anthropogenic effects. The large river systems which were interconnected by channels to develop water transport are “highways” for a variety of living organisms migrating to huge distances from their native habitats. Disturbances of the aquatic habitats might be harmful for or result in the degradation of natural communities which contribute to the rapid colonization by invasive species. Inadequate technical interventions and inappropriate water recharge from foreign river basins are only two examples of the possible actions which support invasion and call for scientific research. The appearance and expansion of non-native animal or plant species might disturb the aquatic food web, might result, in extreme cases, in the extinction of endemic species and may even lead to a number of agricultural, healthcare and economic problems. Therefore, the investigation of biological invasions is gaining importance in current research.

Consequences of global processes

All of the above processes might be aggravated by global trends. The impacts of climate change (extreme meteorological events, changes in water discharge, increasing water temperature, decreasing ice and snow coverage) endanger aquatic ecosystems in multiple ways. The characterization of these complex and interrelated processes shall not be postponed. Further, currently unidentified problems are expected to emerge in the future as the expansion limits of several species are widening due to global warming and the number of non-native, potentially colonizing species is increasing. The appearance of vector organisms (e.g. Asian tiger mosquito) migrating to the north and the emergence of water bird-borne diseases (avian influenza, West Nile fever, etc.) are also expected in Hungary.

Rehabilitation and reconstruction of aquatic ecosystems

The identification and understanding of complex interactions among different organisms and their environment are indispensable not only for the efficient and cost-effective protection and maintenance of functional natural ecosystems, but also for the rehabilitation of deteriorated and destroyed aquatic habitats and the establishment of sustainable artificial systems. The public demand for the restoration of decreasing biodiversity and the reparation of the lost ecosystem functions and services is increasing. The first step of the rehabilitation is often the provision of ecological water demand. When water recharge is needed for the maintenance of an ecological system, besides the questions “how much?” also “from where?” “which composition?” and “at which price?” shall be scientifi-

Reconstruction of Old-Túr at Kölcse village

cally answered. The biological communities are further damaged by the recharge with water of inadequate composition and foreign species might enter the habitat through water transfer. Nevertheless, the maintenance of the connectivity by the establishment of fish ladders, riverbed cuts and ecological corridors shall be a priority for a number of aquatic ecosystems. The (re)introduction of endemic and protected species during rehabilitation and reconstruction (to limit the expansion of invasive species) is only possible if there is sufficient knowledge about their impact on the entire ecosystem.

Rehabilitation shall be planned and realized not only for the water body but also for the littoral zone or even to the whole catchment. The establishment of buffer zones, the modification of land use, creating plant coverage resistant to pollutants and sudden rainfalls might be necessary to fulfil these objectives.

Although habitat rehabilitation is in general strongly supported by the society, the realization of specific projects might affect some of the stakeholders (e.g. farmers) unfavourably. Therefore, public consultation is to be considered during the planning and realization phase. Natural or restored habitats attract high number of tourists but the conditions (limitation of visiting hours and visitor numbers) shall be determined with caution to prevent disturbance.

Key research tasks

Characterization of aquatic ecosystem diversity and functioning

- Assessment of the impact of changing productivity (eutrophication, oligotrophication) on the diversity of aquatic communities and the functioning of aquatic ecosystems
- Development of novel methods for measurement, data analysis and modelling to identify the relationships among biotic and abiotic characteristics (e.g. flow conditions, sediment transport, bed morphology) of rivers and lakes
- Characterization of the ecosystems of aquatic habitats (small streams, drinking water reservoirs, saline waters, caves) and their dependence on climatic changes

Beneficial effects of aquatic ecosystems, ecosystem services

- Comprehensive assessment of ecosystem services of the surface waters in Hungary, specification of quantitative indicators
- Integration of ecosystem services into the cost recovery requirements
- Assessment of the role of the ecosystems of branch systems and floodplains (maintenance of biodiversity, removal and mobilization of nutrients and pollutants) and their dependence on floods
- Investigation of the impact of biota on the sediment balance of rivers and streams
- Investigation of the impact of Kis-Balaton on the water quality of Lake Balaton

Stressors and interventions threatening aquatic ecosystems

- Assessment of the ecological water demand of water-dependent (including groundwater-dependent) and aquatic habitats, ecological research to establish ecological water recharge
- Assessment of the impact of global processes on the biodiversity and functioning of aquatic communities
- Assessment of the impact of the spread of new vector organisms and invasive species in the aquatic ecosystems in Hungary

- Monitoring and modelling the effects of anthropogenic stressors (e.g. agricultural and industrial chemicals, heavy metals, micropollutants, pharmaceutical residues, endocrine disrupting substances, thermal pollution) on aquatic ecosystems
- Identification of the consequences of habitat fragmentation and degradation caused by bed morphological changes (artificial interventions, bed deepening, sediment deposition, change of lateral connectivity)
- Investigation of the impact of the establishment of harbours on water quality, flow conditions, composition of communities and spread of invasive species
- Investigation of the impact of water level fluctuations, high water level, frequent non-seasonal floods on the biota of littoral zones and water bodies
- Assessment of the effect of the absence of winter ice and snow coverage on the functioning of aquatic ecosystems

Rehabilitation and reconstruction of aquatic ecosystems

- Elaboration of the scientific evidence base of programmes aiming at the rehabilitation of aquatic ecosystems

Technology and innovation

- Development and application of ecological fishery management technologies in national fisheries and waters used for fishing. Maximization of fish production while maintaining the functioning of aquatic ecosystems
- Establishment of artificial aquatic ecosystems to manage local wastewater load

Social, economical, legal aspects

- Harmonization of water management with social, ecological and nature protection aspects
- Investigation of the quantitative relationships of the economic advantages and incomes of water-related tourism and water quality, water quantity, the status of aquatic habitats and the water level of water bodies
- Assessment of possibilities of the remediation of economic damages caused by invasive species

6. WATER-RELATED SOCIAL CONFLICTS

Keywords

- social conflicts, water governance
- competing water uses, ecosystem services
- land use, landscape use, full cost recovery
- water crisis, adaptation, embedded water (virtual water)
- water resource law („water law”), legislation, law enforcement
- institutional system
- change in public awareness, state involvement, public involvement
- education, education of professionals, accessible integrated database

Challenges

Water governance

Water-related challenges, even apparently technical or ecological ones, cannot be separated from social problems. The available scientific and technical solutions for the management of challenges typically require extensive resources and significant public commitment. Their applicability thus might be limited by public investment, the regulatory framework or social acceptance. In consequence, successful adaptation to the emerging local, regional or global changes in the future strongly relies on social processes.

Adequate water governance should be based on a comprehensive perspective harmonizing social and environmental issues. Problems related to water shall be managed by mutually supportive adaptive and regulatory instruments. One of the social barriers is that the real extent of water retention and water scarcity problems (as detailed in Chapters 3 and 4) is often not perceived by the stakeholders, while even local water scarcity might affect nature, welfare and even security politics.

Multiple social conflicts emerge from competing and mutually exclusive water uses and the present and prospective limited access to water resources and ecosystem services. The implementation of integrated solu-

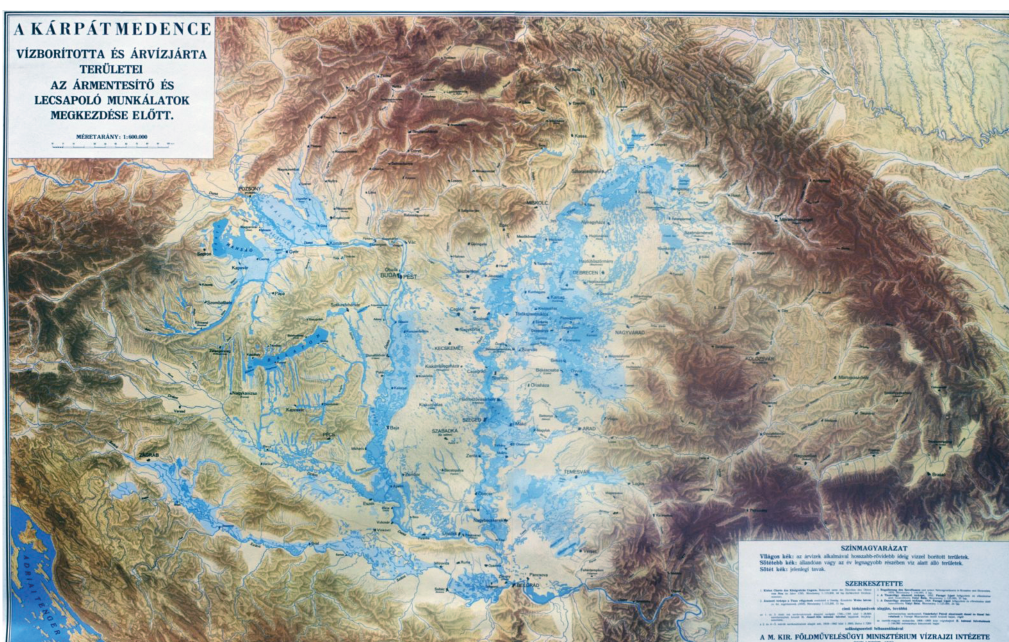
tions based upon ecosystem services shall be definitely more efficient by including a wider range of stakeholders. The expectations (e.g. related to supply safety) often cannot be fulfilled through conventional means due to changes in the demand or the environment. These cases require the adaptation of the entire society or some of its subgroups which is frequently lacking or insufficient. The establishment of an institutional system supporting cooperation, decision-making and control is necessary to implement adaptation and public decision-making.

Harmonization of water and land use based on the actual costs

The evaluation of water regulation activities initiated in the 19th century in Hungary is ambiguous, resulting in conceptual disagreements and economic conflicts of interest in practice. Overcoming these barriers is an essential prerequisite for integrated problem solving. Social science research shall support this objective by identifying historical relationships between landscape use and sustenance (through the investigation of historical documents about the landscape structure and changes in the Carpathian Basin). High level, dynamic harmonization of water and land use might facilitate an increase in the pool of environmental resources. The limited quantity of adequate quality "clean" water for diverse purposes, the significant (and still increasing) uncertainty around its spatial and temporal distribution and the growing and more variable quantitative and qualitative demand call for a conceptual change from water transfer to water storage.

The current distribution practice of water does not reflect the increasingly perceivable quantitative limitations (as identified also during the revision of National River Basin Management Plan) (see Chapter 3). Adaptation with regard to sustainable cumulative water abstraction and gradual redistribution of resources among different uses is necessary to support water uses with more social benefit. In order to ensure cost-saving investments and the decision among alternative ways of exploitation, resources should be distributed – at least in part – by competitive mechanisms. Sustainability and the implementation of interests related to social exploitation shall be considered without violating other basic rights of the stakeholders.

Water use is facilitated jointly by the environment and the built infrastructure systems and thus depends on their status and interactions. Increasing the performance of the infrastructure to maintain (or increase) the current level of use shall be only a temporary solution if the performance of the environment (green infrastructure) decreases. The constant-



Hydrography of the Pannonian basin before river regulation, Ministry of Royal Hungarian Agriculture, Hydrographic Institute, 1938, Budapest

ly growing costs and the changes of external conditions (e.g. increasing consumer demand) further impair performance extension.

Further conflicts arise from the fact that certain costs of sustainable water use (e.g. flood protection) appear only at community level. and the costs related to the limitation of resources or the occasioned environmental load are typically not perceived by the individual water users. Generally, consumers only pay for the operational costs of the infrastructure they use. Therefore, they are not interested in the introduction of more efficient methods of water use and the adaptation possibilities offering mutual advantages are not implemented. One of the key solutions for sustainability is including all actual costs into the decision-making processes about water use. Besides the practical considerations, total cost recovery of water utilities is an explicit obligation of the WFD.

The unperceived but increasing community costs could be reduced by more differentiated land use. In the process of territorial adaptation, land value is not only determined by the economic results of utilization but also by the avoidable emerging community costs (e.g. reduced flood protection costs in areas which are suitable for inundation). The period-dependent pricing of capacity use might offer possibility for differentiation (e.g. use of the excess water drainage system in and outside peak periods of excess water).

The evaluation based on economic parameters (comparison of costs of different solutions, cost distribution among stakeholders of water management, analysis of possible funding sources) is indispensable not only in these examples but also in case of other water management problems discussed in the previous chapters. When certain tasks are not accomplished (e.g. due to the lack of funding), the impact on the entire system should be evaluated (e.g. cost increase and emerging external costs due to the absence or the decreasing frequency of authority clearance or control).

Global and transboundary impacts

The considerably growing human population is one of the most significant global causes of the water crisis, interrelated with religious and ethical issues. Science must closely and efficiently support the development and implementation of action plans for the management of population growth. The impact of global water crisis and the increasing demand for natural resources might be perceived via commerce (e.g. demand for basic food) and population movement in our region as well, although the demographic tendencies point to the opposite direction. Water embedded in different products and services (virtual water) might have significant impact on national water management through international commerce. Distant countries of the world can be considered as common members of a "virtual watershed" – which is essentially the hydrological cycle – in accordance with the concept of virtual water.

Therefore, evaluation and management of transboundary conflicts originating from the global water crisis shall receive regional focus as well. The problem of sustainable population size is closely related to landscape-oriented water management. Long-term and sustainable exploitation of a specific river basin and its natural resources is only possible if the carrying capacity of the territory is taken into consideration. Novel chal-

lenges arising with the technical development such as the expected wide range expansion of robotics and its impact on the labour market should be also evaluated.

Development of legal and institutional systems of water management

Transboundary water management and water protection are especially problematic fields in water law and their evaluation and development shall be continued at international, EU and national level. The country-specific differences of legal documents with regard to the terminology and the calculation methods (e.g. water balance calculation) impair international comparability and cooperation. Several elements of bilateral water management and water protection agreements of Hungary and the adjacent countries are outdated. Development of cooperation to meet the demands and challenges of the 21st century shall be supported by guidelines elaborated by national scientific, government and non-government organizations. Joint use of surface water and groundwater resources need to be more clearly regulated in bi- and multilateral agreements. The institutional structure should also be developed to increase the efficiency of the implementation.

Regulation of transboundary water management and water protection and the resolution of conflicts among the member states are also challenging in EU law and should be managed by deepening this aspect of European integration. Several available documents outline the deficiencies arising during the implementation of the EU water regulation (which is centred around the WFD and the Flood Directive). These documents shall be considered during the development of national legislation and feedback should be given to the EU water regulation as well. Regulation of water management in the Hungarian water law has become confounding. Therefore, a completely new, restructured regulation is necessary which is practice-oriented and based on legal comparison. Novel legal instruments related to the revision of land use and supporting the implementation efficiency of landscape-oriented water management should receive more attention during this process.

Consistent and operational institutional systems, capable for adaption to the changing external factors (both at the level of organization and execution) are indispensable for the predictable performance of a society. The current national institutional system of water management has primarily technical perspective and operates by central planning due to both its historical background of development and its current tasks. The management of unresolved social problems related to water (illegal water use, reconstruction of the aged, inadequate infrastructure, pricing, transboundary impacts) calls for new perspectives and solutions at institutional, regulatory and organizational level.

Solving the problems related to water (and water management in general) requires cooperation among the stakeholders. The integration of water, land and landscape management policies with interrelated criteria is essential. However, this is not entirely supported by the current institutional system of the Hungarian water policy. The institutional structure is very complex and the roles are ambiguous, impairing coordination among the stakeholders. Deficiencies in the execution are more frequent than in the regulation, especially in case of the legal provisions resulting in significant conflicts of interest (e.g. illegal water abstraction, quantitative exploitation limits, appropriate use of excess water drainage systems). Lack of funding for the execution of several professionally relevant tasks is rather the consequence than the root of this situation.

The most important question is the concept and extent of state involvement where paradigm shift is necessary from the traditions of the national water management institutional system. Decentralized, multi-player use of resources and establishment of cooperation at the community level (including supportive regulation and the identification of prerequisites) should receive emphasis in water management especially where problem solving through centralized control is ineffective. The state can participate in different roles in these processes, e.g. both as an owner (exclusive owner in case of groundwater) and as an authority.

Although active public involvement is a strategic objective, public consultation is mostly limited to dissemination and feedback on already developed action plans. This practice is insufficient for resolving social conflicts. The more efficient integration of the results of scientific research and the experiences of international processes into the everyday practice of water management has key importance.

Education and perception formation

Efficient public perception formation and scientific information sharing require carefully selected, differentiated channels in line with the age, social environment and education level of the target groups. As the number of people growing up in urban environment is increasing due to urbanization, entire generations lack sufficient knowledge about the diversity and vulnerability of natural waters. Similarly, scientific, technical, legal and economic aspects of sustainable water use are not or scarcely known. The role of public education should be increased in sharing water related knowledge, starting from raising awareness of (economic) water use in kindergarden and primary school. The task requires the development of age-appropriate education materials.

Neither the operative tasks of water management nor state-of-the-art water research are possible without a sufficient number of professionals with relevant and high-quality knowledge. There is an urgent need to scientifically evaluate data on the lack of experts and knowledge in certain areas and the current situation and deficiencies of training. These data are indispensable for increasing the level and efficiency of higher education. Cooperation and information exchange should be strengthened among educational institutions, research centres and different field professionals. The integrated and multidisciplinary solution of water-related problems and research tasks is not possible without the continuous education of experts and communication among different professional areas.

The establishment of an open access and integrated hydrological database, in line with one of the key recommendations of the Water Science Programme, is yet another indispensable prerequisite. Efficient scientific support of operative water management – including integrated hydrographic data systems required by operative water management and research on technology development – is currently not solved. The effectiveness of the hydrological database use was lost as a result of institutional fragmentation. Climate change has strong impact on the hydrological cycle and beyond posing novel challenges to Hungarian water and meteorological services, is also offering closer cooperation possibilities. The basic issue of providing access to data in public interest for research and operative practice should be resolved on the legal regulatory level. Restructuring the data sources of water management should provide the basis of compatibility in data policy on EU level.

Key research tasks

Water governance, water and land use harmonization and consideration of real costs

- Identification of barriers for the resolution of long-term, national water conflicts by social sciences
- Identification of the changes in landscape structure to increase ecosystem services
- Elaboration of methods and cost analysis for sustainable landscape management (floodplain management, traditional floodplain management)
- Development of adequate water governance in Hungary
- Elaboration of impact prediction methods for programmes with complex water and land use interventions
- Method development for comparative calculation of the economic added value of water use (while considering water resource and use types, water resource classification based on the WFD and geographical location)
- Identification of community investments for integrated water management at landscape level
- Evaluation of historical landscape use and territorial adaptation, preparation of regional water conflict maps

Global and transboundary impacts

- Renegotiation of the bilateral water management and water protection agreements between Hungary and the neighbouring countries
- Establishment of the legal/economic framework for efficient representation of national interests in environmental protection and water management in line with Hungary's downstream character, identification of obligations and conflicts of interest with respect to other adjacent downstream countries
- Model development to evaluate the impacts of the use of embedded (virtual) water on water management and land use
- International increase of the standardization in water management and water protection (terminology, calculation methods, etc.)
- Establishment and development of institutions supporting collective, multinational use of surface water and groundwater resources

Development of the legal and institutional framework of water management

- Development of the legal provisions of the WFD to facilitate achieving the goals of the EU water strategy, identification and elimination of the deficiencies in the regulation and law enforcement during the implementation in Hungary
- Identification of qualitative and quantitative, water-related impacts of agricultural production and land use caused by the agricultural subvention system and market processes
- Identification of novel legal, administrative, economic and financial measures to support water retention inside the country's boundaries
- Evaluation and reformulation (if needed) of the sustainability of current objectives of the expansion of agricultural production
- Establishment of the framework and content of an efficient and continuously developing water policy
- Identification of state and local community involvement to support the resolution of specific challenges related to water and increase the efficiency of the public and private institutional structure

Education and perception formulation

- Utilization of scientific results and experiences of the practice in elementary, secondary and higher education and perception formulation of the public
- Identification of direct application possibilities of novel research results in water-related operative practice

Annexes

Annex 1
Priority areas of international programmes

Strategic Research and Innovation Agenda of the Water Joint Programming Initiative of the European Union

Maintaining ecosystem sustainability
Developing safe water systems for the citizens
Promoting competitiveness in the water industry
Implementing a water-wise bio-based economy
Closing the water cycle gap (while considering the entire water cycle)
http://www.waterjpi.eu/images/documents/Water%20JPI%20SRIA%200%205.pdf

National Water Program Research Strategy

Healthy watersheds and coastal waters
Safe drinking water
Sustainable water infrastructure
Water security (quantitative and qualitative)
https://www.epa.gov/sites/production/files/2015-04/documents/strategy-report-2009.pdf

Water Research Pillar – Research Priorities 2014–2016 of Irish EPA's 2014–2020 Research Programme

Safe water
Ecosystem services and sustainability
Innovative water technologies
Understanding, managing and conserving our water resources
Emerging and cross-cutting issues
http://www.epa.ie/pubs/reports/research/eparesearchstrategy2014-2020/workshopsdiscussiondocuments/water/EPA%20Research%20Programme%202014-2020%20-%20EPA%20Water%20Research%20Priorities%202014-2016.pdf

White Paper – Priority Research Fields of the German Water Science Alliance

Challenges Emerging from Global and Climate Change: Food and Water, Mega-Urbanisation, Risk and Vulnerability
Managing water beyond integrated water resources management: Target Setting, Instrument Choice and Governance

Understanding Matter Fluxes at the Catchment Scale – Safeguarding Our Health and the Environment
New Approaches to Observation, Exploration and Data Assimilation in Water Research
A Community Effort Towards Model Development and Data Integration for Water Science
Water scarcity: new perspectives for a circum-mediterranean research case
http://www.ufz.de/export/data/407/34050_WhitePaper_FINAL_web.pdf

Water Research Strategy of New Zealand

Understanding, valuing and managing water resources, including the life-supporting capacity of aquatic ecosystems
Monitoring systems to track progress towards outcomes
Management at the enterprise and catchment scale
http://gdsindexnz.org/wp-content/uploads/2015/10/Water-Research-Strategy.pdf
http://gdsindexnz.org/wp-content/uploads/2015/10/Water-Research-Strategy.pdf

Annex 2.
Online water science questionnaire

Dear Respondent!
Thank you for filling in this questionnaire and your contribution to the success of the National Water Programme. This survey is aiming at the identification of a wide range water-related problems and knowledge gaps to which professionals are facing in the practice. All water-related aspects might be important in this survey ranging from water safety, water quality and water-related infrastructure to ecological aspects, different types of water use and water diplomacy.

This survey supports the definition of the direction of the national water research for the coming years. The answers contribute to the formulation of the Hungarian Water Programme constituting the scientific background of the strategic goals of the National Water Strategy (Kvassay Jenő Plan).

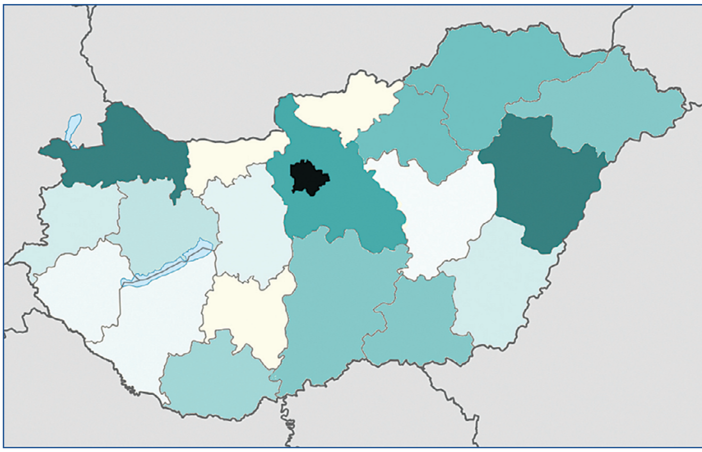
1. Name (optional)	
Age (optional)	
	25 under
	26–35
	36–45
	46–55
	56–65
	65 above
Education (optional)	
	Primary school
	Secondary school
	Higher professional training
	College, BSc, BA
	University, MSc, MA
	PhD or equivalent
	Doctor of Sciences

	2. Type of institution/organization
	Government institute
	Government agency
	University
	Research institute
	Private company
	Public utility
	Scientific association
	Non-government organization
	Individual respondent
	Other (please specify):
	3. Name of institution/organization:**
	3. Name of institution/organization:*
	5. Position
	Management (e.g. head of department, chair, director, etc.)
	Employee
	Student
	Self-employed
	Volunteer
	Other (retired, etc.)
	6. Areas of expertise (more than one might be indicated)*:
	Agriculture
	Aquaculture
	Climate change
	Community development
	Drinking water

	Education
	Emergency response
	Energy
	Flood and excess inland water management
	Forestry
	Groundwater quality
	Groundwater use and abstraction
	Hazardous emission
	Hydroecology
	Industrial water use
	Landscape management
	Law
	Meteorology
	Mineral, thermal and therapeutic waters
	Precipitation management
	Regulation
	Social aspects
	Sociology
	Surface water quality
	Surface water use
	Tourism, recreation
	Transboundary water
	Urban water management
	Wastewater
	Water analysis
	Water infrastructure

	Water retention
	Water reuse
	Water transportation
	Waterborne diseases
	Other (please specify)
7. Please, describe briefly the most important problems and questions related to the themes outlined below which shall be addressed by the national water research (six sections, maximum 500 characters):	
1.	**Safe drinking water** (drinking water safety, access to drinking water, innovative technologies, hygiene)
2.	**Water quality** (surface water and groundwater quality, factors influencing water quality, vulnerable groundwater resources)
3.	**Sustainable water use** (efficient water use, sustainable water abstraction, management of water scarcity, water use for tourism and recreation, industrial and agricultural water use, water transport)
4.	**Water management** (water resource management, remediation of water damages, water exploitation, integrated water management, municipal water management)
5.	**Protection and restoration of aquatic habitats and ecosystems**
6.	**Adaptation to water cycle-related global changes** (extreme meteorological events, climate change, urbanization)
8. Is (are) there any other topic (s) not covered by the above mentioned categories but is (are) important for water research? (maximum 300 characters)	
9. Do you have any other comments or proposals? (maximum 300 characters)	

Annex 3
Distribution of the institutions covered by the online water research questionnaire by location and type



County	Number of institutions
Budapest	106
Győr-Moson-Sopron	22
Hajdú-Bihar	22
Pest	16
Borsod-Abaúj-Zemplén	14
Heves	14
Bács-Kiskun	13
Csongrád	13
Szabolcs-Szatmár-Bereg	13
Baranya	12
Veszprém	11
Békés	10
Vas	10
Fejér	9
Somogy	8
Zala	8
Jász-Nagykun-Szolnok	6
Komárom-Esztergom	4
Nógrád	4
Tolna	4

Figure 1. Distribution of institutions participating in water research management among counties

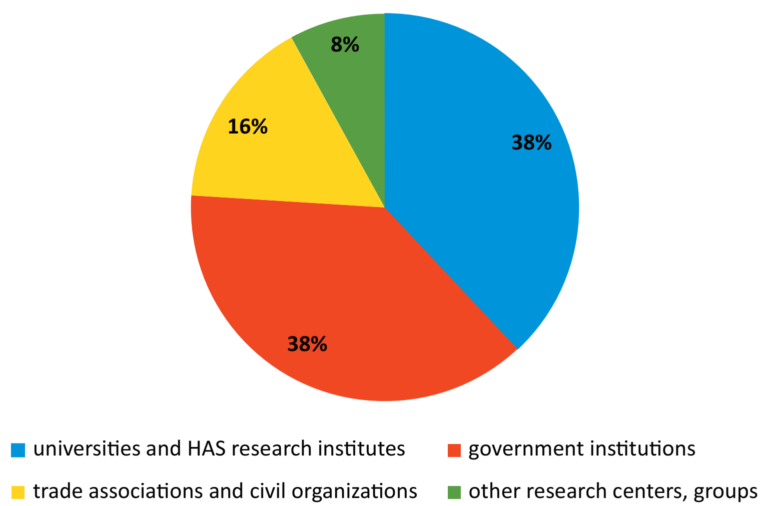


Figure 2. Distribution of the institutions by type (HAS: Hungarian Academy of Sciences)

Annex 4
Distribution of the respondents of the water science survey

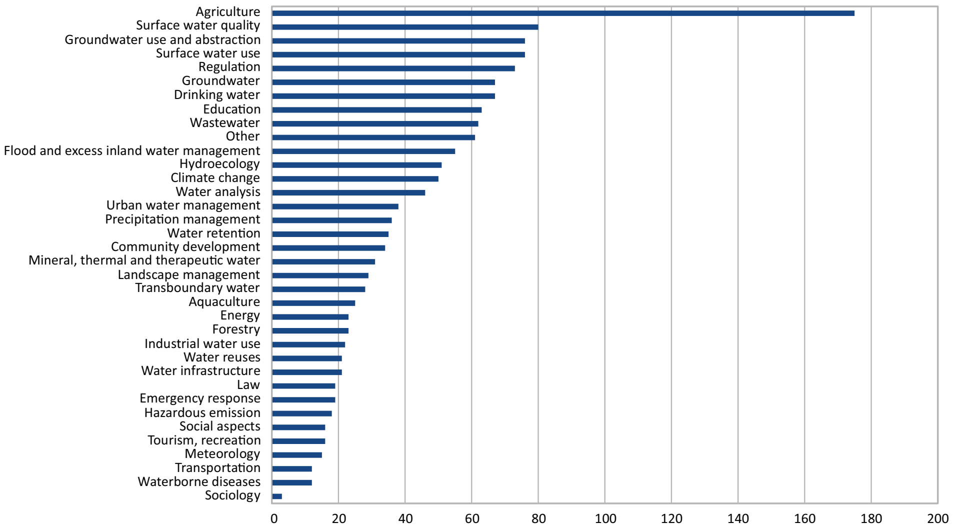


Figure 1. Distribution of the respondents by area of expertise

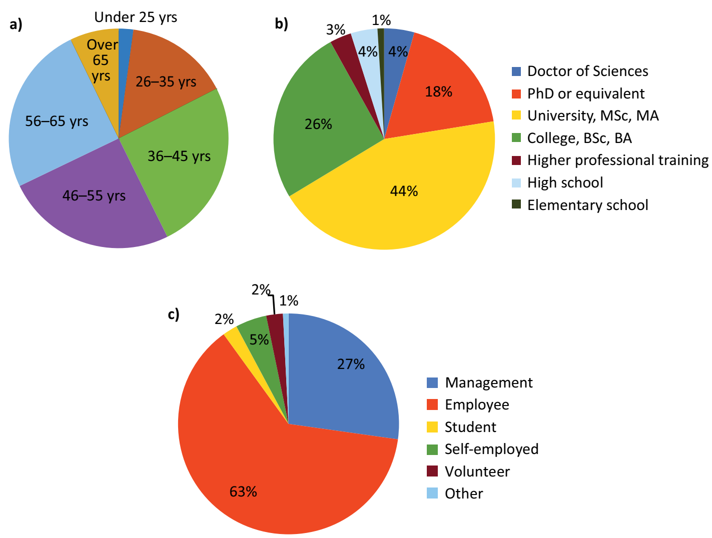


Figure 2. Distribution of the respondents by a) age b) education c) position

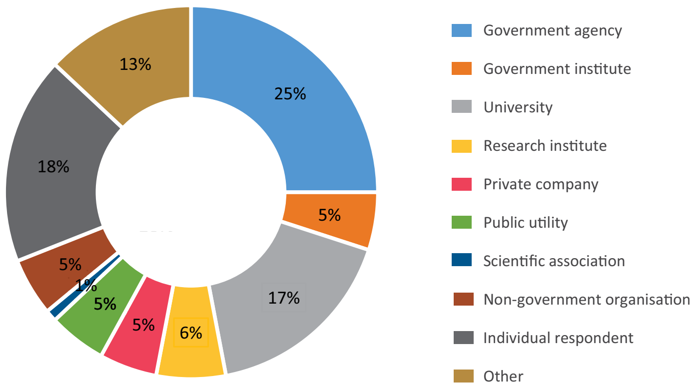


Figure 3. Distribution of the respondents by type of institution

Annex 5
Distribution of the answers and topics

Safe drinking water: Most of the answers and proposals focused on the detection and elimination of pharmaceutical residues, endocrine disrupting substances and other organic or inorganic micropollutants. Strengthening of the protection of drinking water resources, development of drinking water treatment technologies and reconstruction of drinking water distribution systems received emphasis to manage the quality problems of drinking water due to raw water quality and water deterioration in the distribution system. Several proposals focused to the examination of the possibility of household water supply (water for other household uses, not reaching drinking water quality).

Water quality: Most of the questions related to water quality targeted the identification and elimination of the impact of pollution sources (mainly wastewater, agriculture, polluted areas and industrial activities). Technology development of water quality monitoring methods and removal of pollutants (mostly wastewater treatment technologies) were in focus as well.

MTA helyett HAS

vagy

“univ. and MTA” helyett academic

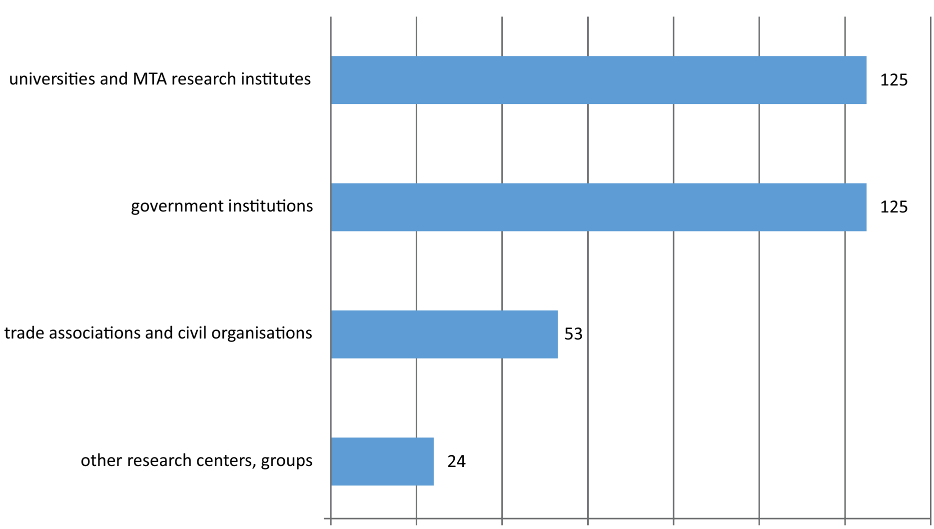


Figure 1. Distribution of the answers and topics

Sustainable water use: Most of the proposals focused on the strengthening of reuse (rainwater and wastewater reuse). Irrigation (with diverse perspectives) and sustainable (energetic and recreational) use of thermal waters received emphasis as well. The importance of economic and efficient water use was highlighted by most of the respondents.

Water management: Water retention and extension of retained water management (floods, excess water) were the most frequent proposals including the introduction of new approaches in flood protection. The need for integrated municipal and territorial water management was also highlighted.

Protection and restoration of aquatic habitats and ecosystems: There were less specific proposals regarding the protection of aquatic ecosystems although the importance of this question was emphasized by most of the respondents. The elimination of pollution sources and the collection of more accurate knowledge and the protection of specific habitats (e.g. saline lakes, wetlands, backwaters) were frequently mentioned. The quantification of ecosystem services was also mentioned by a number of respondents.

Adaptation to global changes related to the hydrological cycle: The answers focused nearly exclusively on the impacts of climate change and highlighted the importance of increasing the preparedness for extreme hydrological regimes, modelling and forecasting. The current research tasks and problems, the need for the education of professionals, and the strengthening of public awareness were often mentioned issues. The stability and transparency of the institutional system and the regulatory background is a prerequisite in the solution of water-related problems.

Topics listed in the answers by priority areas

1. Safe drinking water
Algal toxins
Alternative water resources
Antibiotics resistance
Arsenic, iron, lead, iodine, fluorine
Status of the distribution system, asbestos and lead pipes
Health impact
Individual water supply systems
Rainwater use
Quality and quantity of surface water and groundwater sources
Disinfection by-products
Springwater quality
Pharmaceutical residues, endocrine disrupting substances, organic micropollutants
Household water (including fire hydrant water)
Increasing efficiency in drinking water production
Development of in situ assays
Hydromorphological effects (dams, river regulation, riverbed deepening, filtration layer for bank filtration)
Innovative water treatment methods (more effective elimination of pollutants, reducing water loss, avoidance of remineralization, ferrate water treatment technology, alternative disinfectants)
Reconstruction of drinking water distribution systems
Negligent use of drinking water, quantitative questions
Drinking water strategy
Reconstruction of drinking water technology
Drinking water safety
Drinking water security
Drinking water treatment
Drinking water quality
Overview of the results of the Drinking Water Improvement Programme
Epidemiological risk
Good practices
Increase of karst water level (Transdanubian region/Dunántúl)
Development of the monitoring of individual small-scale water supplies
Cost recovery
Closure of public wells
Re-contamination of wells
Access to drinking water in distant areas
Private wells
Secondary pollution, water quality deterioration in the distribution system
Mechanical water treatment
Affordability
Heavy metals
Prediction of changes in raw water quality
Ecotoxicological methods
Quality of bottled water
Thermal drinking water
Novel pipe materials
Water resource protection
Right to water and sanitation
Increasing the transparency of water utility regulation
Water treatment technologies
Simultaneous management of water quality and quantity
Household water treatment devices

2. Water quality
Development of analytical methods
Mining (gravel mine, waters in abandoned mines, karst deposition)
Rainfall event (combined sewage overflow)
Impact of zones lacking drainage

Impact of water runoff and drainage
Estimation of diffuse load by modelling
Individual small-scale wastewater treatment
Harmonization of emission and immission limit values
Emission inventories
Eutrophication
Relationship of surface water and groundwater resources
Pharmaceutical residues and hormones in surface waters
Transboundary waters, transboundary pollution
Exploitation and disposal of waste
Illegal wastewater discharge
Industrial pollution and emissions
Pollution endangering karst waters
Increase of karst water level
Quality of small streams
Originated from runoff
Atmospheric deposition
Pollution of agricultural origin
Monitoring of micropollutants
Strengthening of monitoring
Nitrate
Overview of nitrate sensitive classification
Nitrate formation
Ecotoxicological methods
Pesticides
Polluted zones
Decomposition of pollutants
Pollution sources (wastewater, industrial pollution, agriculture, waste dumping sites)
Identification of pollution sources
Wastewater
Wastewater as secondary raw material source
Monitoring of irrigation by wastewater
Development of wastewater treatment (new technology, quaternary wastewater treatment)
Synergistic effects
Greywaters
Elimination of soil pollution
Nutrient load
Nature-friendly sludge use
Natural wastewater treatment
Desiccation of treated wastewater or discharge to open reservoir
Impacts of urban areas
Dissolution of pollution from sediment
Decrease of chemical load
Maximum tolerable load of waters (emission)
River basin-specific pollutants
Ecological evaluation of water quality
Accessibility of water quality data
Development of water quality remediation methods in case of water damage
Overview of water quality parameters

3. Sustainable water use

Impact of climate change to water resources
Modification of water abstraction due to climate change
Separated wastewater collection (grey and black)
Forestry (role of forests in water retention)
Data requirement of groundwater models
Renewal of groundwater resources
Sustainability
Preservation of fossile water resources
Microbiological diversity of thermal and bathing waters
Geothermal energy
Therapeutic components of medicinal waters, medicinal water management
Impact of fishing lakes/aquaculture
Exploitation, storage and artificial recharge of used thermal water

Reuse of used waters
More effective water use
Water use (Homokhátság)
Long-term water resource forecasts
Cooling water
Illegal water uses
Resource storage
Reduction of emission, local treatment
Local use of treated water (wastewater)
Renewable energy sources in water abstraction
Water management in agriculture
Change of cultivation type
Rational water use
Ecology or fishing
Ecological water use
Ecological water flow volumes (limitation of water abstraction)
Questions of irrigation (development vs. dry cultivation)
Analysis of accessible resources
Reduction of wastewater quantity
Greywaters
Economic (household) water use
Soil water retention capacity
Soil protection
Soil protection to reduce load
Recharge of groundwater resources
Groundwater monitoring
Decrease of groundwater level (Homokhátság)
Sustainable use of thermal waters
Soil degradation and erosion
Reuse of treated wastewater
Prevention and limitation of overuse
Regulation and control of touristic water use
Reuse in industries of high water demand
Energy use of hydropower
Water transport and its development
Prediction of water demand
Aquatic sports – pros and cons
Decrease of water resources
Distribution of water resources
Quantitative monitoring of changes in water resources
Mapping of water resources
Regulation of water resources
Impact of water abstraction to water resources
Water-wise agriculture
Reduction of water loss
Storm water retention ponds

4. Water management
Floodplain management
Flood retention
Flood forecasting systems
Re-evaluation of flood protections
Flood protection infrastructure (increase of lifespan, reconstruction, prediction of breakdown)
Excess water drainage, complex management of excess water and droughts
Excess water management
Precipitation management
Rainwater use
Rainwater retention
Drainage system (irrigation, excess water drainage)
Water regulation in hilly areas
Elaboration of prediction systems/pilot projects
Subsurface storage
Traditional floodplain management
Gradual evaporation
Damming of rivers by weirs
Transboundary waters
Prediction of emergency situations
Local water management
Meteorological damages
Integrated water management
Intersectoral cooperation
Ice damages
Climate adaptation
Riverbed deepening

Harmonization of technical and ecological perspectives
Meteorological data
Modelling, elaboration of new methodologies
Sustainable urban water management
Bed management at high flows
International cooperation
Rational landscape use
Evaporation research
Preventive protection
Management possibilities of extreme situations in the hydrological regime (adaptation)
Development of sewerage
Change of landscape use
Municipal rainwater drainage
Geoinformatics in hydrology
Territorial water retention
New hydrographic measurement methods
Impacts of urbanization
Flash floods
Water drainage, drainage infrastructure
Development of water management (paradigm shift)
Integration of water management
Water management or community development
Water regime modelling
Water damage remediation
Modelling of the renewal of water resources
Water storage, damming
Water recharge
Water retention (floods, excess water, rainwater, etc.)

5. Restoration and protection of aquatic habitats and ecosystems

Anthropogenic pollution (industry, wastewater, agriculture, chemical use)
Floodplains
Water pollution after floods
Water recharge of Lake Balaton
Waters in caves
Biodiversity monitoring
Habitat rehabilitation
Characterization of living communities
Stress assessment of sensitive areas
Eutrophication
Groundwater-dependent ecosystems
Backwater reconnection
Pharmaceutical residues
Aquaculture
Limitations of fishing and fishery
Characterization of the fish fauna
Fish ladders
Transfer of used thermal waters
Backwaters
Areas with temporary water coverage
Invasion (causes, invasive species, Harbours
Identification of small streams
Problems of small streams and backwaters (temporary water flow, load, sediment deposition)
Climate change (astatic water regime, increasing water temperature, water scarcity)
Connectivity
Wetlands
Bed changes and regulations
Establishment of ecological artificial water bodies
Reed communities, riparian vegetation
International impacts
Assessment of ecological status, monitoring of the changes
Harmonization of ecological and water management aspects
Ecological water resource management
Determination of ecological water demand
Ecosystem services

Buffer zones (protective zone, floodplain forests)
Impact of pollutants to the ecosystem
Saline lakes
Mosquito control
Groundwater
Natural water cleaning, role of ecosystems in water cleaning
Tourism
Protected and endangered species
Vectors (mosquitos, water birds)
Repopulation
Water inflow
Characterization of aquatic habitats
Increase of water surfaces
Biological changes following water management interventions
Water effects needed for the conservation of water-related habitats

6. Adaptation to global changes related to the water cycle

Database
Fragmentation of fields and roles in water management
Permanent regulatory framework
Transparent regulation
Predictable, effective and strict authority behaviour
Financing
Economical calculations
Transboundary effects
Impact assessment
Institutional system
Emission control
Complex perspective
Cost distribution
Lack of common public vision
Strengthening of monitoring
Quantification of ecosystem services
Calculation of ecosystem value
Regulation and implementation
Availability and ongoing education of professionals
Harmonization of perspectives, resolution of social conflicts
Polluter pays
Landscape management pilot programmes
Social demand
Increase of social resilience
Social and public awareness
Raising public awareness, perspective formation, environmental education
Foundation of measures in social and economic policy
Water footprint of products (virtual water)
Strengthening consciousness, public education, education, perspective formation, environmental education
Water resource management (current and future)
Water policy, water law, water governance
Green infrastructure