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Water management

URN: 0156-559927108

This is a translation of the following entry:

Sommerhäuser, Mario; Stemplewski, Jochen (2018): Wasserwirtschaft. In: ARL – Akademie für Raumforschung und Landesplanung (Hrsg.): Handwörterbuch der Stadt- und Raumentwicklung. Hannover, 2867-2881.

The original version can be accessed here:
urn:nbn:de:0156-55992710

Typesetting and layout: ProLinguo GmbH
Translation and proofreading: ProLinguo GmbH

Recommended citation:
Sommerhäuser, Mario; Stemplewski, Jochen (2018): Water management.
https://nbn-resolving.org/urn:nbn:de:0156-559927108.

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Water management

Contents

The objective of water management planning is to maximise the availability of regional water resources to meet the usage requirements of individuals and of society as a whole and to provide effective sewage treatment, flood protection, and groundwater management. The guiding principle of water management is preserving water resources while taking the natural water cycle into consideration. This article lays out the legal framework, the urban water management infrastructure, town and country planning aspects, and future areas for action.

1 Hydraulic engineering and water management – the foundational impetus for civilisations

Water management ▷ *Infrastructure* has been an essential foundation of civilisation since the very beginnings of human settlements. This is reflected in the use of the term *hydraulic civilisations* to describe the early advanced civilisations of Mesopotamia, Egypt, India, and China. Systematic, large-scale flood control and irrigation measures were required before the extensive and fertile river plains of the Tigris and Euphrates, the Nile, Indus, Yellow, and Yangtze rivers could host human settlements.

Systematic interventions at such scales required the formation of highly organised, supra-local societies at an early stage; these were the precursors of the first political state structures. Extant structures still bear witness to their impressive technical accomplishments today. Examples include the Jawa reservoir system in Jordan (over 5000 years old), the clay water pipes of Mohenjo Daro in the Indus valley (2500 BCE), the river dykes in nearly uninterrupted use in China for 4000 years, and even older river diversion and navigation channels on the Nile. However, their great civilisational achievement was actually the written codification of obligations involved in constructing and operating these, and the legally regulated distribution of water for irrigation. The organisation and administration of water management systems required written laws, centrally governed states, political elites (civil servants), and standing armies for defence. It would thus seem to be no exaggeration to equate the invention of water management with the historical beginnings of state structures (Stemplewski 2012).

2 Purpose, scope, and legal bases of water management

2.1 Definition, objectives, and agencies of water management

In Germany, the term *water management* is generally defined as the 'systematic regulation of all human interventions affecting surface water and groundwater' (DIN 4049). The objective of water management planning is to maximise the availability of regional water resources to meet the usage requirements of individuals and of society as a whole. At the same time, it aims to prevent damage due to water-related forces of nature as much as possible. The guiding principle of water management is the preservation of water resources – both qualitatively (its quality as found in nature) and quantitatively – because of their importance for the balance of nature, the needs of future generations, and the development of bodies of water as habitats for animals and plants, i.e. ▷ *Sustainability*.

How water management can contribute to protecting the climate (▷ *Climate protection*) and adapting to climate change (▷ *Climate, climate change*; ▷ *Adapting to climate change*) is particularly important, e.g. for supplying renewable energy, binding CO_2 in semi-natural bodies of water and wetlands, or using water to improve urban microclimates. When there are competing objectives (e.g. hydropower vs. renaturalisation and free flow), a careful ▷ *Weighing of interests*, and a holistic ecological assessment are called for.

Table 1: Water management remits, planning objectives, and measures

Remits	Planning objectives	Measures and technical facilities
Water supply	Meeting the drinking water and process water needs of the population, public institutions, industry, and agriculture	Facilities for water abstraction, treatment and storage; pumping stations and pipe networks; water protection areas
Irrigation and drainage	Site and soil improvements to protect and increase agriculture and forestry yields; polder drainage	Abstraction, transport, and distribution facilities, drainage, receiving waters, sluices, pumping stations
Flood protection	Protection of settlements, farmland, and transport routes	Reservoirs, flood control basins, dykes, stream improvements, floodways and flood channels, flood prediction and warning services, flood risk management
Coastal protection and flood defence	Protecting coastal areas against storm surges	Construction, reinforcement, and shortening of dykes; land reclamation; damming estuaries in tidal zones
Water pollution prevention and wastewater disposal	Preventing or limiting pollution	Local drainage, municipal and industrial wastewater treatment plants, rainwater treatment; raising seasonal low-water levels

Remits	Planning objectives	Measures and technical facilities
Landscape and nature protection	Preserving waterbodies as characteristic features of the landscape; safeguarding their natural functions; developing them according to the principles of the EU's Water Framework Directive to achieve a good ecological status	Development and maintenance of waters according to the principles of semi-natural hydraulic engineering; ecological improvements or renaturalisation aimed at achieving principles-based development goals
Hydropower	Generating electricity and using hydropower to drive machinery (e.g. water mills); storing electrical energy	Run-of-the-river power stations with dams and weirs, hydroelectric power plants with reservoirs, transfers, pumped-storage power plants
Inland navigation	Commercial shipping on rivers and canals	Developing and damming rivers including port, quay, and lock facilities; constructing artificial waterways; transferring water to fill canals
Aquatic leisure and recreation	Preserving and improving ways to use bodies of water for bathing, water sports, angling, and other recreational activities on and in the water	Damming for additional water and shore areas, river engineering measures, water pollution prevention measures, constructing and developing artificial lakes

Source: Jacobitz 2000 (edited)

Water management planners draw on findings from hydrology, hydrogeology, and meteorology when characterising water resources. They use statistical and stochastic methods, while their assessments of management activities are based on cost-benefit calculations or utility analyses. Hydraulic engineering works (reservoirs, river and coastal dykes, navigation channels, sewers and sewage treatment plants, water extraction and processing facilities, etc.) are designed and dimensioned according to hydraulic and soil mechanics calculations (Lecher/Lühr/Zanke 2015).

The construction and operation of such facilities is, depending on their importance, the province of the national, state, or local government or private companies. In many cases, the responsible agencies are water and soil boards, special-purpose associations, or water boards with special legal status.

2.2 The resource: hydrology and the water cycle

While most of the water on Earth is permanently bound in the oceans and deep underground, the water accessible for human use is in a constant cycle of motion and change: evaporation – precipitation – runoff – evaporation. Solar radiation provides the energy needed to maintain this cycle; it evaporates water from land and ocean areas and, through spatial and temporal temperature differences that drive winds, transports water vapour over great distances.

The vast majority of Earth's water is salt water in the oceans (97.2%). Fresh water accounts for only 0.65%. However, only 0.3% of that fresh water, some 38,000 billion m^3, is accessible for human use. In the long run, though, this fresh water reservoir is replenished again and again.

2.3 Uses and functions of bodies of water

The aim of water management planning is to balance competing usage demands while safeguarding bodies of water as part of the natural environment. The following functions of bodies of water beyond the traditional range of uses must therefore be considered, as in the classification by Thurn (1986).

- Supply functions: Water is used directly for consumption or food production, as a raw material, or as an auxiliary production material; here the drinking water supply is quantitatively the least significant but is absolutely vital, with the greatest need for protection. The energy function, harnessing and converting water's potential and kinetic energy, also counts indirectly as one of the supply functions.
- Disposal functions: Water's ability to dissolve and dilute is used to absorb and remove undesirable (waste) materials from people's immediate vicinity. Disposal also includes discharging surplus volumes of natural water.
- Cooling and extinguishing functions exploit water's thermal inertia, e.g. in thermal power plants.
- Transport functions (including ▹ *Inland navigation*): Large surface bodies of water are used as transport routes.
- Recreational functions: People make use of leisure opportunities provided by surface bodies of water, such as swimming, angling, sailing, surfing, boating, and enjoying the natural setting of the aquatic landscape.
- Habitat functions for flora and fauna: Surface bodies of water are biotopes (▹ *Biotope*) that are generally known for their particularly high degree of biodiversity. However, they are also highly sensitive to environmental changes and thus in great need of protection.
- Sustenance function: Regardless of their habitat, all plants and animals – as well as human beings – depend on local water resources as a solvent for nutrients and as a basic component of their bodies.

- Climate stabilisation functions: Leaving aside the role of the world's oceans in the global climate, inland waters and ▹ *Groundwater* (via soil water content) have a significant influence on regional and local climate by moderating temperature fluctuations and slowing winds through evaporation and their ability to store heat.
- Landscape functions: Bodies of water are a component and a defining feature of a landscape's distinctiveness, making them worthy of protection in their own right (▹ *Landscape*).

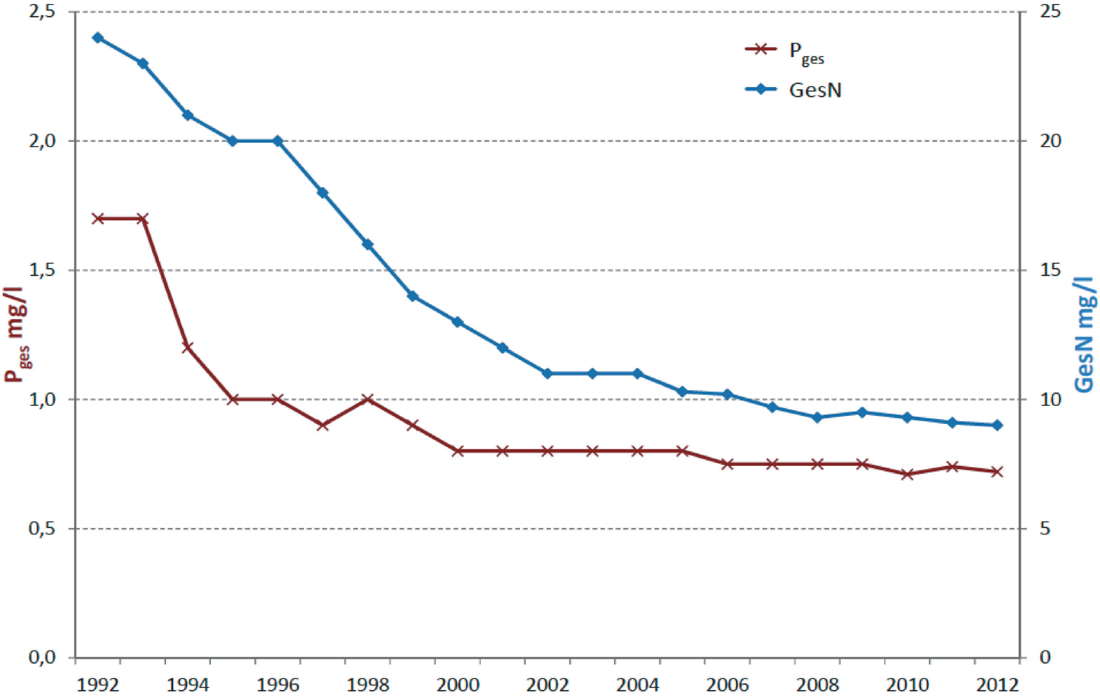
2.4 Water pollution and pollution control

Pressures resulting from water use in industrialised societies lead to pollution from point sources (e.g. wastewater discharge and rainwater drainage) and diffuse sources (agriculture, air pollution, etc.). The latter can only be rectified through integrated environmental policy measures, changes in land use and the like, as measures that focus only on water management are ineffective in these cases. For point-source discharges into surface bodies of water, a combined approach to pollution control is taken:

- Before it is discharged, wastewater must always be treated using up-to-date technology. For municipal and industrial wastewater, this minimum requirement is stipulated in industry-specific annexes to wastewater regulations. These annexes limit wastewater pollutant loads independently of the bodies of water into which the wastewater is discharged (emissions approach).
- Stricter wastewater treatment requirements are imposed in cases of especially high pollution levels or susceptible bodies of water, i.e. receiving waters with a low flow rate in relation to the wastewater volume or concentration (immission approach). The objective of water quality management is to achieve water quality class II (moderately polluted) for all surface bodies of water while not worsening the condition of less polluted stretches of water. This objective is also stipulated in the European Union's (EU, ▹ *European Union*) Water Framework Directive, with detailed additional requirements for ecological and chemical water quality.

These approaches have been successful in Germany: water pollution from wastewater discharge has decreased considerably in recent years, as Fig. 1 shows for nitrogen and phosphorus. Since it appears that the most serious problems for classic water pollution control have mostly been solved, the focus is increasingly shifting to diffuse sources of pollution including contamination by traces of biocides, pharmaceuticals, industrial chemicals, microplastics, and other hazardous materials.

Figure 1: Trend in average concentration of N_{total} and P_{total} in German sewage treatment plant effluents from 1992 to 2012



Source: DWA 2012

2.5 Water law and water management agencies in Germany

Water law is the oldest and most complex part of German ▹ *Environmental law*. Its legal foundation at the national level is the Federal Water Act *(Wasserhaushaltsgesetz, WHG)*, which states its management principle in section 1 as follows: 'This law's purpose is to protect water – as part of the natural environment, as a basis of human existence, as a habitat for animals and plants, and as a useful resource – through sustainable water management.' Section 6 of the Federal Water Act lays out the specific objectives of such sustainable management. These include safeguarding the drinking water supply, protecting the oceans, mitigating the impact of climate change, and ▹ *Flood protection* through large-scale retention.

The Federal Water Act aims to regulate the water supply according to this principle, primarily by subjecting all water use to regulatory approval (licences or concessions). According to section 9(2) of the Federal Water Act, water use includes all 'activities able to cause permanent or significant water quality changes of an adverse nature, in particular by introducing substances (e.g. wastewater discharge), abstracting and diverting water, extracting solid materials such as sand and gravel, raising and lowering water levels, and abstracting, extracting, lowering, diverting, or impounding groundwater. The public use of surface bodies of water regulated in section 25 of the Federal Water Act (e.g. bathing, washing, watering, navigation with small vehicles, or ice sports) is generally exempt from this approval requirement under water law as long as it is not in conflict with the private or other rights of others.

Other basic regulations concern:

- wastewater disposal: the allocation of disposal obligations, minimum requirements for state-of-the-art wastewater treatment, and permits for the construction and operation of sewage plants, including ▷ *Environmental assessment*;
- protection of the public drinking water supply: the designation of water protection areas (▷ *Conservation areas under water law*);
- handling hazardous substances: organisational and technical requirements and permits for facilities to store, fill, handle, produce, treat, and use substances hazardous to water;
- developing and maintaining surface waters: planning approval procedures for creating, eliminating, or significantly altering a body of water and the designation of responsibility for maintenance costs;
- programmes of measures and management plans for implementing the Water Framework Directive.

The Federal Water Act merely provides a legal framework; it is not a complete set of regulations and must be supplemented and complemented by water legislation in each federal state. This combined form of legislation is able to account for the unique aspects of each state's legal system and water management situation. However, it also results in a nearly unmanageable variety of regulations. In addition to the Federal Water Act and the state water laws, there is also a multitude of ordinances at the national level (wastewater ordinance, groundwater ordinance) and the state level (ordinances on dealing with substances hazardous to water, municipal wastewater ordinances, water quality ordinances, etc.) to comply with.

In recent years, European Union regulations have also gained in importance, with the Water Framework Directive (WFD) providing significant contributions to German water law.

Economic support for the regulatory instruments of water law is provided by wastewater levy legislation, which stipulates a fee for pollution caused by wastewater discharges; in accordance with the 'polluter pays' principle, the fee depends on the wastewater's quantity and specific pollutant load. The aim of such instruments is to reduce competitive advantages and provide an incentive to improve wastewater treatment.

The enforcement of water law regulations is the responsibility of the authorities in the federal states. As the supreme federal water authority, the ministry responsible for water management sits at the top of the public water management hierarchy; subordinate to it in the non-city states are the regional governments (where present), which act as the higher water authorities. The county and urban district administrations act as lower water authorities (special municipal-level enforcement agencies). They decide on rights of use, approve engineering works, fund water management measures, and provide legal supervision of the agencies responsible for them, etc.

The water authorities are assisted by regional technical agencies (water management agencies, state environmental agencies, and the like) and in most states by special state authorities or regional offices. To maintain a certain degree of consistency in enforcement, the federal states cooperate in the German Working Group on water issues of the Federal States and the Federal Government *(Länderarbeitsgemeinschaft Wasser, LAWA)*, which works out shared technical objectives and guidelines for water law in the federal states. A special role is also played by technical and scientific associations such as the German Association for Water, Wastewater, and Waste *(Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V., DWA)*, the German Technical and Scientific Association for Gas and Water *(Deutscher Verein des Gas- und Wasserfaches e. V., DVGW)*, or the Association of Engineers for Water Management, Waste Management, and Land Improvement (*Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau, BWK*); these organisations draw up technical regulations and provide professional training.

2.6 Sectoral planning for water management

The 8th amendment of the Federal Water Act in July 2009 continued the radical renewal of the range of planning instruments available for water management, with adaptations to meet the detailed requirements of the WFD. The directive calls for member states to achieve a good ecological status for all surface bodies of water by 2015, with two six-year extensions up to 2027. The target status with good ecological potential is set somewhat lower in the heavily modified waterbodies (HMWB); 37% of the rivers and streams in Germany are currently designated as heavily modified.

To determine the current status, the bodies of water are assessed according to specific biological and chemical criteria. The purpose of the existing guidelines for these criteria is to establish a regional, national, and Europe-wide basis for comparable assessments of the ecological status of surface bodies of water. For all elements of biological quality (i.e. fish, invertebrates, aquatic plants, and algae) and the relevant chemical parameters, the objective of 'good ecological status' stated in the WFD stipulates conditions close to natural reference conditions. These reference conditions, where present, are used as a standard for comparison as they are largely free of anthropogenic influences and uses.

In future, a management plan and a programme of measures must be drawn up for every river's catchment area and updated every six years. Their purpose is to determine the degree to which surface waters have been impaired, analyse the causes, and develop measures for achieving the objective of 'good ecological status' (or 'good ecological potential').

- The management plan's purpose is to summarise information about the river basin; it is not intended to be a legal norm. It includes a description of the bodies of water in the river basin district, the water management objectives, an economic analysis of water use, a summary of the action programmes, and documentation of the ▹ *Public participation*.
- In future, the programme of measures will define the water management activities within a river basin district. It includes the measures to be taken to achieve the management objectives for the entire river basin district or for an individual body of water. These include not only engineering works and restrictions on use but also legal provisions outside of water management that affect matters such as land use.

This comprehensive set of instruments replaces the following earlier planning instruments: (1) the water management framework plan, which did not prove effective as a basis for comprehensive planning; (2) the management plan (old version), which did not adequately address the requirements of the WFD; (3) the wastewater elimination plan, which is being incorporated into the new programme of measures; and (4) the pollution avoidance regulation, which had not been used.

Most recently, the second management plan (2015–2021) with its associated programme of measures was submitted (e.g. MKULNV NRW 2015). The results of the surface water assessments (▹ *Monitoring*) show a significant need for action for rivers and streams: Only some 10% of surface bodies of water (WFD assessment criterion) have a good ecological status; widespread hydromorphological deficits have been identified as a major cause. In addition, there is still contamination by nutrients (nitrate, phosphate) and by the micropollutants or trace substances often detected by modern analytical methods; these include residues from medicines, hormones, and certain industrial chemicals that are found in water and wastewater. Thus far very little is known about their effects on the elements of biological quality that are the basis for assessments according to the WFD. It is already clear that improvements are only achievable with exceptionally high levels of investment in waterbody management and sewage treatment plants. For the improvements in hydromorphological quality that are undoubtedly needed, there is also a great need for land that will be nearly impossible to satisfy in the short and medium term, whether in urban or (especially) in rural areas.

The management plans are subject to regular reviews and updates. For both planning instruments, the objectives, basic principles, and other requirements of ▹ *Spatial planning* (▹ *Objectives, principles and other requirements of spatial planning (Raumordnung)*) must be observed.

3 Urban water management infrastructure services

3.1 The German water supply: technology and organisation

In Germany in 2013, water was supplied to more than 99% of the population (approx. 80 million people) via the public water supply network. Only around 700,000 people in Germany supply their drinking water needs with their own wells, usually owing to the situation in their region. In total, the water utilities supplied 3.5 billion m^3 of water to private households and small businesses in 2013, which corresponds to an average daily consumption of 121 litres per person per day. The amount of water supplied to consumers decreased by at least 26% between 1990 and 2013, mainly as a result of changes in consumer behaviour and modernisation measures carried out in the new federal states. Most of the water (61%) was obtained from groundwater, another 26% from recharged groundwater, spring water, and bank filtrate in nearly equal parts, 12% from surface waters and 1% from rivers.

The widely recognised high quality of Germany's drinking water is monitored by the health authorities according to compliance with limits on the concentration of substances in it, which are stipulated in the Drinking Water Ordinance *(Trinkwasserverordnung)*. The technical purification methods used for treating water are similar to natural purification processes that take place in the ground, such as sand filtration. More complex treatment methods include deferrisation, flocculation, filtration, and deacidification.

Water is not like any other commercial commodity. The water supply does not merely involve the sale of a product, as is clear from the compulsory connection and usage; rather, it entails a public service delivering a public good (▹ *Provision of public services*). Supplying water to private households in Germany is largely the responsibility of municipal companies, public sector special-purpose associations, and a few supra-regional utilities with regional monopolies. Regional and long-distance pipelines compensate for local differences in population density and natural water resources, and the water supply plays a key role in the development of populated areas (ATT/BDEW/DBVW et al. 2015).

3.2 German wastewater disposal: technology and organisation

In Germany, 97% of the population uses the public sewer system. The remaining wastewater from private households is disposed of in small sewage treatment plants or cesspits. Industry and trade (▹ *Industry/trade*) also discharge their wastewater into public sewer systems as indirect dischargers, unless they treat their wastewater themselves (▹ *Utility services*). In combined sewer systems, wastewater and contaminated rainwater are channelled away together and treated in a sewage treatment plant; in separate sewage systems, the collected rainwater is conveyed to the receiving waterbody in separate pipes.

Municipal wastewater in Germany is treated in approximately 10,000 sewage treatment plants of various sizes (cf. ATT/BDEW/DBVW et al. 2015). Of these, 87.5% are equipped with biological or advanced treatment systems, with the elimination of the plant nutrients nitrogen and phosphorus playing a key role. The municipalities are responsible for wastewater disposal if that responsibility is not allocated to its producers (e.g. industrial direct dischargers) by the authorities. Municipalities often join together in special-purpose associations to operate sewage treatment plants, with the operation of the sewage networks generally remaining the responsibility of the municipal administration. Examples of the extraordinary success of the association approach are the water associations with special legal status in North Rhine-Westphalia (Emschergenossenschaft, Lippeverband, Ruhrverband, Wupperverband, etc.), which established the water management foundation for the industrialisation of the metropolitan area. Since the mid-1990s it has also been possible to transfer the responsibility for wastewater disposal to private contractors of various legal forms, an approach quickly adopted by some municipalities and cities. However, this trend is now in steep decline; remunicipalisation is occurring in many places (including Berlin, Bielefeld, Solingen, and Krefeld).

Against the backdrop of ▹ *Demographic change* and the associated decrease in rural populations, particularly in eastern German municipalities, there is increasing discussion about the advantages and disadvantages of centralised or decentralised water management structures (e.g. Herbst 2008; Londong/Hillenbrand/Niederste-Hollenberg 2011). It may be that a socially acceptable distribution of the costs among the connected users will no longer be possible.

4 Spatial demands of water management

As a form of ▹ *Spatially-relevant sectoral planning* that provides infrastructure services as a prerequisite for other land uses, water management has specific spatial demands of its own. For example, urban drainage and wastewater treatment facilities require sites that satisfy certain conditions. Flood protection requires land for its infrastructure (dykes and retention basins), but it also restricts certain land uses. Protecting the drinking water supply places demands on very large swathes of land. In these respects, not only do water management plans and activities have a pronounced spatial component, they often take priority over other interests. Furthermore, the nonuniform distribution of *water* resources in the past led in some cases to an inadvertent interregional allocation of spatial planning responsibilities as sectoral planners made technical decisions (e.g. to establish large-scale, long-distance water supply systems) that resulted in preemptive spatial planning interventions. In extreme cases, this resulted in drastic usage restrictions leading to developmental disadvantages in the areas where water was extracted, while open spaces near the settlements where the water was consumed were abandoned because they were no longer needed for water management. Conversely, from a spatial planning perspective, the spatial needs of water management can be a valuable support for open space policy (▹ *Open space*) (e.g. Hillenbrand/Niederste-Hollenberg/Menger-Krug et al. 2010).

Water law can be used to protect the relevant swathes of land: sectoral planners can designate flooding areas and drinking water protection areas by legal ordinance. In the various types of spatial development plan, especially in regional plans (▹ *Regional planning*), conservation areas, protected areas, and priority areas (▹ *Priority area, reserve area and suitable area for development*) can be designated, important supra-local water management sites and routes laid out, or general water management objectives adopted. In this regard, the consideration of forward-looking approaches (e.g. heat recovery from wastewater, grey water use, or rainwater separation) in regional planning is particularly worthy of mention.

Given the emerging worldwide trend toward strong population growth and its concentration in urban and metropolitan regions (▹ *Metropolitan region*), the issue of 'water in the cities of tomorrow' is becoming increasingly important (e.g. Kruse 2015). To exploit the synergies of water management for protecting the climate and adapting to climate change, extracting ▹ *Renewable energy* from wastewater and waste, and improving health and quality of life with new blue-green corridors in urban spaces, water infrastructures will have to be granted higher priority in planning processes: planning for drinking water, wastewater, and grey water networks must not come last; instead it should be a key component of sustainable urban and spatial planning.

5 Current aspects of water management

Legally binding European regulations such as the Water Framework Directive, the Floods Directive and the Habitats Directive, and global trends like climate change and ▹ *Urbanisation*, entail a variety of tasks for water management; these include achieving a good ecological status or potential in surface waterbodies, preserving ▹ *Biodiversity*, and improving protection against floods and severe rainfall events. Water management can build on its earlier achievements on these issues, but these new and broader requirements pose special challenges, call for more transdisciplinarity and will lead to a need for increased funding.

The technical focus in the coming years will be on issues like micropollutants, energy, and recovering nutrients and metals from wastewater and sewage sludge. In addition, new methods from biotechnology (e.g. microalgae) can serve as a stepping stone on the path from wastewater disposal to resource management, considerably expanding the scope of water management's possible activities (e.g. Stemplewski 2012).

The importance of reducing anthropogenic trace substances in the water cycle has been recognised, but the right strategy is a matter of considerable controversy. Whereas there are demands for the universal introduction of an energy-intensive fourth treatment stage for sewage treatment plants as an 'end-of-pipe' measure (e.g. activated carbon, ozone, or membrane filtration), there are also competing approaches including source-oriented measures (product responsibility) for sustainability and recording all possible sources (e.g. industrial facilities, ▹ *Agriculture*, combined sewer overflows and air). There is still a significant need for research to find the most ecologically effective methods.

The extensive restructuring of the energy supply and the increased use of renewable energy stemming from the energy transition will also affect water management in many ways. In addition to efficiency improvements, sewage treatment plants can make a major contribution by expanding digester gas production, storing energy as hydrogen and methane, or using waste heat from sludge incineration. The same applies to generating energy from hydropower, with consideration for the aquatic ecology requirements.

For sewage sludge disposal, incineration, and the discontinuation of its use as fertiliser in the medium term are being discussed. With the new fertiliser ordinance, it will be difficult in any case to use sewage sludge alongside other agricultural products in the fields. In order to recover nutrients and valuable substances from the sludge, it must be disposed of in an incinerator, and the resulting ash will need to be stored. The necessary capacity for this still needs to be built up in Germany.

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Last update of the references: December 2017