Future City 12

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Urban Water Management for Future Cities

Technical and Institutional Aspects from Chinese and German Perspective

Springer

Future City

Volume 12

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Future City Description

As of 2008, for the first time in human history, half of the world's population now live in cities. And with concerns about issues such as climate change, energy supply and environmental health receiving increasing political attention, interest in the sustainable development of our future cities has grown dramatically.

Yet despite a wealth of literature on green architecture, evidence-based design and sustainable planning, only a fraction of the current literature successfully integrates the necessary theory and practice from across the full range of relevant disciplines.

Springer's *Future City* series combines expertise from designers, and from natural and social scientists, to discuss the wide range of issues facing the architects, planners, developers and inhabitants of the world's future cities. Its aim is to encourage the integration of ecological theory into the aesthetic, social and practical realities of contemporary urban development.

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Editors

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Preface

"Water in the city" has become a key theme of sustainable urban development. This holds especially true with regard to fast-growing mega-agglomerations where requirements of sustainable water management have often been neglected in the past and infrastructures are thus under considerable "sustainability pressure." When it comes to tackling these challenges and developing sustainable urban water solutions, China is certainly a hot spot with its rapidly growing agglomerations and an equally dynamic technologic and scientific development. Like no other country in the world, China combines high urbanization pressures with brisk technological development. China's cities will hence serve, in many regards, as examples and test cases on our global quest for sustainable megacity solutions. With regard to rainwater management, for instance, China has become a pioneer in implementing the so-called "Sponge City" concept by integrating innovative retention, drainage, and reservoir technologies systematically into the urban context. From a European and German perspective, there is, of course, a strong interest to participate in this exciting development in terms of both research and applied technology – most notably also in the water sector.

Against this backdrop and in order to intensify R&D cooperation, the German Federal Ministry of Education and Research (BMBF) has sought close collaboration with the Ministry of Science and Technology of the People's Republic of China (MOST) and linked a comprehensive funding program to sustainable water management directly to the vast Chinese water research program (Mega Water Program). This "mega-water cooperation" with its three major projects SINOWATER, URBAN CATCHMENTS, and SIGN (see sino-german-major-water.net), and in particular the SIGN subprojects, which deal with urban water management, is forming the framework of the collaborative research presented in the present volume.

It is an important specialty of both the above research cooperation and this volume that the urban water challenges are viewed from a multidisciplinary perspective including the various technical aspects and engineering approaches – in the first part of the book – but also the seminal challenges regarding urban water governance in its second part. The contributions related to urban water governance demonstrate the great significance of legal, financial, organizational, and capacity-related features of urban water management. These contributions also show that China acknowledges the need to foster developments in these regards, too, and they display a large variety of development options.

All in all, we believe that this book is presenting a strong basis for further research, development, and international exchange. It takes stock of the state of affairs and research with regard to urban water management, and it provides both a firm basis and rich inspiration for further collaboration in our global quest for sustainable urban water management.

As editors we wish to thank all authors for their excellent collaboration and for the exciting and fruitful exchange in the preparation of this book and in the frame of the underlying research project. As to both the organization of the collaborative research and the preparation of this book, we owe special thanks to our research assistants *Meiyue Zhou*, *Ting Feng*, and *Baixin Shen*. This work would not have been possible without their strong commitment and manifold support.

Hanover, Germany — Stephan Köster
Leipzig, Germany — Moritz Reese
Beijing, China — Jian'e Zuo
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Book Abstract

For several decades now, China has been experiencing rapid industrialization and urbanization. Water infrastructures, however, were often incrementally amended but not systematically developed to cope with steeply increasing demand, wastewater volume, and rainwater runoff from ever more sealed area. As a consequence, many cities are increasingly troubled by water shortage, severe surface- and groundwater quality problems, and pluvial floods. Climate change is often worsening the situation. It is apparent that water infrastructures and management systems are not meeting sustainability requirements and need further development in many cases.

Against that backdrop, this book features expert contributions on key sustainability aspects of urban water management in Chinese agglomerations. Both technical and institutional pathways to sustainable urban water management are developed on the basis of a broad, interdisciplinary problem analysis.

This analysis includes a comparative approach with Chinese experiences being reflected from the perspective of German experiences and experts, respectively. The contributions present the results of a great interdisciplinary and comparative research effort made in the frame of a Sino-German Mega Water Project "SIGN" (http://www.water-sign.de and http://sino-german-major-water.net/de/projekte/sign/). The book is addressed to urban water managers and scholars in their quest for sustainable water infrastructure for future megacities – in China and beyond.

Unique Selling Points

- Offers a platform to understanding China's featured urban water management challenges
- Provides lessons and inspiring experiences for other fast-developing countries, via comprehensively analyzing China's urban water issues
- Raises awareness in interdisciplinary/cross-boundary/international cooperation on handling the complex urban water management challenges

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Part I
Innovative Technologies and Implementation: Urban Planning and Urban Water Management

Urban Stormwater Management and Sponge City Concept in China

Wu Che and Wei Zhang

Abstract To mitigate the negative impacts of urban stormwater problems related to rapid urbanization in China, a new term “sponge city” was proposed, with related practices and implementation approaches examined in depth. The components and main goals of the sponge city concept and stormwater management criteria were introduced, while the relationship and difference between sponge cities in China and urban stormwater management systems in developed countries were compared and analyzed. Moreover, the policy and regulations that have been released were summarized, and recommendations for the future of sponge city development were provided.

Keywords Low-impact development · Stormwater management · Sponge city · China

1 Introduction

Over the last three decades, China has undergone a period of rapid urbanization, just like in the developing world (Chauvin et al. 2017). Such growth, accompanied by great achievements in construction, has also resulted in a series of problems of urban ecology, environment, resources, and security in most Chinese cities. The environmental issues are largely perceived as obstacles impeding sustainable economic development (Wang et al. 2015).

Serious urban flooding and eutrophication in urban surface waters are common problems in most cities in China. An investigation of urban flooding in large- and

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medium-sized cities was carried out by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in 2010. The results indicated that urban flooding occurred in 62% of investigated cities, with 137 of 351 cities investigated having endured more than 3 flooding events during the period from 2008 to 2010.

Urban drainage problems result both from climate change and a low design standard of existing drainage infrastructure. Certainly, the rapid urbanization in China is another important factor that should not be ignored. According to *China Statistical Yearbook*, the urbanization rate of China grew from 19.4% in 1980 to 51.3% in 2011(China Statistical Yearbook 2012). The continuing growth of the urbanization rate in China in future is foreseeable, and the negative effects of urbanization on urban drainage will be more acute if no countermeasures are adopted.

A series of practices, including the publication of mandatory regulations, policy support, standard updates and revisions, etc., have been proposed to address these drainage problems in China since 2013. Besides the reconstruction and upgrading of the traditional drainage infrastructures (gray infrastructures), such as sewer systems, detention tanks and pump stations, the green stormwater infrastructures (GSI), and low-impact developments (LID), are other important components of modern engineering practices (Che et al. 2014; Fletcher et al. 2015). The GSI provide an alternative approach to urban sustainable stormwater management (Wang et al. 2013) and is a relatively new method even for developed countries (Fletcher et al. 2015).

The GSI have a greater application potential in developing countries such as China. First, GSI practices are more feasible in newly developed districts than in older urban sections. A large number of new districts are developing or will be developed in the near future: these provide an important precondition for implementation of the GSI. Second, compared to developed countries, stormwater problems such as nonpoint source pollution and local flooding are more serious in older urban districts in China. The pressure and demand to mitigate the negative impacts of urban stormwater problems are thus more urgent in these districts. Hence, the driver to popularize and implement the GSI in Chinese cities is stronger than in developed countries.

In order to address the problems of the urban environment and promote the construction of GSI, a new concept and related technical methodology, called "sponge city," was proposed in 2013. A pilot city study was adopted to test the concept. Until now, 606 km^2 of urban area has implemented sponge city-related construction in 30 national pilot cities and 90 provincial pilot cities. In total about 370 cities have prepared special sponge city development planning; about 10,200 km^2 of urban area will be developed or redeveloped according to sponge city requirements.

Combining the existing research and projects of urban stormwater management and sponge city development in China, the framework and main component of sponge city must first be summarized to provide a support to the future development of the sponge city concept. Furthermore, the sponge city concept in China and urban stormwater management systems in developed countries will be compared and analyzed to find aspects which can be utilized and improved. Moreover, the policy and regulations that have been heretofore released will be summarized, and the recommendations for future development regarding urban stormwater management and the sponge city concept will be proposed.

2 Sponge City and Urban Stormwater Management

There has been a rapid growth in the use of terms such as "low-impact development" (Department of Environmental Resources 1999), "sustainable urban drainage systems" (SUDS) (CIRIA 2000), "water-sensitive urban design" (Whelans et al. 1994), and "best management practices" (BMPs) (Schueler 1987) and alternative techniques (Azzout et al. 1994). The history and evolution of each of the common terms associated with urban drainage have been discussed according to scope and principles in previous research (Che et al. 2014). There is significant overlap between various terms, but there are also important differences between the terms according to the focus and specificity (Fletcher et al. 2015).

Urban stormwater management research has been ongoing for at least the last 20 years, but GSI engineering implementation started relatively late in China (Che et al. 2010, 2014; Zhang and Che 2016). Interestingly, China's cities have experienced a late development advantage, enabling them to incorporate new technologies and experiences into their GSI implementation. Although a series of works have been implemented in China, these represent only a preliminary attempt in this field. However, the projects implemented were far from sufficient to solve the existing stormwater problems. The GSI in China are more prevalent than before but still less than needed.

The term "sponge city" proposed in China is similar to the popular new terminology surrounding urban drainage, such as GSI and WSUD, but it is not limited to urban drainage concepts, rather comprising aspects of urban planning, urban drainage, landscape, and more. From a broader perspective, the sponge city concept can be considered as an approach to urban sustainable development and with the target of livable cities including five water-related aspects, water ecology, water environment, water resources, water security, and water culture.

In addition to important measures to mitigate and solve environmental issues, sponge city development can also be viewed as the birth of a new driving force toward economic and social developments which must be nurtured and hastened. Downward pressure on China's economy has continued to grow, and there is enormous potential in sponge city development. It will be a powerful force driving the economic growth and urban development transformation in China.

3 Framework and Main Components of Sponge City

3.1 Components and Goals

Through nearly 20 years of urban stormwater management research and nearly 3 years of sponge city practices, the sponge city theory and methodology have gradually improved and been fundamentally established. Sponge city encompasses four major components, including runoff source control systems, urban drainage sewer systems, major drainage systems, and basin flood control systems. The four systems are linked to each other and form a unified sponge city to address a series of urban stormwater problems, such as total runoff volume control, runoff peak value control, runoff pollution control, and rainwater harvesting (Fig. 1). Urban stormwater management is the core and key to sponge city, consistent with international practices of urban stormwater management such as WSUD, LID, BMP, SUDS, etc. (Fletcher et al. 2015).

The approach will contribute to response to a series of urban water issues, including ecology, security, environment, resources, culture, and other aspects. Urban stormwater is one component of urban water, and forming practical solutions to serious urban water issues requires cooperation and synergies between urban stormwater system and other water-related systems (e.g., wastewater system, water supply system), as well as cooperation with urban planning, landscape design,

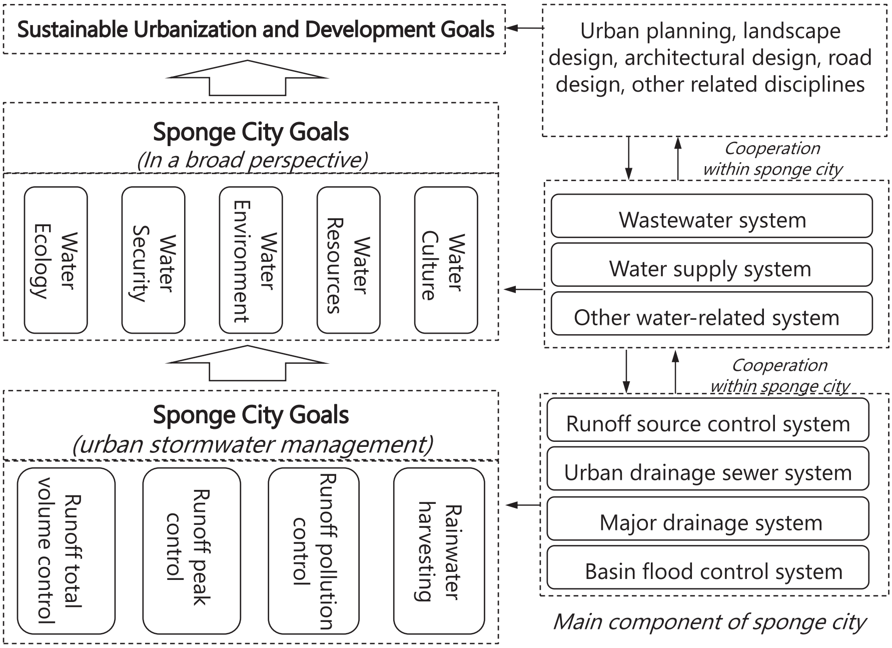

Fig. 1 Components and goals of sponge city

architectural design, road design, and other related disciplines within the sponge city development. Furthermore, sustainable urban water development is a critical base for future sustainable urbanization, which will provide key support to achieve the sustainable development goals.

3.2 Stormwater Management Criterion

The stormwater management criteria include water quantity and water quality aspects. For the water quantity, the criteria can be classified into four levels according to the functions of four main components (Fig. 2).

The criterion of source control is targeted toward low rainfall ("little rain"), in which the return period is normally less than 1 year, expressed as the volume capture ratio of annual rainfall, which is similar to the design rainfall (24 h) used in WSUD, LID, and SUDS. Rainfall with return periods from 1 to 10 years will be controlled by the urban drainage sewer system. This is the main form of the urban drainage system, and its design methods and standards are clear in the current national and industry standards in China. In urban areas, there were previously no design measures enacted to respond to rainfall during larger return periods than those of urban drainage sewer systems. The major drainage systems should be planned and implemented in urban areas to encounter rainfall events which exceed the current design standards in order to mitigate urban flooding. The major drainage system is designed to convey runoff from a 100-year storm while minimizing health and life hazards, damage to structures, and interrupted traffic and services. Major storm flows can be conveyed through the urban street system (within acceptable depth criteria), channels, storm sewers, or other facilities. Additionally, according to

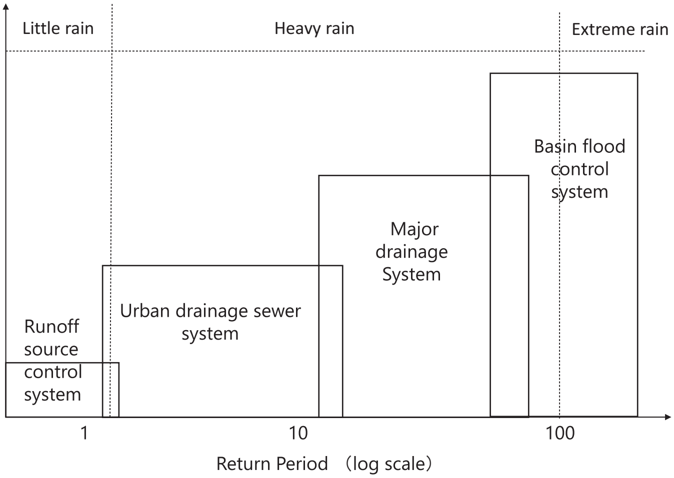

Fig. 2 Stormwater management criteria of sponge city (water quantity)

China's current situation, urban flooding control and watershed/basin flooding control are governed by two different departments, respectively. Hence, urban flooding control measures should involve cooperation with basin flooding control to promote the sponge city development.

Besides water quantity, runoff pollution control (water quality) is another important aspect of urban stormwater management criteria in a sponge city. Zhang et al. (2016) discussed the relationship between initial runoff and volume capture ratio of annual rainfall and introduced the requirements of runoff pollution of a sponge city. It is noteworthy that the combined sewer system is used in older districts in Chinese cities. Hence, pollution control through combined sewer overflows (CSOs) is one of the primary focuses in a sponge city. The CSOs' spill frequency is usually used as a criterion to control CSO pollution, similar to common practices in developed countries (Blumensaat et al. 2012; Roesner and Traina 1994; Morgan et al. 2017).

Furthermore, as the requirements of the sponge city are applied nationally, it is also necessary to take into account regional spatial differences. For cities in Northwest China, for example, an indicator is proposed for water scarcity which represents the situation with respect to rainwater harvesting and rainwater utilization rate in these areas.

The stormwater management criteria are thus no longer determined according to a single return period of design rainfall events in the traditional drainage system but a series of criteria including water quantity and water quality in a sponge city. Through the establishment and improvement of four major systems, the urban runoff volume, peaks, and pollution will be more effectively controlled, and rainwater resources will be better utilized.

3.3 Development and Implementation

Based on the defined goals, components, and related criteria, effective implementation is a crucial step toward sponge city development. Figure 3 illustrates the implementation approach.

The implementation of the sponge city concept is oriented toward actual problems and objectives. Combining aspects of the water ecology, water security, water environment, water resources, and water culture (5W) goals, stormwater management systems and related indicators are established, prioritizing local conditions and local water problems. The stormwater management goals will be pursued using stormwater management technologies, of which there are more than 30 types which can be divided into 6 categories: infiltration, detention, retention, purification, harvesting, and drainage. Guided by the principles in Fig. 3, according to the approach of "source+process+system," the technical route can be determined through scientific selection of technical measures.

The technical route determination should consider at least five relationships, namely, water quality and quantity, decentralized and centralized infrastructure, landscape and function, ecology and security, and green and gray infrastructures.

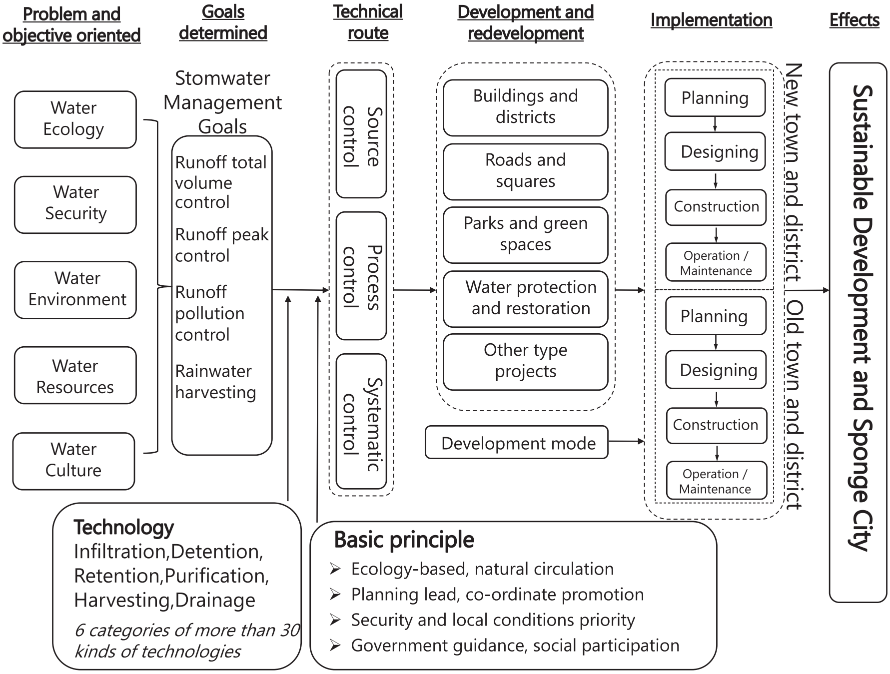

Fig. 3 Implementation approach of sponge city development

Technology selections should include all categories and relationships to avoid simplification. Additionally, new and old town/districts should be differentiated. Buildings and districts, roads and squares, parks and green spaces, water protection and restoration, and other types of projects will be addressed according to most important characteristics in order to implement sponge city development and redevelopment. Through planning, designing, construction, operation, and maintenance and whole process development, sponge city goals will be achieved to realize sustainable urbanization and development.

3.4 Policy and Regulations

Policy and regulations are an essential means to guarantee the implementation of urban stormwater management (Schuetze 2013). A series of measures and polices have been proposed by the Chinese government since 2014. In early 2015, after a suitability comparison process, 16 cities were selected as the first batch of national pilot cities for sponge city development. In the next 3 years, a special financial assistance (around 3.2 billion USD) will be provided by the central government of China to support sponge city development in these 16 pilot cities. However, the special financial assistance only accounts for a small part of the total investment of sponge city development. For example, the total investment of sponge city development for Nanning, 1 of 16 pilot cities, is around 1.5 billion USD. It is estimated that the market scale of sponge city construction and related aspects, including technical services, materials, engineering, equipment, management, and residential environment improvement, may be up to 300 billion USD in the period from 2016 to 2020. In early 2016, another 14 cities were selected as the second batch of national pilot cities for sponge city development.

The development and implementation of the sponge city concept are only a part of a series of measures to address environmental problems. The measures include administrative requirements at both the local and national levels and sponge city planning and design technical standards. These standards include national, local, and industry specifications which cover the requirements of planning, designing, operation, and maintenance for sponge city. Specific requirements and regulations for different land use applications and various regional scales were proposed in these specifications. The Sponge City Construction Technical Guide, the first national guide of the sponge city concept (edited by Beijing University of Civil Engineering and Architecture), was published in 2014. The mandatory provisions of GSI application and promotion were proposed first at the national level in China. Until now, more than ten sponge city-related national standards have been published or amended according to sponge city requirements in China.

However, the actual performance and effectiveness of the mitigation measures must be examined further in detail. Expectations are high, but there are still many problems with respect to engineering implementation. Potential problems should be taken into account, and a comprehensive and adequate preparation should be undertaken. One important problem is the lack of cumulative experience for planning, designing, construction, and maintenance of GSI practices. Moreover, GSI related research is still insufficient in China. Some key scientific issues have not been effectively resolved.

4 Conclusions

There is no doubt that there will be “a big market” in China’s sponge city implementation and construction brought by the national sponge city development over the next few years. Although sponge city development has been implemented in pilot cities only at present, the market potential will be larger once the concept is implemented nationally in China’s 661 cities. In addition, there will be a huge demand for both theoretical research and engineering applications.

The lack of engineering and research experience will be the main obstacles to implement sponge city development. The engineering performance of GSI must be further assessed to verify whether the design objective can be achieved.

Although there are still some problems with respect to sponge city development in China, after years of practice and exploration, the concept shows tremendous promise. China’s experiences will contribute to advanced urban stormwater management in other areas, especially in developing countries.

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Maintenance and Safety of Sponge City Infrastructure

Stephan Köster

Abstract Sponge City development is embedded in a realignment of urban development with a strict focus on water. In recent years, especially China has undertaken many concrete efforts and high investments in order to promote the Sponge City approach and to galvanize the decision makers to action. China aims at shaping water sponging cities to better cope with climate change and to especially mitigate negative impacts of extreme rainfalls on urban spaces. However, the advantages of green and spongy cities only will develop their full potential if operation and maintenance (O&M) are performed adequately and accurately. Especially, maintenance must be seen as a core element of asset management. In the Sponge City case, adapted preventive maintenance strategies should be pursued comprehensively considering the local (climatic) circumstances so that unnecessary performance losses and further negative side effects do not occur in the Sponge City infrastructure. Sufficient financial resources must be available for this task. In order to minimize future efforts and costs, the findings from previous maintenance activities will be crucial for design modifications or adjustments. Maintenance in Sponge City environments stimulates innovation, assures feedback, shows weak points, enhances reliability, and provides reason to improve the entire urban water system (including the underground infrastructure). If the implementation is successful, the Sponge City might be the starting point for further developments that fuel urban transformation.

Keywords Sponge City development · Asset management · Urban water infrastructure · Operation and maintenance · Best practice

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1 Introduction

In recent years, many slogans have been used in the imagining of future cities: smart, green, eco, resilient, soft, spongy, and many more; all are used to promote the idea that cities should become (more) sustainable, should assure the welfare of the urban dwellers, and should offer well-functioning services for the public. However, a sweeping look around the urban world reveals that we are still clueless about shaping a sustainable city. Cities must be designed not only to become more sustainable but also less vulnerable to relevant global developments. All countries and cities will have to deal with the effects of climate change. The respective forms of this change can vary greatly at the local level. However, in the ongoing urban epoch, cities have turned out to be highly vulnerable in climatic terms – especially if water issues remain disregarded in urban development. It has become apparent that there is an urgent need for fresh solutions on how to better manage water in cities. In this regard, urban surfaces increasingly have played a bigger role in sustainable urban water management in recent years. Approaches such as water-sensitive urban design (WSUD), low impact development (LID), or sustainable urban drainage systems (SUDS) already promote measures on the surface and consequently promise a higher flexibility in coping with heavy rainfalls and urban flash floods.

With regard to the matters raised, it is worth taking a special look at China. Throughout much of its economic ascent over the past decades, China has turned out in many regards to be a trendsetter within the age of urban-industrial societies. China also must cope with difficult climatic changes and effects. Thus, it is important to identify relevant factors and drivers that have led to a new Chinese focus on both urban water management and urban development. The following points are interesting statements and assessments from China:

- Repeatedly, extreme weather events (possibly as intensifying effects of ongoing climate change) demonstrate cities' vulnerability and heavily compromise cities' resilience.
- "In recent years, urban flooding caused by extreme rainfall events have increasingly occurred across China, with serious socioeconomic impact attracting wide media attention" (Jiang et al. 2017).
- "China is a country with severe water problems" (Jiang et al. 2017).
- Ren et al. (2017) speak of an urban water crisis in China.

As response, recently China has initiated the far-reaching approach of Sponge Cities which represents a paradigm shift in urban development – away from concrete and land sealing toward green, "soft," and spongy cities (Workman 2017). This trend is attracting worldwide attention and rapidly taking root. In recent years the phrase "Sponge City" already could be found sporadically in specialist literature; however, since 2014 China has been the leading pioneer under this slogan. To this end, China took wide political action in order to put this approach into practice, with the main target to provide an impressive urban water storage capacity to locally contain 70% of surface runoff. By the year 2020, at least 20% of the constructed areas in Chinese cities must achieve this goal; by 2030 this threshold must be achieved by 80% of the constructed areas. In concrete terms, China pursues the target to reshape urban spaces in order to improve rainwater storage and urban environmental management. In addition to the objectives relating to urban flood control, the Sponge City approach is also extended by the components of rainwater harvesting, water quality improvement, and ecological restoration (Jia et al. 2016).

From the author's point of view, there is a priority topic which will be crucial to the long-term performance of the Sponge City approach and is currently not sufficiently addressed by scientists and decision makers. This topic relates to the maintenance of the extensive green infrastructure that is currently under construction in China. As part of the scientific review on Sponge City implementation, only very few assessments are made with regard to the operation and maintenance of Sponge City facilities. For example, Jia et al. (2016, 2017) point out that after the completion of a Sponge City project, maintenance of the facilities will become a decisive factor affecting project sustainability and that "the lack of information on maintenance requirements and costs would contribute to uncertainties in Sponge City budget estimates." Li et al. (2017b) evaluate operation and maintenance (O&M) as an unaddressed issue in the Sponge City context. Compared to traditional stormwater management systems, Sponge City measures may require more frequent, periodic maintenance. Maintenance requirements vary depending on the specific measures, their functions, and local conditions.

Finally, too little attention is paid to O&M issues with respect to the intended size of Sponge City infrastructure. Thus, the real scale of O&M tasks has not become evident yet. In view of the current pace in implementation progress, important challenges will soon be addressed, and O&M issues inevitably will receive more emphasis. This general view is followed up by specific questions in terms of responsibility, financing, and qualified implementation:

- What is the appropriate O&M strategy?
- What is the real technical scale of the O&M tasks to be fulfilled?
- Who will be in charge?
- What is the economic scale of O&M tasks to be fulfilled?
- Who is paying for permanent and reliable O&M service?

In view of these questions, this chapter serves to give a first answer to the issues raised. For that purpose the present study discusses the following key points:

- Implementation of Sponge City infrastructure
- Operation and maintenance issues and challenges
- Maintenance strategies and best practice for Sponge Cities
- Expected costs. How to finance Sponge City O&M measures?
- Conclusions and recommendations

2 Implementation of Sponge City Infrastructure

2.1 Scope of Sponge City Elements and Functions

In the course of implementing widespread Sponge City urban ecosystems, based on sporadic examples from previous attempts, green or even urban ecological infrastructures have been incorporated – in some cases to a considerable extent. The entire city becomes porous just like a sponge. The citywide comprehensive planting on ground, roof, and façade surfaces increases water retention and storage capacity. In addition, pervious surface materials further increase permeability and activate the sponge function supplemented by a widespread network of retention, treatment, and infiltration facilities. In the end, the entire Sponge City infrastructure must have suitable interfaces to the underground drainage systems.

There are many descriptions concerning the services to be provided by a Sponge City. Liu et al. (2017) stress the urban transformation in such a way that a new "green infrastructure could capture, control and reuse precipitation in a useful, ecologically sound way." According to Li et al. (2016), "the Sponge City concept development promotes water security, water environmental protection, and water ecological restoration." Thus, apart from rapid draining services, the Sponge City facilities serve to perform functions of retention, storage, cleaning, seepage, use, and drainage of rainwater. Jia et al. (2017) call it the "six-word" principle: infiltrate, detain, store, cleanse, use, and drain.

The overall aim is to create a comprehensive urban water landscape consisting of manifold mostly green facilities (with hydraulic and biological functions) – in harmony with nature and, in terms of plant design, in accordance with functions known from nature, e.g., compare (Liu et al. 2017). What can be seen from this? The Sponge City concept measures, pushed by very ambitious political objectives, turn China toward a more sustainable urban development. Nowadays, Sponge City is an idea, a guiding principle. Such a far-reaching claim will inevitably have a considerable impact on the future configuration and aesthetics of cities.

To examine the concrete measures that will be used to achieve the Sponge City objectives, it is first helpful to look at the numerous visual representations describing the Sponge City approach. These are mostly eye-catching illustrations such as Fig. 1 which circulate in worldwide media coverage. As a commentary, it should be added that these images – usually showing a large sponge as a substructure of a modern city – do not accurately portray the entirety of main features of a Sponge City. Most of the measures to implement the Sponge City approach take place on the surface.

To ensure infiltration, detainment, storage, purification, utilization, and discharge of rainwater (Liu et al. 2017), main features will include citywide series of components such as sunken greenbelts, permeable pavements, green roofs, regulative ponds, wet ponds, stormwater wetlands, bioretention facilities, cisterns, constructed treatment wetlands, and other elements. Hence, most of the individual technical components/facilities used to implement the Sponge City concept are not actually new and in fact are equally important components of the LID, WSUD, and SUDS

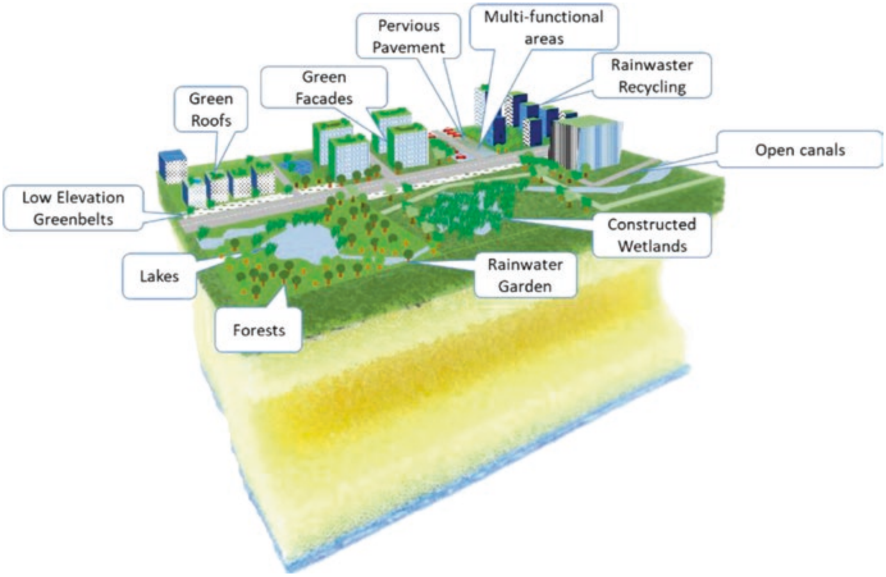

Fig. 1 Typical Sponge City components

concepts introduced previously. In contrast to the latter concepts, however, the Sponge City approach is a targeted and concerted aggregation of many well-established individual measures under the umbrella of a comprehensive water-oriented urban planning. Thus the novel aspect is the extensive and citywide placement and distribution of all these elements and their interaction and integration into urban development. For this purpose, further concept names have been recently suggested, such as “Urban Water System 3.0” (Ren et al. 2017).

2.2 Individual Components Within Sponge Cities

On the way to a spongy urban fabric, a large number of permeable building and surface materials, retention areas, green spaces, and water treatment facilities are brought together. Four general fields of interventions can be identified (Liu et al. 2017); specifically these are measures (1) for in and around buildings, (2) for increasing the permeability of traffic areas, (3) for the construction of green areas with retention and purification properties, and (4) for the rehabilitation of urban waters (Fig. 2).

Sponge City’s new infrastructure must be connected to and operated in close interaction with existing urban water systems. Liu (2016) points out that “once in place, the sponge infrastructure should be combined with conventional drainage systems, particularly in areas of medium- and high-intensity urbanization.” Urban water bodies will be also connected, in particular by integrating and linking

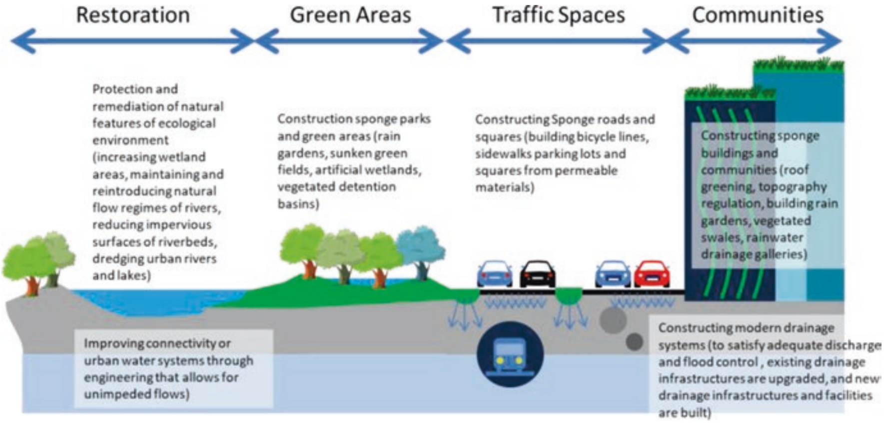

Fig. 2 Allocation of measures for Sponge City implementation – visualization according to specifications of (Liu et al. 2017)

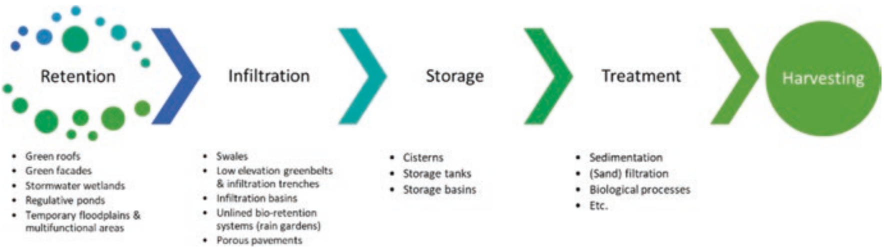

Fig. 3 Scope of features of the LID technologies used for Sponge City implementation

additional ponds, basins, wetlands, and water biotopes. The rehabilitation of urban waters by excavation of sediments and by complete redesign of the riverbank (in order to regain a natural appearance) also massively supports the Sponge City approach. In individual cases, even river water treatment plants may be used if the pollutant load from the urban catchment area cannot be sufficiently reduced.

Regardless of their particular configuration, the Sponge City and associated LID elements should perform the following multiple functions, retention, infiltration, storage, treatment, and harvesting as shown in Fig. 3, which give examples of services performed by multiple installation types.

With regard to the associated hydraulic functions, the following fundamental distinctions have been recommended (Eckart et al. 2017):

- Retention-based techniques such as green/grass roofs, stormwater wetlands, regulative ponds, temporary floodplains/multifunctional areas, and cisterns/storage tanks for rainwater harvesting
- Infiltration-based techniques such as swales, low-elevation greenbelts/infiltration trenches, basins, unlined bioretention systems (rain gardens), sand filters, and porous pavements

Methods are constantly sought to reduce burden on the natural aquatic environment from urban catchment-derived substances. Urban runoffs play a decisive role here because these runoffs can disperse significant concentrations and contaminants (e.g., tire debris as microplastic source and vector for adsorbed pollutants and pathogens, etc.). Thus, besides the hydrological functions, the pollutant removal capacities of the LID installations play a major role. Past experience has shown that reducing pollution from the catchment area is a very demanding task. LID plants are intended to contribute to improving the retention of substances in the catchment area. The used individual LID systems can be simple or complex, depending on the intended scope of water-, ecological-, and climate-regulating services. In order to effectively provide retention of contaminants by LID systems, some questions have to be answered beforehand: Where in the catchment area does pollution occur? Where can the pollution be removed from the system? What are the main contaminants and which technologies are particularly suitable for the treatment? For example, a filter passage provides higher particle separation performance than sedimentation. However, filters are more difficult to clean than sedimentation tanks. If the systems are designed for water and pollutant retention and thus technically more complex (e.g., "retention soil filters"), operational issues become increasingly important.

However, the greatest expectations exist with regard to flood prevention in urban areas. Of course, there is a noteworthy effect with regard to the hydrological performance of the Sponge City facilities. Authors have compiled rich performance data in review articles (Eckart et al. 2017; Li et al. 2017a). Eckart et al. (2017) considered concrete measurement results from large-scale applications as well as results from simulations. The achievable hydraulic performances are very strongly dependent on local conditions (e.g., climate, soil, plant operation). The team around Eckart compiled several overviews of hydraulic performance of LID control measures and reduction rates in pollutants loading – all taken from reports on field studies (Eckart et al. 2017).

The expert literature shows very large ranges in the plants' assessments. An even more important point is that individual plants are only mosaic pieces in the Sponge City infrastructure. Thus, the quantification of the efficiency of individual plants is of interest but not very meaningful in the overall Sponge City context. Finally, it is important to assess the hydraulic benefits of a Sponge City, as they result from the interaction of all plants. To this end, rather elaborate approaches are recommended, which should be pursued before choosing the right design and final Sponge City arrangements. For example, Jia et al. (2015) give an insight into how the composition of the LID and related best maintenance practice measures can take place, always with the goal in mind to achieve "best runoff control benefits and/or least costs." This includes, in particular, an IT-supported scenario analysis, which can be carried out using the EPA-tool SUSTAIN, for example. The authors propose a multilevel procedure for the planning process, which they have summarized in a chart. Especially, when designing the plants, particular attention must be paid to the following aspects:

- What are the climate and rainfall patterns and what effect does the local climate have on plant operation and performance?
- What are the soil characteristics with respect to infiltration?

- How severe is the runoff pollution and to what degree should it be reduced?
- What is the sensitivity of receiving waters in terms of pollution from the catchment?
- Is there a demand for rainwater harvesting?
- Which links to the underground infrastructure must be created?

2.2.1 Some Illustrative Examples from Sponge City Implementation in China

Especially in China, new green and blue elements will be prominent features of future cities. The growing spongy infrastructure exclusively strives to control water that can cause considerable damage in the city. In the first round, China's central authorities announced 16 pilot Sponge Cities. In 2016, another 14 were nominated to be pilot cities (MoF). The implementation is in full swing at the pilot sites in the selected cities, and China's efforts to pursue the Sponge City's approach continue unabated. Thus, further (pilot) Sponge City (infra-)structures will be set up in the future. Selected impressions of the most recent Chinese efforts are presented below. Figure 4 shows different types of permeable road and parking surface coverings, while Fig. 5 gives an impression of a rainwater garden during the construction phase. Figure 6 introduces the Sponge City component of a "Sunken Greenbelt" which was implemented in Jiaxing. In addition, Fig. 7 provides an impression of a showpiece green roof in Beijing. Finally, Fig. 8 shows a construction site in Beijing where, among other things, water-permeable materials for car parking lots were used.

2.3 Further Positive and Negative Impacts of Sponge City Implementation

In addition to the above examples of the individual Sponge City components, relevant positive and negative effects on the urban environment are described and discussed below.

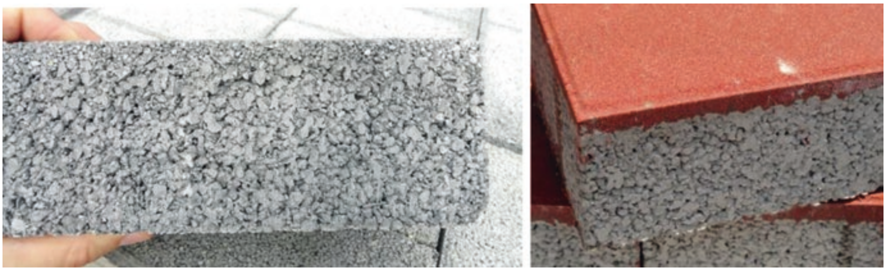

Fig. 4 Examples for pervious pavement materials

Fig. 5 Rain garden under construction in the first round Sponge City Jiaxing (September 2016)

Fig. 6 Sponge City component “Sunken Greenbelt” in Jiaxing (September 2016)

Fig. 7 A showpiece green roof in Beijing (May 2017)

Fig. 8 Sponge City construction site in Tongzhou District, Beijing (May 2017)

First of all, the positive aspects: The Sponge City implementation provides vital improvements for urban water management. As a new aboveground infrastructure, new options for water management in the urban context are emerging. In this regard, numerous researchers put a strong emphasis on the mediation of water flows in urban centers and the maintenance of species life cycles, habitat, and gene pool protection (Silva and Wheeler 2017). Thus, the potential positive effects can go far beyond the improved handling of water or extreme rainfall events. Sponge City implementation is a driver to pave the way for green(er) cities. The approach massively contributes to green urbanization, with introduction of additional urban greening by using rainwater as new and additional water resource. Overall, urban ecosystems are perceived very positively. Many publications propose ecosystems as infrastructure with positive effects delivering important ecosystem regulation services. Green infrastructure is supposed to be flexible and serves multiple functions (Li et al. 2017a). Attributed functions of the urban ecosystem (UES) are that they improve ecology, cool down urban temperatures, increase humidity and thus regulate the urban microclimate, and mitigate the Urban Heat Island Effect. Furthermore the UES provide habitat service and assure accessibility of public green spaces as a sociocultural service (Grunewald et al. 2016). Other effects are supported by green elements such as carbon storage, air pollution regulation, and noise reduction. Derkzen et al. (2015) provide a detailed analysis of selected urban green spaces (UGS) and quantify their relative contribution to different environmental services.

Another important point is that all abovementioned effects reduce the risks to public health (Liu et al. 2017). The WHO has emphasized that there is an overwhelming evidence of health benefits of green spaces (WHO 2016). Sponge City concepts can bring green areas close to the citizens, which means they can be reached within walking distance. This means that people can also come into contact with urban nature outside their leisure time and, under certain circumstances, even involuntarily. This can result in unintended health benefit effects, such as stress reduction (Ekkel and Vries 2017). The extent to which a social benefit of urban green spaces is achieved depends in particular on the factors of access, maintenance, amenities, and perception of aesthetic attractiveness and safety (Ives et al. 2017). Further research indicates that the different types of urban green spaces are to be considered individually when describing the relationship between green spaces and the mental health of the urban population. This should not lead to a simplifying aggregation, which classifies green spaces as “simply green” or according to the size of forested areas in urban areas (Akpinar et al. 2016). According to Andersson-Sköld et al. (2018), “natural environments are known to have positive health effects and stimulate physical activities (therein referring to (Bell et al. 2008)), but few quantitative correlations between these effects and specific biophysical structures (trees, shrubs etc.) have been published.” The first individual findings are available on the effects that blue spaces in cities can have on the health of the urban population. Thus, these results point to potential health benefits of outdoor blue spaces, particularly in terms of mental health and well-being and the promotion of physical activity (Gascon et al. 2017). For example, the “enactment” of water in urban recreational areas can become a more beneficial contribution to improving public health. In view of the published results, the conclusion may be drawn that a greener and bluer urban environment is evidenced by numerous positive health effects such as stress reduction, improved mental health, improved cognitive functions, reduced cardiovascular morbidity, and a general reduction in mortality (WHO 2016).

For the sake of completeness, it should be noted that “living with nature” (Jia et al. 2017) in urban environments does not solely lead to benefits but also to certain inherent risks. The risks which potentially go hand in hand with Sponge City implementation are to be found in the categories of accidents, diseases, and exploitation risks. In the first category, there is a fundamental risk of injury when entering or using the facilities. The multi-functionality of these places may mean an increased danger potential, as was discussed intensively, for example, when the first playgrounds were planned and implemented, which were designed for increased retention during heavy rainfall but carried increased risks of child injury/drowning. Disease risk would be increased when using the wrong selection of plants (e.g., highly allergenic trees), which can be a starting point for an increased occurrence of allergies and asthma. All plant protection and pest control measures (pesticides, herbicides) can result in increased exposure of city dwellers to these substances. A further mechanism of potential pathogenic effects of green spaces can be the exposure to disease vectors (standing water surfaces are the cause of an increased occurrence of mosquitoes) and zoonotic infections that are shared between animals and people. The issue of unforeseen and unwelcome wildlife problems such as animals, vermin activities, and also mosquito problems has to be considered in detail (US EPA et al. 2009; US EPA 1999). Other risks relate to the use or exploitation of the rainwater collected. If rainwater is insufficiently treated or stored, warm climatic conditions can have a considerable effect on the quality of the rainwater to be used. For this reason, the storage and delivery of rainwater – depending on its intended use – must be subject to an appropriate quality control. Indeed, wherever there is standing water, the extent to which the following phenomena occur must be checked: waterfowl, undesirable plant communities, water quality degradation, and mosquito problems. In general, the health benefits including stress reduction are unlikely to be enjoyed if the area is not perceived to be safe (Ekkel and Vries 2017). The latter point in particular justifies a more detailed look at the maintenance issues raised in this paper.

2.4 Lessons Learnt So Far

In China a unique and massive experiment is currently going on. It is therefore all the more important that the Sponge City implementation is complemented by a simultaneous scientific feedback. Encouragingly, the Sponge City implementation recently has found increasing scientific review and follow-up. In the relevant publications, a general consensus has been reached that the Sponge City concept is a decisive step forward toward greener and more sustainable cities – as already described in detail above. From a scientific perspective, many positive effects have been attributed to the Sponge City approach. Besides these positive appreciations, also some critical observations were made. Thus, when listening to (mostly Chinese) scientists, it is of particular interest what the essential challenges discussed are to be overcome. The following points are addressed by most scientists:

1. The conceptual approach: What can the concept actually achieve?
2. Planning and design: Are there enough tools in the toolkit?

3. Implementation: Can everything be implemented as planned?
4. Financing: Where do the funds for investments and O&M come from?

1. *The Conceptual Approach*

"The Sponge City approach is a complex concept that not only includes urban flooding inundation control and water utilization but also relates to water environment protection and water ecology restoration even though it was originally developed from the LID concept" (Li et al. 2016). Or even more philosophical: "Seeking a long-term balance between urbanization and natural environment, the wisdom of 'design with nature' has been seriously taken into account by the Sponge City concept" (Liu et al. 2017). Thus, it can be concluded that Sponge City implementation stands for an amalgamation of many individual measures in different contexts which will take on the dimension of a new infrastructure. Professor Che Wu is quoted (Workman 2017) as saying that the Sponge City must simultaneously achieve the goal of protecting the water environment, water ecology, water resources, and water safety. Li et al. (2016) point out the complexity of the Sponge City approach by emphasizing that the approach not only includes flood protection and water use but also includes water pollution control and water ecology. The pilot implementation soon made it clear that a large variety of actors had to be involved. This is not always easy, despite political pressure. Jia et al. (2017) point out that the inertia of traditional approaches and the associated resistance to change had to be lifted, and the lack of close cooperation between agencies had to be overcome at the local level. In addition, the pace of implementation has been called into question. Only a few years lapsed between the programmatic announcement in 2013, the competitive selection of the first 16 Sponge Cities in 2015, and the evaluation of the pilot settlements which began at the beginning of 2018. However, this high implementation speed does not only offer advantages.

2. *Planning and Design*

From a technical point of view, there are certainly some measures that can be implemented in a short period of time. Long-term testing and adaptation to local conditions, however, will not be sufficiently successful. Thus, Jiang et al. (2017) also refer to experiences elsewhere in Sponge City implementation by emphasizing that unrealistic and inappropriate planning significantly increases the risk of poor project quality. They also point out the importance of taking into account local conditions in the planning and design phase in order to achieve maximum impact through innovative technical measures for urban water management and consider this link to be insufficiently taken into account in China. In fact, there was insufficient time remaining to plan locally adapted technologies. The lack of site-specific technical guidance and product certification, outdated supporting technologies, and the limited availability of technical instructions for the planning, design, and evaluation of LID systems often resulted in a lack of site-specific technical design (Jia et al. 2016; Jia et al. 2017; Xia et al. 2017). Another impression from a European perspective is that scientific support is lagging behind in the execution of the large-scale engineering projects. There is little possibility of influencing or correcting the ongoing projects. However, scientific monitoring can provide important inputs and can ensure that local conditions are sufficiently taken into account. In China, the construction of Sponge Cities is mainly concentrated on the LID approach in the order of magnitude of city cells, such as residential areas. Therefore, a deeper embedding in the "theory of an integrated urban water system" is necessary. The team of authors around Xia therefore calls for a special "Sponge City Plan" (Xia et al. 2017). Ren et al. (2017) propose to use the Sponge City concept to establish an "Urban Water System 3.0" (Ren et al. 2017). And in general, many scientists hope for a better coordination between the numerous planners and implementation actors as well as a better integration of the Sponge City approach in an overarching planning (Xia et al. 2017; Jia et al. 2016; Jia et al. 2017).

3. *Implementation and Monitoring*

Although these are still pilot projects, the demonstration areas for the Sponge City implementation in China may be insufficient (Xia et al. 2017). The accompanying and subsequent monitoring shows which water management effects may be assumed in the future. The first success stories that have already been reported refer almost exclusively to runoff attenuation for individual urban areas. For example: "after an initial implementation round, several of these sponge city projects were tested by the Ministry of Housing and Urban-Rural Development (MOHURD). The results so far have been positive. As far as flood protection is concerned, the researchers found out that 85 percent of precipitation runoff can be controlled" (Shepard 2016). However, these successes do not entirely satisfy public expectations, which might anticipate a Sponge City to provide a complete solution to the urban flooding problem. In this way, the public sometimes takes a critical view of the program, especially if, despite the measures taken in the Sponge City, there are still incidents of flooding within the city. The fact that the new Sponge City infrastructure alone is not enough to solve the problem of urban flooding shows that the implementation of the Sponge City concept forces the cities equally to deal intensively with existing deficits of the underground sewer system and to fix the detected deficits. Since the systems are complementary and cannot be operated independently of each other (Li et al. 2016), it is not advisable to create a Sponge City on the surface as long as the underground infrastructure has considerable shortcomings. Only if all systems are functional and interactive will the Sponge City be able to fully exploit its potential to reduce the effects of (heavy) rainfall. However, there is still a need for further development in order to integrate the required interaction of both systems into modern control concepts. It should also be noted that in many Chinese pilot cities, the Sponge City concept is being implemented in so-called new areas, i.e., new districts. In this case, there are other and much more diverse design possibilities than in existing urban districts, whose transformation is often carried out under public objection. In summary, the challenges of implementation will only be overcome if China succeeds in establishing suitable technical and locally adapted measures, institutionalizing the implementation in compliance with good water governance and making available sufficient financial resources (Jiang et al. 2017).

4. *Financing*

The sums invested in China are and will be considerable. The Sponge Cities' initiative can be effective if China commits to appropriate technical, governmental, and financial measures to overcome the implementation challenges (Jiang et al. 2017). In this context, Jia et al. (2016) refer to insufficient investment and yield estimates. While the necessary investments are gaining momentum, questions of the return on investment remain largely unanswered. The PPP initiative launched to involve private companies in the development of Sponge Cities shows the current uncertainty of those in charge with respect to how plant O&M can be financially secured in the long term.

3 Operation and Maintenance Issues and Challenges

When dealing with problems and challenges in operation and maintenance (O&M) of Sponge City components, it is appropriate to distinguish between two operating states: standby times and system load in cases of (heavy) rainfall.

Sponge Cities are made for extreme weather conditions. Under load the designated technical performance must be fully available. This draws attention to the standby times (between load cases) which must be coped with without compromising performance. Even in prolonged standby phases under adverse climatic conditions, the functionality of the systems must be maintained. This is a considerable challenge in view of the large number of services that the individual plants may provide – as indicated in Fig. 9.

It is worth taking a closer look at the circumstances in which O&M must take place and to determine the most relevant influencing factors in the Sponge City context, to be utilized in the later definition of a suitable maintenance strategy for the Sponge City infrastructure. It is safe to assume that the following factors determine the essential O&M efforts:

- Local climate and extreme weather conditions
- Appropriateness of technical and biological design
- Adequacy of the operation and maintenance approach

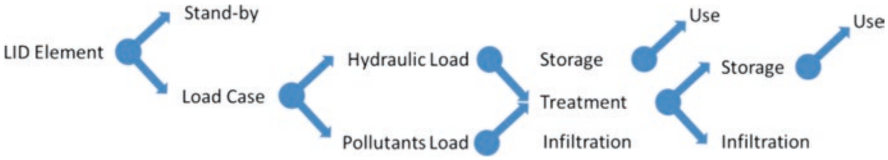

Fig. 9 Operating states and potential features of LID elements in a Sponge City

3.1 Local Climate and Extreme Weather Conditions

The Sponge City concept is based on many biological components such that the whole system is highly climate-sensitive. However, Sponge City is being built according to the local climate, and the climate is not a constant predictable parameter. Of course, there are often strongly developed variations.

All in all, the local urban climate should be described as precisely as possible and used as an essential basis for planning. Of particular interest is the description of the load cases for which the spongy infrastructure is designed. Here, extreme weather conditions are inevitably the focus of attention. All serious climate forecasts assume an increase in the frequency and intensity of weather extremes. However, at the local level, it is hard to capture the real threat of climate change. Most of the experts are in agreement that extreme weather conditions make the operation of a Sponge City even more complex and lead to even more substantial efforts required to maintain system's functionality. Long periods of dryness, drought, or heat can impair or even cause lasting damage to the basic functionality of the infrastructure (increasing risk of subsequent dysfunction). Heavy rainfall events can in turn lead to overloading of the Sponge City infrastructure, which also increases the risks of minor and major damage to the system.

In the Chinese capital Beijing, the average annual precipitation is a little less than 600 mm. If this amount of rain would fall evenly distributed throughout the year, there would be few problems; however, it is not so. For many years now, there have been extreme annual heavy rainfall events in Beijing, which can account for up to one third of the total annual precipitation. According to NASA and with reference to news agencies and newspapers "the heaviest rainfall in 61 years fell on the Chinese capital city of Beijing on July 21, 2012. The state news agency Xinhua reported that rainfall over Beijing averaged 170 millimeters, and reached 460 millimeters in the city's Fangshan District" (NASA 2012). Li et al. (2017c) also highlight this rainfall event and note that "the Beijing metropolitan region (BMR) has experienced heavy rainfall events exceeding 20mm/h from time to time during warm seasons (i.e. from 1 May to 30 September), resulting often in severe urban flooding." The actual extent to which climate change will result in a deteriorating situation with regard to heavy rainfall events will continue to be observed. Referring to many years of research, Zhou et al. (2017) point out that for the Jing-Jin-Ji City Cluster, all cities show downward tendencies in extreme rainfall. However, the effects of heavy downpours are flooded streets and underpasses with collapsed traffic, flooded subway tunnels, and many more. Pictures of local flash floods are widely distributed in Chinese media, and the resulting economic damage can be enormous.

Heat waves can also be dramatic, particularly with respect to biological and societal systems. For example, the summer of 2003 is considered one of the biggest environmental disasters in Europe accounting for many heat deaths. "The fairy tale summer, which was celebrated in the media, was indeed one of the biggest natural catastrophes in the history of the European continent" (Gunkel 2013). Despite noble intentions, the Sponge City concept is not expected to deal with all extreme weather events perfectly. Even in a Sponge City, precipitation events can be so severe that urban drainage systems collapse under the strain of the heavy downpours.

3.2 Appropriateness of Technical and Biological Design

When selecting technical and biological systems, much attention must be paid to site-specific factors that can impair the functioning of biological systems in particular (e.g., cold winters, dry periods).

The more goals to be achieved with a single LID plant (Fig. 9), the more complex the plants become. The plant design does not only include hydraulic dimensioning but also complex and essential biological components. The following aspects can be detrimental if they apply:

(i) Faulty technical and biological design
(ii) Insufficient coordination with neighboring infrastructures
(iii) Inaccurate implementation:

(i) An incorrect technical design can usually be traced back to inaccurate planning data. Unreliable or incorrect information increase the risk for fundamental errors in the selection of technologies and composition of the biological systems. In this context, the achievement of Sponge City objectives largely depends on biological systems. The biological systems and vegetation used are highly dependent on the local climate; for example, plants may not receive adequate precipitation during prolonged periods of drought. Thus, it must be confirmed whether the biological components are designed to withstand the local climate. What are the side effects of the selected biological systems? Do the plants cause allergies? Was the hydraulic design done in a way to avoid mosquito infestation? Such aspects demand a painstaking selection of the appropriate vegetation. An incorrect estimation of the general pollution and/or specific substance loads from the catchment area can lead to the overloading or even insufficient loading of the facilities. How do the systems react when loads change? Are all important pollutants and pollutant groups addressed? Urban runoff is often quite polluted, e.g., by tire debris which contains microplastics and polycyclic aromatic hydrocarbons (PAHs). Other important factors that may cause errors are the following:

   - Errors in design due to too many objectives to be achieved
   - Insufficient experience with the cross-linking of all (individual) Sponge City measures
   - Implementation of system enhancements not envisaged in the planning phase

(ii) An insufficient coordination with neighboring infrastructures applies if the individual Sponge City components are not correctly connected to each other, and in addition, the connections to the other water infrastructures have not been properly established.

(iii) It is not always easy to determine the true causes of dysfunctionality. Are they planning or execution errors? Certainly, many malfunctions are due to the latter aspect, and inaccurate implementation can be a big problem. Specialist companies are required to guarantee the necessary execution quality.

3.3 Deficient or Unsuitable Operation and Maintenance

All aspects and shortcomings mentioned above are decisive factors in determining the amount of time and effort required to operate and maintain the Sponge City system. Shortcomings due to unsatisfactory design and execution will present a long-lasting burden and will have to be compensated by greater efforts and higher O&M expenses. "If maintenance does not take place facilities will lose function" (Hering 2017). Many problems such as malfunction and reduced life span are caused by the absence of a maintenance strategy. Thus, the decisive step appears to be to pursue an appropriate maintenance strategy in order to assure an adequate and tailored asset management. Chapter "Urban Drinking Water Challenges and Solutions: Energy Nexus" presents the main outlines for developing a customized strategy.

Below are some examples that illustrate some positive and negative examples and highlight the challenges that may arise when implementing an O&M strategy for Sponge Cities. Figure 10 shows the excessive land sealing in conflict with urban vegetation. Figures 11 and 12 show two cases of an unclear situation with regard to undesired wastewater discharges. Figures 13 and 14 show two neighboring wetlands, one in a good and functional state and the other in a dysfunctional state. Figure 15 illustrates the widespread problem of littering in open urban waters.

Given the examples above, it becomes apparent that the Sponge City infrastructure has some special features that distinguish it from the underground sewer systems. The following two points should be emphasized in particular:

- Green vs. gray: Sponge City infrastructure is largely based on biological systems – compare considerations in 3.2.
- (Intended) public access to most Sponge City facilities.

On the latter point, aboveground facilities of urban water management show increased vulnerability per se. Since a Sponge City is mainly built on the urban surface, it inevitably takes place in public. A Sponge City is thus a living space for the city dwellers and becomes an integral part of the inhabitants' lives. Sponge City assets are designed in such a way that they also serve partly as urban recreational areas. Therefore, these open-to-the-public facilities are easily accessible and therefore vulnerable to all types of human interference. The facilities' setup on the surface

Fig. 10 Excessive land sealing in conflict with urban vegetation

Fig. 11 Unclear situation with regard to undesired wastewater discharges

Fig. 12 Further unclear situation of undesired wastewater discharges

Fig. 13 Wetland in Shenzhen – in a good condition

Fig. 14 Wetland in Shenzhen – in a bad condition

Fig. 15 Littering of urban waters

leads to more far-reaching external interferences than in an underground system. Human nature and its bad points must be taken into account here. It is necessary to clarify how the installations can be protected against vandalism, littering, illegal waste dumping, and other negative effects (as illustrated in Fig. 15). In addition, there is an increased duty of care toward the citizen, e.g., by ensuring safety especially in case of multifunctional spaces and temporary floodplains.

4 Maintenance: Strategies and Best Practice for Sponge Cities

Maintenance is a core task of asset management, which keeps the entire system in a good condition and helps to achieve the longest possible life cycle by carrying out inspection, repair, and replacement. The most important prerequisite for a successfully practiced maintenance is that exact knowledge is available regarding the real condition of a system. This must be ensured by a regular check of the condition of the systems and by regular monitoring of system performance.

Collecting and making such data available in order to provide a basis for strategy development shows the significant efforts required for proper maintenance. Many criteria influence the choice of appropriate maintenance approach. Thus, to keep the systems in the best possible shape, the correct maintenance strategy must be defined and implemented. How to proceed is described below.

4.1 Eligible Maintenance Strategies

When dealing with maintenance strategies, corrective and preventive maintenance must be distinguished. Corrective maintenance refers to a reaction to damage and other incidents that affect the operation, i.e., immediate action is taken when a problem occurs. It is more or less a “firefighting” strategy based on quick reaction times. Major damage is usually detected quite quickly. However, problems are more likely to be caused by repetitive small damages, which are not obvious and sometimes difficult to detect.

In any case, preference should be given to a preventive approach to maintenance, since it seeks to avoid the occurrence of technical problems. By definition the preventive approach aims for maintaining equipment in satisfactory operating condition by providing systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects. The preventive maintenance approach comprises two complementary concepts: (1) planned maintenance and (2) condition-based maintenance as briefly introduced in the following:

(1) Planned (preventive) maintenance (PPM): In this case, measures are implemented according to a previously created maintenance plan (scheduled maintenance).

The current condition of the plant does not play a decisive role. One example could be the replacement of still functioning plant components to promote a longer system life span.

(2) Predictive maintenance or condition-based maintenance (CBM): This approach is based on condition assessment and prediction. Continuously updated indicators are used to predict, as precisely as possible, when devices or plant components will fail or their performance will deteriorate. Compared to the other strategic maintenance approaches, condition-based maintenance leads – at least in theory – to the largest cost savings.

Figure 16 recaps the different maintenance approaches and shows their effects on equipment life span.

Preventive maintenance approaches are thus preferable to corrective approaches. As these approaches do not lead to or significantly reduce the number of system failures, maintenance costs are usually significantly lower than those for corrective maintenance. The reason for this is that the maintenance tasks are triggered only on the basis of the detected status of a plant. This means that especially the more complex maintenance tasks (esp. repair and replacement) will only be carried out when it becomes apparent that a system is going to fail. Thus, this approach largely exploits the potential life span of an installation or equipment. And this approach is also suitable for the maintenance of the Sponge City infrastructure. How to configure this approach to suit the Sponge City case is discussed below.

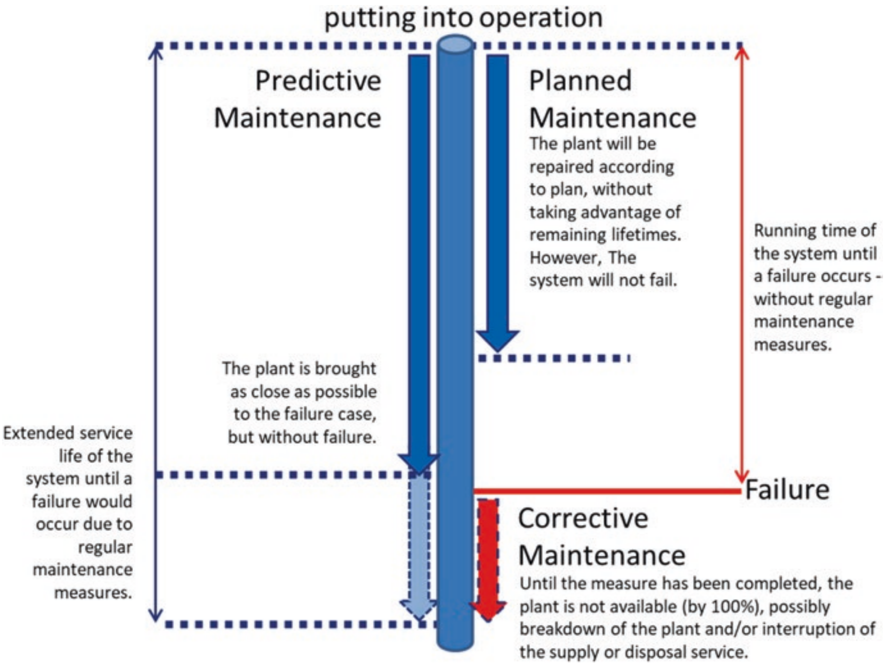

Fig. 16 Different types of maintenance approaches and effects on equipment life span

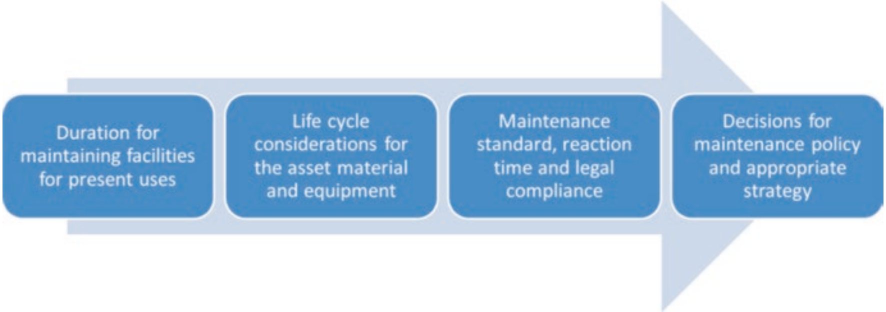

Fig. 17 Proposal for the procedure for defining a maintenance strategy according to specifications of Lee und Scott (2009)

4.2 Basic Considerations for the Maintenance Strategy of Sponge Cities

It is essential to avoid the testing of different maintenance alternatives via trial and error. A basic agreement is required as to which type of maintenance is valid for the Sponge City. Figure 17 gives a concrete form to a possible procedure for defining a suitable maintenance strategy.

In view of the problems and challenges outlined above, it becomes clear that there is no off-the-shelf solution for maintenance of Sponge City infrastructures. Primarily, Sponge City maintenance must assure that 100% of the hydraulic and substance retaining performance is available when needed. In addition, there are other tasks to be considered such as removing negative impacts on the habitat, solving problems of plant safety and urban health, and ensuring that the installations have the most aesthetic appearance possible. Some preliminary and basic considerations for the necessary maintenance, taking into account the special requirements in a Sponge City, are given below – referring to the following aspects:

1. On-off operation of Sponge City facilities
2. Preservation of complex biological systems
3. Citywide expansion of Sponge City infrastructure

1. *On-Off Operation of Sponge City Facilities*

Two operating states have been discussed above. Over longer periods of time, the main basic functions of the Sponge City components are not used as long as no significant rainfall event occurs. It is not possible to predict how long the respective on and off phases will take, in order to be able to reliably align a long-term operating concept. Ultimately, a strategy is needed to handle both operating modes well. The (after) load-case phase indicated in Fig. 18 requires particular attention with regard to the maintenance tasks. It represents a clear exception from routine work during the standby phases.

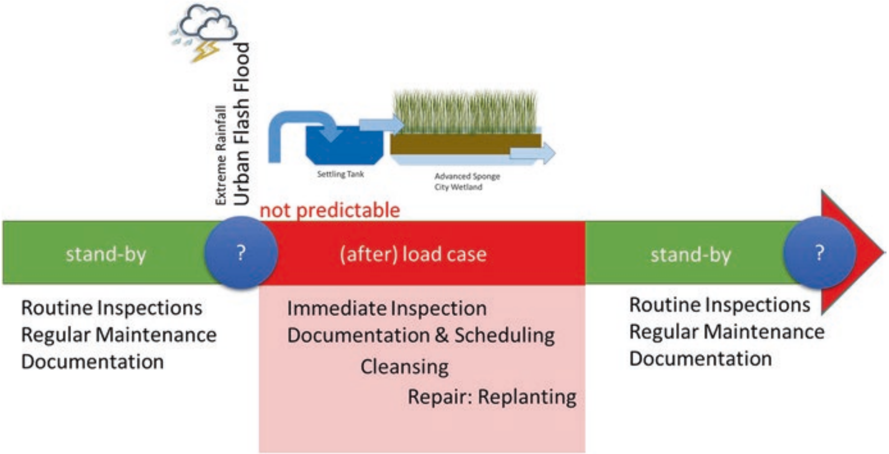

Fig. 18 Maintenance of a retention soil filter for the standby phase and unpredictable operational case for which the system was designed

2. *Preservation of Complex Biological Systems*

A Sponge City contains a high proportion of vegetation and is thus highly dependent on the local climate. The individual plant design and the O&M support must ensure that there is no loss of performance due to prolonged standby periods. In this regard, on-off operation mode is a quite relevant aspect. If precipitation events, for example, do not occur sufficiently often, this should have considerable implications for the selection and O&M requirements of the plant species used (e.g., irrigation requirements, specific measures to preserve and protect the biological system).

3. *Citywide Expansion of Sponge City Infrastructure*

The Sponge City system encompasses a mosaic of green elements, biotopes, tanks, wetlands, and pavements ready for heavy-duty operation, i.e., being soaked by rainwater as response to heavy rainfall events. Thus, Sponge City denotes a citywide aboveground infrastructure with numerous single elements which are in part interconnected. In the case of megacities, "citywide" means enormous areas requiring a vast comprehensive maintenance effort. Li et al. (2017b) also emphasize "one unique maintenance challenge posed by sponge city measures is that they are often scattered around a large area, and some are located on private property, making it difficult for public agencies to ensure that proper maintenance is carried out. Sometimes sponge city projects may be filled in or removed during other projects by private owners."

Technical design and layout measures must shape the Sponge City system in a maintainable format. This means that the design must already consider the extent to which it is suitable for the simplest possible maintenance. For the entire life span, there are many reasons to implement a predictive maintenance approach in the Sponge City context. However, there is still a need for further diversification. Many Sponge City facilities will require much routine and seasonal work. Thus, there is also some evidence for planned maintenance activities, especially when it comes to plant service. Finally, the planned maintenance appears to be preferable for plant service supplemented by condition-oriented and also corrective maintenance tasks especially after the occurrence of extreme weather events. Therefore, the best maintenance practice (BMP) for Sponge Cities resulting from the above considerations is introduced below.

4.3 Best Maintenance Practice for Sponge Cities

Regarding the scope of Sponge City's maintenance, it must be stated clearly: Simple gardening is not sufficient. For example, Li et al. (2017b) point out that the "tasks may be as simple as weeding a vegetated swale and removing debris from curb cuts, or as complex as maintaining a large-scale wetland or an underground storage tunnel with multiple functions." As an example, Fig. 19 shows a selection of tasks that are required for the maintenance of a LID component whose functional principle is (also) based on a biological system.

The following (quality) features of a comprehensive maintenance system for Sponge Cities are specified:

1. Precise task definition and allocation
2. Definition of responsibilities and provision of skilled maintenance staff
3. Documentation and appropriate data management
4. Maintenance planning
5. Maintenance execution

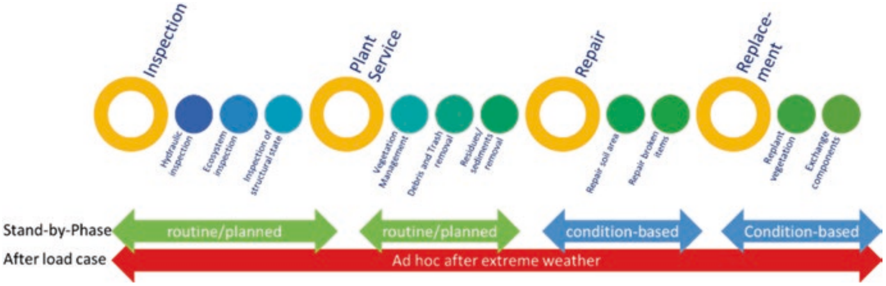

Fig. 19 Inspection, upkeep/plant service, repair, and replacement

- Inspection
- Plant service
- Repair and replacement

1. *Precise Task Definition and Allocation*

It should be noted that all the maintenance measures mentioned must be placed in an entire infrastructural context, which means that citywide maintenance work planning and execution must be carried out. An isolated approach to individual installations would be completely inadequate; in this regard, all plant-related measures must be coordinated. They are to be grouped and combined into routes. Financial, logistic, and human resources planning must be provided so that the work can take place as effectively as possible. Concrete guidelines also should determine how other functions such as that of an ecosystem also can be taken into account when carrying out maintenance. Furthermore, convincing solutions must be identified when it comes to the disposal of residues such as mowed material and debris collected during maintenance while also considering possible contamination of these residues which would require special disposal. Finally, in view of the existing abundance of tasks to be carried out, the recommendation is to also use computer-aided management tools. For this purpose, computerized maintenance management systems (CMMS) are available on the market that would require adaptation to the Sponge City needs.

2. *Responsibilities and Maintenance Staff Skills*

Proper maintenance requires a responsible party. Potential stakeholder for maintenance can be (US EPA et al. 2009):

- Professional engineers and specialized contractors
- Municipal inspectors and maintenance crews
- Commercial, institutional, and municipal owners
- Concerned citizens and adjacent homeowners
- Homeowners associations
- Property managers

Tasks should only be delegated if the person(s) responsible is/are capable of carrying out this task. Obviously, the qualifications of the persons in charge can vary widely. EPA defines skill levels from "0" to "3." "0" means that there is no special training but a basic training of the person in charge. "3" means that it is a professional engineer or consultant who is responsible (US EPA et al. 2009).

3. *Sponge City Documentation and Appropriate Data Management*

In the absence of data acquisition and management, preventive maintenance cannot be successfully done. Availability of accurate data is a crucial prerequisite for modern and smart O&M, especially when supported by data processing systems and adapted software solutions. For example, Shao et al. (2016) explain the advantages that comprehensive data integration and its computer-aided application in Sponge City construction can have. Thus, documentation of the existing assets and

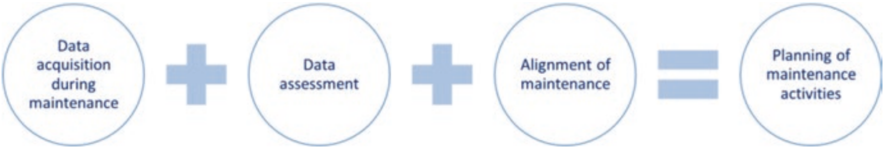

Fig. 20 The cycle of data acquisition, evaluation, and maintenance planning

all operational and maintenance measures carried out is essential. The technical documentation from the construction phase is to be transferred to the operating phase and must be available for planning of maintenance tasks. In this context, any changes made during the construction phase with regard to technical planning must also be entirely documented. The documentation includes, for example, the spatial distribution of the facilities, the actual technical equipment, hydraulic calculations, operating instructions, etc. The documentation or database must be up-to-date and reliable. This means that the condition described in the documents should always correspond to reality. The indicators describing the (age-related) condition of an installation must be continually maintained and refined. In the operating phase, the subsequent data management and planning cycle are made up as follows: data acquisition, data assessment, if necessary alignment of maintenance approaches, and concrete planning of maintenance activities – as visualized in Fig. 20.

In addition to this, Table 1 specifies important data management activities and defines them as essential preparatory work for maintenance planning and implementation.

4. *Maintenance Planning*

The maintenance planning ensures that the chosen approach/strategy is consistently implemented by a robust scheduling and route planning. Based on the collected and evaluated data, a precise and component-specific planning should be carried out. This comprises also a detailed allocation of necessary resources (e.g., staff, funds, spare parts, tools, logistics). Thus, maintenance requires an excellent stock management maintaining the necessary or most frequently used spare parts.

5. *Maintenance Execution*

During the actual implementation of maintenance, the preparatory work described above is thoroughly considered. Thus, implementation includes both routine work and the condition-based tasks. In the Sponge City context, maintenance must ensure constant readiness for operational cases the system was designed for (i.e., extreme weather conditions). This results in an alliance of the following activities: inspection, plant service, and repair and replacement, which are described in more detail in Table 2.

Finally, maintenance will be a core element of Sponge City asset management. Without maintenance the Sponge City approach cannot work in the long run. Performance losses and further potential negative impacts of Sponge City implementation can be massively increased due to insufficient maintenance quality.

Table 1 Important data management activities as preparatory work for maintenance planning and execution

Activity	Subjects
Data acquisition	Ensure data collection which records all data from inspection measures based on the implementation planning and documents the condition of the plants
	Monitoring system, including in particular the following steps:
	Current condition (written and visual documentation)
	Exact documenting structural changes
	Exact documenting maintenance measures
	Regular update of previous records, esp. failure frequency, failure track record, etc.
Data processing tools	Paper documentation
	Modern/electronic data storage including regular backups
	Use of modern software tools such as
	Mapping, geo-referencing by GIS, using (specific Sponge City) layers to combine identical or related space-related objects
	Use of computerized maintenance management system in order to assure a systematic support of maintenance procedures by software solutions
	Integration into building information modeling (BIM) solutions
Data assessment	Data interpretation by queries/targeted assessments
	How extensive are the works?
	How often must this work be carried out?
	What kind of maintenance does each component actually need?
	How can the resources be used as effectively as possible?
	Can imprecise information be dealt with using experience?
Approach alignment	If necessary, flexible adaptation of maintenance approach (i.e., adjustment of inspection intervals, repair needs)

An adapted preventive Sponge City maintenance strategy must consider specific local circumstances (climate, type and frequency of load cases, achievement of further goals such as habitat function and recreational use) with the aim to achieve best stormwater control performance when it is actually needed. The following examples indicate the efforts that will be required for Sponge City maintenance.

4.4 *Examples for Best Maintenance Practice*

The complexity of spongy elements selected in the course of implementing the Sponge City concept varies widely. Alongside simple measures such as sunken green belts in urban streets, there are also much more complex components that collect rainwater, store it temporarily, and qualify it for local reuse by means of (wide) cleaning (see Fig. 9). Below are some examples of what maintenance of individual elements can look like. However, please note that the entire Sponge City infrastructure must be maintained. This means that the necessary work will be

Table 2 Contents of the maintenance implementation

Activity	Description
Inspection	Inspection reveals structural and functional deficits which must be remedied. However, it is best to avoid any damage through repair before a failure occurs. Hence, inspection plays a particularly important role in the context of the preventive maintenance approaches. Inspection serves to record the actual condition and to detect problems needing maintenance attention. A central question that can be answered by means of the inspection is which cleaning requirements exist, i.e., additional or nonperiodic cleansing measures due to outlet blockages, leakages, or (clogged) low-flow conditions. It can also be seen whether any constructional repair work is required due to, e.g., structural damages or rodent activities. In addition, inspection also serves to monitor the success of previously implemented maintenance measures. The maintenance log should describe in detail all the maintenance measures carried out, particularly repair and replacement. It should be stated what types of pollution were found and what type of cleansing was carried out. If (functional) tests have been carried out, the results must be explicitly documented. General and specific observations must also be noted in the log. Another aspect is that not only the water management functionality must be considered but also other functions such as that of an ecosystem. It must be determined which suitable inspection methods are to be used for the eco-components and ecological urban areas
Plant service	Plant service must meet operational requirements. This type of upkeep includes work that serves to maintain functionality but does not constitute repair or replacement measures. In daily practice routine, work includes measures such as cleaning (removing debris/trash), vegetation care (mowing, harvesting, and removal of invasive plants), clearing of blockages and hydraulic obstacles, and sediment and muck removal by means of dredging, fighting rodents, and others
Repair and replacement	The repair of a plant or (broken) system/mechanical components restores a good and functional condition after damage. This includes tasks such as repair of pipes and conduits or the repair of eroded and bare soil surfaces as well as the repair of damages caused by animals. Replacement becomes necessary when a repair is no longer practical or economically favorable. This includes, for example, structural restoration or even structural modifications as well as replacement of components and replanting vegetation

coordinated in such a way that the costs are kept as low as possible by optimizing routes, creating synergies, and through predictive maintenance, improving the lifetimes of the installations and their components. However, the following examples do not replace maintenance manuals, are not complete, and are only used to show the scope of the necessary maintenance tasks. In the following, three examples (of increasing complexity) are provided – also referring to the fields of intervention shown in Fig. 2:

- Pervious pavement (traffic areas)
- Green roofs (communities)
- Constructed wetland (green areas)

These examples show that in addition to hydraulic integrity, the preservation of ecosystem functions also constitutes a significant part of the maintenance work.

Table 3 Activities for maintenance of pervious pavements (NRMCA 2015; Department of Environmental Protection of Montgomery County 2013)

Activity	Specifications[a]
Regular/planned inspection	Monthly visual inspection to ensure that it:
	Is clean of debris
	Dewaters between storm events
	Is clean of sediments
	Annual inspection of the pavement surface for deterioration or spalling
Plant service	Planned/routine debris removal: Work to be repeated at fixed intervals, removal of weeds and vegetation
	Keep the pervious pavement surface free of sediments by blowing, sweeping, or vacuuming
	Condition-based: Vacuum or pressure washing – As necessary
	Maintain upland and adjacent grassy areas
Repair and replacement	Replace pavement
	Seed upland and adjacent bare areas

[a] This list serves to identify examples of maintenance and is not complete

Example 1: Aspects of Maintenance of Pervious Pavement

Permeable/pervious pavement is considered to be an important component for including traffic areas (see Fig. 2) in the Sponge City concept. However, this also results in special requirements with regard to their maintenance. It is obvious that the “drainage capacity of pervious concrete pavements will be greatly decreased once the pores become clogged” (Zhang et al. 2017). In this way, everything that could lead to clogging of the pores must be avoided or remedied. For example, blockage of the pores can be triggered by misuse of abrasives (sanding), by resealing or resurfacing/re-paving activities with non-pervious materials, and by the application of flawed washing/cleaning methods (Department of Environmental Protection of Montgomery County 2013; NRMCA 2015). Furthermore, there is the recommendation to divert “excessive water flow carrying debris towards the pavement” (NRMCA 2015). This reflects the fact that heavy rainfall and urban flash floods can cause a considerable (possibly longer lasting) impairment of the water-permeable coverings. To what extent diversion of solid-loaded water flows will be feasible for citywide applications of porous materials, especially in extreme weather conditions, is still under question.

Water-permeable surfaces require periodic maintenance in order to avoid a (permanent) blockage of the porous structure (Chandrappa und Biligiri 2016). From this, the following essential maintenance activities can be derived (Table 3).

Example 2: Aspects of Maintenance of Green Roofs

The roof greening system consists of numerous components in which together form a multilayered structure. The structure from top to bottom comprises the following layers: “vegetation (landscape materials), growing medium (substrate), filter, drainage material (moisture retention), root barrier, water proofing membrane, insulation layer and structural layer” (Besir and Cuce 2018). The danger of dry periods, even in humid locations, requires robust combinations of vegetation and substrates for a long-term roof function (Johannessen et al. 2017). Green roofs treat exclusively the rainwater from the roof surface. "The increase in green roof area directly and linearly increases the percentage of roof runoff being treated and therefore the overall peak runoff reduction" (Chui et al. 2016). As far as the use of green roofs under difficult climatic conditions is concerned, there are still further points to be clarified. For example, green roof systems which are able to maintain the retention capacity of the roof permanently even in cold and wet regions have so far been largely unexplored (Johannessen et al. 2017).

Besir and Cuce (2018) refer to information on the classification of green roofs according to type of use, design, and maintenance requirements. Maintenance requirements vary depending on the complexity of the design. Extensive green roofs are considered to be low-maintenance, whereas intensive green roof are seen as high-maintenance (Vijayaraghavan 2016). In principle, there is a requirement that extensive green roofs should be as low-maintenance as possible after construction. For another example, the design of the (prefabricated) building materials should be such that a sustainable plant community is supported from the very beginning by means of suitable green roof substrates (Rumble et al. 2018). However, all green roofs require maintenance to ensure that the basic functions remain operative. Silva et al. (2015) distinguish maintenance measures for green roofs into three phases, which are oriented to the requirements of vegetation. The actual maintenance phase begins after the third or fourth year – when the post-implantation phase (1 and 2 years) and maturing phase (2 and 3 years) are completed and the vegetation covers about 90% of the roof surface. Table 4 summarizes (phase-independent) work associated with the maintenance of (intensive) green roofs.

Example 3: Aspects of Maintenance of a Constructed Wetland or Bioretention Pond

Constructed wetlands are particularly designed to fulfill a variety of tasks and objectives, such as improving water quality and urban hydrology, as well as satisfying biodiversity and aesthetics needs. Correct installation and regular maintenance are critical to effective constructed stormwater wetland operation (Hunt et al. 2011). Hunt et al. (2011) also note that many constructed wetlands are unlikely to achieve all their design goals due to lack of supervision and proper maintenance. Constructed wetlands are regarded as resilient systems that, if well designed and sufficiently inspected, can operate efficiently over long periods of time and with minimal maintenance. Thus, even after a longer period of time with regular inspection but only minor plant service, constructed wetlands can offer satisfactory performance in terms of the reduction of peak runoff and also of pollutant removal (Al-Rubaei et al. 2016). Table 5 shows how extensive the inspection and subsequent maintenance tasks can be in the case of constructed wetlands. In this regard, Table 5 highlights regular as well as immediate maintenance activities using the example of a vegetated bioretention system. The frequency of implementation of the regular measures should be condition-based. Immediate action must be taken after all heavy rainfall events.

Table 4 Activities for maintenance of (intensive) green roofs (Kelly Luckett 2009; Vijayaraghavan 2016), completed by own specifications

Activity	Specifications[a]
Regular/planned inspection	*Structural state and hydraulic inspection*
	Inspect drains
	Inspect holes or depressions in soil media
	Ecological check
	Inspect vegetation-free zones
	Inspect irrigation system and moisture levels
Plant service	*Structural and hydraulic care*
	Remove debris
	Care of vegetation
	Hydration – the requested level of irrigation depends on the green roof type
	Fertilizer application
	Weeding
	Invasive species control
	Control of plant pests
Repair and replacement	Repair work on the green roof
	Replacement of components/layers

[a] This list serves to identify examples of maintenance and is not complete

5 Costs for Implementation and Maintenance of Sponge Cities

As far as investment costs are concerned, relatively precise statements can be made. However, only rough estimates can be made for the costs of O&M. Nevertheless, the following is an attempt to estimate the costs of maintenance and to provide initial evidence of the expected costs.

5.1 Investment Costs of Implementing the Sponge City Concept

Rough estimates assume that investments of 100–150 million RMB (EUR 12–19 million) per square kilometer are required for the construction of Sponge Cities. These cost estimates are below the costs actually incurred to date for pilot cities. Li et al. (2017a, b, c) give a city-by-city overview of the scope of the investments for the 30 pilot implementations, resulting in an average investment of 200 million RMB/km^2 (EUR 25 million/km^2). The highest specific investment volume calculated is EUR 53 million/km^2 (Changde), and the lowest is EUR 13 million/km^2 (Jiaxing). Each of the pilot cities receives an annual special grant of 600 million RMB from the central government (for the provincial capital) or 500 million RMB

Table 5 Maintenance tasks for a vegetated basin – specifications based on US EPA et al. (2009), Heal (2014), and US EPA (1999), augmented with own entries

Activity	Specifications[a]
Regular/planned inspection	*Structural state and public safety*
	Access possible or not?
	Can the basin and its function be identified?
	Mechanical elements are functional?
	Damages
	Erosion at shoreline, bare soil
	Broken signs, locks, and other dangerous items
	Debris and trash accumulation
	Hydraulic inspection
	Standing water: Even after longer dry periods, water remains in the basin and is not discharged away
	Inadequate filtration/ponding due to clogged filter surface, pipe leaks, and blocked inlet and outlet as well-clogged underdrains
	Any low-flow orifices
	Any clogged pipes
	Permanent pooling
	Any dry pond areas
	Short-circuiting and deep zones
	Sedimentation buildup/deposition
	Floating debris
	Ecosystem/ecological check/inspection
	General state of vegetation
	Overgrown surface/uncontrolled plant cover
	Wetland plant composition and health: Undesirable/invasive plants, plant diseases
	Irrigation requirements for hydrophytes or obligate wetland species in case of dry conditions
	Health inspection
	Mosquito production, wildlife problems
	After heavy rainfall
	Is the rain event over? Did it cause urban flooding? Did the structure function as planned?
	Has damage occurred? Documentation of the damage and quantification of the necessary maintenance work including immediately required repair

(continued)

Table 5 (continued)

Activity	Specifications[a]
Plant service	*Structural and hydraulic care*
	Remove litter and plant debris
	Complete forebay maintenance and sediment removal when needed: Dredging and muck/sediment removal
	Ecosystem care
	Irrigation (condition-based): e.g., irrigation throughout periods of persistent drought
	Mowing – mow turf areas
	Weeding and pruning
	Harvest wetland plants
	Treat plant diseases
	Remove invasive plants
Repair	*Structural*
	Correction of damaged tank/basin inlets and drains
	Repair of pipe leaks
	Repair of further specific components
	Repair undercut, eroded, and bare soil areas
	Pipe and riser repair
	Vegetation
	Repair of eroded areas
	Remove and replace dead and diseased plants
	Further repair activities: Replace tree stakes and wires if needed
Replacement	*Structural*
	Add new mulch and/or re-mulch void areas
	Removal of the upper soil layer and replanting
	Removal of top 2–3 inches of discolored planting medium and its replacement with fresh mix, when ponding of water lasts for more than 48 hours
	Replacement of specific components – pipe replacement if needed
	Vegetation
	Replant wetland vegetation

[a] This list serves to identify examples of maintenance and is not complete

(for the municipality directly under the central government) or 400 million RMB (for other cities), cf. (MoF). According to this information, the Chinese government's 3-year grants are in principle not sufficient to cover investments alone, such that the cities still must to raise their own funds. In addition, there are other government incentive and reward mechanisms. For example, there is an additional 10% for the realization of public-private partnerships (PPP) and a further 10% for a positive evaluation.

Table 6 Specific capital costs for implementation of individual LIDs (Houle et al. 2013)

Item	LID measure capital cost (US$ per hectare of IC treated)
Porous asphalt	53,900
Bioretention	53,300
Vegetated swale	29,700
Gravel wetland	55,600
Wet pond	33,400
Dry pond	33,400
Sand filter	30,900

*IC treated = impervious cover (IC) treated

If the target for 2030 is to convert 80% of the city areas into a Sponge City in all Chinese cities, the calculated total investment for China amounts to around EUR 1 trillion. This figure is based on a total urban area to be transformed in China of 43,465 km^2 (80% of 54,331 km^2, Area of Built District for the whole of China (MOHURD 2018)) and around EUR 25 million investment volume per km^2 of Sponge City. This magnitude is realistically estimated, as Dai et al. (2017) state that the Sponge City projects will require investments of hundreds of billions of RMB (Dai et al. 2017) and represents a considerable investment for China. For comparison: In Berlin, with a built-up area of 892 km^2, this would result in an investment volume of more than EUR 20 billion. Based on the 3.6 million inhabitants of Berlin, this would correspond to specific costs of almost EUR 6000 per inhabitant. The above area-related figures do not provide information on the costs for individual installations. The absolute costs for a single installation are also not especially meaningful. Only specific costs allow proper allocation. For example, there are specific “unit costs” that indicate the cost per hectare or per square meter of connected urban catchment area. Table 6 lists some examples of specific capital costs for the implementation of individual LIDs.

One cost element that should not be underestimated is the cost of acquiring land. Especially in inner-city locations, the land prices can be high, so that acquisition costs would be extreme. Further cost information has been elaborated in recent works (Joksimovic und Alam 2014; Chui et al. 2016).

5.2 *Cost for Sponge City Maintenance*

As stated above, it is even more difficult to provide generally applicable information in terms of maintenance costs. The costs for personnel and logistics vary greatly. Houle et al. (2013) showed that annual maintenance expenses as a percentage of capital costs ranged from 4% to 19%. The same authors also point out that these estimates may vary, of course, and that economies of scale may arise with larger systems. If such shares are included, substantial costs are incurred, especially when

Table 7 O&M maintenance costs for selected LID elements taken from Houle et al. (2013), ha of IC treated (IC = flow from impervious cover)

Item	US$ per year and hectare
Vegetated swale	2280
Retention pond	7830
Dry pond	6150
Sand filter	7210
Gravel wetland	5550
Bioretention pond	4940
Porous asphalt	2270

looking at the abovementioned investment costs of up to EUR 25 million per km^2. Further examples of costs for individual systems can be found in the literature. For example, the annual costs listed in Table 7 refer to individual LID systems and the connected impermeable or effluent inducing covers in the catchment. Further information concerning costs for O&M of LID items can be found in Chui et al. (2016).

There are repeated references in the specialist literature to the fact that Sponge City maintenance should be lower in cost in comparison to the other urban water systems. Geiger states that "compared with the customary gray infrastructure, not only LID construction and maintenance costs are lower, but also it provides more effective protection for urban environment" (Geiger 2015). There is no convincing argument for this presumption, however. No existing infrastructure will be replaced in the case of Sponge City transformation. In addition to the existing infrastructures, additional costs will be induced. Therefore, cost reductions are not to be expected. It can only be emphasized to keep the unavoidable additional costs as low as possible with the best possible results. In this context, efforts are being made to create self-sustaining structures for O&M of the entire Sponge City infrastructure.

For a several years now, public-private partnership (PPP) has attracted wide interest in China, and there are high hopes for the success of the PPP market. In examining the suitability for such schemes with regard to Sponge City, it is recommended to consider the experiences made so far with PPPs in other countries. Substantial amounts of money are currently being invested in the Sponge City implementation as an additional protection system. In terms of stormwater management, it helps to avoid damage, but it is not necessarily productive. When looking at the growing Sponge City infrastructure, the risk of the cities' authorities being confronted with essential follow-up (O&M) costs is quite high. Thus, the question is, where is the promising PPP business model? Would it also work without lavish incentives and initiatives to attract PPP investments, especially in cases of the state being unable to obtain loans at a lower cost than companies that are active in PPP schemes? The PPP option in association with Sponge City infrastructures is also seen rather critically in the scientific discussion. Considering the fact that PPPs are officially demanded and promoted for Sponge Cities (Jia et al. 2016), it is nevertheless evident that "a business model attractive to the investment from private sector is needed but is currently lacking" (Jiang et al. 2017). Jia et al. (2017) come to the same conclusion by finding that there is "no clear economic incentive for using

LID" in the PPP context. A glance at Germany shows that PPP projects have been criticized for several years now. Most of the former expectations in terms of PPP and more (cost-)effective water services have faded. To put it concisely: PPP has proven not to be thoroughly satisfactory in terms of high-quality public water services. Nowadays, there is an obvious trend to "undo" the PPP projects. In numerous cases the public sector takes over the tasks of public services again by rebuying the infrastructures and taking over O&M responsibilities.

Clear advantages are seen on the economic system side. Jia et al. (2017) state that "under the current economic climate of over-capacity-reduction (in China), the Sponge City projects can offer good business opportunities for manufacturers producing pervious concrete, permeable bricks, infiltration pipes, etc." However, someone must pay for these materials and products. If spongy schemes are also used for rainwater harvesting, then a business idea could emerge there. This requires that the local water management system permits such solutions and does not make it more difficult, for example, due to too low and subsidized fresh water prices. As long as operator models for Sponge Cities have only poor economic prospects, then it is difficult to see which business model could attract private investors. However, the immature nature of the considerations on long-term infrastructure financing entails essential risks. A lacking revenue source can lead to lower efforts to be put in O&M. This could substantially weaken the entire Sponge City system. In the absence of a source of revenue which attracts investors, perhaps the Sponge City should be understood as a pure public service.

6 Conclusions

In recent years, China has undertaken many concrete efforts and high investments in order to promote the Sponge City approach and to galvanize the decision makers to action. Sponge City development is embedded in a realignment of urban development with a strict focus on water. Thus, China aims at shaping water sponging cities to cope with climate change and to especially mitigate negative impacts of extreme rainfalls on urban spaces. In this respect China's efforts have surpassed those of all other countries. The Chinese public strongly supports Sponge City policy (Wang et al. 2017), but there are also high expectations regarding the improvement in flood prevention. The Chinese government's campaign must now find its way to long-term success.

The advantages of green and spongy cities only will develop their full potential if O&M are performed adequately and accurately. It is unfavorable if a maintenance strategy is completely absent and/or maintenance is carried out improperly. Reasons for an immature maintenance strategy can be, for example, a lack of money or even a fundamental misunderstanding regarding the tasks to be fulfilled. The emerging Sponge Cities must be understood as very complex hydraulic systems, which are able to effectively cope with even extreme situations with regard to both the hydraulic loads and nutrient/pollutant loads. The essential investments made for Sponge City implementation also must be safeguarded in the long run by minimizing risk of failure ensuring functional integrity and robustness of the Sponge City facilities. In other words, without maintenance, Sponge Cities cannot work. Maintenance is a core element of asset management. Moreover, simple gardening work is not enough to maintain Sponge Cities. Professional service is required. Adapted preventive maintenance strategies should be pursued comprehensively considering the local circumstances. Should responsible administrations wish to achieve real success, they must consider how to ensure long-term functionality of the entirety of Sponge City assets. In particular, faulty technical design and inaccurate implementation can massively impair performance. Thus, the design review and follow-up remain as critical additional tasks. Technical design is a decisive factor in determining the extent to which future maintenance work will be necessary. In order to minimize future efforts and costs, the findings from previous maintenance activities will be crucial for design modifications or adjustments. The specifications for the technical design must be formulated in such a way that it is not possible to come up with off-the-shelf solutions but rather that the local characteristics are adequately taken into account.

Currently, the forerunners are in the phase of building and construction. A convincing concept for the long-term operation phase should be presented. This includes a clear definition of who pays for the necessary maintenance. Further reasonable financing models must be developed here, which should not consist solely of rough PPP considerations.

If done in this way, there are substantial opportunities offered by maintenance. It stimulates innovation, assures feedback, shows weak points, and enhances reliability. And it is essential for the further development of the approach. Where is all this going to lead? Probably to Sponge City 2.0. The experiences with the implementation of Sponge City are very important to further develop the concept so that finally all expectations may be satisfied. In any case, there is a need for further development of the urban water systems in Sponge Cities in order to find even better answers to the questions arising from the (increasing) occurrence of heavy rainfall events in urban areas. The ambitious goals of coping with heavy rainfall events can only be achieved if large volumes of rainwater storage are available. Perhaps the Sponge City idea subsidizes the climate change gamble through a finally still insufficient approach. Even though the urban area will increasingly be covered with extensive water landscapes – interconnected and serving as large volume interceptors – in addition, suitable interfaces to the (existing) underground infrastructure must be created. Thus, the Sponge City implementation provides reason to improve the entire urban water system. In this regard, the actual aboveground retention capacity determines to which extent potential reserve discharge capacities in the sewer systems must be made available. To maintain long-term performance of a Sponge City demands a completely new type of urban ecosystem service.

Sponge City will also trigger other urban developments. For example, measures are also being taken to mitigate the high level of land sealing that is typical for cities.

Here, the focus is on traffic areas in particular, with the aim of achieving water permeability, e.g., through the use of suitable materials. It can be expected that the Sponge City will be the starting point for further developments that fuel urban transformation. The consistent continuation of the implementation of the Sponge City concept will undoubtedly entail a number of innovations, such as vertical greening of buildings, redesigned traffic areas, and improved interfaces to underground infrastructure. In view of the actual vulnerability of cities, development must be handled with greater care. This means deeper integration into urban development concepts by routine, utilizing new urban areas for implementation. If this is successful and the "proof of concept" is completed, the Sponge City approach can have a profound impact on future urban development and thus play a decisive role in determining the appearance of future cities.

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Future-oriented Strategic Planning of Wastewater Treatment Plants

Nina Manig, Maike Beier, and Karl-Heinz Rosenwinkel

Abstract Current planning situations in Europe and China include upgrading or replacing of existing WWTPs (mainly in Europe) and the construction of new WWTPs (mainly in China). Both planning situations are increasingly confronted with future uncertainties due to high system complexity and rapidly changing conditions. In contrast to this, the long service life of over 30 years and the high capital commitments required lead to entrenched wastewater treatment concepts fixed over decades by the first design decision. In order to complement established WWTP planning methods, a methodology of future-oriented strategic planning focusing on WWTPs is presented in this chapter. The main purpose of this methodology is to define, simulate and evaluate potential long-term technological strategies for a WWTP. The basic steps of the methodology include (i) defining long-term technology concepts and (ii) corresponding transformation paths of a WWTP under different future scenarios. Finally, the methodology allows (iii) an ongoing control of scenario assumptions and (iv) an early support to start adapting the defined long-term technological concepts to current conditions. By this, the methodology will support the finding of robust and economic transformation paths and evaluated construction steps.

1 Introduction

The main questions in the planning and decision-making process of WWTPs are the following: What is an appropriate future treatment concept of an existing or newly built WWTP, and when is the best time to invest in new technologies under rapidly changing conditions to avoid expensive disinvestments? Moreover, what are useful WWTP upgrades or expansions to fulfil all future requirements, and how can these

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expansion steps be controlled and adapted before final decisions on long-lasting technological installations are made? These questions arise for both European countries and China, who are subject to different WWTP planning challenges. In Germany, many of the structural components of existing WWTPs will reach the end of their originally designed lifetimes in the upcoming years. Around 9300 public WWTPs are operated to treat an average daily amount of wastewater of approximately 26.9 million m^3 (in 2013) – this corresponds to 97% of the population being connected to the mostly centralized wastewater system (Destatis 2015). Operators and planners are currently facing the task to upgrade their existing plants and make corresponding long-term reinvestments in the starting investment cycle. In contrast, planning and design of entirely new WWTPs is one of the major topics in urban water management in China. Fast-growing cities and economic growth result in rapidly increasing amounts of wastewater and, therefore, the need to build appropriate wastewater infrastructure to treat it. By the end of 2013, 3508 WWTPs had been built in 31 provinces and cities with a total treatment capacity of 148 million m^3/d (Zhang et al. 2016). The technologies used most often in WWTPs are AAO and oxidation ditches, which together account for over 50% of the existing WWTPs (Zhang et al. 2016).

In both planning situations, challenges arise due to the long service life of around 30 years and the high capital commitments required. Moreover, European countries as well as China are increasingly confronted with higher construction and design risks due to future uncertainties due to high system complexity and rapidly changing conditions in the WWTP environment. These risks are amplified due to the wide variety of already available and innovative technological options, e.g. for extensive carbon recovery and utilization, elimination of micro-pollutants, disinfection as well as the deammonification process for N-elimination.

To integrate long-term future uncertainties in decision-making processes, strategic planning approaches have become more and more popular in various water and wastewater infrastructure projects. Different methodologies, tools and implementations are available in literature, e.g. the "Dynamic Adaptive Policy Pathways approach" (Haasnoot et al. 2013; Kwakkel et al. 2015), the "Regional Infrastructure Foresight method" (Störmer and Truffer 2009) and others (Dominguez 2008; Dominguez et al. 2011; Truffer et al. 2010; Lienert et al. 2006; Henriques et al. 2015). This chapter presents a novel methodology of future-oriented strategic planning, focusing on the decision-making process on WWTP upgrades and expansions. The general idea is to integrate an additional future-oriented strategic planning level as internal controlling process into existing organizational structures of the WWTP operator. In this way, existing traditional WWTP design procedures will be complemented by a more strategic technological perspective. The main goal is to continuously support WWTP operators and local decision-makers in the definition of potential long-term technological directions of the overall WWTP. Moreover, specific transformation paths from the current plant situation to future-oriented technological plant concepts can be defined. The following issues will be addressed in this chapter: (1) overview of traditional WWTP planning methods, (2) main principles of the developed future-oriented strategic WWTP planning process and (3) overview of potential influencing factors.

2 Overview of Traditional WWTP Planning Methods

The existing and established WWTP planning methods enable a detailed technical planning of preselected technological alternatives using state-of-the-art guidelines (e.g. design of activated sludge tanks using the German guideline DWA-A 131 2016) and state-of-the-art technologies. Cost analysis and comparisons of the designed technological alternatives are used as basis for the final decision-making (e.g. German guideline DWA 2011).

Beside investments (as capital costs including depreciation and interest rates), it is of crucial importance to consider operational costs (energy, personnel, materials and effluent charges) in the economic evaluation of different technological alternatives. The significance of operational costs is illustrated in Fig. 1, which contains exemplary annual cost structures of two German WWTPs.

The distribution of annual costs of the two exemplary WWTPs shows that operational costs can vary significantly with treatment concept and location. Although the variations among percentages of operational costs can be wide, capital costs are maintained around 50%, while operational costs are a significant portion of annual costs.

This detailed technical planning process is usually initiated after the identification of a specific planning reason (event-driven planning action). These planning reasons include, among others, the fact that effluent requirements cannot be met anymore or technical components have passed their technical service life. Moreover, the traditional WWTP planning process is completed with the successful implementation of one selected technological alternative (one-time planning action).

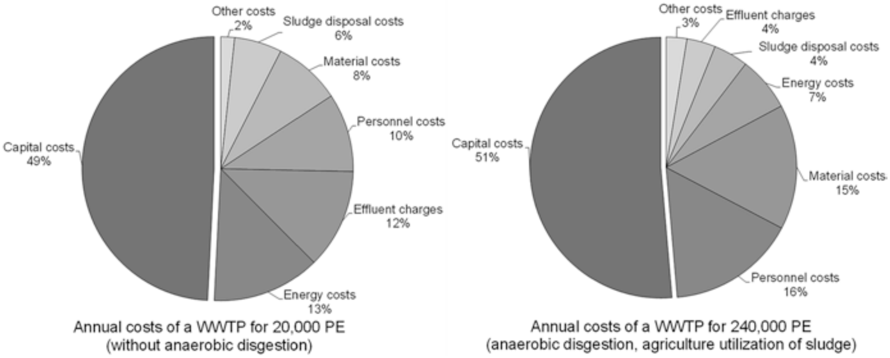

Fig. 1 Exemplary distribution of annual costs of two German WWTPs

The required database of the traditional WWTP planning process usually includes real past and present data received during plant-specific process monitoring. Furthermore, the preselected technological alternatives are usually oriented to the existing WWTP concept (tendency to a more present-oriented planning). The established WWTP planning is traditionally applied as a stepwise design approach that is usually based on point forecasts of specific design parameters including loads and fixed effluent requirements. Figure 2 illustrates the principles of the traditional WWTP planning process.

The traditional WWTP planning process, with its strong orientation towards the current situation, usually favours an adherence to the existing predominant technological system with a tendency to focus on replacement investments. A systematic consideration of potential long-term technology directions that are independent from the current WWTP concept is usually not included in traditional WWTP planning. Therefore, it is difficult to include the wide range of rapidly changing conditions or unexpected future changes in these planning approaches (e.g. changing socio-economic, environmental or political conditions).

Overall, traditional WWTP planning is essential to design and construct technological alternatives in a detailed and comprehensive manner. But to integrate a higher flexibility in the decision-making process and a long-term planning perspective considering the increasing future uncertainties, additional methods are needed to support WWTP operators and planners. This is especially important as WWTP operators and local decision-makers in European countries and particularly China are increasingly confronted with uncertain planning conditions that require a more flexible approach.

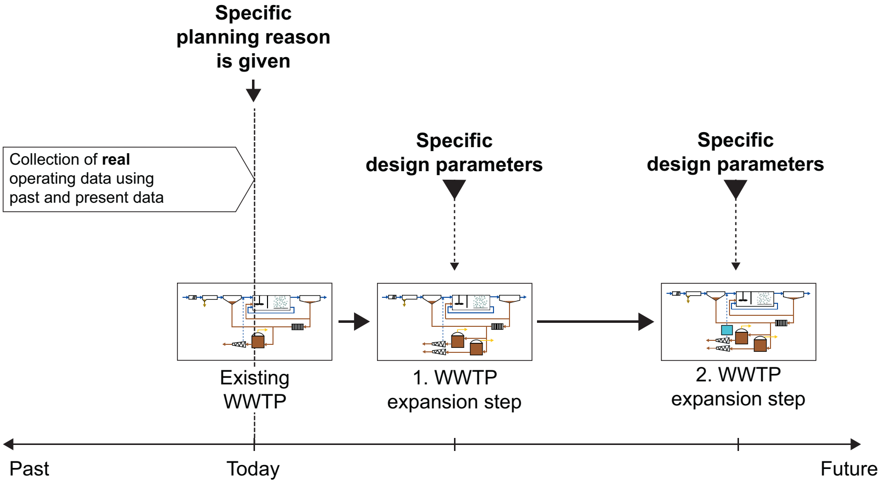

Fig. 2 Principles of traditional WWTP planning. (According to Manig 2018)

3 Main Principles of a Future-Oriented Strategic Planning Process

The developed methodology of future-oriented strategic WWTP planning can be seen as a supplement to existing traditional WWTP planning approaches. The main goal is to continuously support WWTP operators and planners by integrating a more future-oriented planning perspective in their decision-making processes. This means that broader long-term visions of possible technical future concepts of a specific WWTP are systematically integrated in the decision-making process considering a wide range of possible future uncertainties. In general, the methodology is a plant-specific planning process addressing individual catchment characteristics as well as local conditions of a specific WWTP. This is important, as these characteristics and conditions are strongly regionally dependent and WWTPs in different locations will face different future developments and challenges.

The main principles of the future-oriented strategic WWTP planning process are illustrated in Fig. 3. The definition of future-oriented WWTP expansion strategies independent from the current plant situation is of significant importance in this methodology. These WWTP expansion strategies include on the one hand different potential long-term technology concepts and on the other hand specific transformation paths acting as bridge between the current WWTP and potential future con-

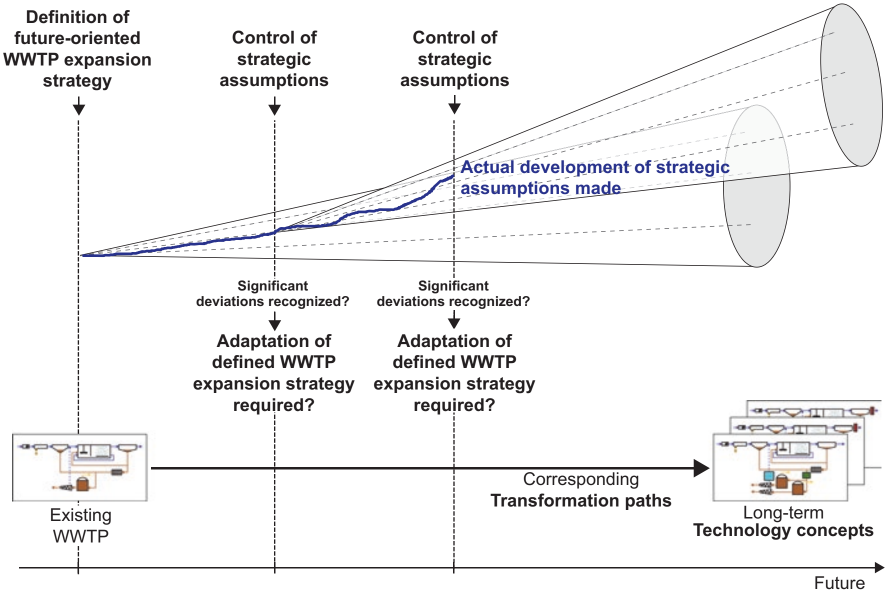

Fig. 3 Principles of future-oriented strategic WWTP planning. (According to Manig 2018)

cepts. Instead of taking into account a single point forecast, a wide range of possible future developments at catchment and global scale (as scenario funnel) are considered in the planning process as strategic assumptions. The methodology allows for an ongoing control of these assumptions and an early adaptation of the defined long-term technological concepts to current conditions before starting the construction of a WWTP upgrade or expansion.

As basis for the developed methodology, already established strategic management methods mainly developed for commercial companies are used (e.g. Götze and Rudolph 1994, Krystek and Müller-Stewens 2006). However, some of the basic principles have been adapted to the special situation of wastewater treatment infrastructures. As the methodology of future-oriented strategic WWTP planning can be seen as a continuous and forward-looking planning and controlling process (see also Beier and Manig 2017; Manig et al. 2018), the major steps form a control loop that is presented in Fig. 4. Beside this control loop, the interfaces between the superordinate strategic planning level and the traditional WWTP planning methods are illustrated.

The main output of the strategic WWTP planning process is the continuous analysis of potential future-oriented WWTP technological directions of a specific WWTP under different future scenarios. In addition, specific recommendations on the next WWTP upgrade or expansion step can be derived to support the traditional WWTP planning process.

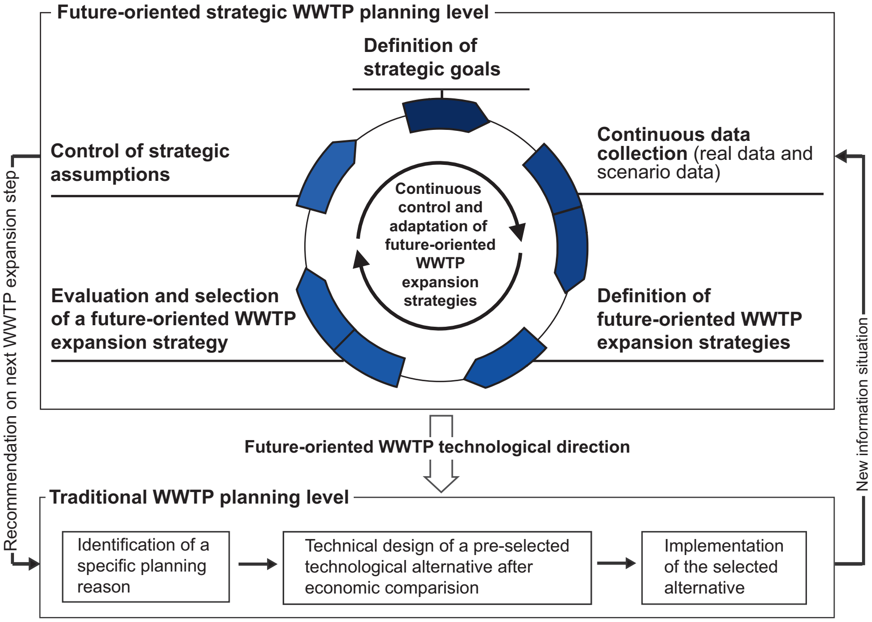

Fig. 4 Major steps of the future-oriented strategic WWTP planning level as complement to the traditional WWTP planning process. (According to Manig 2018)

The major steps of the control loop are explained briefly in the following:

1. Definition of strategic goals

In this step, long-term objectives which the WWTP aims to achieve in the next decades are defined. These strategic goals directly determine the criteria for the evaluation of future-oriented WWTP expansion strategies. For example, a strategic goal can be an increasing overall economic efficiency of the future WWTP. Hence, minimum annual costs consisting of investment and operational costs are identified as evaluation criteria. Beside economics, possible strategic goals could include increasing energy efficiency by minimizing the external energy demand.

2. Continuous analysis of real and forecast data

In this step, the basis for continuous collection and processing of planning data and assumptions required in the strategic planning process is provided. This includes real data and information on the specific WWTP to describe the current WWTP and catchment situation including, for example, available technologies, WWTP inflow conditions, but also the current cost situation. On the one hand, this real data is used as basis to develop scenarios for potential future developments at catchment or global scale. On the other hand, real data is required to compare the actual situation with strategic assumptions made during the controlling process. Besides real data, it is of crucial importance to provide appropriate forecasting data describing potential future developments (using scenario planning). For scenario planning, the main influencing factors in a specific region must be identified, and their future development must be predicted.

3. Definition of future-oriented WWTP expansion strategies

In this step, potential future-oriented WWTP expansion strategies are defined. Based on developed scenarios, potential long-term technology concepts that are independent from the current WWTP concept must be developed based on expert knowledge. Moreover, the WWTP expansion strategies include specific transformation paths acting as bridge between the current WWTP and their potential future concepts. These transformation paths describe the chronological order in which the selected technologies should be introduced and implemented. To integrate already established or innovative technologies in the strategy formulation and evaluation (see next step), it is necessary to collect and document relevant technical and economic information on potential technologies in the form of "technology profiles". These "technology profiles" include information such as specific energy consumption and necessary specific investment costs of the technology.

4. Evaluation and selection of defined WWTP expansion strategies

In this step, the defined WWTP expansion strategies must be evaluated based on the defined evaluation criteria (see first step) and the strategic assumptions made (see second step). In order to estimate the evaluation criteria of each WWTP expansion strategy under different scenarios, a simplified plant-wide mass balancing/design model is utilized. This simplified model must be extended by a rough dimensioning of all considered technologies. Furthermore, a cost estimation tool is required in order to calculate cost effects of strategies as one major input criterion for the evaluation process. It is of crucial importance to keep the model as simple as possible as there can be a wide variety of possible strategies and future developments, and, hence, a higher number of required simulation runs.

5. Continuous control of strategic assumptions

The final step of the control loop describes the continuous control of the selected future-oriented WWTP expansion strategy. This step is critical as it allows an ongoing control and early adaptation of the selected WWTP strategy according to future changes, before the design and construction planning of a next WWTP expansion step begins. A careful and systematic scanning of the main strategic assumptions is needed in order to identify whether it is reasonable to continue to pursue the selected strategy or reject it due to expected changing conditions.

Table 1 summarizes the main characteristics of both planning principles, the traditional and the future-oriented strategic WWTP planning. A significant difference of both planning procedures is the overall reason for planning. Traditional planning is usually a noncontinuous process with the clear objective to plan and design appropriate technology alternatives. It ends with the final decision for one alternative and its realization. In comparison, the methodology of strategic planning can be seen as a continuous process which encourages WWTP planners and operators to constantly focus on possible long-term technology options for the specific WWTP.

Table 1 Characterizations of future-oriented strategic WWTP planning compared to the traditional design and construction WWTP planning

	Future-oriented strategic WWTP planning	Established WWRP design and construction panning
Planning purpose	Continuous understanding and adaptation of potential long-term technological WWTP directions	Plan and design of WWTP technology alternatives and final construction of one alternative
Planning reason	Identification of planning reasons	Specific planning reason is given = event-driven planning
Planning process	Proactive	Tendency to reactive
Planning frequency	Continuous process: Frequency repeated to control and adapt long-term WWTP strategies to future changes	One-time planning action: Planning process ends with the final decision
Forecasting principles/Future uncertainties	Scenario technique with ongoing control and adaptation of assumed future developments	Point-forecast of load parameters and fixed effluent requirements
Level of detail	Rough dimensioning and cost estimation of developed future-oriented strategies	Detailed dimensioning and economic evaluation of technology alternatives
Considered technologies	Wide variety of established and new WWTP technologies and treatment concepts	Limited number of mainly established WWTP technologies

In this manner, the strategic planning highlights resulting technological and economic consequences due to changing future developments in the specific catchment and global environment. The longer time horizon of strategic planning and the wide range of possible future developments in terms of technology options or catchment conditions allow WWTP planners and operators to gain a deeper understanding of existing or newly created technological path dependencies.

4 Overview of Potential Influencing Factors

In the second planning step of future-oriented strategic WWTP planning (Step 2: Continuous analysis of real and forecast data), it is of crucial importance to identify relevant influencing factors and their potential future developments using scenario analysis. These influencing factors are used as “warning” indicators for ongoing control of selected future-oriented WWTP expansion strategies and the assumptions made therein. If a warning indicator is no longer within the assumed range, then the recommendation on the next WWTP expansion step must be adapted. Generally, influencing factors and their corresponding critical values are highly plant-specific depending on the existing WWTP concept and catchment situation, the predefined strategic goals and the selected long-term technology concept.

Figure 5 shows a schematic view of both (1) key parameters of the traditional WWTP design and construction process including investment and operational costs of defined technology alternatives for economic evaluation and (2) additional exemplary influencing factors that should be integrated in the strategic WWTP planning process.

The uncertain influencing factors of the strategic planning process can be classified into two major categories. The first category includes future trends in the specific catchment area, e.g. social, economic and environmental conditions as well as possible infrastructure management measures. These future trends have a significant impact on future WWTP inflow volumes and composition, which in turn influence the required WWTP technologies and their dimensions (investments) and the plant performance including operational costs. The second category includes future trends of the global environment such as political and legal standards as well as technical and financial conditions. Further requirements as well as rising concerns over scarce resources can also lead to changing design values. Conditions in the catchment area and global environment are highly dynamic, and some of them may change drastically over long WWTP lifetimes, for example, population development due to demographic change or the number of extreme rainfall events as a result of climate change. Because the number of influencing factors can be huge, it is crucial to reduce the number to only consider the dominant parameters by prioritization. Dominguez et al. (2006) take a first step in the development of a method to guide the practitioner through the identification of project-specific driving forces.

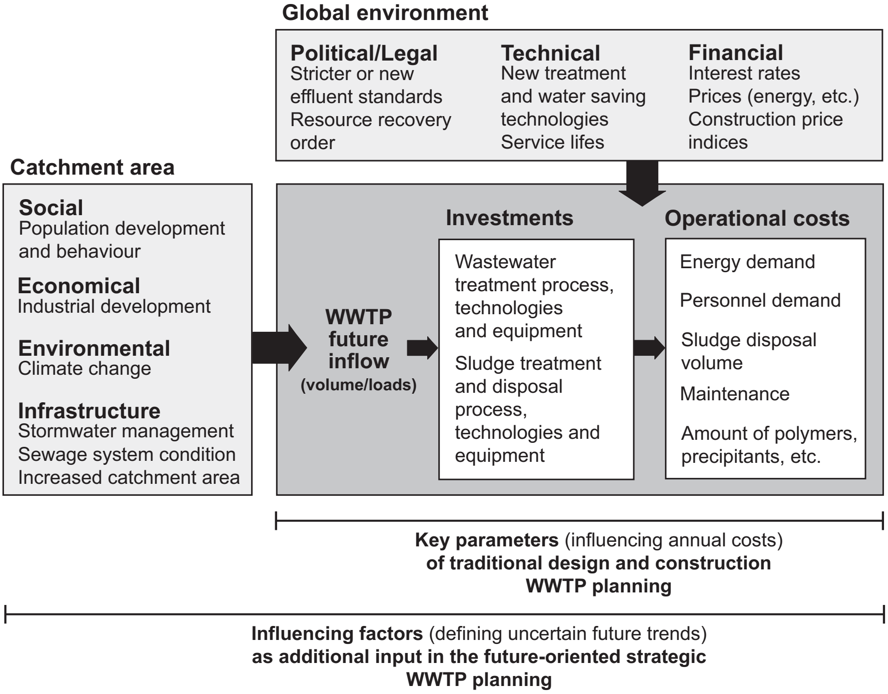

Fig. 5 Examples of required key parameters for traditional planning processes and influencing factors for future-oriented strategic planning

5 Summary

This chapter presents a brief overview of the developed methodology of future-oriented strategic planning, focusing on WWTP upgrades and expansions. The continuous planning and controlling process should be implemented as an additional superordinate planning level in already existing organizational structures of the WWTP operator. The implementation can be time-consuming and can vary with the plant operator as responsibilities must be clarified and internal planning processes adapted. To evaluate potential long-term technology concepts, a simplified plant-wide mass balancing/design model is required. Moreover, there is a need to build up a systematic data management system to manage the required databases of real and forecast data.

Overall, the developed methodology can be seen as a new approach before the detailed traditional WWTP design and construction planning phase begins. The idea of the methodology is to continuously support WWTP operators and planners in their long-term investment decisions by getting a deeper understanding and transparency of long-term investment consequences and technological path dependencies.

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Part II
Innovative Technologies and Implementation: Drinking Water Supply

Urban Drinking Water Challenges and Solutions: Energy Nexus

Kate Smith, Ying Liu, and Shuming Liu

Abstract The water-energy nexus describes the connection between water and energy. Here we focus on energy for water supply to urban areas of China. Electricity use is one of the main costs for water companies and tends to be the main source of greenhouse gas emissions during water supply. In a country where reducing energy use and emissions is now an important part of the national agenda, managing energy use will become a major focus for the water industry. This chapter provides an overview of energy use at each stage of water supply in China: sourcing and transfer, water treatment, central distribution, and distribution within high-rise buildings. We then focus specifically on water distribution, which is a major energy user, and use statistical data from four cities in China and Japan to draw conclusions on how city layout affects the energy needed to supply water.

1 Introduction

The water-energy nexus is a term used to describe the connection between water and energy. The number of studies focusing on this topic has increased over the past decade in China. One side of the nexus is *water for energy*, meaning water consumption as a result of energy production and capture. Energy is a large water user, particularly in a country like China where most electricity is produced by coal-fired power stations which require large volumes of water for cooling. The other side of the nexus is *energy for water*, meaning energy consumption throughout the water cycle. Transferring water from the source to the water treatment plant, treating water to potable standards, distributing water from the treatment plant to the user, and treating the resulting wastewater all require energy for pumping, aeration, or other processes.

This chapter focuses on energy for water supply and provides an introduction to the energy requirements of water supply to urban areas of China. In China many

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cities are affected by water scarcity, and contamination of water bodies is a major problem. As such, the main priorities for the Chinese water sector have been to assure that demand and quality standards are met. But electricity use is one of the main costs for water supply companies and tends to be the main source of greenhouse gas emissions during water supply. In a country where reducing energy use and emissions is now an important part of the national agenda, managing energy use will become a major focus for the water industry.

The chapter consists of two sections. The first section provides an overview of energy use at each stage of water supply in China: sourcing and transfer, water treatment, central distribution, and distribution within high-rise buildings. The second section focuses specifically on water distribution, which is a major energy user in water supply. We use statistical data from four cities in China and Japan to draw conclusions on how city layout affects energy consumption for water supply within cities. We consider the impact of various spatial factors on energy use for municipal water supply, secondary water supply (i.e., pumping within high-rise buildings), and overall energy use for water supply.

2 Energy Use for Water Supply to Urban Areas of China

Electricity use is a major cost for water companies and one of the main sources of greenhouse gas emissions from the water sector in China. This section discusses energy use for water supply for both conventional water sources (groundwater and surface water) and alternative water sources (desalination, wastewater reclamation, and water transfer), which account for an increasing percentage of water usage in China, and provides suggestions for reducing energy use for water supply.

2.1 Energy Use for Water Sourcing and Transfer in China

There are three main origins of freshwater in China: locally sourced surface water, locally sourced groundwater, and surface water transferred from one province to another.

Of total freshwater withdrawals, the majority (around 80%) is withdrawn as surface water, with the remainder groundwater (Food and Agriculture Organization 2016). Groundwater use is most common in the north of China, where surface water resources are limited and demand is large. For example, as shown in Fig. 1, only 6% of water used in Beijing is local surface water, whereas 46% is local groundwater (Beijing Bureau of Statistics 2016). Surface water is the main water source in the south, where water is generally more plentiful. Around 95% of water used in Guangzhou is surface water (Guangzhou Water Authority 2015).

Abstraction of groundwater tends to require more energy than surface water due to the requirements of pumping water against gravity. In Beijing, where almost half

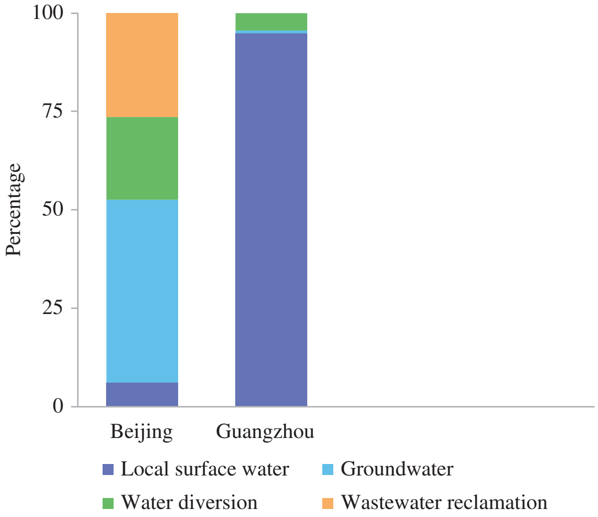

Fig. 1 Water sources used in Beijing (northern China) and Guangzhou (southern China) in 2015. (Figure source: Smith et al. 2018. Data source: Beijing Bureau of Statistics 2016; Guangzhou Water Authority 2015)

of water used is groundwater, sourcing and treating processes are estimated to account for around 37% of total energy for sourcing, treatment, and distribution (Smith et al. 2017). By comparison, in the southern city of Changzhou, where almost all water used is surface water, sourcing and treating water are estimated to account for only 4% of total energy for sourcing, treatment, and distribution (Zhou et al. 2013).

China has a number of major installations which transfer water between provinces, and two main factors influence the energy used during transfer, namely, the distance over which it is transferred and the need for vertical pumping during transfer. In particular, the need to lift water against gravity is a major energy burden. For example, water delivered to cities along the Eastern Route of the world's largest long-distance transfer, the South-North Water Transfer Project, must be raised around 65 m during the transfer process. This is the difference in elevation between the source in the south and Dongping Lake, which water passes through on the way to northern cities like Qingdao (Wen et al. 2014). Each cubic meter of water transferred along this route to major northern cities like Jinan and Qingdao consumes over 1 kWh of electricity (Li et al. 2016). This is more than three times the total average energy required to source, treat, and distribute water in Chinese cities (0.29 kWh/m^3) (Smith et al. 2015). Qingdao receives water from the Yangtze River through the South-North Water Transfer Project and water from the Yellow River through another transfer project that uses an estimated 0.696 kWh/m^3 for transfer and treatment. Water from the Yellow River is lifted over 30 m and travels 290 km during the transfer process. Both transfer projects require more energy for sourcing and treatment than with local surface water, which uses 0.426 kWh/m^3 (Wen et al. 2014).

Water transfer that takes advantage of gravity requires little in the way of operational energy. An excellent example is the South-North Water Transfer Project Middle Route, which uses minimal energy to supply cities like Beijing and Tianjin with water: around 0.05 kWh/m^3, not including treatment (Li et al. 2016). Gravity transfer was made possible for the Middle Route by engineering the height of Danjiangkou reservoir (source dam) so that the original water level rose by 13 m (Barnett et al. 2015).

The distance between the source and the water treatment plant also affects energy use, although to a lesser extent than elevation. Tianjin, for example, is estimated to require slightly more electricity for water transfer along the South-North Water Transfer Project Middle Route than Beijing due to the greater pumping distance (Li et al. 2016).

Energy for water transfer as discussed in this section only considers operational energy and does not include energy embedded in construction. In general, an enormous amount of energy goes into the construction of water transfer projects. This energy is used both directly (e.g., to run machinery during construction) or is embedded in materials (e.g., in the extraction of materials) and is not included in energy figures from daily operations. The South-North Water Transfer Project Middle Route may require little in the way of operational energy but it is made up of over 1000 km of canals, the construction of which required an enormous amount of energy (Kahrl and Roland-Holst 2008).

2.2 Energy Use for Water Treatment in China

The energy involved in treating water for use in China depends on the water source. Most groundwater and surface water can be conventionally treated. As a result, water treatment tends to be a low energy process compared to sourcing and distribution. If seawater or wastewaters are used as source water, water treatment costs increase dramatically and can be the largest contributor to total energy use for water supply.

Groundwater and surface water is often treated using a combination of coagulation, sedimentation, filtration, and disinfection (mostly with chlorine) (Ye et al. 2009; Zhang et al. 2016). Data on energy use for individual processes is not openly available in China, but energy use for each process is likely less than 0.03 kWh/m^3, according to data for the United States (Plappally and Lienhard 2012). The energy demand for treatment is estimated to account for only 1% of the total energy used for water supply in Changzhou, where most water is sourced from the Yangtze River (see Fig. 2) (Zhou et al. 2013).

The energy required to treat water transferred from other provinces tends to be similar to the energy required to treat local groundwater and surface water because the same standard treatment processes are used. For example, water transferred to Beijing from Hebei province is treated in Beijing's Ninth Drinking Water Treatment

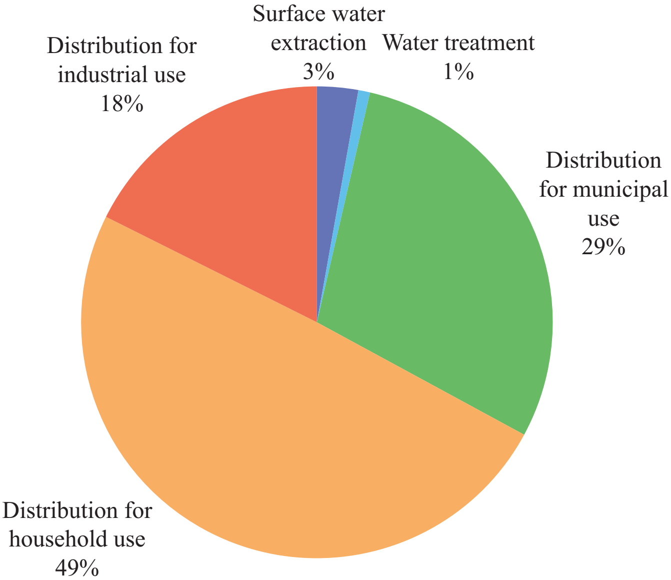

Fig. 2 Energy use for centralized water supply in Changzhou. (Data source: Zhou et al. 2013)

Plant using coagulation, sedimentation, filtration, and disinfection, with one main additional process (granular activated carbon adsorption) (Can et al. 2013).

Seawater desalination is not yet widely used in China, but its use is increasing. It can constitute less than 5% of total water consumption in cities where it is used (Li et al. 2016). Reverse osmosis is the main technology used to produce desalinated water in China (65% of capacity) (State Oceanic Administration 2016) and tends to use less electricity than other common desalination technologies. Electricity required to run seawater reverse osmosis (SWRO) in China varies between 3.30 and 5.20 kWh/m^3, according to values available in the literature (Li et al. 2016; Zheng et al. 2014). Multi-effect distillation is the other major desalination technology in China and is more energy-intensive than SWRO. See Fig. 3 for examples of electricity use for SWRO (for the real case of Qingdao and an estimation for Jinan) and multi-effect distillation (for Tianjin and Beijing).

Wastewater is often used as a source of water in China, particularly in northern cities. The percentage of urban wastewater that is reused has increased from around 8% to over 9% between 2014 and 2015 (Ministry of Housing and Urban-Rural Development 2015; Ministry of Housing and Urban-Rural Development 2016). The energy to recover a cubic meter of usable water from wastewater depends on the size of the wastewater reclamation plant, the wastewater composition, and the treatment processes used, which can be linked to the intended use of the reclaimed wastewater. For a selection of four plants generating reclaimed wastewater for major northern cities, electricity use varies between 0.95 kWh/m^3 and 1.23 kWh/m^3

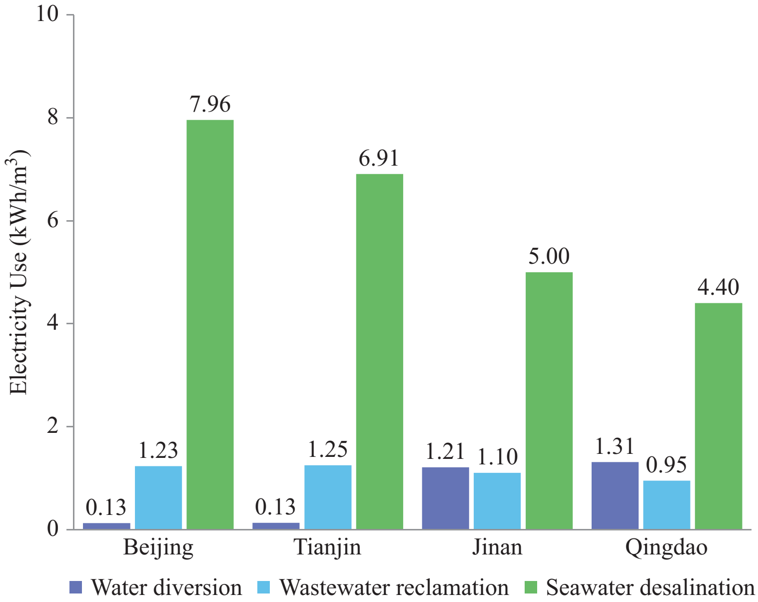

Fig. 3 Electricity use for transfer, reclamation, and desalination for four northern cities in China. Beijing and Tianjin receive water from the South-North Water Transfer Project Middle Route, and Jinan and Qingdao receive water from the Eastern Route. (Figure source: Smith et al. 2018. Data source: Li et al. 2016)

(Li et al. 2016). This includes sewage collection and all wastewater treatment stages (i.e., primary, secondary, and tertiary) (Li et al. 2016).

2.3 Energy for Distributing Centrally in Cities

The main energy users during water distribution within cities in China are pumping systems. Regulations in China recommend that a minimum of 28 m of head be maintained at all points within municipal water distribution systems (Ministry of Housing and Urban-Rural Development 1999). Pumping systems at the outlet of water treatment plants or in booster stations located within the city are responsible for maintaining this pressure. As a result, central distribution often accounts for a major percentage of the total energy for central water supply (i.e., sourcing, treatment, and central distribution) within a city. For example, it is estimated to account for 44% of energy used for sourcing, treatment, and central distribution in Taipei and 96% for Changzhou (Cheng 2002; Zhou et al. 2013). In Beijing, distribution requires approximately 0.19 kWh/m^3, or 63% of total energy use for central water supply (Smith et al. 2017). On the other hand, when gravity distribution is possible, energy use for distribution can be reduced (Wu et al. 2015).

2.4 Energy for Pumping Water Within High-Rises

Water required by residents living above six stories must be pumped using a separate on-site pumping system. The pressure provided by the central distribution system is not sufficient to reach these floors.

Three on-site pumping systems are commonly used in high-rise buildings in Chinese cities. The first of these is a roof tank system, in which water enters the building from the central water distribution system, is pumped to a break tank on the roof of the building (usually by a constant speed pump), and then reaches the user by gravity. Roof tanks are progressively being replaced in Chinese cities due to concerns over water quality and security, so energy values mentioned in this chapter focus on the following two systems. The second system is a booster pump and break tank (BPBT) system, in which the break tank is located at the base of the building. Water from the central distribution system enters the break tank, where it is stored at atmospheric pressure. It is pumped from the break tank to users on upper floors using a variable speed pump. The third system is referred to as an entirely pressurized booster (EPB) system. The configuration of this system is almost the same as the second system, but the break tank is replaced by a small pressurized tank. Water that enters this tank with a particular pressure does not lose pressure; instead water remains pressurized and the energy it contains is retained. The variable speed pumps that lift water to users are then able to build on the pressure already provided by the central distribution system.

The entirely pressurized booster system tends to use less electricity than the BPBT system (see Fig. 4) (Smith et al. 2017). Based on a sample of nine entirely pressurized booster systems and five BPBT systems located in ten residential buildings, the former uses 0.010 ± 0.001 kWh/m^3·m, around 45% less energy on average than the latter (0.019 ± 0.005 kWh/m^3) (Smith et al. 2017). A comparison of the two pumping systems within a building complex (maximum height 17 stories) showed a significant decrease in energy after a change in pumping system. The electricity use for a flow of 668 m^3 was originally 699 kWh but decreased by 52% to 336 kWh when the original BPBT system was replaced with an entirely pressurized pumping system (Smith et al. 2017).

The difference in energy use between these two systems is largely due to the difference in tank components of the two pumping systems. The break tank component of the break tank and booster pump system loses much of the pressure contained by water entering from the water distribution system. For example, if water enters a high-rise building with 28 m of pressure, this pressure will be lost when the water enters the break tank and must then be added again by the variable speed pumps. On the other hand, the pressurized tank in the entirely pressurized booster system stores water at the pressure at which it enters, meaning that variable speed pumps only need to build on this pressure in order to lift water to users. It should be noted that another factor influencing the difference in electricity use between the two systems is pump efficiency. In other words, certain pumps may have been better fitted to water demand within the building and work at greater efficiency (Smith et al. 2017).

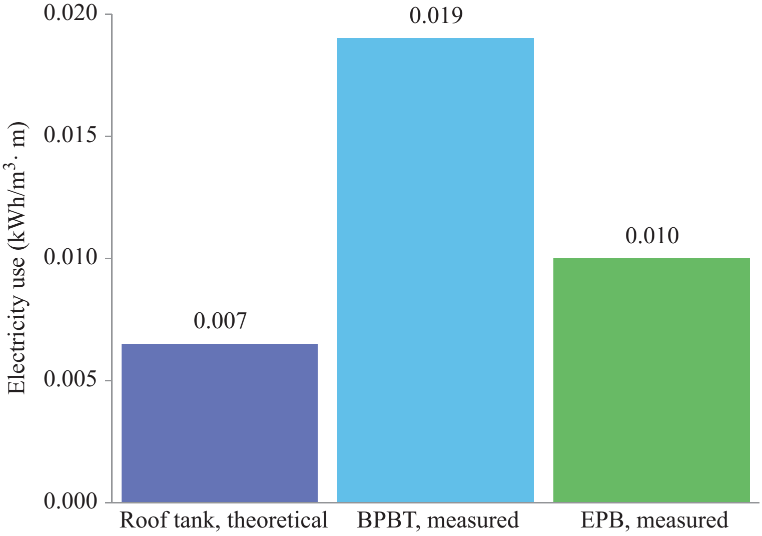

Fig. 4 Electricity use for three pumping systems commonly used in China to distribute water within buildings. (Data source: Cheng 2002; Smith et al. 2017). *BPBT* booster pump and break tank, *EPB* entirely pressurized booster. The theoretical value for the roof tank system was calculated by normalizing the value 0.14 kWh/m^3 provided by Cheng (2002) by the lift of the pumps (21 m)

2.5 Comparison of Energy Use Along the Water Supply Process and Suggestions on Reducing Energy Use

The main energy user within conventional water supply in urban areas of China is generally distribution. This includes distribution within the central distribution system and distribution within buildings. By contrast, treatment of surface water and groundwater is generally the smallest energy user within the conventional water supply process.

To supply water to people living in high-rise buildings, pumping water over the last 50 or so meters (i.e., within the building) uses the most energy. For example, in the hypothetical situation of a 20-story building in Beijing, pumping within the building using a BPBT system would account for around 80% of the total energy required to source, treat, and distribute water (see Fig. 5) (Smith et al. 2017). This estimation uses data for sourcing, treatment, and central distribution from Beijing water treatment plants and data on water distribution within ten high-rise buildings, both in Beijing and other Chinese cities (Beijing Waterworks Group 2013) (Smith et al. 2017).

Within major cities, distribution within buildings can account for a significant part of total energy consumption for water supply. Based on extrapolation of census and water supply data, it is estimated that 9% of the total urban population in China lives on floors 7 and above and that the electricity to supply water to these people (including sourcing, treatment, central distribution, and distribution within their buildings) accounts for 32% of total electricity use for water supply to urban areas

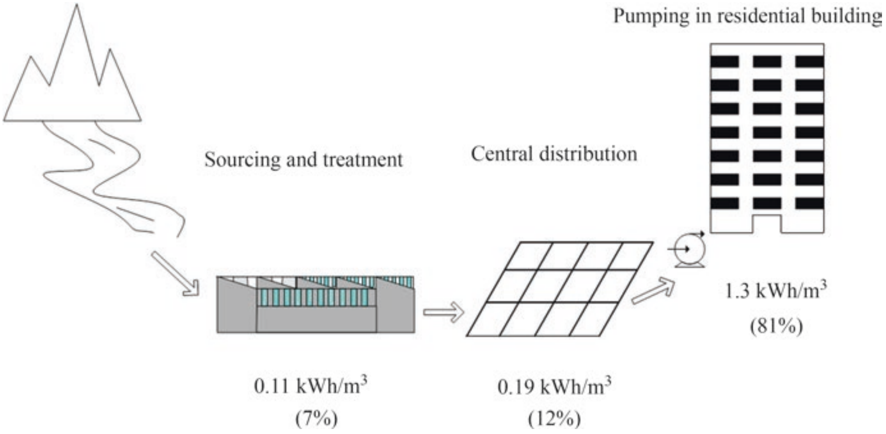

Fig. 5 Electricity use for water supply to a hypothetical 20-story building. (Figure source: Smith et al. 2017)

(Smith et al. 2017). In other words, the small percentage of people living in high-rise buildings can be responsible for a disproportionately large percentage of electricity use for water supply within cities.

Since water distribution in high-rises is a major energy user within the urban water supply process, this step should be targeted to reduce overall energy use, particularly since increasing rates of urbanization and high-rise habitation will likely exacerbate the problem. The number of Chinese families living in buildings of seven stories or higher more than doubled between 2000 and 2010 (National Bureau of Statistics 2010). This trend looks likely to continue into the future, when China's urban population increases to an estimated 60% of total population by 2020. As mentioned earlier in the chapter, use of entirely pressurized pumping systems can significantly reduce energy use within residential buildings. While this system is not suitable for use throughout the entire water distribution system, use in a portion of buildings of seven stories or higher is feasible (Smith et al. 2017). As an example, if this system is used instead of break tank and booster pump systems to meet 25% of demand for pumping within residential buildings, the savings would equate to around 3% of total daily electricity use for water supply to urban areas of China (Smith et al. 2017).

To cut energy use in the remainder of the water supply system, leakage should be a focus. Water that leaks out of distribution systems is not only a waste of water – it is also a waste of energy. Leaked water requires energy for sourcing, treatment, and distribution, but does not meet consumer demand. Provinces of China with higher leakage and loss rates tend to use more electricity for urban water supply as a percentage of total provincial electricity use. For most provinces, combined leakage and loss (including physical leakage, meter failure, and theft) is between 10% and 30% of total water supplied (Smith et al. 2015), meaning there is likely still significant room for leakage reduction.

When alternative rather than conventional water sources are used to meet water demand within cities, energy for treatment or sourcing can exceed energy for distribution. For water transferred against gravity via long-distance pumping (as in the example of the South-North Water Transfer Project Eastern Route), sourcing tends to be the major energy user in the water supply process. Thus, incorporating gravity into water transfer is ideal, albeit not always possible. Engineering a water transfer project to use gravity may also require significant public sacrifice: gravity transfer via the Middle Route was made possible only through the relocation of hundreds of thousands of people (Barnett et al. 2015).

When seawater or wastewaters are used as source water instead of groundwater or surface water, energy for water treatment increases and can be the largest contributor to total energy for water supply. Figure 3 shows values for reverse osmosis and multi-effect distillation for four northern Chinese cities. These values are much higher than other alternative water sources and many times higher than the average total energy for sourcing, treating, and central distribution in China (0.29 kWh/m^3) (Smith et al. 2015). Energy use can be reduced through energy recovery during the reverse osmosis process (Deng et al. 2010) and through use of waste heat from thermal power plants or iron and steel industries during the multi-effect distillation process (Deng et al. 2010; Ma et al. 2012, Zheng et al. 2014). However, even with energy recovery, desalination is still a very energy-intensive option in China. Reclaimed wastewater is generally a less energy-intensive option than seawater, although treatment energy is usually still greater for freshwater, particularly if the energy for secondary and primary treatment of wastewater is included and energy is not recovered during the wastewater treatment process.

Figure 3 shows the energy required for complete wastewater reclamation for a Beijing plant (1.23 kWh/m^3). Figure 5 shows that central distribution of this water requires, on average, much less energy (0.19 kWh/m^3).

3 Impact of Urban Spatial Characteristics on Energy Use for Water Supply

3.1 China's Urbanization and Construction of Water Distribution Networks

China has undergone rapid urbanization since the end of the twentieth century. In 2000 the urban population was 485 million and the urbanization rate was 36.2%; the urban population then grew by over 200 million between 2000 and 2010. In 2011, the urbanization rate reached 51.3%; as of 2015, it had reached 56.1% (National Bureau of Statistics 2001).

Water supply is the lifeline of a city and occupies a vital position in urban planning and construction. During China's rapid urbanization, the construction of water distribution networks (WDNs) has increased to meet new demands. In 2001, the total pipe length for urban water supply was 188,987.79 km; pipe length reached 500,266.59 km in 2014, an increase by a factor of 2.6 (China Urban Water Association 2002).

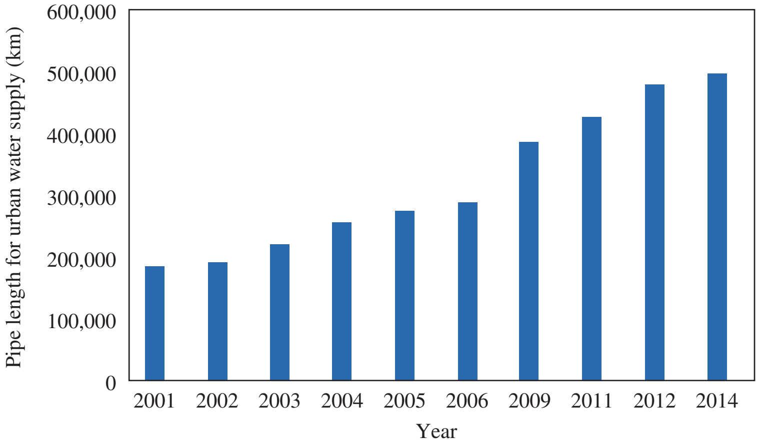

Fig. 6 Development of pipe length for urban water supply in China

Figure 6 shows the development of pipe length for urban water supply in China. The design of WDNs must consider population, water demand, water pressure, pipe length, diameter and material, spatial layout, and other factors (People's Republic of China 2016). Once WDNs are constructed, it is difficult to make significant adjustments or upgrades because networks are belowground and upgrades interrupt supply. Therefore, WDNs should be efficiently designed from the beginning.

3.2 Energy Use for Water Supply

Urban water abstraction, treatment, and distribution consumed an average of 0.29 kWh/m^3 and 33.2 kWh per capita in 2011, for a total of 10.36 TWh of electricity, which accounted for 0.22% of China's national electricity consumption (Smith et al. 2016). These values exclude energy use for secondary water supply (SWS) in high-rise buildings, which are increasingly common in densely populated cities. Urban water supply systems in China only support enough pressure (approximately 28 m) for buildings of six stories and below (People's Republic of China 2016). Hence, buildings over this height need separate pumping systems to add pressure for top floors. SWS within buildings consumes a considerable amount of energy in cities with many high-rises.

As urban population growth leads to increasing water demand and increased high-rise residency rates, the combined effect of these factors has the potential to greatly increase energy demand for water supply. Most research regarding energy conservation in the water supply sector focuses on pump optimization, pressure management, and leakage control to save energy in the operation phase (Hashemi et al. 2013; Nazif et al. 2010; Xu et al. 2014a, b; Loureiro et al. 2014; Creaco et al. 2016; Giacomello et al. 2013; Giustolisi et al. 2013). These methods are most relevant after water supply systems have already been constructed, rather than during the planning and design phase. Although optimization of water distribution network design has also studied, the goals are mainly to optimize the diameter and material combination of pipelines to cut costs (Ekinci and Konak 2009; Haghighi et al. 2011; De Corte and Sörensen 2013; Norouz and Rakhshandehroo 2011; Srinivasan et al. 2008), not to reduce energy consumption. Gaps still remain in the water sector's energy-saving plan. There are few studies exploring the impact of urban spatial layout on energy use for water supply. Urban WDNs extend underground along with the city's margins; thus urban spatial layout influences the development of WDNs and energy use for water supply. To realize sustainable development, proper city spatial planning and concurrent reduction in energy use for water supply are of critical importance in the urbanization process.

3.3 Urban Spatial Characteristics

Spatial layout of WDNs is primarily determined by the spatial distribution of buildings and people. Buildings and population are the basic elements of a city, and nearly every residential building is connected with a WDN to satisfy water demands. Thus, how residences are distributed spatially has a significant influence on characteristics of WDNs and energy use requirements for water supply.

To quantitatively analyze the impact of urban spatial characteristics on WDNs and energy use for water supply, indicators should be defined to represent urban spatial characteristics. The urban spatial characteristics discussed here are mainly the spatial distributions of buildings and population. They are composed of two dimensions: horizontal and vertical characteristics. Usually, it is difficult to acquire specific data with respect to number, area, and distribution of buildings in a city. Since every district and community and even every building and resident is connected to the WDN, the WDN in some respects acts as an underground map of the city. Therefore, the spatial characteristics of WDNs are largely dependent on urban horizontal characteristics. Five indicators of WDNs are designated in this chapter to represent urban horizontal characteristics: per capita pipe length ($L_{\text{per cap}}$), per square kilometer pipe length ($L_{\text{per area}}$), people served per meter pipe ($Pop_{\text{per pipe}}$), water volume distributed per meter pipe ($V_{\text{per pipe}}$), and average diameter (D) of pipes for water distribution. Among the five indicators, $L_{\text{per cap}}$ and $L_{\text{per area}}$ describe pipe length in a way that is standardized for different city populations and areas; $Pop_{\text{per pipe}}$ and $V_{\text{per pipe}}$ represent the service load of WDNs; D indicates the general size of pipes. The height distribution of people/households – that is, number of people/households residing in buildings within a given height range – and the average height of residential buildings with secondary water supply systems (h_s) are both available or can be calculated from population census data and are used to represent vertical characteristics. The horizontal indicators have direct influence on energy use for municipal water supply (MWS), while the vertical indicators directly affect energy use for SWS.

Two modes of residential building distribution are commonly seen in cities now, as shown in the following.

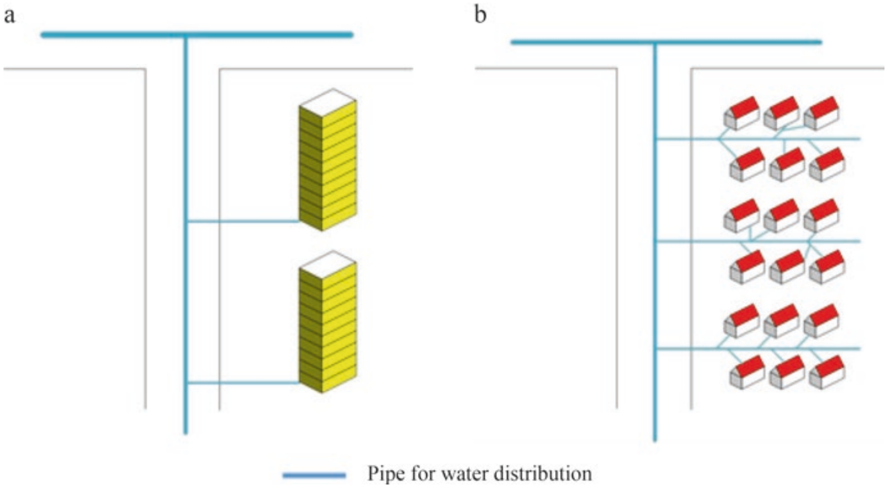

Fig. 7 Buildings and water distribution pipes

Figure 7 Mode (a) makes more use of vertical space. Residential buildings here are high-rise apartment complexes which accommodate many households in one building. To satisfy sunlight, ventilation, and fire protection requirements, high-rise buildings should be spaced at a large distance from other buildings (Geng et al. 2014; People's Republic of China 2002). Thus buildings are distributed sparsely and pipe length per area and capita is small. In other words, the service load of WDNs is heavy, and a large pipe diameter is needed, since each meter of pipe must supply many people. In this case, shorter pipe length and larger diameter may lead to less energy use for MWS. But energy use for SWS in each building will be high due to the height of the building. On the contrary, in mode (b), individual houses with smaller heights predominate, with just one family in each house. There is no need for a large interval between buildings, and horizontal space is put to greater use. Buildings are positioned more densely but are shorter on average. As a result, pipe length per area is greater, service load is lighter, and a small pipe diameter is sufficient. More energy may be consumed for MWS, but energy use for SWS in each building is low. Typically a city will contain both modes (a) and (b), and the proportions of these two modes affect the total energy use for water supply in a city.

3.4 Impact of Urban Spatial Characteristics on Energy Use for Water Supply

In this chapter, energy use for MWS includes energy for water abstraction, treatment, and distribution within the central water distribution system; energy for SWS only includes energy for pumping water in high-rise buildings. The authors selected four cities with varying populations and sizes in China and Japan for a case study to explain how urban spatial characteristics affect energy use for water supply. B1 in China and B2 in Japan are both large cities with over 10 million people and have similar terrains including both hilly and flat areas. S1 in China with 1 million people and S2 in Japan with 0.4 million people are much smaller cities, and areas served by urban water supply are relatively flat. All case cities are densely populated but have different spatial characteristics. As a result, their WDNs are different and energy required to supply water varies by city.

3.4.1 Horizontal Characteristics and Energy Use for Municipal Water Supply

Table 1 displays the horizontal characteristics in case cities. B1 and S1 in China have shorter pipe length per capita and per km^2, heavier service load of WDNs, and larger average diameter than B2 and S2 in Japan. Applying principles of hydraulics, the pipe length, diameter, and pressure influence energy use for water distribution. Longer pipes and smaller diameters cause more head loss, and higher pressure requires more pumping energy. Because of the different requirements of water pressure in China and Japan, energy use for MWS is compared using energy use per cubic meter of water per meter head. The five horizontal indicators are divided into three categories: pipe length, service load, and diameter. Service load has a close relationship with diameter because pipes with a heavy service load require a larger diameter. Actually, service load is also related to pipe length because service load is defined as the number of people served or water volume distributed per meter pipe.

The impact of pipe length and diameter on energy use for MWS in case cities is shown in Fig. 8. If pipe length is short and diameter is large, water head loss should be relatively small. According to this logic, bubbles in the lower right corner of Fig. 8 (i.e., high average diameter, low per capita pipe length) should be smaller than those in the upper left corner, which is consistent with what can be seen in Fig. 8. Compared with B2 and S2, B1 and S1 have smaller per capita pipe length and larger average diameter; thus energy use for MWS per m^3 per meter is lower, too. Shorter pipe length per capita and per km^2, heavier service load, and larger diameter imply that buildings tend to be taller and more sparsely distributed, as in B1 and S1, leading to lower energy consumption per m^3 per meter for MWS.

Table 1 Horizontal characteristics in case cities

Horizontal characteristic		B1	B2	S1	S2
Pipe length	$L_{\text{per cap}}$ (m/cap)	0.53	2.07	0.83	2.02
	$L_{\text{per area}}$ (km/km^2)	6.57	12.42	1.91	6.85
Service load	$Pop_{\text{per pipe}}$ (people/m)	1.88	0.48	1.20	0.50
	$V_{\text{per pipe}}$ (m^3/m)	108	59	191	54
Diameter	D (mm)	279	168	321	133

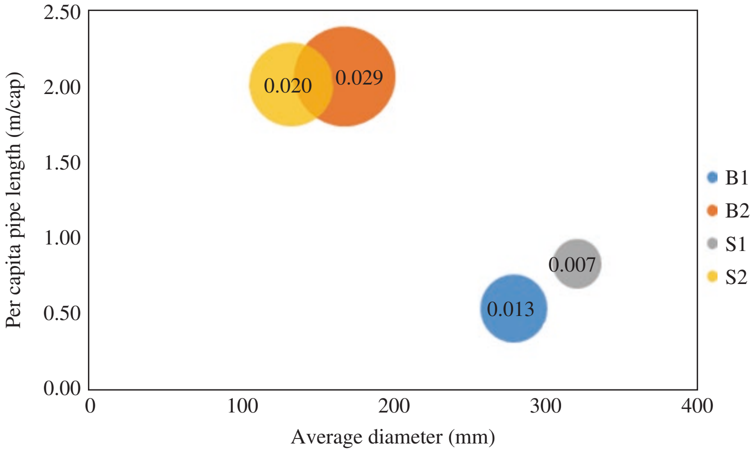

Fig. 8 Impact of pipe length and diameter on energy use for MWS. The size of each bubble represents energy use per cubic meter water per meter head for MWS (kWh/m^3·m) of each city

3.4.2 Vertical Characteristics and Energy Use for Secondary Water Supply

There are a number of different types of secondary water supply (SWS) systems. The booster pump and break tank (BPBT) system is chosen for this study. The energy use per cubic meter of water per meter lift for BPBT systems is 0.019 kWh/m^3·m (Smith et al. 2017). Standards of municipal water supply pressure are different in China and Japan. Most buildings of seven or more stories in China require SWS systems; in Japan, SWS are required for buildings of four or more stories (People's Republic of China 2016; Ministry of Health Labor and Welfare of Japan 2014). The number of households residing in buildings of seven or more stories in B1 and S1 in China and of four or more stories in B2 and S2 in Japan (i.e., served by SWS) can be obtained from census data.

The percentage of households residing in buildings of various heights is shown in Fig. 9. There are more households residing in taller buildings in B1 and B2 than in S1 and S2, which is reasonable because bigger cities usually have more high-rises. Approximately 70% of households reside in buildings of one to three stories in both S1 and S2. Only 2% of households in S1 live in buildings of seven or more stories.

Average height of residential buildings with SWS systems (h_s) is 51.7 m, 18.5 m, 42.7 m, and 15.8 m in B1, B2, S1, and S2, respectively. Average height in S1 and B1 is about 2.3–3.3 times that of S2 and B2.

Figure 10 displays the impact of vertical characteristics on energy use for SWS. S1 has the lowest energy use for SWS. It is only 12.7%, 7.6%, and 6.5% that of S2, B2, and B1, respectively, likely due to the fact that only 2% of households in S1 require SWS systems. B1 has the highest h_s and largest proportion of households served by SWS ($HH_{s,\%}$), causing it to have the highest energy use for SWS among case cities. Other than S1, the cities all consume a considerable amount of energy

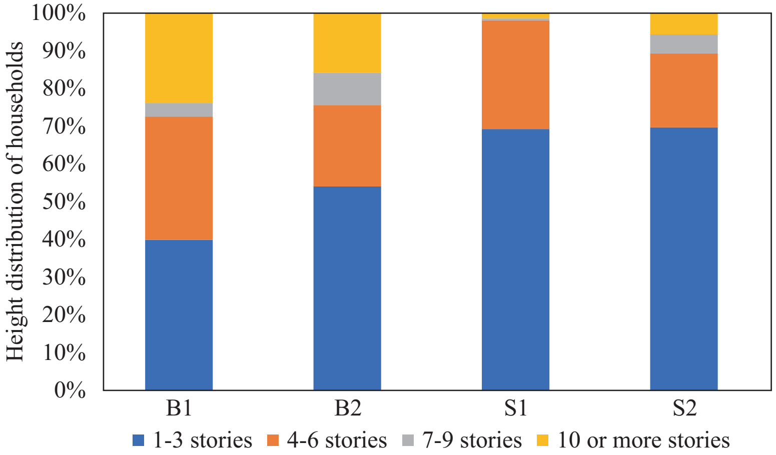

Fig. 9 Household percentages residing in buildings of different heights

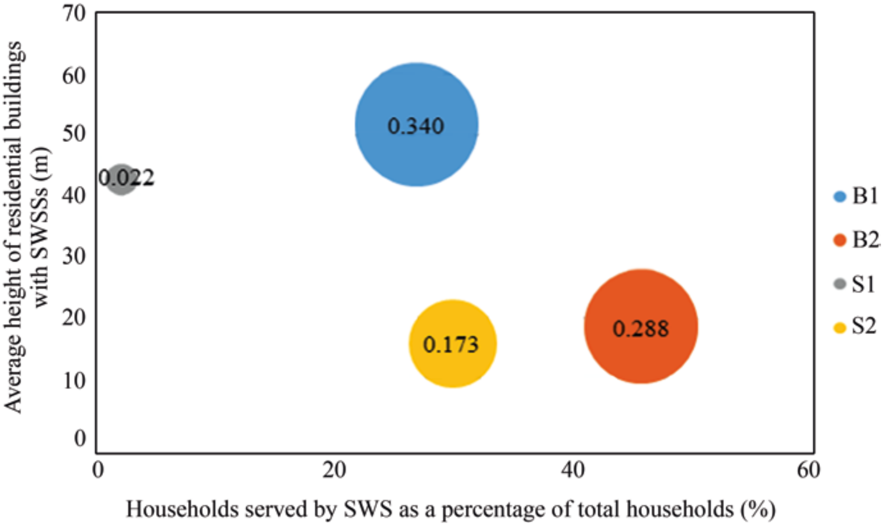

Fig. 10 Impact of vertical characteristics on energy use for SWS. Bubble size represents energy use per cubic meter for SWS (kWh/m^3) of each city

for SWS. The variables h_s and $HH_{s,\%}$ both greatly affect energy use for SWS. The main ways to reduce energy consumption for SWS are controlling building height and the percentage of households that require SWS.

Table 2 Total energy use for water supply and the proportions of energy use for MWS and SWS

	B1	B2	S1	S2
Total energy use for water supply per m^3 (kWh/m^3)	0.661	0.777	0.195	0.513
Proportion of energy use for MWS (%)	49	63	89	66
Proportion of energy use for SWS (%)	51	37	11	34

3.4.3 Total Energy Use for Water Supply

Table 2 shows the total energy use for water supply and the proportions of energy use for MWS and SWS. In city B2, energy use for water supply is 0.777 kWh/m^3, which is the highest value among case cities and is followed by values for B1, S2, and S1. Energy use per cubic meter of water for MWS accounts for 49%, 63%, 89%, and 66% of total energy use per cubic meter of water for water supply in B1, B2, S1, and S2, respectively. MWS consumes the bulk of total energy use for water supply in all cities other than B1. Energy use for SWS tends to be ignored because it is difficult to obtain data. In some cases, however, it occupies a large proportion of total energy use for water supply.

3.5 How to Reduce Energy Use for Water Supply When Laying Out a City

Proper city design is a practical way to reduce energy use for water supply. In the case study, we find that cities with smaller areas, S1 and S2, require less energy for water supply than the big cities, B1 and B2. As urban areas grow, WDNs become larger, meaning water must travel a greater distance and thus consume more energy during transport. Buildings should thus be carefully distributed. Distributing buildings and population properly is a realistic way of saving energy use for water supply. Building distribution directly influences the structure of WDNs and thus energy use for MWS. Densely distributed buildings usually lead to a large ratio of service connection pipes which can cause more head losses than trunk pipes. Relatively tall buildings are suggested because they are spaced at a reasonable distance from other buildings and can contain many households, leading to shorter pipe length, heavier service load, and larger pipe diameter, like B1 and S1. Energy use for MWS is low due to those factors. The third point is to control the height of buildings. If a city has a large number of high-rises, energy use for water supply will increase sharply. The height of buildings should be limited below the highest altitude that the nodal pressure can support, to avoid the need for SWS systems. Departments in charge of urban planning and design should pay more attention to urban spatial characteristics in order to reduce energy use for water supply.

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Fostering Water Treatment in Eutrophic Areas: Innovative Water Quality Monitoring, and Technologies Mitigating Taste & Odor Problems Demonstrated at Tai Hu

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Abstract The Tai Hu (Tai Lake) is used as a raw water reservoir for approximately ten million inhabitants predominantly in Jiangsu province, China. Algal/cyanobacterial blooms occur frequently in the eutrophic shallow lake and present a challenge for drinking water treatment. Furthermore, occasionally taste and odor (T&O) problems have been reported in drinking water. Due to the impacts of wastewater and surface water runoff, pesticides and emerging pollutants such as pharmaceutical compounds must be considered as well.

In our study, a large spectrum of emerging pollutants was analyzed in the northern part of Tai Hu. In a Zhushan Bay wetland, emerging pollutants such as perfluorooctanoic acid (PFOA) and the pharmaceuticals ibuprofen and diazepam were detected. Additionally, pesticides were present in the lake water in concentrations of 0.1–0.5 µg/L. The occurrence of antibiotic resistances at the microbial level was examined in water and sediment samples. In particular the antibiotic resistance

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genes *sul1* and *sul2*, which encode for resistance against sulfonamide antibiotics, were detected in all samples. Furthermore, the tetracycline resistance gene *tet*(C) was detected frequently and *tet*(B) in 10% of the samples. Also, the genes bla_{TEM} and *ermB* were detected in Tai Hu samples encoding for resistances against beta-lactams and macrolides, respectively.

The T&O problems observed in drinking water of the Tai Hu region could not be attributed to the algae burden T&O compounds such as geosmin or 2-MIB. This study demonstrates the effects on the water treatment process caused by high amounts of dissolved organic carbon (DOC) and dissolved organic nitrogen (DON). The elevated concentration of organic compounds in raw water results in a short life span of ozone during advanced treatment. In the disinfection process, the remaining nitrogen-containing organic compounds undergo subsequent reactions. In particular, amino acids might trigger the formation of chloramine-type T&O compounds. Amino acids were detected in raw water samples taken at the inlets of the Tai Hu water treatment plants and were shown to be present in fluctuating concentrations. Most probably, lysis of algae cells during drinking water treatment due to oxidation processes such as pre-ozonation results in the release of intracellular compounds and elevated aqueous phase concentrations of DOC and DON (containing proteins, peptides, and amino acids). In laboratory experiments, it was shown that algae could be removed effectively by ultrafiltration, thus proving to be a suitable pretreatment

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process while avoiding cell disruption and subsequent formation of T&O compounds.

Based on analysis of Tai Hu field samples and laboratory experiments, pilot-scale proof-of-concept studies were developed. Future studies will focus on online monitoring of drinking water treatment performance including the precursors of T&O compounds. Also, the removal of emerging chemical and microbiological pollutants will be emphasized in order to ensure high-quality drinking water.

1 Introduction

The Tai Hu (Tai Lake) near Shanghai in China is a huge shallow lake used as a raw water source for drinking water production. The water treatment technologies used by Chinese water treatment plants are state of the art; nevertheless, occasionally there are taste and odor (T&O) events as well as nitrogen-containing disinfection by-products (N-DBPs) found in drinking water at the tap, typically during or immediately after the algae season. Depending on yet unknown parameters, these events are more or less pronounced (Ma et al. 2013; Qin et al. 2010; Fang et al. 2010). Furthermore, there is increasing concern with respect to emerging pollutants such as pharmaceutical residues and antibiotic-resistant bacteria in the raw water used for drinking water production.

The Tai Hu is located in a heavily populated area and is used as a drinking water reservoir for nearly 10 million inhabitants. In the Tai Hu region, there are both agriculture and a wide range of industrial facilities. Drinking water treatment plants (DWTPs) are found all around the lake, and each of them supplies more than 100,000 people. Overall the climatic situation, the availability of nutrients, and the shallow characteristic of the lake are considered the main reasons for the occurrence of algal/cyanobacterial blooms. Normally algal blooms occur in late summer; occasionally, however, such blooms appear earlier in the year. The lake has a mean depth of around 2 m. Therefore, deposited algae or soil from the bottom of the lake are stirred up easily by wind turbulences. This leads to the visual observation that the lake may change its color from blue to green and brown within 1 day.

Algae are subject to different kinds of stress and may release organic matter that contains proteins, peptides, amino acids, sugars, and a wide range of other organic compounds (Li et al. 2012; Wert et al. 2014). A large amount of this organic material is degraded by bacteria in the lake. However, some fraction of algae and dissolved organic matter will enter the drinking water treatment process.

It is commonly accepted that algal/cyanobacterial blooms are a major source of water quality issues (WHO 1999); however, mitigation strategies are not yet fully informed with respect to the underlying mechanisms of by-product formation in drinking water production. Within the Sino-German project SIGN and the Chinese Major Clean Water Project, the stated target was to understand the mechanisms for the formation of by-products and simulate the treatment process in the laboratory (Dohmann et al. 2016; Schmidt et al. 2016).

Chinese DWTPs around Tai Hu are designed and adapted to local water-quality conditions. Depending on the location and the typical algae concentrations in raw water, DWTPs may use an initial oxidation step to destroy algae at the start of the treatment process. In all cases there is a flocculation and sedimentation step followed by sand filtration. Afterward, in advanced DWTPs a (second) oxidation step and in some cases an activated carbon treatment follow the sand filter. Finally, disinfection (typically using chlorine) is applied in all DWTPs.

The problem of algal blooms in Tai Hu leads to an extreme situation where these "state-of-the-art" DWTPs are incapable of producing high-quality drinking water (Ma et al. 2013). On the one hand, there is an interest of the DWTPs for emergency operations (Zhang et al. 2010); on the other hand, it is worth looking at alternative technologies that produce high-quality drinking water independent of the season.

Previous investigations have shown that organic nitrogen concentrations of both raw and treated water are relatively high compared to other areas of the world; it is also well established that amino acids are a major source of organic nitrogen which may be converted into nitrogen-containing disinfection by-products (N-DBPs) (Fang et al. 2010).

A further objective of the Sino-German project SIGN and the Chinese Major Clean Water Project was to understand the mechanisms that lead to T&O formation. Additionally, analysis of emerging pollutants such as pharmaceuticals and antibiotic resistances was performed in order to create a comprehensive understanding of pollutant profiles in Tai Hu. Based on this understanding, suitable technologies may be recommended for efficient drinking water treatment ensuring a high water quality at the consumer's tap.

2 Analysis of Pesticides and Emerging Pollutants

Generally, as described above, the algal blooms are considered one of the largest threats for the environment and drinking water production in the Tai Hu region. In addition to algae, other organic pollutants are also a matter of concern. Previous studies have shown a wide range of organic pollutants within Tai Hu (e.g., Wang et al. 2003). In order to gain further insight, several sampling campaigns were conducted between 2015 and 2017. Here, not only lake water was sampled but also other environmental sources: first, artificial wetlands, which play a crucial role in pollution control at Tai Hu, as they are used to pretreat urban runoff prior to release into Tai Hu, and, second, both raw and drinking water, as the fate of organic pollutants within Chinese DWTPs in the region is not yet well understood.

All water samples taken in China were directly prepared for later analysis in Germany by filtration and solid phase extraction. In total, about 200 different organic pollutants were analyzed in more than 80 water samples. The group of pollutants includes pharmaceuticals, pesticides, polycyclic aromatic hydrocarbons (PAHs), industrial chemicals, and volatile organic compounds. The results presented

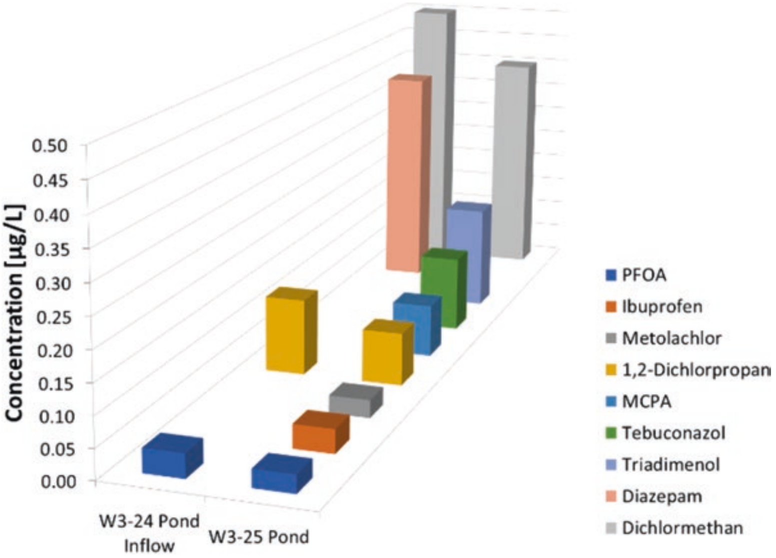


Fig. 1 Results on organic pollutants from the first sampling campaign in 2015 in the Zhushan Bay wetland (not all pollutants included)

in this study focus on preliminary data points, based on analysis performed at the time of publication.

The results for the wetland near Zhushan Bay, in the northwestern part of Tai Hu, are illustrated in Fig. 1. Here, two ponds within the wetland have been sampled. The first pond features four different organic pollutants, mainly industrial chemicals and pharmaceuticals, while at the other pond, eight organic pollutants have been detected. Whereas these compounds are very similar in both ponds, the latter pond also includes pesticides. As these pesticides are defined as persistent, different flow patterns and/or catchment areas within the artificial wetland may be assumed. This wetland acts as a barrier/sink and has no direct flow connection to Tai Hu, which shows that its application in Tai Hu region is successful by preventing polluted run-off to reach the lake itself.

Within the lake, samples were mostly taken in the northern part, as most of the larger inflows occur in the three northern bays of Tai Hu: Zhushan Bay, Meiliang Bay, and Gonghu Bay. Furthermore, the algal blooms, induced by high nutrient loads, take place primarily here as well, which indicates the importance of this region for pollutant occurrences. Figure 2 shows the occurrences and concentrations of pesticides in the three northern bays. Several pesticides, such as atrazine and triadimenol, were detected at all eight locations, mostly in similar concentrations. This shows that even though the bays feature different catchment areas, similar applications of pesticides in the entire region can be assumed. Figure 2 also shows that most pesticides are found in Zhushan Bay, which is in accordance with most of the pesticides found in the artificial wetlands of Zhushan Bay (Fig. 1). In addition to the

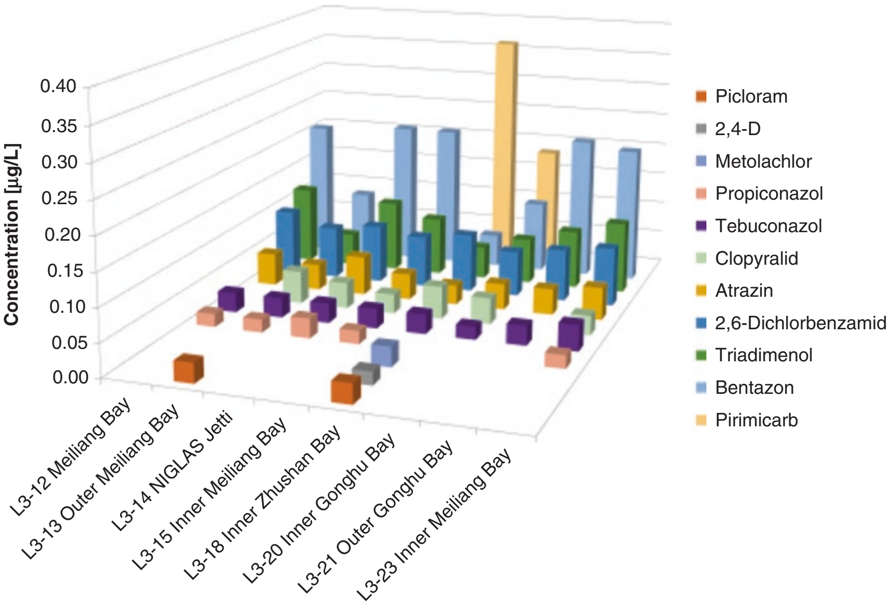


Fig. 2 Results on pesticide concentrations from the first sampling campaign in 2015 in the northern part of Tai Hu: Zhushan Bay, Meiliang Bay, Gonghu Bay (not all pollutants included)

overall pattern, some pesticides, such as 2,4-D, picloram, and pirimicarb, were primarily detected here, which reflects the heightened agricultural practices in the catchment area of Zhushan Bay.

In addition to the sampling of artificial wetlands and the lake itself, three DWTPs were sampled. Only raw water results were heretofore available. These showed that depending on the abstraction point of raw water, a wide range of pharmaceuticals, pesticides, PAHs, industrial chemicals, and volatile organic compounds are found. It was also evident that the raw water quality varies strongly, which makes it difficult for DWTP operators to adjust the various treatment steps.

Further objectives of the presented study focused on spatial analysis of organic and inorganic pollutants, toxicity tests, environmental and human risk assessment, and recommendations for actions.

3 Analysis of Antibiotic Resistance Genes

Microbiological water quality monitoring includes the detection of bacteria, viruses, and protozoa; novel parameters such as antibiotic resistance genes should be considered as well. The widespread application of antibiotics in human and veterinary medicine has led to the emergence, selection, and dissemination of antibiotic-resistant bacteria and antibiotic resistance genes in different environmental compartments (Berendonk et al. 2015). Recent studies in, e.g., Europe, Australia, or China, have shown the occurrence of antibiotic-resistant bacteria and antibiotic resistance genes in surface water (Lou et al. 2010; Stoll et al. 2012; Tao et al. 2010; Stange et al. 2016), groundwater (Ji et al. 2012), drinking water (Guo et al. 2014), and sediments (Yang et al. 2016). The dissemination of antibiotic-resistant bacteria and antibiotic resistance genes is facilitated by horizontal gene transfer enabling the exchange of antibiotic resistance genes among different strains or bacterial species and beyond the habitat of the original host. Clinically relevant antibiotic-resistant bacteria and antibiotic resistance genes that are released from anthropogenic sources, together with the excessive use of antibiotics in both human and veterinary medicine, constitute a serious health problem. Despite extensive research there is a lack of knowledge with respect to the origin of antibiotic-resistant bacteria and antibiotic resistance genes in different surface waters and their removal during water treatment and risk assessment. For these reasons the occurrence of different antibiotic resistance genes was investigated at Tai Hu (Fig. 3).

At Tai Hu, the sulfonamide resistance genes *sul1* and *sul2* were detected most frequently, in all water as well as sediment samples. The tetracycline resistance genes *tet*(B) and *tet*(C) were also found in both types of samples. In addition, the antibiotic resistance genes *dfrA1*, *bla*$_{\mathrm{TEM}}$, and *ermB* were detected. Overall, the

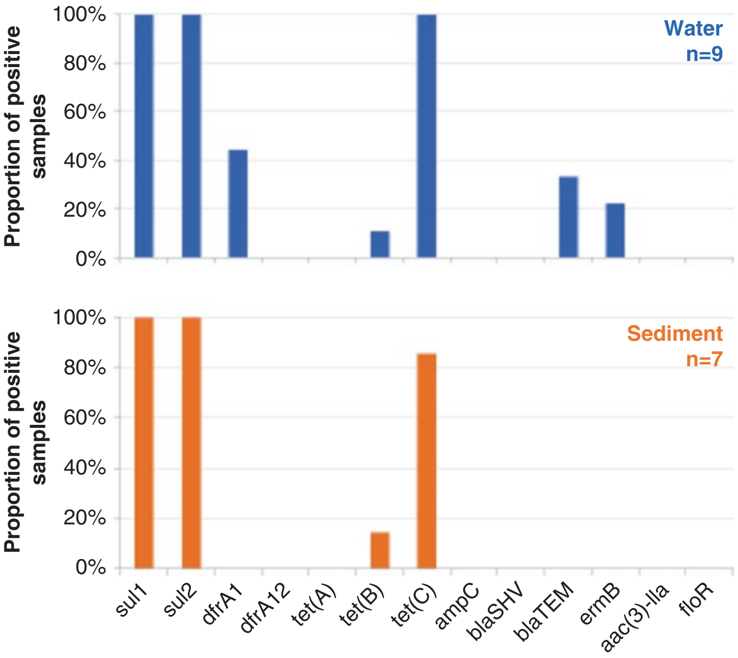


Fig. 3 Detection of antibiotic resistance genes (ARGs) in the Tai Hu (sampling campaign in May 2015)

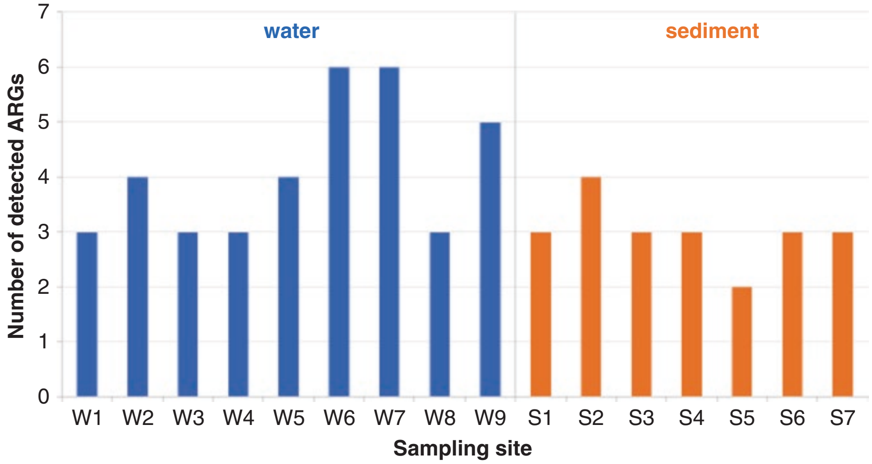


Fig. 4 Number of antibiotic resistance genes (ARGs) in water and sediment samples from Tai Hu (sampling campaign in May 2015)

results showed the wide distribution of antibiotic resistance genes in the Tai Hu (Fig. 4).

Extensive dissemination of sulfonamide resistance genes in different aquatic compartments like surface water and groundwater has been reported all over the world (Stoll et al. 2012). This prevalence of *sul1* and *sul2* genes is most likely due to easy dissemination of these genes via highly mobile genetic elements and their extensive use in human and veterinary medicine.

Tetracyclines are also used for the treatment of bacterial infections in animals and humans. The resistance to tetracyclines is mainly caused by two mechanisms: efflux pumps and/or ribosomal protective proteins. So far, over 38 different tetracycline resistance genes have been described in literature. Three of the genes encoding for efflux proteins were included in the studies. Prevalence of *tet*(C) was high for Tai Hu compared to a German/Australian study (Stoll et al. 2012). This could be due to country-dependent differences in the application of tetracycline antibiotics.

Little is known about the presence of macrolide resistance genes in the aquatic environment. Berendonk et al. (2015) suggest inter alia *ermB* as possible genetic determinant to assess the antibiotic resistance status in environmental settings. For the selection, criteria such as clinical relevance, prevalence in the environment, and association with mobile genetic elements and/or potential to be acquired by any mode of horizontal gene transfer were considered.

Overall, the results demonstrate the occurrence of antibiotic resistance genes in Tai Hu. However, there is a lack of knowledge with respect to the origin of antibiotic-resistant bacteria and antibiotic resistance genes and their removal during water treatment.

4 Studies into Taste and Odor (T&O) Compounds

4.1 *Composition of Raw Water from Tai Hu*

As advanced treatment, DWTPs at Tai Hu use an oxidation step after flocculation and sedimentation. Under normal operation conditions, the algae-bound T&O compounds like 2-MIB and geosmin are removed from the water during the purification process in the DWTPs before pumping into the distribution network. There are regulatory limits for the major compounds, which are also tested (Rice et al. 2012) and confirmed in the DWTPs.

Therefore, it is assumed that a major source for occasional T&O events may be other than the algae-derived compounds. One other known source of T&O compounds may be amino acids which during disinfection with chlorine may form chloramines (Grübel 2013). As the situation is complex, for a basic understanding of the challenges for a time series of 1 year, the Tai Hu raw water was analyzed in 2015 and 2016 with respect to amino acid concentrations in the raw water as the potential source of N-DBPs that might be T&O products. However, soluble microbial product (SMP)-like substances were largely present in both intracellular organic matter (IOM) and extracellular organic matter (EOM) as shown in the fluorescence excitation emission matrix (EEM) images (Li et al. 2012). These organic compounds are primarily responsible for the formation of haloacetamides, a type of highly toxic N-DBP (Chu et al. 2010a, b; Plewa et al. 2008). Therefore, it is possible that chloramination of the algae organic matter (AOM) produced N-DBPs. As a conclusion, formation of DBPs should be avoided for improvement of the drinking water quality at Tai Hu (Li et al. 2012).

The results from a time-series measurement of raw water amino acids (in ng/L) show a wide variation (Fig. 5). Especially during algae/cyanobacteria seasons, it is found that concentrations may change within a short period of time, which is an additional hurdle for DWTP operation to produce high-quality drinking water. In addition, a series of measurements with hourly samples of the amino acid concentrations in raw water was performed for 1 day in January 2017. Figure 6 shows that the variation for 1 day is relatively high, highlighting the unstable situation faced by DWTP operators.

For the analysis of amino acid concentrations, the raw water was analyzed after filtration with a 0.45 µm laboratory filter to remove all stable algae cells and bacteria. It must be considered that algae mechanical stability might contribute to the strong variation. If algae/cyanobacteria are damaged by different kinds of stress, cells might lyse and release organic material during the sample preparation step and thereby increase the dissolved organic material including the amino acid concentration.

In addition, it is known that besides amino acids also proteins and peptides might be present in the raw water (Mulholland et al. 2002; Rutherfurd and Gilian 2009). The data suggests that removal of algae before the start of processing may lead to a

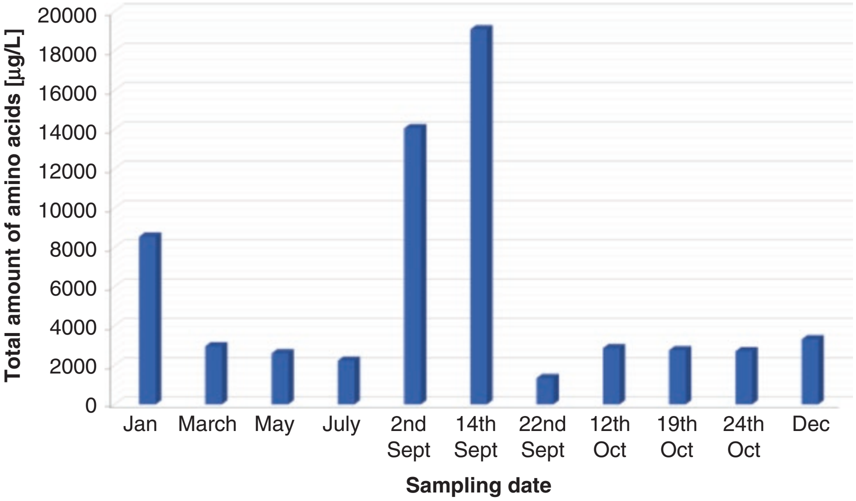


Fig. 5 Sum of all amino acids found in raw water during measurement cycle in 2016. The measurement method including the sample preparation with SPE is reported elsewhere. (Hupert and Santiago-Schübel 2016)

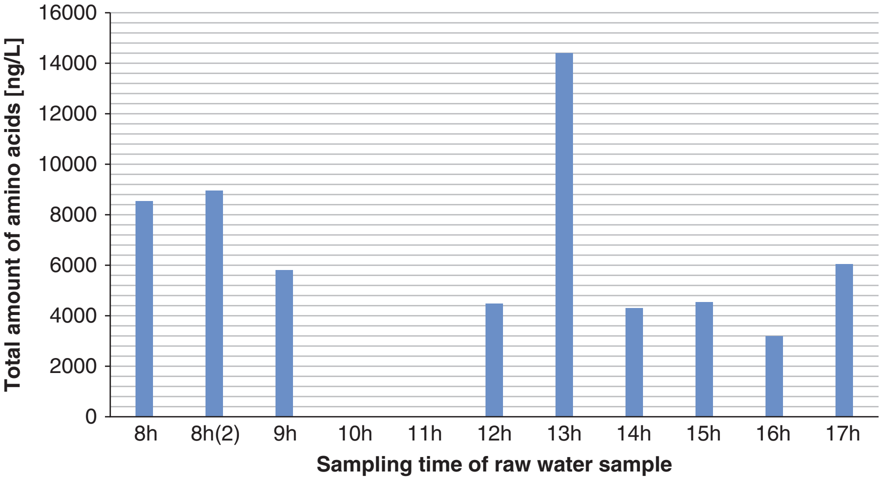
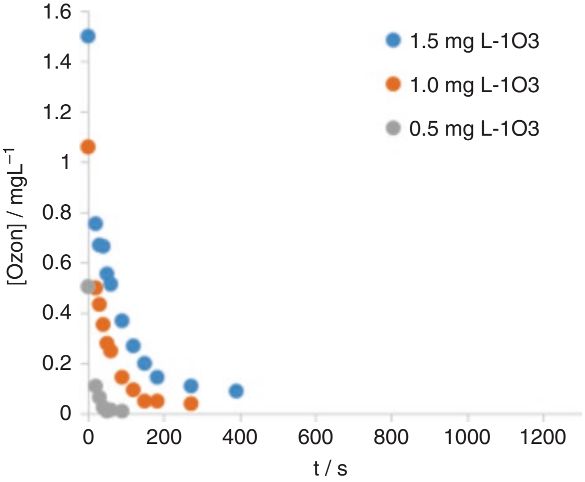


Fig. 6 Sum of all amino acids in Tai Hu raw water taken for 1 day (samples taken at 6th of January 2016) – sampling at 8 a.m. was performed twice as reproducibility test

more stable situation for the treatment in the DWTPs and therefore fewer problems with N-DBP and/or T&O compounds.

Figure 7 shows the ozone depletion profiles in raw Tai Hu water. For typical ozone concentrations, a rapid decrease was observed. Most probably, ozone is consumed mainly by reactions with algae organic matter and is therefore not available for the degradation of micro-pollutants.

Fig. 7 Ozone depletion in Tai Hu Water, pH, 8.0; T, 20–25 °C; DOC, 2.3 mg/L



The ozone depletion gives a clear hint that the organic material may be one of the reasons why in some extreme situations the production of fresh water, even using sophisticated technology, may be difficult. As some DWTPs use pre-ozonation during algae season to improve flocculation and sedimentation, a laboratory approach was chosen to test the behavior of two *Microcystis* obtained from the Freshwater Algae Culture Collection at the Institute of Hydrobiology (FACHB-collection), China, under ozone stress. The two typical cyanobacteria from Tai Hu were cultivated and treated with ozone at different concentrations.

4.2 Algae Under Ozone Stress

As the test set up the two cyanobacteria strains *Microcystis aeruginosa* FACHB TH1334 and FACHB TH98, isolated from Tai Hu, were cultivated. Model water containing these algae was used to perform a laboratory experiment to simulate a simplified process using ozonation, and later on chlorination, to look at potential formation of N-DBPs from amino acids. The model water was also used for testing the removal of the algae with ultrafiltration. The conceptual approach was to test (1) the monitoring of intracellular compounds such as the amino acids as markers for the AOM, to study (2) the removal of the algae itself, and to reduce (3) the potential of forming N-DBPs in the final drinking water.

First, algae cells treatment using ozone and/or by filtration using an ultrafiltration membrane was evaluated. The cell density of cyanobacteria incubations was counted under the microscope. To simulate the algal bloom situation in the lake, each algal culture was diluted to a cell density of 10^7 cells/L as the bloom-occurring threshold. The simulated algal bloom water was separated by membrane ultrafiltration. The concentrations of cyanobacteria strains *M. aeruginosa* FACHB TH1334 and FACHB

TH98 before and after ultrafiltration were measured by a Phycocyanin Lab Analyzer (bbe PhycoLA) from the company bbe (Germany) (Beutler et al. 2002, 2003; Schmidt et al. 2009).

These two selected algae species were also chosen for treatment with ozone without ultrafiltration. As an indicator for the stability of the algae, the binding of phycocyanin was used. Phycocyanin is one of the components of the phycobilisome in cyanobacteria and can be detected, for example, by fluorescence. The identification of the intact photosystem with integrated phycocyanin, or the released pigment after cell damage, is used as an indicator for the physiological state of cyanobacteria (Wlodarczyk et al. 2012) exposed to strong oxidant species, chemical stress, or physical stress.

Typically, pre-ozonation is the first step in advanced drinking water production processes in China. Therefore, also here the two *Microcystis* strains from the Tai Hu and their behavior after ozone treatment were investigated.

There are two effects that contribute to the measured results (Fig. 8). First the ozonation can lead to cell damage and phycocyanin detachment from the photosystem that can be observed via fluorescence (Wlodarczyk et al. 2012). Over time the phycocyanin and chlorophyll-a were also degraded especially in the samples with high ozone concentrations (5 mg/L). The treatment of *Microcystis* strain FACHB TH98 with 1 mg/L ozone seemed to only partly damage the cells as there was still low photosynthetic activity observable after 24 h. Those damaged cells are likely more vulnerable for further treatment. On the other hand, the 3 mg/L dose was high enough to lead to cell lysis and a release of organic matter, but only limited oxidation of the released matter. The organic material including the phycocyanin was still dissolved and would have to be removed by subsequent process steps.

One conclusion derived from these simple tests is that the removal of algae by careful filtration might lead to a much more equilibrated condition of the process water, which in turn might enable better control of the drinking water manufacturing process. For this concept two prerequisites are essential: (1) algae can be removed by an ultrafiltration membrane efficiently and effectively, and (2) algae do not release organic matter by means of mechanical stress during ultrafiltration.

4.3 Removal of Algae by Ultrafiltration

The removal of algae from the raw water using ultrafiltration was examined in the laboratory. The ultrafiltration was performed in parallel for water with and without ozone treatment. For removal experiments, standardized small modules supplied by the company inge (Germany) were used. The 30 cm modules were prepared with 10 Multibore® capillaries each (0.9 mm diameter) with a total surface area per module of 0.051 m^2. As testing equipment, a Poseidon unit bought from the Dutch company Convergence was applied (for more information see https://www.convergence.com/). With a flux of 100 L/m^2 h and a filtration time of 45 min, the experimental

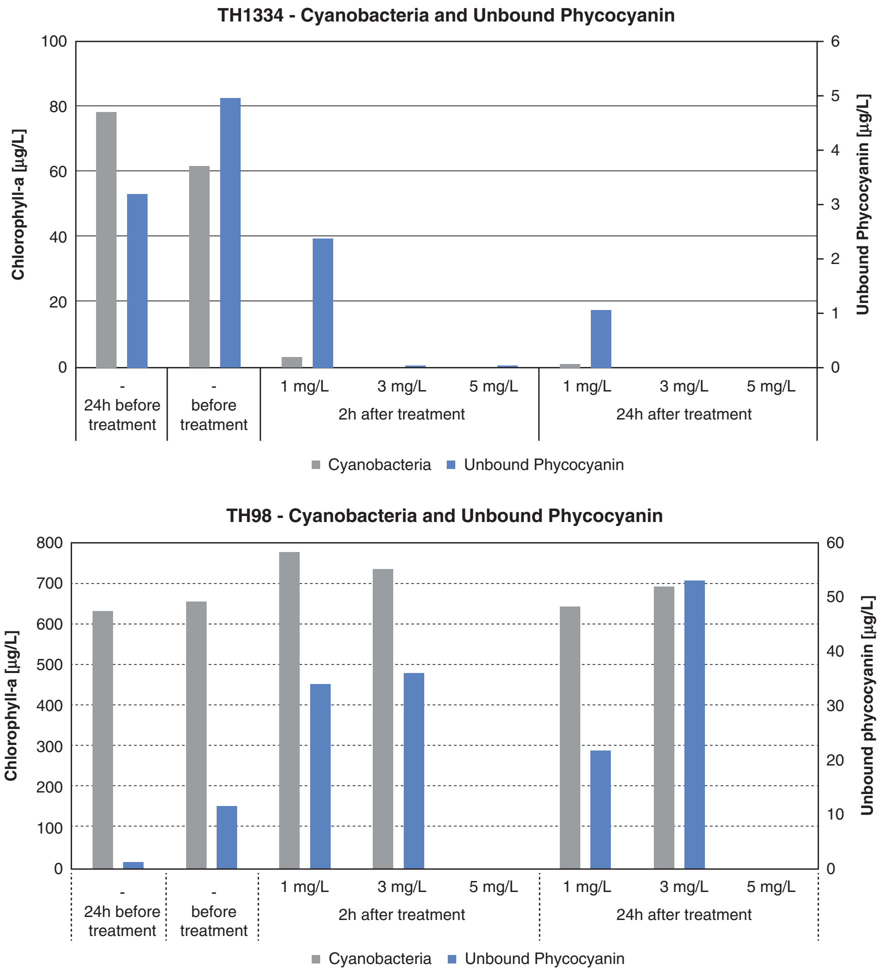


Fig. 8 Effect of ozonation on the concentration of cyanobacteria (determined by chlorophyll-a analysis) and the formation of unbound phycocyanin as indicator for the release of organic cell compounds; determination for two different algae species (*Microcystis* strains FACHB TH1334 and FACHB TH98)

conditions for operation of the ultrafiltration modules were similar to full-scale field conditions. Samples were taken after 30 min of operation.

As shown in Table 1, membrane ultrafiltration leads to a high removal efficiency of cyanobacteria in water.

Additionally, for algae removal, the release of intracellular organic material was determined. Therefore, the algae were investigated by fluorescence measurement with respect to the algae state using a PhycoLA, bbe instruments. Operation conditions are given elsewhere (Beutler et al. 2003; Schmidt et al. 2009). The results are given in Fig. 9.

Table 1 Removal efficiency of simulated algal bloom water by ultrafiltration

Microcystis aeruginosa species	Original concentration µg/L	After ultrafiltration µg/L	Removal efficiency %
TH1334	78.4 ± 4.2	0.23 ± 0.02	99.7
TH98	623.2 ± 33.1	7.33 ± 0.08	98.8

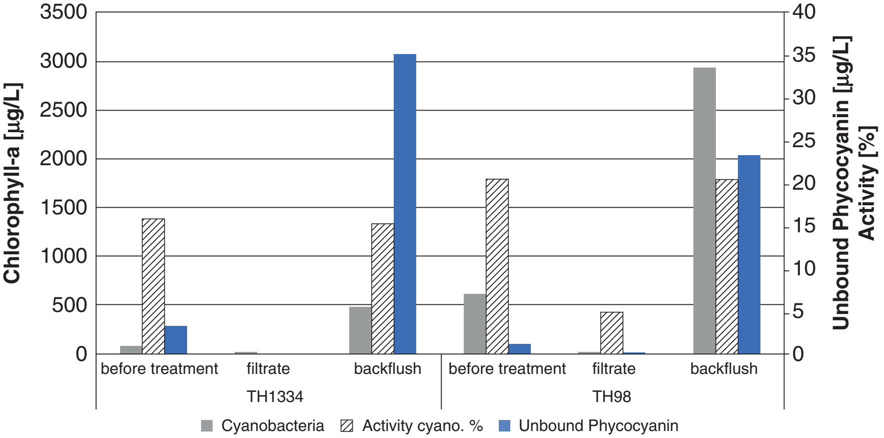


Fig. 9 Total concentration of cyanobacteria, unbound phycocyanin, and activity before ultrafiltration, in the filtrate, and after backflushing the membrane for the algae species *Microcystis* strains FACHB TH1334 and FACHB TH98

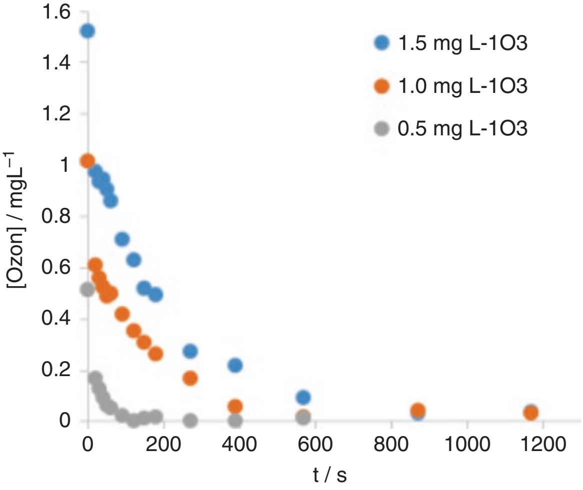
Most of the algae were removed via ultrafiltration (Fig. 9). The *Microcystis* strain FACHB TH1334 was removed almost completely, while there was still 7 µg/L chlorophyll-a from cyanobacteria showing low photosynthetic activity found in the *Microcystis* strain FACHB TH98 filtrate. The filtrated algae were concentrated in the backflush of the ultrafiltration membrane. The rise of the unbound phycocyanin compared to cyanobacteria indicates mechanical stress and moderate cell damage.

In conclusion, the treatment with flocculation and membrane filtration removes a considerable amount of organic matter. This results in longer lifetimes of ozone and may reduce the dosage necessary for disinfection and pollutant degradation as demonstrated for raw water from Tai Hu and illustrated by the comparison of Figs. 7 and 10.

4.4 Combination of Ultrafiltration and Ozonation/Chlorination

For the selected algae samples, the amino acid concentrations were determined before and after ultrafiltration, and finally all samples were treated with chlorine as shown in Fig. 11. The total concentrations of amino acids in the samples without

Fig. 10 Ozone depletion in Tai Hu water after treatment by flocculation and ultrafiltration, pH, 7.8; T, 20–25 °C; DOC, 1.6 mg/L



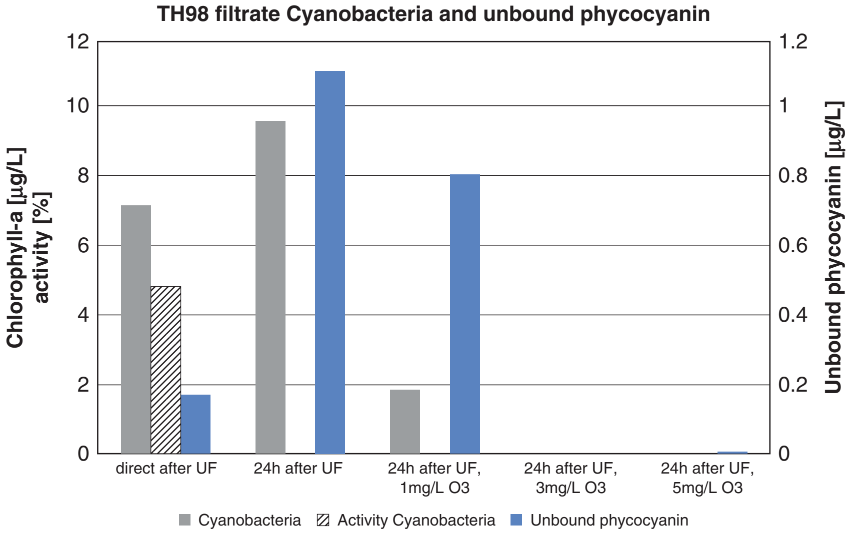


Fig. 11 Effect of the overall process on cyanobacteria, determined by chlorophyll-a and unbound phycocyanin analysis as indicator for the release of organic cell compounds, example presented for *Microcystis* strain FACHB TH98

ultrafiltration obviously increased after ozonation with an ozone dose of 1 mg/L, while the total concentration decreased with the increase of the ozone dose. Overall, the total concentrations of amino acids in the samples without ultrafiltration were much higher than that in the samples with ultrafiltration during ozonation treatment. The results indicate that amino acids can be controlled with algae effectively removed by ultrafiltration. Increasing the ozone concentration from 1 mg/L to

5 mg/L would further reduce the amount of amino acids due to two effects: On the one hand, ozone destroys the algae and brings the organic material into solution; on the other hand, ozone will also degrade organic material.

Without ultrafiltration, the concentration of amino acids increased after ozonation and decreased after chlorination. This indicates that the amino acids may react with chlorine to form DBP.

When algae were removed by ultrafiltration, there was no significant increase of amino acids during ozonation. During chlorination, however, the concentration of amino acids increased. This indicates that chlorine may break down proteins and peptides already in the water phase which were not removed by ultrafiltration (Fig. 12).

5 Outlook

This study demonstrates that algae/cyanobacteria in Tai Hu are one major source of organic material that on the one hand contain algae-/cyanobacteria-based T&O compounds and on the other hand release algae organic matter which might lead to N-DBPs, thus creating new T&O compounds such as chloramines. Therefore, a strategy was developed to remove the main part of intact algae by membrane filtration before the oxidation steps in water treatment. Successful application of a fluorescence sensor to monitor cell lysis was demonstrated. The online sensor facilitates process control to optimize ozonation, active carbon, and chlorine treatment in order to reduce T&O events to an absolute minimum. In addition, a wide range of organic pollutants such as pharmaceuticals or antibiotic resistance genes was found in Tai Hu raw water, which should be removed during drinking water treatment.

An alternative strategy as shown below will be tested in pilot plant operation within the joint Sino-German project with the partners at Tai Hu (Fig. 13).

For demonstration of this strategy, a pilot plant is currently in operation at HuaYan DWTP in Wujiang, China. The pilot plant consists of two independent lines each equipped with a module containing 6.5 m^2 of the inge patented Multibore® membrane. The membrane is made of a modified polyethersulfone with seven capillaries in one fiber, with fibers having an inner diameter of 0.9 mm. Long-term performance stability is tested at Tai Hu DWTP. For monitoring the bbe PhycoLA, a cost-efficient fluorometer based on LED light excitation and fluorescence detection on two sensitive photo sensors, is used to differentiate between unbound and bound phycocyanin together with five algal classes and their photosynthetic activity, as well as yellow substances and turbidity.

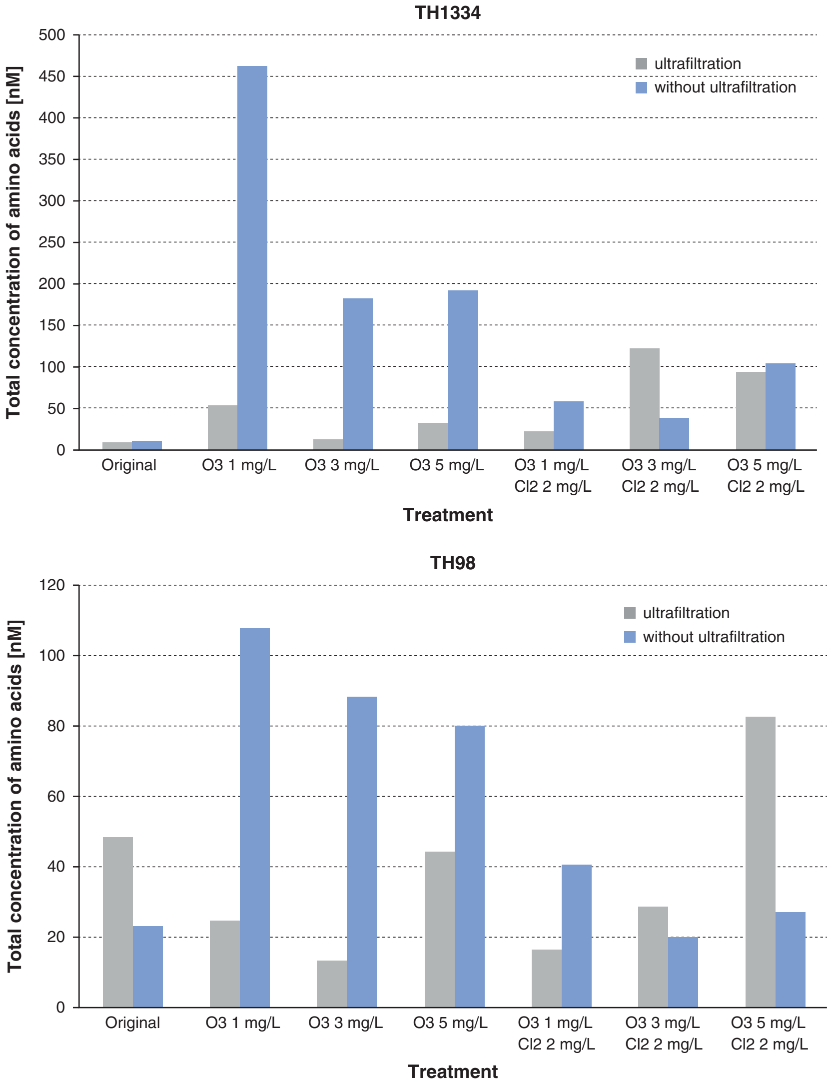


Fig. 12 Comparison of total concentration of amino acids in *Microcystis* strains FACHB TH1334 and FACHB TH98 simulated water during different treatments

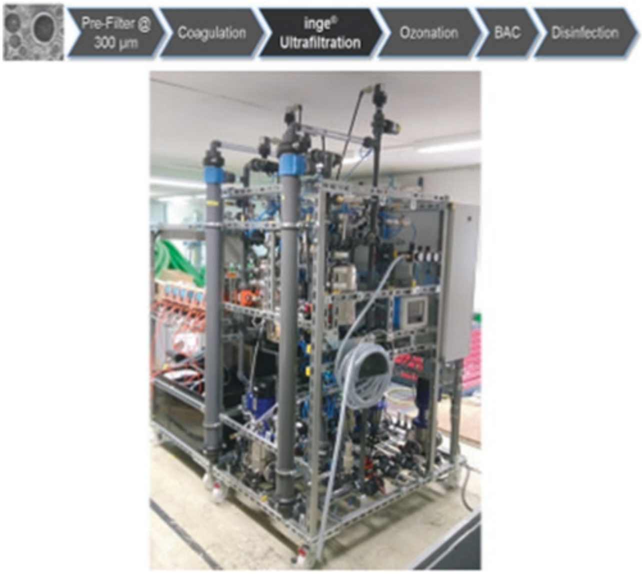


Fig. 13 Inge ultrafiltration pilot plant as part of the integrated treatment scheme for high-quality drinking water production

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Part III

Innovative Technologies and Implementation: Urban Drainage and Rainwater Management

Preventive and Customized Maintenance of Underground Water Infrastructure

Fangfang Zhao, Regina Haußmann, and Johannes Pinnekamp

Abstract Maintenance of sewer networks is essential for their efficient and stable operation. Although sewer maintenance is basically the same regardless of network type, the specific situation of a particular network will determine how much and how often maintenance is needed. Therefore, the current state of a particular network must be described in detail to identify deficiencies and formulate targets of sewer maintenance which can be tailored to the network. In this article, we present the status quo of sewer networks and their maintenance in Germany and China and suggest how to maintain sewer networks in a customized way. In particular, we place special emphasis on adapting networks to current policy requirements in China using the concept of "sponge cities (海绵城市)" and the concept of "urban landscapes and ecological restoration (Shuangxiu 城市双修)."

1 Maintenance

1.1 Definition and Necessity

Underground wastewater infrastructure is one of the largest and most important infrastructure types of modern society. It promotes general well-being, public health, and environmental protection. Since it plays such a great social and economic role for all who use it, it is subject not only to increasing demands upon its performance but also to inevitable obsolescence and erosion. For these reasons, societies must maintain wastewater infrastructure appropriately and efficiently to provide the public with a means for sustainable development.

Maintenance is defined as the "combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" (DIN EN 2017).

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In addition, operation is the "combination of all technical, administrative and managerial actions, other than maintenance actions, that results in the item being in use" (DIN EN 2017).

The German technical standard DIN EN 13306 (DIN EN 2017) subdivides maintenance into improvement, preventive maintenance, and corrective maintenance (see Fig. 1).

Improvement covers all measures intended to enhance the intrinsic reliability and/or maintainability and/or safety of an item, without changing the original function. When preventive maintenance is carried out, sewer networks are either maintained and renovated at fixed intervals or inspected regularly; moreover, maintenance is carried out if the inspection reveals that treatment is necessary. Corrective maintenance is performed after a fault has been detected, either immediately after the detection to avoid adverse consequences or deferred but according to fixed maintenance rules.

In practice, these kinds of maintenance are carried out in sewer systems more or less simultaneously. For example, overflow tanks are normally cleaned after a rain event, while maintenance of pumping stations is carried out regularly at fixed intervals. An accident or a breakdown will be addressed and/or repaired immediately. The advantage of preventive strategies is that work can be planned because tasks are – at least partly – known and intervals can be fixed. The precondition for this, however, is that operating performance of the sewer network is known and documented.

Figure 2 shows how the costs and extent of maintenance change in relationship to each other. There is a minimum of maintenance costs relating to work extent. Maintenance costs include both the direct costs of maintenance and those resulting from the interruption of assets when the network does not function properly or at all. While costs of maintenance rise proportionately to the work extent, costs due to disturbance are very high if the network is maintained only when a part of the system collapses ("fire-fighting strategy") and decline quickly if maintenance is pro-

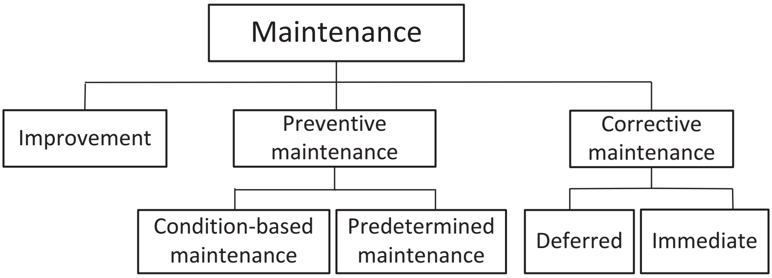

Fig. 1 Maintenance types according to DIN EN 13306 (DIN EN 2017). (Reproduced by permission of DIN Deutsches Institut für Normung e.V. The definitive version for the implementation of this standard is the edition bearing the most recent date of issue, obtainable from Beuth Verlag GmbH, Burggrafenstraße 6, 10787 Berlin, Germany)

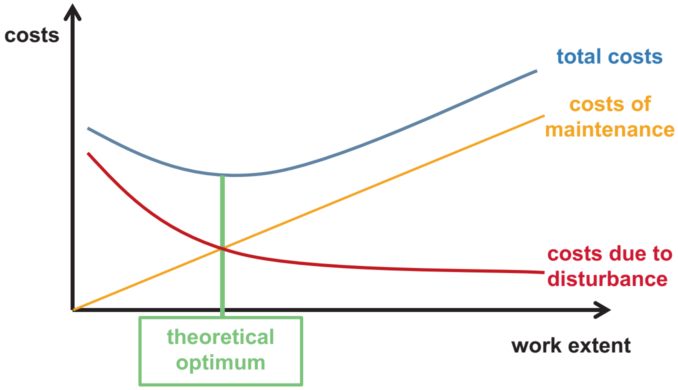

Fig. 2 Costs of maintenance related to work extent. (Referring to DWA-Themen 2009)

vided in a more preventative manner. However, costs due to disturbance cannot be eliminated entirely; therefore at certain scales, more work does not further reduce relative costs of disturbance.

If a system is only maintained when an item (e.g., a pipe) fails completely, costs due to disturbance are significant because measures for repair start only after the failure: pipes must be ordered and the pipeline constructed, while in the meantime, the wastewater must be pumped over to the lower sewer system.

If the responsible department finds the optimal range of work intensity, costs of sewer maintenance can be efficiently reduced.

Sewer networks are very expensive infrastructure and, for this reason, are designed to last a long time. In Europe a lifetime of sewers of 80–100 years is expected. To preserve this huge value, regular maintenance is critical.

The biggest challenge for operation and maintenance (O&M) of sewer systems in comparison to other facility maintenance is that the majority of infrastructure is buried underground and thus invisible in everyday life. For these reasons, people recognize damage at sewer pipes only if there is a blockage that causes flooding, or the ground above the pipe collapses. Therefore, O&M is often neglected. If O&M has not been carried out in previous years both timely and properly and if the whole system is in poor condition, decision-makers should compile a priority list of goals, tasks, and parts of networks which require urgent repair.

New trends in sewer construction and operation challenge maintenance of sewer systems as well. Multi-utility tunnels or fiber-optic cables within sewer pipes impinge upon the working conditions of the maintenance staff. In addition, political decisions can change the operation of the networks and therefore their maintenance. For instance, the current concepts in China, called “sponge city” and latest “urban landscapes and ecological restoration,” which are explained in Sect. 2.2, are changing the working conditions within the sewer systems and also the maintenance tasks.

1.2 Preventive and Customized Maintenance: Goals

A maintenance department has to keep urban drainage and stormwater handling systems operating around the clock. Because local situations differ, each maintenance department has to formulate the goals they want to reach and adapt working processes to the given conditions.

There are two ways to prioritize the necessary work. First, with collected data from field surveys and previous rehabilitation work, the sewers are categorized into critical or noncritical states. Critical sewers should be inspected personally or using CCTV (closed-circuit television, the most used method employed to inspect the interiors of pipelines); together with other assessments, such as hydraulic performance, structural condition, water quality, allowable discharges, and ecological damages, the sewers should be evaluated in order to formulate an integrated action plan. The second concept is to evaluate the overall sewer condition. Using complex databases – including pipe diameter, length, material, age, cover depth, and so on – researchers have been trying to develop an algorithm to rank the sewers (Fenner 2000).

Besides presenting new technologies for inspection and sewer repair, maintenance studies analyze historical event data and sewer information in order to provide more targeted and economical maintenance. The sewer data are being integrated into GIS software, making it possible to evaluate the consequences from a failure and the costs of reconstruction. Furthermore, the probability that individual sewer pipes in networks fail can be evaluated based on their significant characteristics and condition. In addition, hydraulic, environmental, structural, economic, and social performance indicators should be introduced in an assessment module to support the decision-making process (Fenner et al. 2000; Anbari et al. 2017; Baah et al. 2015).

To improve maintenance practices, planners require good documentation, qualified information systems, and extensive databases, most of which are, unfortunately, lacking. Since data are not standardized and consistent and reliable records are missing, planners often find it difficult to predict the amount of work needed, as mentioned above (Fenner and Sweeting 1999). Another challenge maintenance planners face is linking different data and information, such as fixed asset financial databases and maintenance management records (Grigg 1994); other examples are the digitization and link between sewer information and various data such as customer complaints, historic sewer data and past events such as blockages and flooding, and also GIS data. Furthermore, planners must learn how to handle the monitoring data obtained from diverse technologies, online as well as offline (Fenner 2000).

From a financial point of view, a whole-life costing approach of sewer management requires that all relevant costs and revenues incurred during the asset's life should be taken into account, including design and building costs, operating costs, maintenance costs, associated financing costs, and depreciation and disposal costs (Barringer 2003). A special feature of whole-life costing of sewer systems is the reduction of consequences due to failure, such as environmental damages, social disruption, and financial losses. By preventing and removing incipient failures through systematic inspection, detection, and fault repair before they become actual or major failures, preventive maintenance is more appropriate than reactive maintenance. Preventive maintenance thus aims to ensure the performance of sewer systems and avoid/minimize the consequences from their failure but also reduce their service-life costs.

2 Current Situation in Germany and China

2.1 Current Situation in Germany

2.1.1 Sewer Length

In Germany, 96.9% of the population is connected to a sewer system (Berger et al. 2016). Figure 3 shows that the length of the sewer network increased continuously from 1995 to 2013. By 2013 the total length of sewers was 575,880 km, an average length of 7.14 m per inhabitant. During this time, the proportion of combined sewers fell slightly, whereas that of the other two forms rose. The separate sewer system

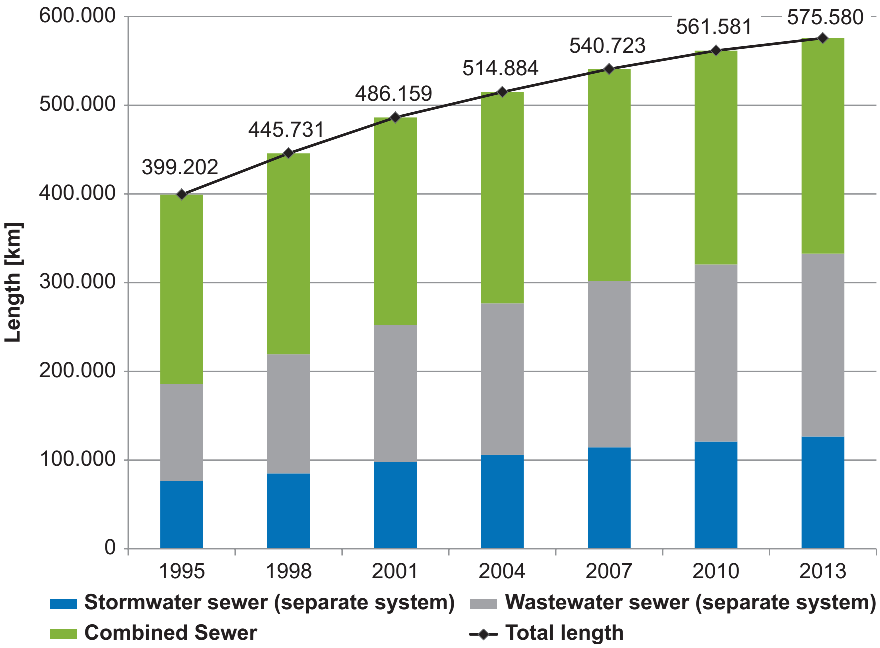

Fig. 3 Sewer length in Germany, 1995–2013. (Berger et al. 2016)

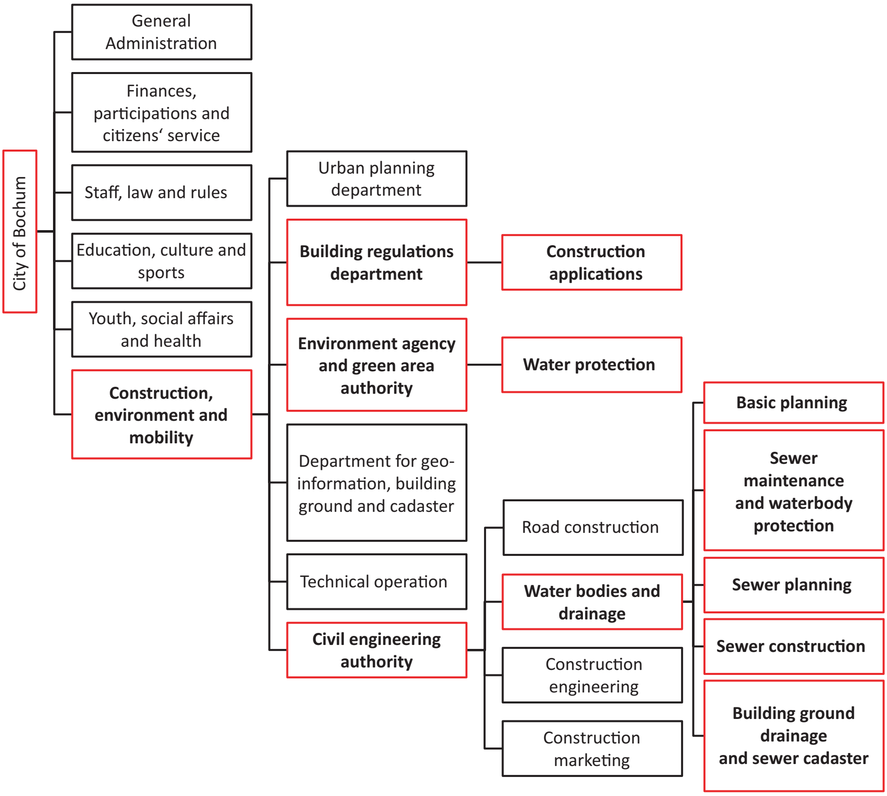

Fig. 4 Organizational chart of the city administration of Bochum, Germany (based on (Bochum 2017), state October 2017)

is dominant in rural areas and in new housing estates of big cities (Brombach and Dettmar 2016).

2.1.2 Sewer Maintenance Departments

The civil engineering authority in municipal administrations is responsible for sewer maintenance; normally, it is in charge of all relevant water management topics. To give a clearer picture of the preferred administration structure of cities in Germany, Fig. 4 shows the organizational chart of the city administration of Bochum as an example. Within this structure authorization, planning, building, operation, and monitoring of the sewer system and water body pollutant control are all responsibilities of the Department of Construction, Environment, and Mobility, which is the city's highest authority of civil engineering. Due to this arrangement, all tasks concerning sewer networks are gathered in one department.

Application for construction falls under the control of both the Building Regulation Department and the Civil Engineering Authority. The Building Regulation Department delegates sewer-based construction to the Civil Engineering Authority.

Water protection is under the control of three departments, each with different duties. The Environment Agency and Green Area Authority issue permits of stormwater discharges, while the Planning Department secures permission of water protection works, and the Sewer Maintenance and Water Body Protection Department formulates the concept and implements measures for water body protection.

This administrative structure enables the city of Bochum to construct, operate, and maintain sewer systems efficiently.

Other cities administer the responsibilities differently. For example, a municipal administration may contract out the operation and maintenance of wastewater management to a privately owned company, and the civil engineering authority will supervise such a company. This is how sewer management in Cologne and Hamburg is organized.

2.1.3 Regulations on Maintenance Work and Its Frequency

Sewer maintenance in Germany has been developed continuously since construction of sewer systems started at the end of the nineteenth century. Standards, guidelines, and regulations on sewer construction, operation, and maintenance are well established. In addition to the European Water Framework Directive (WFD) and the national legislation, there is a wide range of regulations and directives at different levels of administration.

Worksheets from technical associations give detailed assistance on concrete tasks of sewer planning, building, operation, and maintenance. Regarding sewer O&M, the directive "Requirements for Operation and Maintenance of Sewer Networks" (*Anforderungen an den Betrieb und die Unterhaltung von Kanalisationsnetzen*) (DWA-Arbeitsblatt 2017) suggests how and how often different components of sewer systems should be inspected and cleaned. In addition, the worksheet "Operating Extent for Sewer Networks – Recommendation on the Amount of Personnel, Vehicles and Equipment" (*Betriebsaufwand für die Kanalisation - Hinweise zum Personal-, Fahrzeug- und Gerätebedarf*) (DWA-Arbeitsblatt 2005) provides recommendations on how many personnel, vehicles, and equipment are needed on average to fulfill these tasks properly.

Some German provinces have released self-monitoring regulations that provide guidelines concerning the scope and frequency of sewer monitoring and the regulatory requirements for operation and repair of sewer networks.

The Water Management Act (*Wasserhaushaltsgesetz*), German Wastewater Ordinance (*Abwasserverordnung, AbwV*), and German Federal Immission Control Act (*Bundes-Immissionsschutzgesetz, BImSchG*) all stipulate that "best available techniques" are required in sewer networks to guarantee appropriate environmental protection. This does not only mean advanced procedures and facilities but also optimized operations to limit emissions and ensure plant safety and a high level of environmental protection.

2.1.4 Status Quo of Sewer Networks and the Maintenance of Sewer Systems

Because legislation, standards, and guidelines are carefully regulated, the documentation about sewer facilities and their maintenance is, for the most part, advanced in Germany; the condition of private lateral sewers, however, is mostly unknown.

German authorities have made first attempts at entering different data of the public sewer system into a geographic information system (GIS) (Ostermann 2009). In North Rhine-Westphalia, relevant data from wastewater treatment plants and receiving waters are freely available in the public domain on the web (Wasserinformationssystem n.d.). But data of such sewer systems have not been integrated in this project yet.

2.2 Current Situation in China

2.2.1 Sewer Length

China has been undergoing rapid economic development with a great amount of construction activity in the last 20 years. During this time, the length and, thus, coverage of the urban drainage network in China have increased rapidly, as shown in Fig. 5. Most of Chinese sewer networks are separated systems. Combined sewer systems exist only in some historical city centers.

By 2015 the total length of sewers was 539,567 km, an average length of 0.39 m per inhabitant (calculated all over China; 1371 billion inhabitants in 2015). Between 2010 and 2015, new sewers were primarily constructed as separate sewers.

In 2015, the percentage of wastewater treated was 91.9% in Chinese cities, while the rate in the countryside and in towns was about 51% and 85%, respectively. This shows that in the countryside, a lot of work must still be done because the national standard requirement of wastewater treatment rate is 85% and 95% in towns/rural areas and in cities of China, respectively (National Bureau of Statistics of China 2015) (Outline of the 13th Five-Year Plan 2016).

The percentage of sewer connections in Western China, such as provinces Xizang, Qinghai, and Xinjiang, are still very low. In 2015, the sewer connection rates in these three provinces amounted to 19.1%, 60.0%, and 83.4%, respectively, whereas the cities of Shanghai and Beijing had connection rates of 92.9% and 88.4% in the same year (National Bureau of Statistics of China 2015). Western Chinese authorities have prioritized the completion of the sewer networks as fast as possible.

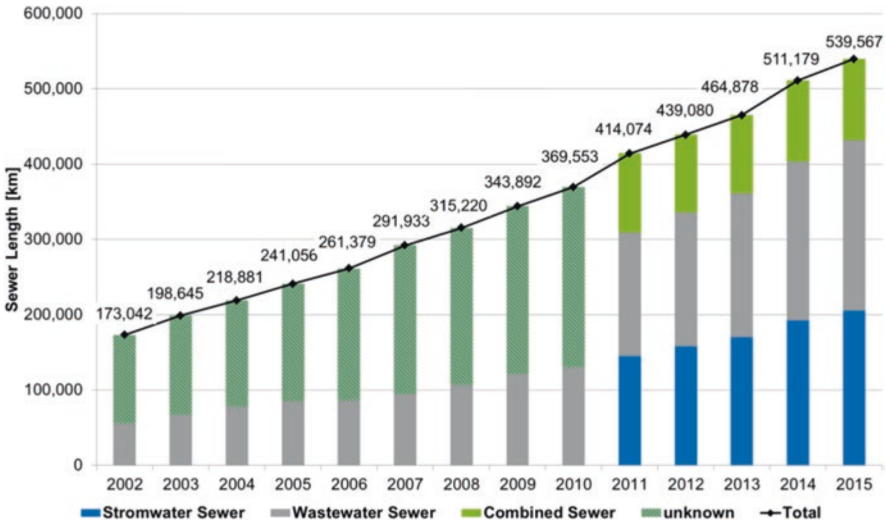

Fig. 5 Sewer length in China, 2002–2015. (Data from National Bureau of Statistics of China n.d.) By the year 2010, statistics recorded only wastewater sewers while summarizing all other sewers. Since 2011 statistics distinguish combined sewers from wastewater and stormwater sewers as is common practice in other countries

Although efforts are being made to construct new sewer networks to keep up with rapid urbanization, there are often reports about city water clogging, flooding, environmental pollution, and ecological damage due to sewer failures. Researchers give the following reasons for these phenomena:

- The complex situation of underground and aboveground terrain, geomorphology, landscape, and buildings on the surface of the catchment area is not taken into consideration enough, or not at all, when sewer systems are planned. There are also cities without overall sewer network data: for example, the direction, diameter, and elevation of the sewer network may be undefined. This makes it difficult to connect the sewers from each part of the city (Zhang 2010; Wu n.d.).
- The sewer design lacks a medium- to long-term vision. When urban sewer systems are designed, engineers do not adequately consider the development and the change cities may undergo. Unfortunately, city planners often do not allow for a rapide increase in the amount of wastewater, the increase in rainfall intensity, the impakt of urbanization, climate change, and future sea level rise, etc. in their urban wastewater plans (Zhang 2010; Wu n.d.; Liu and Zeng 2013).
- Coverage of the sewer system in urban areas is regularly incomplete, and the design standards are low. The drainage system is often designed based on a 1- to 3-year rainfall intensity, and the capacity of sewers is depleted because urbanization is so rapid and wastewater quantities rise so quickly. The sewer system is thereby susceptible to clogging and flooding (Liu and Zeng 2013).

- Commonly, planners pay attention to the construction of sewer networks and wastewater treatment plants, but maintenance and management of the existing networks are not prioritized. Advanced detection methods which assess the sewer network condition are barely used. Seldom is there scientific, systematic, and regular maintenance. This leads to a poor structural condition and functional performance of the sewer system (Zhang n.d.-a; Yang n.d.).
- Financial restrictions may cause an imbalance between urban construction and development of wastewater disposal systems. Moreover, sewer construction lags behind the construction of wastewater treatment plants, and lateral sewer construction lags behind the construction of main sewers. Illegal cross-connections and wastewater disposal are frequent (Zhang n.d.-a, b).
- Poor availability of data and unreliable data are common. Information on system design and system reliability (e.g., failure data, historical records) is usually lacking. Meanwhile researchers have suggested using the Internet for real-time detection of the whole sewer system, but not enough attention is paid into putting this idea into practice (Yang n.d.; Deng n.d.).
- In China, the condition of sewer networks varies greatly. Sewer networks along the east coast are relatively well constructed, while the construction of sewers in western regions is seriously inadequate (National Bureau of Statistics of China 2015).

In general, different researchers report that as long as underground wastewater infrastructure performs its intended function, there are few concerns about its long-term maintenance. However, with greater public understanding of the necessity of efficient sewer networks, so increases the demand for well-organized maintenance.

2.2.2 Responsible Departments of Sewer Maintenance

In China, water-related responsibilities are often shared between different departments. Due to the organizational structure of city administration, different organizational levels (e.g., decision, technical, operational) may be insufficiently integrated, however (Zhang n.d.-a).

Clear structures for the responsibilities of the sewer system facilitate the development of a well-functioning sewer system. In general, there are two types of city administrative structures governing water management in China (see Figs. 6 and 7). As examples, the city administrations of Wuxi and Jiaxing in the Lake Tai (Tai Hu) catchment area have been chosen.

In Jiaxing all water-related tasks – including wastewater drainage, rainwater drainage, wastewater treatment, flood protection, water saving, and also water supply – are regulated and coordinated by one central department, the Five-Water Comprehensive Control Office (五水共治办公室), which is one of the 33 departments under the city government. The operator of all water issues is Jiaxing Jiayuan Water Investment Group Ltd., a state-owned enterprise, which is led by the State-owned Assets Supervision and Administration Commission. This commission is responsible for the staffing and assessment of the department. The Municipality and

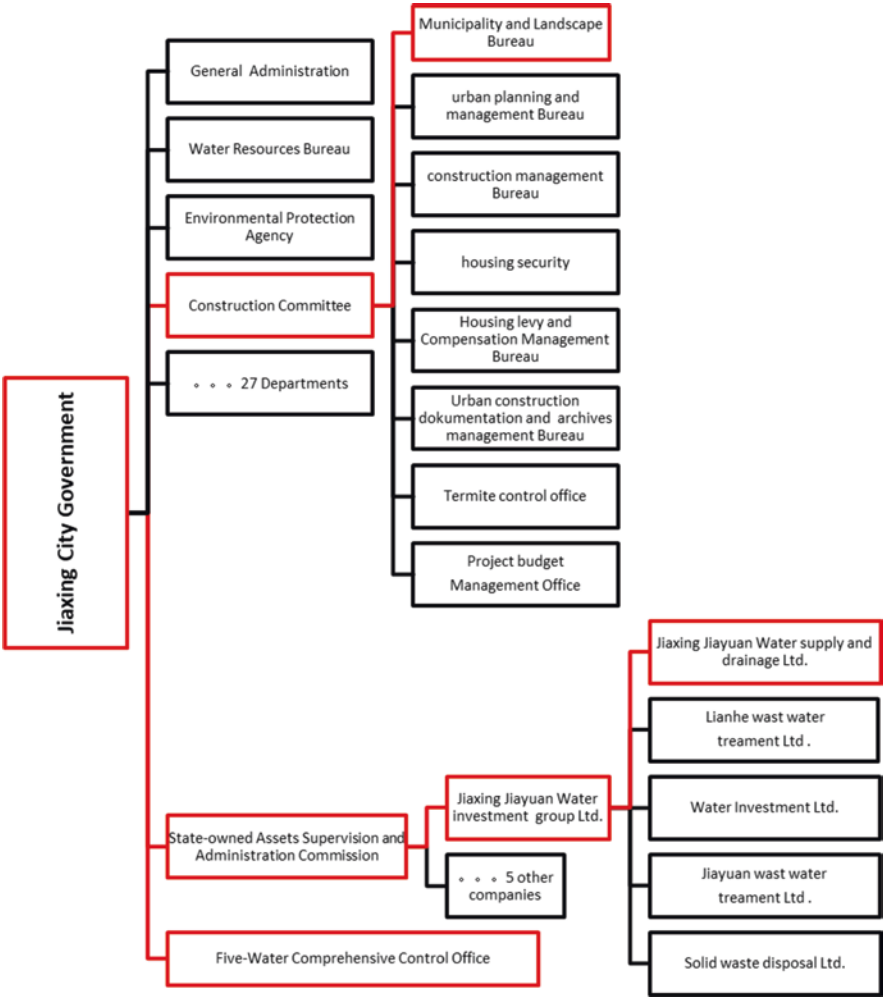

Fig. 6 Structure of the city administration in Jiaxing, China, 2016. (Government n.d.)

Landscape Bureau, which is under the Construction Committee, is in charge of the supervision and operational guidance of the company.

This structure allows for an efficient cooperation between different sections of water management. However, there may be problems with facility management if the sewer operation is connected to other infrastructures, such as street and landscape. This kind of organization is found only in relatively new and smaller cities.

In the city of Wuxi, a public authority is in charge of operating the sewer system. This company belongs to the Department of State-owned Assets Supervision and Administration Commission, which is one of the 54 departments of the city government. The Municipality and Landscape Bureau, another parallel department of

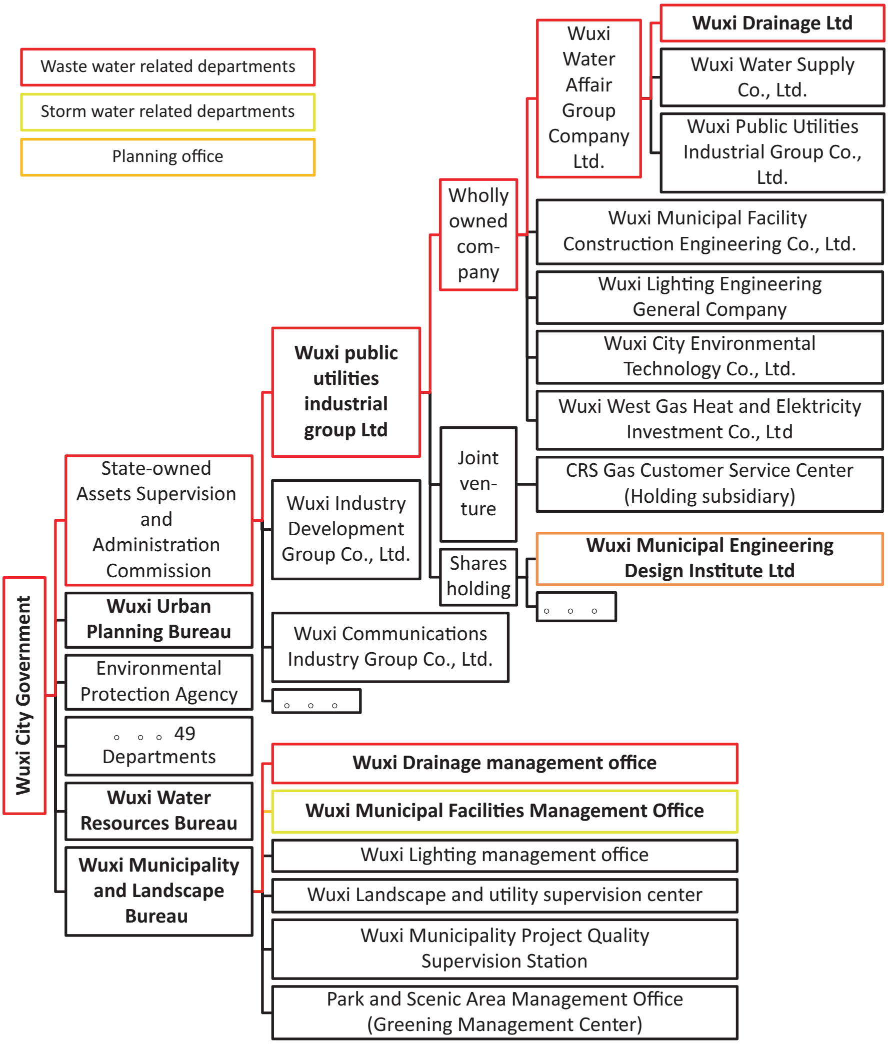

Fig. 7 Structure of the city administration in Wuxi, China (state: 2017)

administration, is responsible for the management and supervision of the sewer operation. Stormwater management in Wuxi is organized by the Municipal Facilities Management Office (Fig. 7).

A difficulty of this tripartite responsibility is to define the interfaces between rainwater, sewage, and surface water properly so that no important task is neglected. One major challenge is to address cases in which water changes from one field of responsibility to another, for example, due to improper connections of different drainage systems to each other.

In both organizational types, different institutions are often in charge of construction, operation, and maintenance of the sewer networks. Commonly, the network owner is allowed to design and construct parts of sewer networks according to special development needs, but supervision of the construction quality is often lacking. All of this means that there is no integrity and uniformity of the entire sewer network. In addition, construction without maintenance of the sewer system is the status quo in some cities (Cai and Li n.d.).

In short, if the responsibility for different water streams is given to different departments, it is more difficult to get a full overview on sewer system dynamics. The more centralized the administrative structure, the easier it is to organize the activities efficiently.

2.2.3 Chinese Regulations and Legislation Regarding Sewer Systems

Series of national standards and manuals exist for the construction of sewer systems (see Table 1).

In addition, planners can fall back on the Design Manual of Water Supply and Drainage (给排水设计手册), eight application-specific standards from the Chinese Association for Engineering Construction Standardization (CECS standards, CECS 137–143 and 145), and the National Architecture Standard Design Atlas (国家建筑标准设计图集). But the regulation of sewer maintenance is still missing. Since 2014, the regulation on urban drainage and sewage treatment (城镇排水与污水处理条例) has been officially valid in China. This regulation stipulates that the opera-

Table 1 Chinese national standards for the construction of sewer systems

English title	Chinese title	Standard no.
Code of urban wastewater engineering planning	城市排水工程规划规范	GB50318-2000
Code for design of outdoor wastewater engineering	室外排水设计规范	GB50014-2006
Technical code of water supply and sewerage of urban areas	城镇给水排水技术规范	GB50788-2012
Code for earthquake-resistant design of outdoor water supply, sewerage, gas, and heating engineering	室外给水排水和燃气热力工程抗震设计规范	GB50032-2003
Structural design code for special structures of water supply and wastewater engineering	给水排水工程构筑物结构设计规范	GB 50069-2002
Structural design code for pipelines of water supply and wastewater engineering	给水排水工程管道结构设计规范	GB50332-2002
Code for construction and acceptance of water and sewerage pipeline works	给水排水管道工程施工及验收规范	GB50268-2008

tor of sewer networks should maintain the sewer system regularly and ensure its functionality. The technical specifications for maintenance of sewers, channels, and pumping stations in cities (城镇排水管渠与泵站维护技术规程, CJJ 68-2007) recommend regular maintenance, but this is not an enforced clause.

Technical regulations for operation and maintenance of drainage pipes in cities and towns (城镇排水管道运行与维护技术规程,浙江省) are published by the Department of Housing and Urban and Rural Development of Zhejiang province (浙江省住房和城乡建设厅) and only applicable to the management and maintenance of sewer systems in Zhejiang province. This is one of the first attempts to provide a legislative framework for maintenance work. Shenzhen, Nanjing, Lianyungang, and Hebei province have planned and conducted similar work. Nevertheless, extensive and detailed regulations and manuals regarding sewer maintenance are still lacking in China.

2.2.4 Status Quo of Sewer Networks and Maintenance of Sewer Systems

The status quo and maintenance of sewer systems in every single city are very different, depending on the state of development of the city, the economic situation, and the water-related organization of the city administration.

Along the eastern coastal areas of China, economic development is advanced. Sewer networks are widespread, and the cities are establishing advanced sewer management systems. Wuxi in the Tai Hu catchment, for example, has the highest sewer density in the mainland of China, and the responsible departments are now focusing on setting up an information management system for sewer operation, monitoring, and coordination. Data from sewer networks will be collected and integrated in GIS. In this way, public authorities will be able to incorporate information management of the sewer system and monitor data via mobile terminals online. This should be a precondition for online remote control of the sewer system. The maintenance of Wuxi's sewer networks has been contracted out to a certified company, which is required to keep all the visual data on record and use advanced techniques to maintain the system (Liu 2017).

In Shanghai and Beijing, sewer management practices are also advanced. In 2011, maintenance plans were already detailed and appropriate, and experience with respect to sewer maintenance was abundant. Big efforts were made in integrating sewer network data into GIS and model building for the drainage system. Now, public authorities are not only able to monitor water quantity online but also the quality needed to support daily maintenance (Li 2011; Kuang 2011).

2.2.5 Political Requirements

In the Chinese "13th Five-Year Plan" for the years 2016–2020, the following aims related to sewer systems have been defined in the part "National Urban and Municipal Infrastructure Constructíon":

- Sponge city construction

The sponge city concept focuses on the city’s internal drainage system and the exploitation and management of rainwater. These systems not only provide city drainage and flood protection but also ecological and environmental protection in urban areas with a variety of engineering measures for rainwater management, such as low-impact development (LID) and water-sensitive urban planning and design (Yu 2015).

The 13th Five-Year Plan – which stipulates that 20% of Chinese cities must be reconstructed to sponge cities by 2020 – aims to adapt the existing sewer systems to the sponge city concept. In particular, dimensioning and construction of sewer systems must employ different technical measures because both water quality and quantity will be changed by the construction works.

Depending on the measures within the catchment area, O&M of sewers will involve smaller amounts of water, but more sedimentation, as sponge cities will keep the water within the city.

- Construction of comprehensive urban underground utility tunnels

Comprehensive urban underground utility tunnels will be built to avoid the necessity to open the surface multiple times for various infrastructures, such as electricity, communications, radio and television, water supply and drainage, heat, gas, and other municipal pipelines. By 2020, 30% of new and 2% of old urban areas should be equipped with comprehensive underground utility tunnels according to the Chinese 13th Five-Year Plan. In these areas, maintenance will become easier because inspection and renovation can be done within the tunnel.

- Black and odorous water body governance
  “黑臭水体整治”

According to the guideline for urban black and odorous water body governance, which has been issued by the Ministry of Housing and Urban-Rural Development in 2015, a “black and odorous water body” is defined as a water body with unpleasant color and/or unpleasant odor within urban areas. Depending on the degree of water color and its odor, the water bodies should be subdivided into two categories, namely, “light black and odorous” and “heavy black and odorous.” The parameters for the classification of urban black and odorous water bodies include transparency/turbidity (25–10 cm light black and < 10 cm heavy black and odorous water body), dissolved oxygen (DO) (0.2–2.0 mg/L light black and < 0.2 mg/L heavy black and odorous water body), redox potential (ORP) (−200–50 mV light and < −200 mV heavy black and odorous water body), and ammonia nitrogen (NH_3-N) (8.0–15 mg/L light and > 15 mg/L heavy black and odorous water body).

Black and odorous water bodies should be reduced to less than 10% of all water bodies in urban areas by 2020. The interfaces between treatment of black and odorous waterbodies and sewer systems are the leakage of sewers and combined sewer overflows (CSO) or stormwater overflows in separate systems, which are typical diffuse pollutant sources for water bodies. When sewers are properly maintained, the rate of sewer leakage can be controlled down to a low level. The first flush of a rain event is highly loaded, and its discharge into surface waters through overflows is one of the most important nutrient sources that cause eutrophication. Therefore, the first flush should be drained to a treatment plant (Angrill et al. 2017).

- Urban landscapes and ecological restoration (double restoration)
  “城市修补、生态修复(双修)”

The tasks of “double restoration” have been scheduled and should gradually repair the disrupted natural ecosystems in urban areas. On the one hand, cities, especially old city areas, should be rehabilitated to create better living conditions. On the other hand, the ecological function of surrounding areas of cities should be restored through the repair of disturbed water bodies, wetlands, vegetation, abandoned land, and polluted soil. The goal is to repair 40,000 hectares of land area (Ministry of Housing and Urban-Rural Development of the People’s Republic of China (MOHURD) 2017). Different from environmental remediation, the “double restoration” targets urban infrastructure and public service to enhance sustainability and livability. As an important infrastructure, the sewer system is relevant to many environmental aspects, for example, water bodies, wetlands, and soil.

- Smart city construction

Smart city construction has been requested from the CPC Central Committee and the State Council of China (CPC Central Committee and State Council 2014). The 13th Five-Year Plan formulates a general aim of smart city construction: a regulatory platform for municipal infrastructure should be constructed in every prefecture-level city in China. Smart city construction aims to provide intelligent urban management and operation and, furthermore, to create a better life and promote harmonious and sustainable development of cities.

The “Internet of things” (IoT) is the most important instrument to make the smart city a reality. IoT comprises the use of advanced information technologies to acquire comprehensive data, transfer it through the Internet, and evaluate it and respond appropriately and automatically. The machine-to-machine communication (M2M) and intelligent processing and control capabilities are characteristics of IoT (Zanella et al. 2014). Smart city construction with IoT for sewer management means establishing sensor systems in sewer networks to obtain the necessary information on sewer operation, transferring the data through the Internet in real time, as well as centralizing and securing data analyses. But it also entails managing the data and achieving the service functions automatically, through online monitoring, location tracking, alarm linkage, scheduling command, plan management, remote control, security prevention, remote maintenance, statistical reporting, decision support, and so on.

3 Maintenance Optimization

3.1 Goals of Maintenance Optimization

Overall goals for improving O&M are ensuring the safety and health of the population, drainage performance, and protection of the environment and also optimizing cost-effectiveness. The number of structural and functional failures, the risk of failing, and, as a result, both repair costs and losses should be reduced. Well-organized sewer maintenance can assist in balancing the performance, risk, and cost in the short- and long-term operation of sewer networks. The optimization of sewer maintenance should be adapted to specific local circumstances, such as economic framework, environmental situation, climate condition, and local policies. It is advisable to use SMART criteria, which can guide in the setting of objectives (Steffens 2015). Using SMART criteria, clear and coherent objectives are set at strategic, tactical, and operational levels. Each objective should be evaluated according to clear criteria and measured through standardized metrics. The optimization aims of sewer maintenance should be substantiated as follows:

- S (**S**pecific goals): Concrete goals of sewer maintenance optimization must be defined based on the local situation. In Germany as in Beijing and Shanghai, authorities are optimizing their efforts by focusing on online data collection and automated sewer network control. In contrast, some cities in Western China are only now completing their networks. Their goals of optimization should be the maintenance-oriented planning and construction of new sewer networks. In some cities, where functioning sewer networks already exist, goals can include digitalization of operation data, data documentation, and establishing maintenance strategies and concrete maintenance schedules.
- M (**M**easurable): Progress of sewer maintenance optimization should be quantifiable. For example, 90% of the urban area should be connected with a well-designed sewer system, or 100% of the sewer data should be collected and digitalized, or once a year the sewer system in the cities should be cleaned.
- A (**A**ssignable): The goals of sewer maintenance optimization must be achievable. For instance, in cities where no authority or more than one authority is in charge of sewer maintenance, a responsible unit should be assigned to obtain sufficient resources to reach the defined goals.
- R (**R**elevant): The goals of sewer maintenance optimization should lead to the final relevant aim – that the sewer system works better and reliably through adequate maintenance. The operation of sewer networks can be improved continuously.
- T (**T**ime bound): The deadline for reaching the goals should be set; however, there must be a realistic chance to reach them. Otherwise efforts will be lacking. The Chinese five-year construction plan, for example, can be a proper reference timeline because of the political influence and also the financial plan. However some aims will require other deadlines (either shorter or longer).

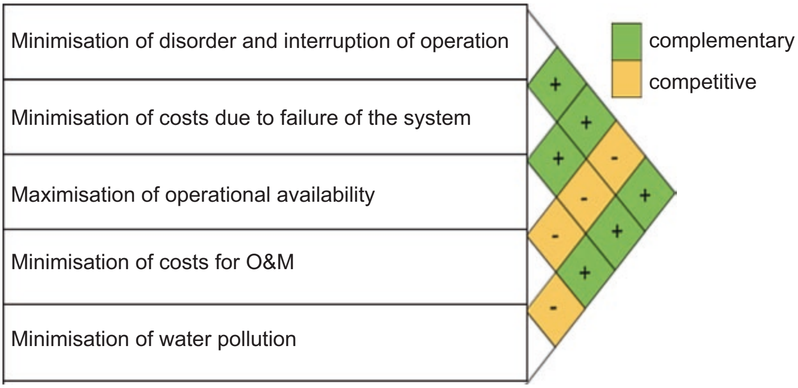

Fig. 8 Possible overall goals for optimization of sewer O&M and their interdependencies. (Haussmann 1995)

It is not easy to set unambiguous aims for maintenance optimization. But it is necessary to set tactical, short-/medium-term goals, with a realistic long-term strategic goal. Otherwise the optimization will not work.

Different objectives have different interdependencies. Some of them promote each other, but some of them compete against each other. Obviously, reducing costs competes against all other objectives (Fig. 8). Based on the evaluation of sewer performance, priorities for measures and investments in sewers must be defined with respect to the risk and magnitude of failure so that the limited financial capabilities, sewer performance, and risks can be balanced. It is also essential that the organization's strategic, tactical, and operational objectives are aligned and systematic monitoring and verification are undertaken at each level of authority and operator consistently.

3.2 *Maintenance-Oriented Planning*

Future-oriented sewer planning does not only mean dimensioning a sewer system but also modifying its operation and maintenance to the city's development and precipitation changes. In case authorities already integrate maintenance when planning a sewer system, they make this work more efficient and easier during the sewer system's service life. Current trends in sewer maintenance are gradual mechanization and automation so that labor intensity can be reduced, working conditions improved, and operational safety ensured.

When parts of buildings and technical devices are standardized and built with high quality, the labor intensity of O&M can be reduced and components easily replaced. If it is possible, planning should ensure that sewers do not have physical

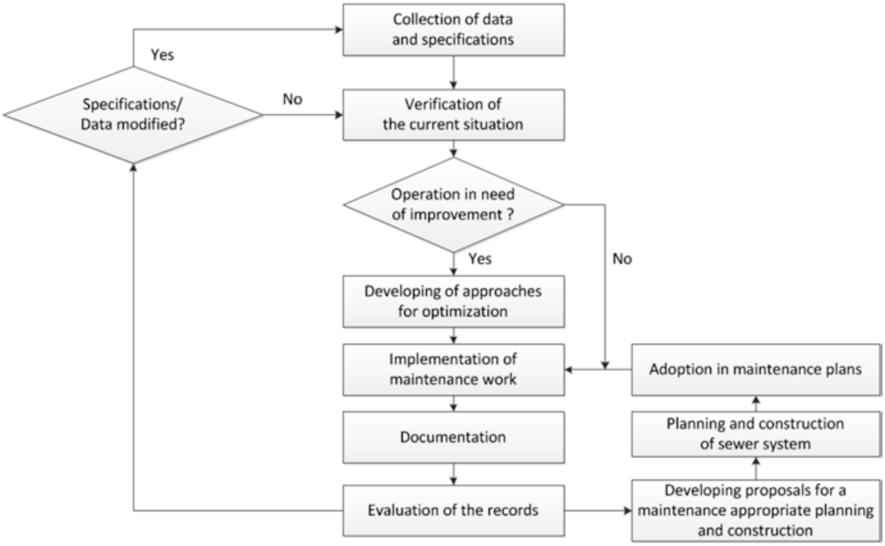

Fig. 9 Procedure of maintenance optimization. (Haussmann 1995)

barriers at positions that may disturb maintenance. Manual work in sewers and tanks should be replaced by mechanized and automated solutions so that manual work can be reduced as far as possible. Another important part of maintenance-oriented planning is safety: for example, designing escape routes and good ventilation but also avoiding construction that can cause accidents.

3.3 Procedure of Maintenance Optimization

Optimization of sewer maintenance must be adapted to the local situation. It is an ongoing process that must be repeated frequently to make sure that new developments, which may influence the sewer system, have been taken into account. Figure 9 shows the procedure flow chart in general.

The central question of the procedure is whether operation should be improved. For that to happen, data must be collected during operation and maintenance work. Evaluation and verification of the collected data are indispensable. If improvements are necessary, a maintenance and future-oriented plan should be established using SMART criteria. If it is not necessary to change a maintenance plan, the state of the system can be evaluated with data collected after each operation, and decisions for further actions can be made based on the results of the evaluations.

4 Conclusion

Maintenance of sewer networks ensures that sewer systems operate efficiently and safely. The targets of sewer maintenance should be formulated according to the local conditions and restrictions. China is a typical example of a country with a huge variety of sewer systems with varying conditions and extent of coverage. Making maintenance preventive and customized will only be successful when reliable information and data are available and when the decision-makers understand the political, social, environmental, and constructive constraints, set clear and appropriate targets, and orient their work toward future challenges.

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Implementing Real Time Control Systems to Minimize Emissions from the Sewer System

Michael Pabst

Abstract This chapter gives an overview of real-time control (RTC) systems in sewer systems. The first sections introduce some of the fundamental concepts and terms of RTC and give a brief overview of German guideline documents on the design of RTC systems. Subsequent sections then describe a case study in Hildesheim, where a general global control system is implemented in the sewer network.

1 Introduction

Real-time control (RTC) systems provide a commercially interesting alternative compared to conventional structural extensions of sewer networks. It is obvious and has been demonstrated in numerous cases that RTC allows better utilization of the existing sewer infrastructure (which constitutes an asset of high monetary value) and the reduction of pollution discharges. Furthermore, it allows the sewer system to be better prepared for future changes in flow patterns, including those induced by climate change. Additional benefits are obtained, such as increased energy efficiency (e.g. through prudent operation of sewage pumps). Further environmental benefits can be activated by an integrated control of the sewer system and wastewater treatment plant.

2 Main Principles of Real-Time Control in Sewer Systems

This section introduces some of the fundamental concepts and terms of RTC given by Schütze et al. (2004) and DWA (2005) or Schütze et al. (2008).

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2.1 Definition and Key Terms

An urban wastewater system is controlled in real time if process variables are monitored in the system and, (almost) at the same time, used to operate actuators during the flow process.

In principle, control of the process can be schematized by means of control loops (Fig. 1), which may be implemented by hardware components including sensors, which monitor the process evolution; actuators, which influence the process; controllers, which adjust actuators to achieve minimum deviations of the controlled process variable from its desired value (set point); and data transmission systems transmitting data between the different devices.

RTC in urban drainage wastewater systems poses stringent requirements on sensors, such as measurement accuracy and reliability, physical and chemical resistance and suitability for continuous recording and remote transmission.

Main sensors used include:

- Rain gauges such as weighing gauges, tipping buckets and drop counters. Rain measurement can also be obtained by meteorological radars enabling also short-term rain forecasts.
- Water level gauges such as floating hydrometers, bubblers, pressure inductive gauges and sonic gauges. Water level gauges are essential for monitoring the state of sewer storage or to convert levels to flow rates where backwater effects are not dominant.
- Flow gauges such as level-flow converters, ultrasound velocity metres or electromagnetic metres.
- Quality gauges such as sensors for organic pollution (TOC, readily biodegradable COD), nutrients (total, ammonia and nitrate nitrogen and phosphorus),

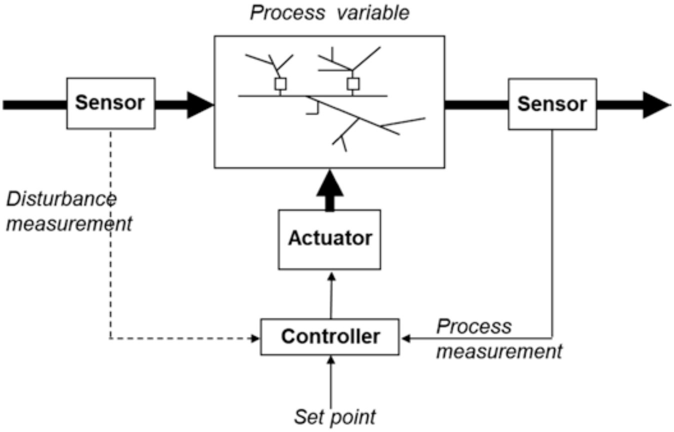

Fig. 1 Feedforward control loop (disturbance measurement) and feedback control loop (process measurement); bold letters indicate hardware components, and italic letters indicate transferred informations (variables)

biomass (turbidity, respiration activity or sludge level), toxicity (via respirometry), etc. These sensors supply high information value; however, they also require significant operation and maintenance skills. Simpler but more robust measurement devices, which are often used as surrogates for the actual variable of interest, include sensors for pH, conductivity, redox potential and UV and IR absorbance. However, considerable efforts are required to create the interpretation modules that convert the raw sensor output into the required information (Schütze et al. 2004).

Actuators in urban wastewater systems include:

- Pumps (axial or screw) with constant or variable speed.
- Gates (sluice, radial or sliding) or throttles which restrict the flow in a sewer or at the outlet of a detention tank, usually activated by motors and used for generating in-line storage or for diverting flows into other parts of the system.
- Weirs (transverse, side spill) which can either be static structures (e.g. to reduce overflow discharges over combined sewer overflows (CSO)) or moveable and adequately positioned in order to generate storage volume.
- Valves which are used to restrict and direct flows.
- Other actuators, such as movable air-controlled siphons used for storage and movable flow splitters which separate flow into two or more paths.
- Chemical dosing devices that adjust the conditions in the tanks to achieve a certain performance, e.g. supply of readily biodegradable COD to enhance denitrification, injection of acid/base to control pH within a biologically acceptable range, addition of polymer or ballasting particles to enhance settling of biological flocs, etc.
- Aeration devices which are an essential and cost-determining part of most of the wastewater treatment plants. Oxygen is indeed necessary for some of the important biological pollutant removal processes, e.g. nitrification. Many different types exist; currently fine bubble aeration systems are the most cost-effective (Schütze et al. 2004).

The control loop defined above is the basic element of any RTC system. In feedback loop control, commands are actuated depending on the measured deviation of the controlled process from the set point. Unless there is a deviation, a feedback controller is not actuated. A feedforward controller anticipates the immediate future values of these deviations using a model of the process. Then it activates controls in advance to avoid the predicted deviations. A feedback/feedforward controller is a combination of these two types.

A standard controller used for continuously variable actuator settings is the proportional-integral-derivative (PID) controller and its simplifications (P, PI, PD). Its signal to the actuator is a function of the difference between the measured variable and the set point.

The parameters in that function must be calibrated unless the controller is equipped with an auto-tuning function. Calibration is performed through analysis of the underlying differential equations or through either real or simulated experiments.

Two-point or on/off control is the simplest and most frequently applied method of discrete control. It has only two positions: on/off or open/closed. An example is the two-point control of a pump to fill a tank: the pump switches on at a low level and off at a high level. The difference between the two switching levels is called dead band. Three-point controllers are typically used for actuators such as gates and movable weirs, etc. In the middle position of the controller, the output signal remains in its previous state, and in the other positions, it assumes either maximum or minimum, respectively.

Today, digital programmable logic controllers (PLC) control and coordinate all functions of an outstation (i.e. a monitoring and/or control site in the field). These include acquisition of measurement data; preprocessing (smoothing, filtering, etc.); checks for status, function and limits; temporary data storage; calculation of control action; and receive and report data from and to the central station. In the control room, a supervisory control and data acquisition system manages all incoming and outgoing data. Alarms are generated here, and operators monitor and control the processes (e.g. change of set points). Data transmission systems may be realized by means of leased or dedicated telephone lines or by wireless communication systems.

RTC systems, in particular those with frequent man-machine interaction, also must be equipped with user-friendly operator (user) interfaces (Schütze et al. 2004).

2.2 Control Type

In relation to the degree of automation of the RTC system, the type of control may be:

- Manual if the actuators are adjusted by operators
- Supervisory if the system actuators are actuated by automatic controllers with their set points being specified or approved by operators or by a supervising system
- Automatic if the control is realized in a fully automatic way by a controller, including in all cases manual override capabilities

With regard to the complexity of a RTC system, the following distinctions are made in the literature: A system is operated on a local control level if the actuators are not remotely operated from a control room and if process measurements are taken directly at the actuator site (Fig. 2 left). Local control may represent a good solution in the case of one actuator only, but if the system is more complex or if all actuators must be operated jointly, global control may be more effective. In this case, sensors communicate their data to actuators located in other parts of the system. Alternatively, a central control room receives all the measurement data of local sensors and centrally operates the actuators in a coordinated way (Schütze et al. 2004) (Fig. 2 right).

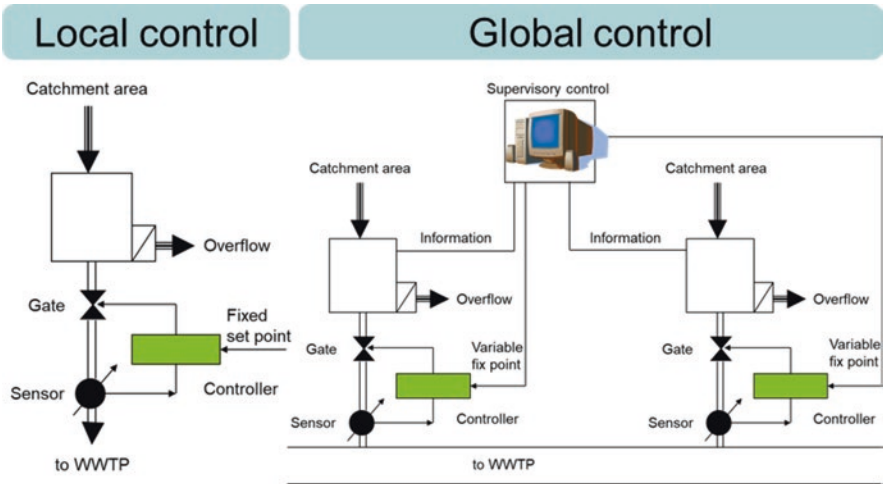

Fig. 2 Schematic figures of local control (left) and global control (right) for storage tanks in sewer system. (Pabst 2017)

In the last 20 years, research has focused on integrated control (e.g. Seggelke 2002; Krebs and Rauch 2002; Seggelke et al. 2005; Muschalla et al. 2009). This control level involves simultaneous and coordinated control of the sewer system and treatment plant, possibly also of the receiving water body and of wastewater production (including forms of source control) (Fig. 3).

This approach allows for the analysis of quantitative and qualitative aspects of wastewater and for controlling the environmental conditions of the receiving waters (Schütze et al. 2002; Rauch and Harremoes 1999; Meirlaen and Vanrolleghem 2002; Meirlaen et al. 2002). This opens up significant additional potential for controlling and improving the performance of wastewater systems. It has been shown in studies (e.g. Seggelke et al. 2005) that many examples of wastewater systems do indeed have control potential when applying integrated control, even in cases where neither local nor global control scenarios appear to increase the performance of the wastewater system. Practical examples of control which take into account some of these concepts include Quebec (Pleau et al. 2001, 2005) but also Bröhltal (Hilmer 2008) and Wilhelmshaven (Seggelke et al. 2013).

2.3 Control Objectives, Fundamental Strategies and Control Algorithms

When formulating objectives of control or, in general, defining performance indicators for sewer systems, usually auxiliary criteria such as overflow volumes or frequencies are used. Additional objectives could include, e.g. avoidance of flooding and the equalization of peak discharges to the treatment plant or the reduction of

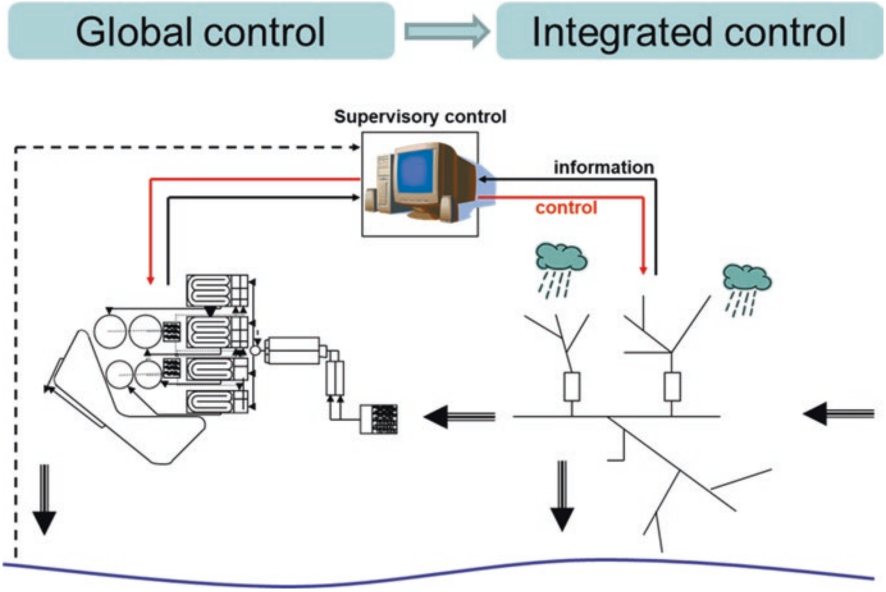

Fig. 3 Schematic figure of integrated control. (Pabst 2017)

sewer sediments by deliberate flushing. In practical applications, the reduction of costs also constitutes an important objective, if not the driving one, of RTC implementations. Control aims at improving the performance of the system, by using essentially the existing infrastructure (or, at least, trying to avoid large investments for static extensions of the system in order to meet the demands) in a sophisticated way. For some case studies, RTC contributed to significant cost savings (Schütze et al. 2004).

In most case studies, control algorithms must be designed specifically for the given drainage system. Recent research has been oriented toward general procedures (e.g. Pabst et al. 2011; Pabst 2017; Dirckx et al. 2014; Marcantini et al. 2016); however, these sources include one or several of the following fundamental strategies:

- Uniform utilization of storage capacities within the system.
- Discharges should be allowed only when all storage is utilized.
- Preferred usage of storage volume for heavily polluted wastewaters.
- Avoiding sedimentation.
- Equalization of inflows to the wastewater treatment plant.
- Consideration of current status of the wastewater treatment plant.

There are two main ways for developing and expressing control algorithms for RTC of urban drainage systems: control algorithms can be developed “offline” and expressed either as set of if-then rules, decision matrices or multivariate controllers (Fig. 4). Here, a set of rules (or of controller parameters) is developed by iteratively

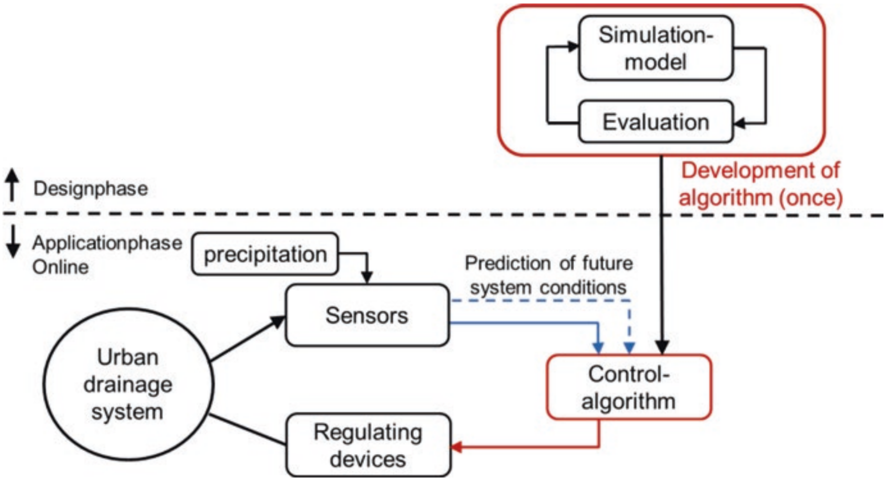

Fig. 4 Development of RTC algorithms by offline development. (DWA 2005, adapted)

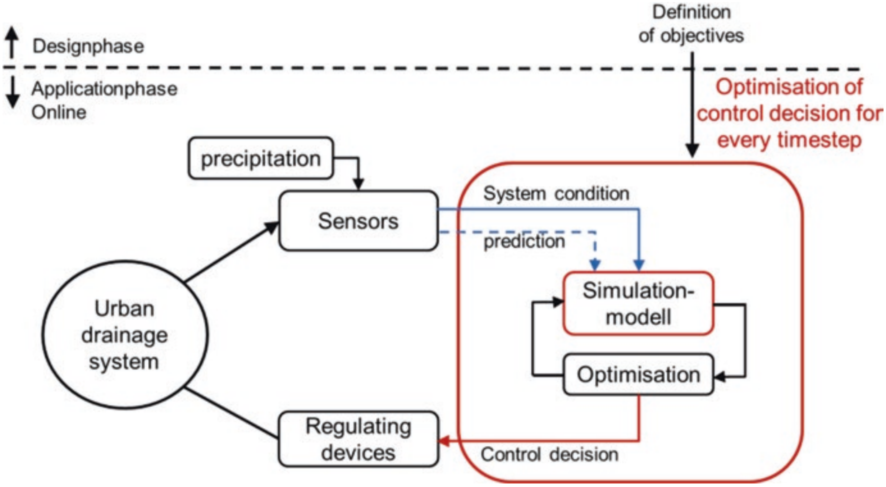

Fig. 5 Development of RTC algorithms by online optimization. (DWA 2005, adapted)

running a simulation model for a predefined control algorithm and, depending on the evaluation of such simulation runs, altering it until satisfactory behaviour of the control algorithm has been achieved in the simulation study. Then the developed algorithm is implemented in the control system (Schütze et al. 2008).

An alternative approach, illustrated in Fig. 5, to determine a control procedure consists in setting up an online simulation model, which, at every control time step (e.g. 5 min), evaluates the impacts of a number of potential control actions and then actually applies the most beneficial action as determined in the evaluation procedure (model-based predictive control). For determining the best possible control action, optimization routines can be applied as well (online optimization). Depending on the complexity of the model used, calculation time can be a critical issue, since a potentially large number of different control actions and their impacts on the wastewater system must be evaluated within a fairly short time (Schütze et al. 2008).

3 German Guideline Documents

The working group "Integral Real-Time Control" of the German Water Association (DWA) has prepared a guideline document on planning of RTC systems for urban drainage catchments (DWA 2005). These guidelines will assist consultant engineers, wastewater system operators and authorities in estimating the RTC potential for their system and in planning and developing RTC systems in a structured manner. This section gives a short overview of the guidelines and some current results of the working group. For detailed information, see DWA (2005), Schütze et al. (2008), Beeneken et al. (2013) and Schütze et al. (2017).

In order to facilitate the development of control systems, the working group proposes a stepwise approach to the evaluation of the control potential for a given site (see Fig. 6).

The first step is a preliminary ad hoc assessment of the drainage system. The PASST program (RTC planning aid) of the DWA helps network operators carry out a simple assessment and evaluation of the potential for RTC in their drainage systems. The second step involves a simulation study on a coarse system model. At this stage, various types of control can be assessed with respect to complexity and suitability for a given drainage network and technological and monetary boundary conditions.

A very useful check on the RTC potential (in terms of reduction of overflow volume) is given by the central basin approach suggested by Einfalt and Stölting (2002). By conceptually removing all throttle flow limitations and accumulating all storage volume in the system at one location (the "central basin"), this approach, by a single additional simulation run, provides an upper boundary (theoretical optimum) of the reduction of overflow volume achievable by control.

If the evaluation of various scenarios has resulted in RTC being the preferred option, the next step will consist of detailed planning of the control system (Schütze et al. 2008).

Whilst RTC of urban drainage system has proven to be beneficial in many cases, at this time, a comprehensive example does not exist. The working group is currently developing a manual, illustrating in detail the assessment of RTC potential on the Astlingen example, which serves as a benchmark example for the set-up and evaluation of RTC strategies (Schütze et al. 2017).Other guideline documents for RTC systems are found in Italy (Campisano and Sanfilippo 2011) and in the UK (Kellagher and Osborne 2013).

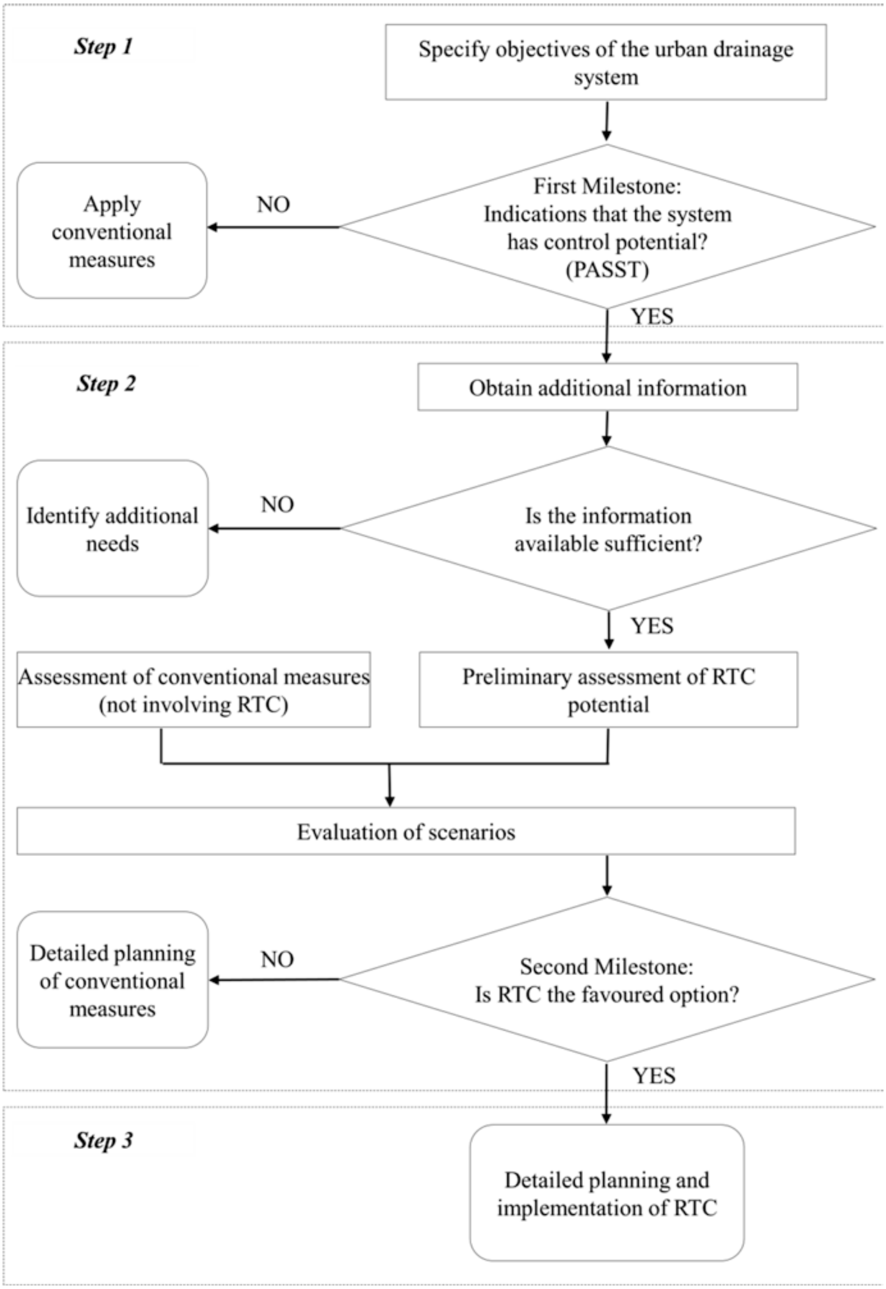

Fig. 6 Flow chart of RTC planning procedure. (DWA 2005, adapted)

4 Case Study from Germany: City of Hildesheim

Despite the bundle of benefits provided by RTC, it still does not seem to be applied widely in practice. One reason for this is the fact that, so far, the development of control strategies, in particular for complex sewer networks, is a time-consuming and thus costly task.

The vast majority of RTC control algorithms applied in practice are individual solutions which cannot be transferred to other sewer systems. No tool for the simplified creation, realization and implementation of a RTC system has been available recently on the market.

This was the idea behind the ADESBA project and the ADESBA RTC system box. The objective of this project, which was funded by the German Ministry of Economics and Technology, was to facilitate the implementation of a preassembled control algorithm within a physically preassembled control box in order to simplify the implementation of RTC systems, making it faster and more easily manageable.

The general control algorithm, developed at ifak Magdeburg, has been implemented in standard process controllers with the hardware subsequently tested by SEGNO Automation Company in Bremen. The Institute of Sanitary Engineering and Waste Management (ISAH) of Leibniz University of Hannover has confirmed the validity of the algorithm by additional simulation studies and has implemented this type of RTC system into practice in the city of Hildesheim in cooperation with SEGNO (Pabst et al. 2011; Pabst 2017).

4.1 Control System Design and Control Algorithm

The general-purpose control algorithm is the key step in the development of the ADESBA RTC system box and is described in greater detail by Alex et al. (2008) and Schütze et al. (2005). The development and implementation of this general-purpose control system algorithm makes possible a preassembled, configurable control system based on a small number of securely predefined input parameters.

The basic idea behind the ADESBA control system is the coordination of combined wastewater flows in the various branches of the system in order to ensure uniform utilization of storage capacities of the entire sewer system. The control system elements are the throttle valves of the storage facilities and of the other overflow structures of the sewer system. The overall objective is the reduction of CSO discharges.

The SIMBA simulation software (Schütze et al. 2017b) was used to develop, test and refine the underlying control algorithm. The interface between the mapping of features in the simulation model and their actual implementation in the PLC was facilitated by a SIMBA block, permitting the description of automation functions in the structured text language (IEC 61131-3 Standard). This enables control algorithms developed and tested on the basis of simulation to be implemented in PLCs rapidly and with minimal error.

Furthermore, the concept of a general-purpose control algorithm enables the possibility of a modular design principle. That means that the key elements of the sewer system are considered in a modular fashion, implying that identical control boxes can be installed in other locations (Pabst et al. 2011).

4.2 Catchment Area of Hildesheim

The city of Hildesheim is situated in northern Germany (Fig. 7). Hildesheim's sewer system, serving a population of 103,000, is partly a combined sewer system and partly a separate sewer system. Overall storage volume amounts to 16,061 m^3, corresponding to a specific storage volume of 26 $m^3/A_{impervious}$.

The attached WWTP is designed for a population equivalent of 240,000. The annual average rainfall amounts to 580 mm. The combined sewer system consists of ten hydraulically separate sub-catchments with nine stormwater overflow tanks and one stormwater overflow. Compared to the total storage volume, Tank 4 (Schützenallee) stands out with its 3822 m^3 capacity and its attached impervious catchment area of 140 hectares. Except for the Bergmühlenstrasse tank and the Große Venedig stormwater overflow, data on water levels in all tanks (in the tank and at the stormwater overflows) and on flow quantities upstream of the throttle are available online at a temporal resolution of 1 min. Figure 8 illustrates the system

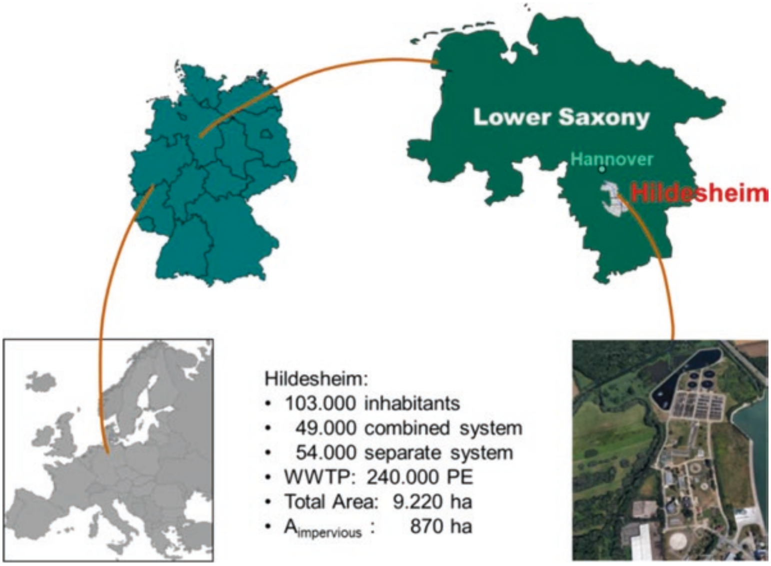

Fig. 7 Case study in the city of Hildesheim, Germany

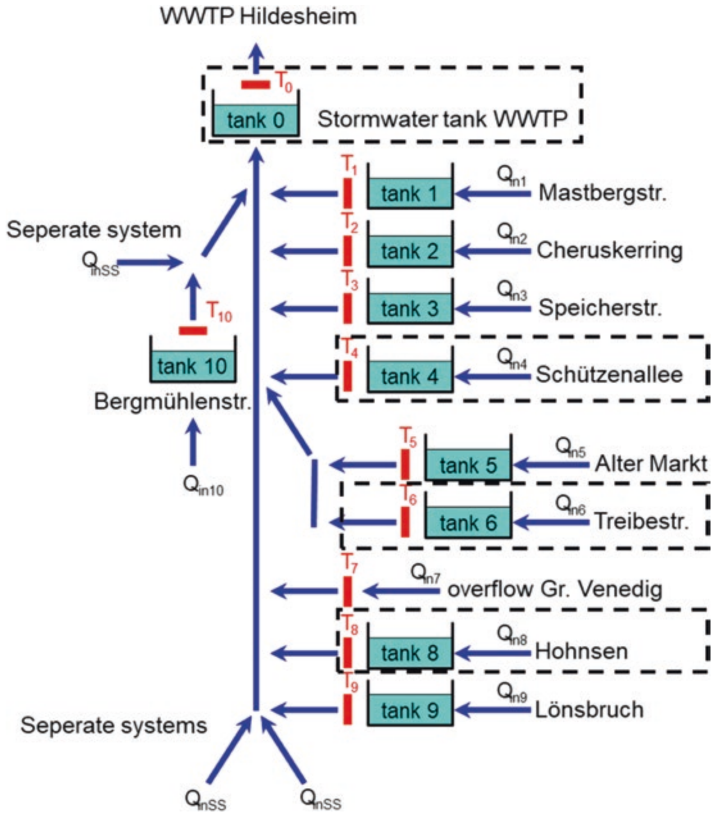

Fig. 8 System schematic of Hildesheim sewer network. (Pabst 2017, adapted)

layout. At present, four of the ten storage tanks have been selected for control. Their outflows are controlled dynamically to minimize the total overflow volume.

4.3 *Simulation Study and Proof of Pollution Reduction*

Since 2007, the Hildesheim urban drainage department has implemented a stepwise optimization of the throttle settings. The first and second step is static optimization. In a further step in 2010, with the implementation of the RTC system, the dynamic control of the stormwater overflow tanks was further optimized. For this purpose, first of all, a hydrological sewer network model was set up in SIMBA, thus allowing the simulation and analysis of the control algorithms in a flexible manner. To ensure that the wastewater is properly discharged from the catchment by new (higher) throttle settings, a hydrodynamic simulation of the sewer network was performed using the hydrodynamic SWMM block in SIMBA. The model was calibrated and

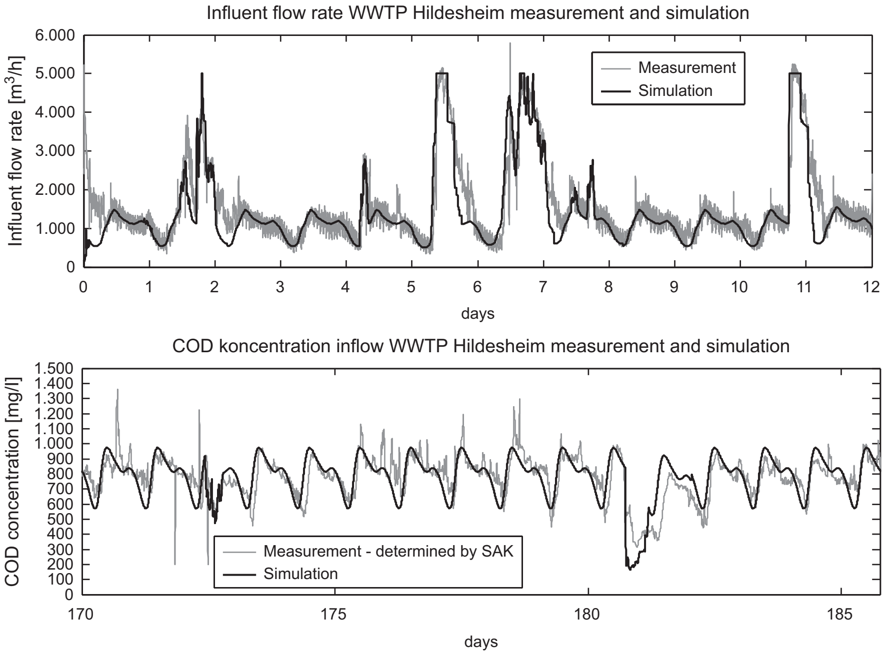

Fig. 9 Results from verification at the inflow of WWTP of Hildesheim. (Pabst 2017)

verified; Fig. 9 presents a comparison between simulated and measured wastewater treatment plant inflows for influent flow and COD concentration.

After calibration, the described general control algorithm was implemented, tested and optimized in the simulation model. Next, multiple case studies and rainfall scenarios were analysed and performed (Pabst 2017).

Figure 10 shows the results from a simple case study with three controlled tanks (tank 0, tank 4 and tank 6 of the sewer system in Hildesheim). The dotted lines represent static simulation results; the solid lines show the results using the control algorithm. Analysing the maximum utilization of the stormwater tank capacity in the treatment plant (tank 0), the basic principle of uniform utilization of storage capacities becomes clear. It increases from below 40% in the case of stationary throttle settings to 90% in the case of RTC system control (bottom figure).

The results of all simulations and case studies show a considerable reduction in the quantities of CSO when using the RTC system. Confirmation of this basic suitability of the control algorithm is given in Figs. 11 and 12 in the form of a long-term simulation (28.2 years) and the proof of pollutant load reduction for each implementation step.

The long-term simulation for verifying the load reduction showed a considerable reduction in stormwater discharges (32%) compared to the basic stationary state. Compared to the maximum control potential based on the central basin approach (DWA 2005), the degree of ADESBA control system efficiency, assuming uniform

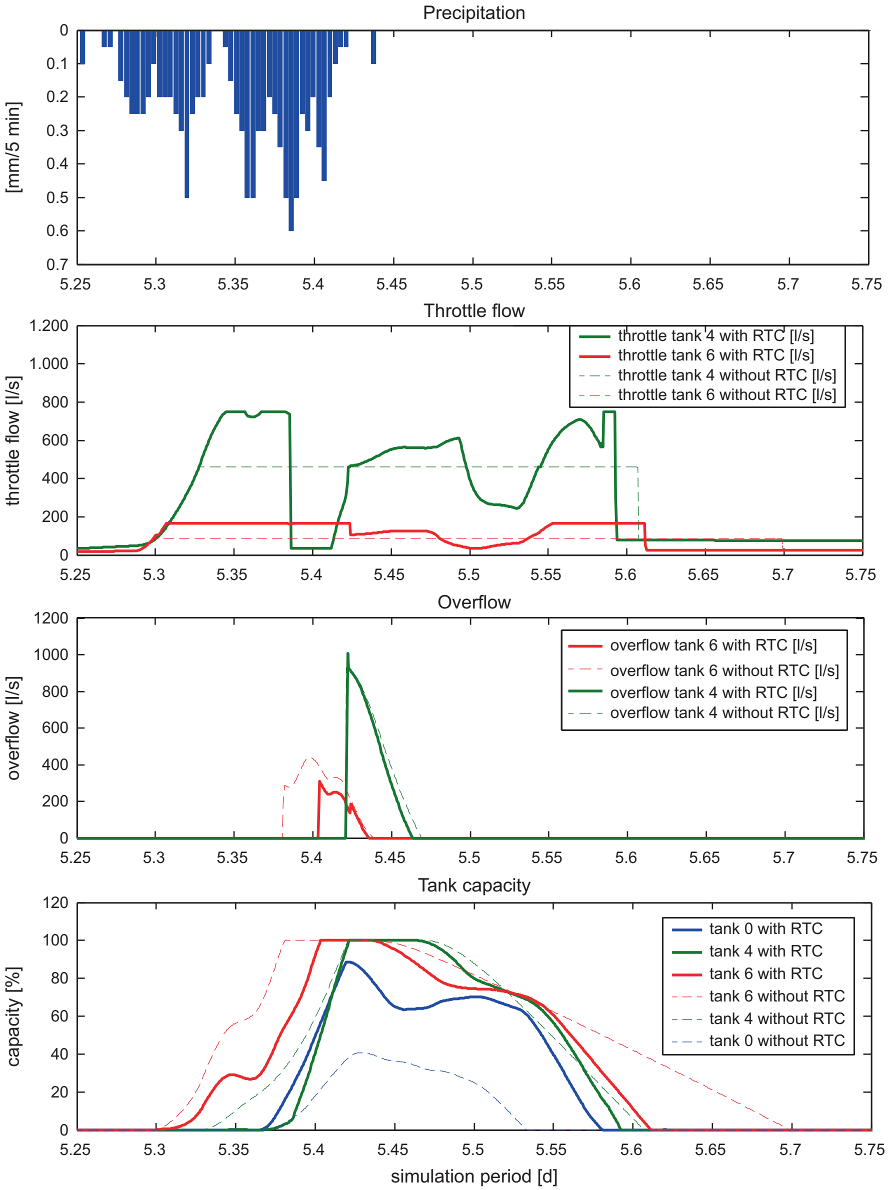

Fig. 10 Simulation results from a simple case study with three controlled tanks (Pabst 2017)

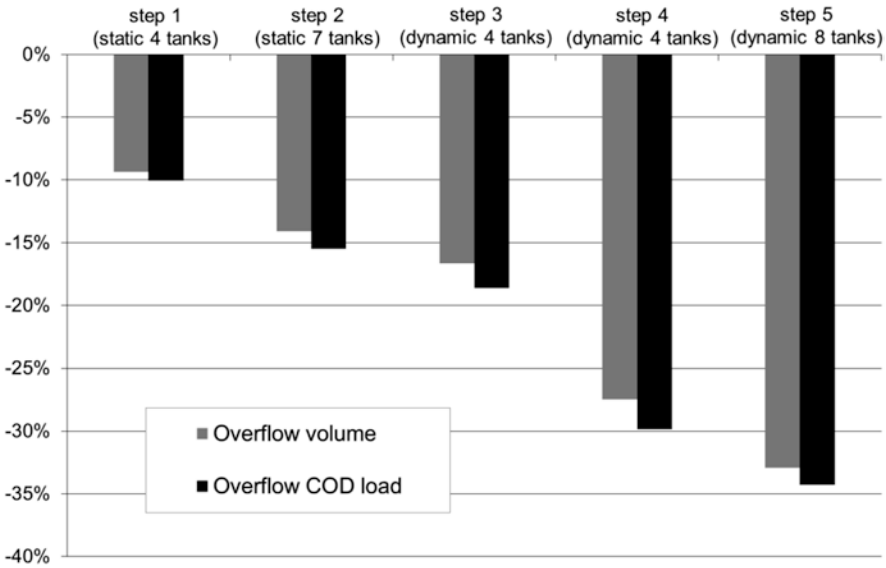

Fig. 11 Simulated (28.2 years) CSO reduction in main system in comparison to the basic state. (Pabst 2017)

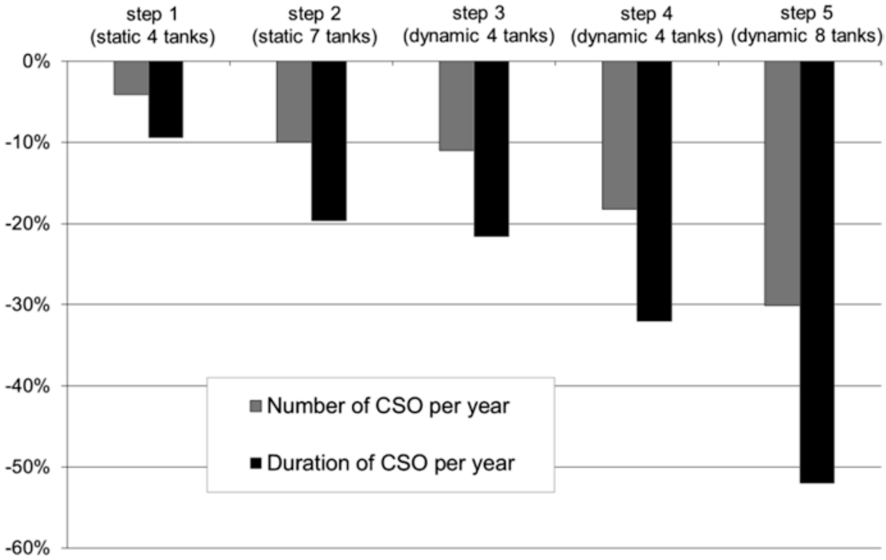

Fig. 12 Simulated (28.2 years) CSO reduction in main system in comparison to the basic state. (Pabst 2017)

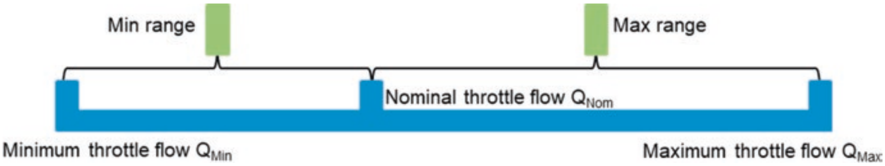

Fig. 13 Schematic figure of ranges for parameter setting of throttle flows. (Pabst 2017)

distribution of rainfall, amounts to 82% and 92% relative to the amount discharged for RTC of eight tanks and four tanks, respectively. Simulation studies with non-uniform rainfall show that the real control potential of ADESBA is even higher. Additional optimization potential (e.g. by boundary conditions of very sensitive-receiving waters) emerges from the possibility of prioritizing the various tanks, especially with the aim of minimizing the pollutant load of CSO. For this and for stepwise implementation, the parameter setting of the general control algorithm is variable within the boundaries in Fig. 13 (Pabst 2017; Pabst et al. 2011).

4.4 Implementation of the ADESBA RTC Module at Hildesheim

According to the basic concept of a preassembled control system, the following aspects were realized through development of the ADESBA RTC system box (hardware):

- Full adaptability to standard technologies (hardware and software components)
- Possibility of application as a local control unit in stand-alone mode as well as within a global RTC system
- Possibility of decentralized (on the structures) and centralized application (control room)
- Data storage and data management
- Possibility of visualization and parameterization from control room
- Utility as an engineering tool for testing and initial operation

For the catchment area of Hildesheim, Siemens products were used for PLC. Moreover, a test of the RTC module performed during the project showed that it can be completely adapted to standard, commercially available programmable logic controllers.

At Hildesheim, numerous structures are installed underground, so that in this case, GPRS could not be used as the communication medium. In collaboration with the municipality of Hildesheim, SEGNO has instead used a DSL (broadband Internet) network. The result was that, in the case of Hildesheim, network control was additionally centralized since the cables to the treatment plant’s central PLC were already available.

In addition to having control and communication tasks, the RTC system box can – and should – also be responsible for data storage and data management in the sewer network. For the purpose of displaying, inputting or outputting data on the spot, the box has been designed to allow the data to be captured via an OPC interface to a visualization system (InTouch made by Wonderware). An additional interface was created for the purpose of configuring the module from the visualization system directly. In this form, even after system commissioning, the operator has been provided with a tool that facilitates adjustments to the parameter settings. This enables the module's control behaviour to be directly influenced, whilst operating convenience is enhanced (see Fig. 14).

Moreover, an engineering tool that supports the operation of the ADESBA box with historical data has been developed (Fig. 15).

Thus, it has been successfully verified that the behaviour of the physical ADESBA control box is identical to that of the model blocks. This simplifies the actual realization of the control box and verification management of the linked control system considerably.

Project execution covered not only development but also the testing of the RTC system box – i.e. ensuring intercommunication between all the modules involved and their interfaces. Another question of considerable importance to sewage system operators is how the quality of the ADESBA RTC system box can be demonstrated and proven. A fundamental problem when testing any RTC system for sewer systems is the non-reproducibility of rainfall events. That means control behaviour of

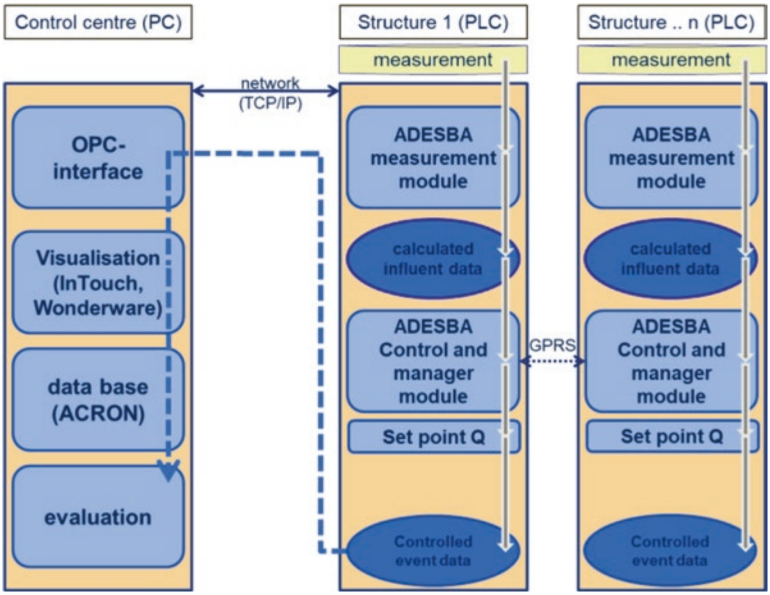

Fig. 14 Schematic structure of the ADESBA RTC system box. (Peikert et al. 2010, adapted by Pabst 2017)

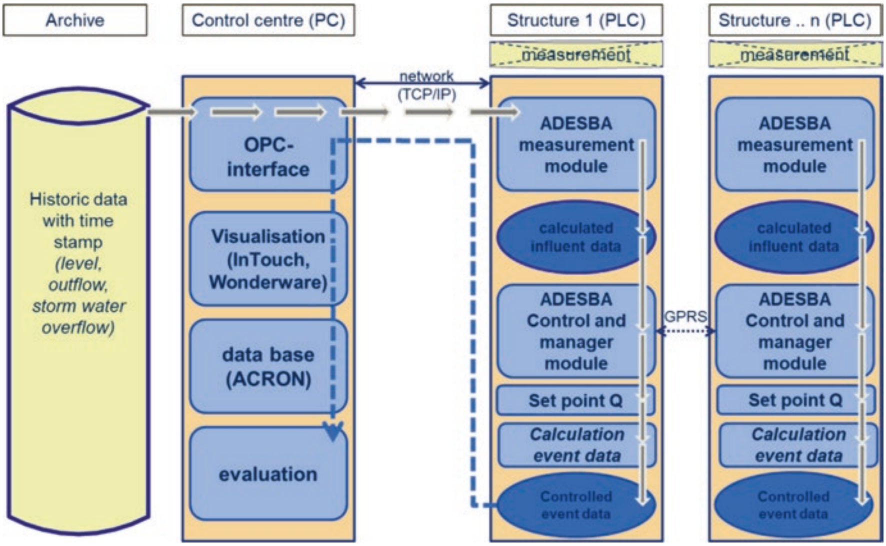

Fig. 15 Engineering tool – test set-up with historical data. (Peikert et al. 2010, adapted by Pabst 2017)

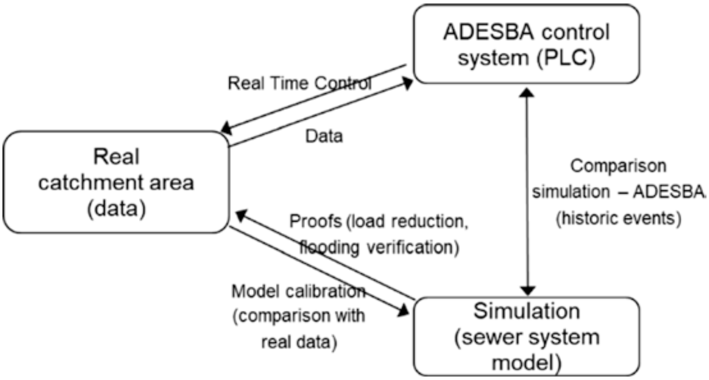

Fig. 16 Scheme of the "tools" simulation and ADESBA control system. (Pabst 2017)

control systems cannot be accurately assessed solely on the basis of simulation studies – the developed engineering tool compares data on actual events with data on controlled events, thus permitting an assessment of ADESBA's control behaviour. In its "control centre", the test set-up provides for a PC with an interface for processing historical data, an (OPC) interface to the various PLCs, a visualization system and an evaluation database. Furthermore, it is possible to match the results produced by the ADESBA box with those of the simulation in SIMBA. Especially

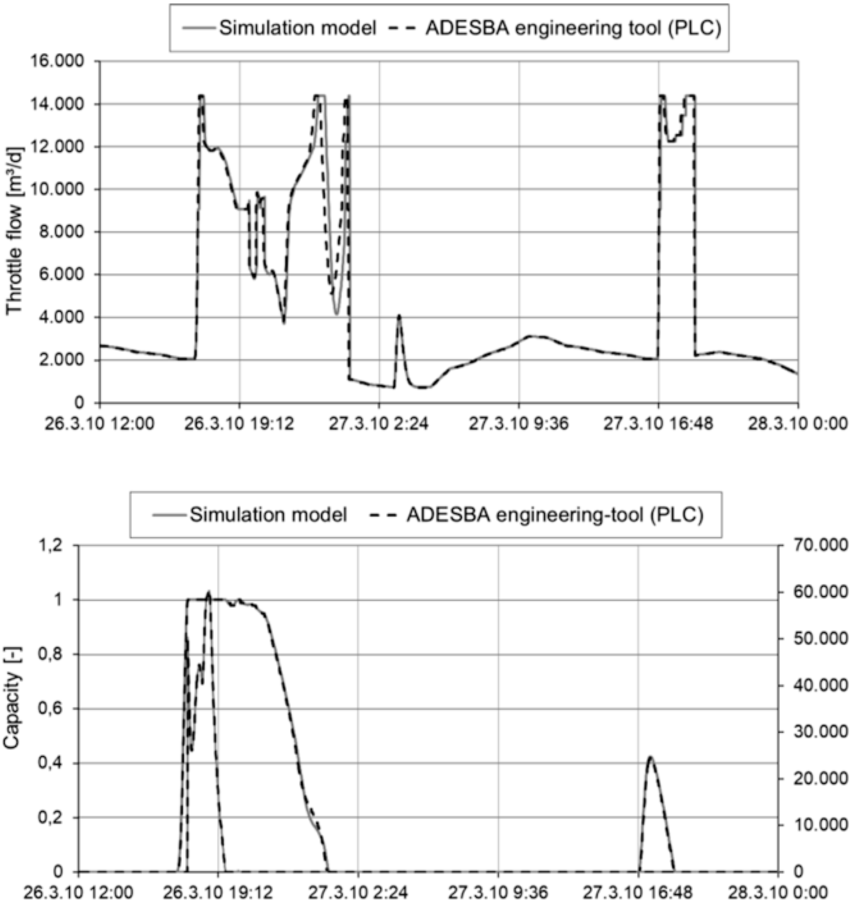

Fig. 17 Results of comparison ADESBA engineering tool – simulation model throttle flow (top), tank capacity and overflow (bottom). (Pabst 2017)

when the purpose is verification, this ensures a considerable improvement in the presentation of control system behaviour. Figure 16 shows a scheme of the "tools" simulation and ADESBA control system. Figure 17 presents this matching operation for the results of simulation with the SIMBA model and the engineering tool in the city of Hildesheim (Pabst et al. 2011).

Currently, the control system is being implemented in the Hildesheim sewer network. The switchover from the test system to actual deployment of the ADESBA control system highlights a further advantage of utilizing the preassembled module. In the validation phase, the prefabricated interfaces and the high degree of compatibility enabled the control system module to be used first as an engineering tool for the development of a RTC system and to support the verification process, before being integrated into the system.

With the possibility to set the minimum and maximum throttle discharge, the operator can, gradually and in a controlled fashion, switch over from a conservative throttle control system employing stationary values to the complete dynamical RTC set-up. The gradual implementation of a dynamic sewer network RTC system of increasing complexity is thus considerably simplified and rendered more practicable (Pabst et al. 2011).

5 Conclusions

RTC, in the context of urban drainage engineering, denotes actively influencing the flows in the sewer system by dynamically varying controllable devices such as gates, movable weirs and pumps, depending on the current state of the drainage system. Such active control allows better utilization of the existing sewer infrastructure (which represents an asset of high monetary value) and the reduction of pollution discharges.

A common misconception is that RTC is necessarily complex – often it is associated with rainfall prediction using radar techniques, complex remote sensing, data transmission demands, etc.

However, the described case study in the city of Hildesheim shows that incorporating even simpler forms of RTC, such as relying only on water level and flow information, can lead to improved system performance.

The ADESBA module is a preassembled RTC system box designed for controlling discharges in sewage systems. It was developed with the aim of considerably simplifying the sewage network RTC system and making it more manageable, thus helping to widen its utilization.

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Wetland Ecological Restoration Using Near-Natural Method

Chun Ye and Chun-Hua Li

Abstract Wetland restoration efforts are increasing due to loss and degradation of many natural wetlands. Eco-cities' harmony with nature is considered an essential goal for sustainable development worldwide. Among different methods for wetland restoration, the 'near-natural' method of ecological restoration has been widely proven to be an effective and practical method for eco-city construction. The development history of the near-natural method is here reviewed, and the nature and properties of the near-natural method are summarized. The differences between the near-natural method and constructed wetland method are analysed, while the phenomena and origin of pseudo-ecological engineering are presented. Finally, Zhushanhu wetland ecological restoration is used as an example to illustrate the design process of the near-natural method, and the ecological restoration results have shown that this method is more effective, sustainable and longer lasting than other methods and thus a practical prospect.

Keywords Near-natural · Ecological restoration · Wetland · Buffer zone of lake · Pseudo-ecological engineering

1 Introduction

In 2008, for the first time in human history, half of the world's population resided in cities. In addition, with concerns about issues such as climate change, energy supply and environmental health receiving increasing political attention, interest in the sustainable development of our future cities has grown dramatically (Höjer et al. 2011). Making existing cities and new urban developments more ecologically sound and liveable is an urgent priority in the global push for sustainability (Kenworthy 2006). Eco-cities are considered to be important features in future planning.

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An eco-city is a city with a rational structure, an efficient function and a harmonious relationship with the environment.

Wetlands are important resources, providing valuable ecosystem services, including water purification, flood regulation, storm protection, biodiversity islands and corridors, climate regulation (carbon sequestration), human relaxation and nature observation or education. However, natural wetlands have suffered great loss and degradation due to wetland reclamation throughout history, in addition to more recent increases in water pollution, overuse of biotic resources and invasive speciation. According to a TEEB (The Economics of Ecosystems and Biodiversity) study, the world lost half of its wetlands in the twentieth century alone; wetlands were reduced from 25 million km^2 to the current 12.8 million km^2. Humans started to pay more attention to the protection and restoration of wetlands as the importance of wetlands became clearer. An increasing amount of engineering projects have been conducted on wetlands around the world.

Among different methods for wetland restoration, the ‘near-natural’ method of ecological restoration has been widely proven to be an effective method of eco-city construction in practice. In 1713, a German named Carlowitz first raised the concept of ‘near-natural forestry’ in his proposal for sustainable utilization. The near-natural method is based on the concepts of potential natural vegetation and succession theory in vegetation ecology (Miyawaki 1998; Wang et al. 2002). In 1938, Seifert raised the concept of ‘near-natural river construction’, which included the concept of near-natural torrent control, characterized by higher biodiversity, density and productivity. Additionally, according to the concept of ‘ecological engineering’, first proposed by H.T. Odum in 1962, the near-natural method is a fundamental idea. The definition of ecological engineering is ‘environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are coming from natural sources’ (Mitsch 1994, 2003; Odum 2003).

In China, many practices have demonstrated the near-natural method. For example, Da and Guo (2014) proposed the use of the near-natural method to construct an urban ecosystem in the city of Shanghai and introduced a theory and methodology for the creation of near-natural forests and near-natural water systems. All the cases have demonstrated that restoration using the near-natural method can be more effective, longer lasting, and economical compared to existing methods and that this method is now worthy of being promoted as a means of constructing environments for human settlement (Da and Guo 2014).

However, some pseudo-ecological engineering has been occasionally put into practice, with negative results such as introduction of alien species and excessive sediment dredging. Therefore, it is necessary to clarify the nature of positive wetland ecological restoration, based on sound ecological principles.

2 Why Not Pure-Natural?

Some may wonder why we do not use a pure-natural method. Odum noted in his book (*Fundamentals of Ecology* 1971) that a purely natural environment is not currently suitable for human beings, since no organism's population is allowed to increase beyond a natural balance, according to natural laws. To find a harmonious coexistence between human beings and nature, the concept of 'near nature' is put forward. Furthermore, a pure-natural self-recovering process tends to be slow. Usually, ecological engineering can help recover the degraded environment by saving as much as 15–20 years compared to self-recovery using pure-natural power.

3 Differences with Constructed Wetland

Constructed wetlands have been used widely to purify polluted water. However, there are many differences between the constructed wetland method and wetland ecological restoration with the near-natural method. A constructed wetland is an artificial wetland created for the purpose of treating municipal or industrial wastewater, grey water or storm water runoff. It may also be created for land reclamation after mining, refining or other industrial activities that require mitigation due to loss of natural areas as a result of development (Hoffmann et al. 2011). Wetland ecological restoration with the near-natural method has the following properties: (1) follows the laws of nature and ecology, (2) restores vegetation and hydrological conditions with respect to a healthy natural wetland in a similar environment, (3) allows some temporary artificial measures, (4) supports these artificial measures with sufficient scientific proof, (5) prioritizes the importance of the relationships and balance among different organisms in the wetlands and (6) aims for the ultimate goal of self-sustainability.

The differences between the constructed wetland method and the near-natural method are summarized in Table 1.

Table 1 Differences between constructed wetland method and near-natural method

	Constructed wetland method	Near-natural method
Strength of artificial measures or facilities	Artificial wetland	Relatively fewer artificial measures or facilities are adopted; stimulates its self-purification ability
Persistence of artificial measures	Most of these artificial measures are permanent	The artificial measures are temporary. As wetland ecosystems are restored, these measures will be taken away gradually
Maintenance strength	Regular maintenance and management are required	The ultimate goal is to achieve self-sustainability

4 Pseudo-Ecological Engineering

Ecological restoration work is in full swing now, especially in China, with numerous wetland ecological restoration projects being conducted simultaneously. One adverse consequence of this increased activity is that some projects were not thoroughly analysed before implementation; thus, some defects and deficiencies began to be exposed gradually after the completion of these projects.

In recent years, the term ‘pseudo-ecological engineering’ has been put forward to describe and criticize ecological engineering projects that lack sufficient scientific basis. The fallacy of pseudo-ecological engineering is mainly reflected in the misunderstanding of ecological engineering concepts and resulting deviation in practice. Here are summarized several of the more common features of pseudo-ecological engineering.

4.1 Coarse and Simple Repetition

Since there was not enough time to analyse each project carefully, some projects were designed to simply imitate the demonstration projects. Some project designers forgot that ‘there is no cookbook available for ecological engineering design’. In fact, each setting for ecological engineering design has a unique history and set of interactions. Simple and coarse imitations deviate from the nature of ecological engineering.

4.2 Against the Brachistochrone Curve

In mathematics and physics, a brachistochrone curve, or curve of fastest descent, lies on a plane between point A and a lower point B, where B is not directly below A, on which a bead slides frictionlessly under the influence of a uniform gravitational field to a given end point in the shortest time (Hazewinkel 2001). In other words, from one point to another, a straight line is the shortest path, namely, a distance, but the arc of a circle requires the least time to reach the destination when gravity effects are included. Figure 1 shows an example of the brachistochrone curve.

The shape and nature of brachistochrone curves may be used to gain insight into several aspects of the process of wetland ecological restoration, such as reforming basal morphology, water quality improvement, plant restoration and restoration of aquatic animals. However, these steps cannot be conducted at the same time and must be followed in a certain order to achieve the desired restoration effect.

During the process of wetland ecological restoration, the shortest path is to take all restoration measures at the same time. However, if the shortest path is chosen, the maxim ‘haste makes waste’ will likely hold true. For example, plant restoration

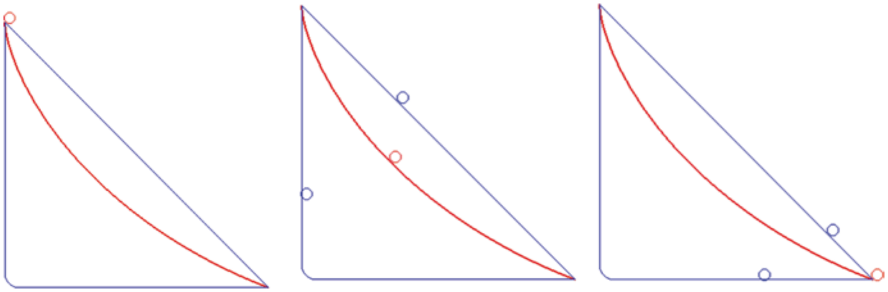

Fig. 1 Brachistochrone curve (the figure from left to right represents three moments: initial, intermediate and end state; the middle curve in the triangle is a brachistochrone curve)

should not be implemented before properly reforming basal morphology; otherwise, plants cannot support themselves stably. After years of practice, the 'brachistochrone curve' could be adapted to the following actions step by step, namely, reforming basal morphology, water quality improvement, plant restoration and biomass and species management based on food webs.

4.3 Dike Construction

Many dikes were built surrounding wetlands for the purpose of flood prevention or landscaping during the past decades. However, dikes occupied the same areas as aquatic macrophytes, which led to a massive decrease in aquatic macrophytes and aquatic animal habitats and resulted in lower biodiversity.

In this respect, many studies have shown that natural barriers (e.g. marsh vegetation) cause less damage than dikes. However, natural barriers are not as effective in coping with extreme hydraulic changes. Therefore, it is critical to find a win-win strategy for both flood prevention and ecological improvement, for example, to build a dike outside of wetland vegetation.

4.4 Excessive Sediment Dredging

Sediment dredging is the main technique for cleaning out endogenous pollution. Dredging depth, mode, equipment and the treatment of sediment must be scientifically analysed to protect the aquatic ecosystem. However, improper sediment dredging is routinely performed by local governments every year, resulting in a substantial loss of benthos in the sediment. The loss of benthonic organisms will lead to imbalances in wetland ecosystems.

4.5 Unscientific Plant Selection

Unscientific plant selection is characterized by the introduction of alien species and the use of single indigenous species, i.e. monoculture. With increased globalization, biological invasion of exotic species is a threat that ecologists and natural resource managers must cope with. In wetland ecosystems, the best example in China is *Eichhornia crassipes*, introduced deliberately from South America during the 1950s. As the fastest-growing aquatic plant in the world, the growth area of *E. crassipes* can be doubled once every 6 days, and within 8 months, it can produce 600 thousand strains. As an exotic species, *E. crassipes* has no natural enemies in China, which makes it in theory capable of unlimited growth. The Chinese government has prioritized reducing the spread of *E. crassipes* and has spent a lot of their efforts. In other cases, although no alien species were used in certain wetland restoration projects, the species mix was too simple to form a stable biocoenosis with low biodiversity. At the same time, low biodiversity also affects the landscape and aesthetic functions of wetlands.

5 A Case Study on Wetland Restoration Using the Near-Natural Method

To explain the restoration process and principles of the near-natural method, the Zhushanhu wetland restoration project is used as an example. This wetland is located in Yixing City of Jiangsu province, China (Fig. 2), within the buffer zone of Taihu (Tai Lake), with a total area of 0.3 km^2 and water surface of 0.06 km^2. The Zhushanhu wetland has an irregular strip shape with a length of 1.8 km and an average width of 105 m (Fig. 3). Zhushanhu wetland has a small catchment: about 0.89 km^2. This wetland is surrounded by grassland and woodland; its southeast side is close to the dike of Taihu; its northwest side is a highway. There are some farmlands adjacent to the highway whose runoff has been collected through ditches to the treatment ponds and then enters into a river flowing into Taihu. Therefore, the outer pollution load from its catchment derives mainly from the storm water runoff. During the ecological restoration process, no significant difference on storm water runoff in its catchment was observed.

5.1 Ecological Restoration Objectives of the Zhushanhu Wetland

The Zhushanhu wetland was once a swamp, containing sediment dredged from Taihu and some waste construction materials (Fig. 4). The objectives of its ecological restoration included the following: (1) improvement of water quality, (2) restoration of aquatic organisms and (3) landscape and leisure.

Fig. 2 Location of the Zhushanhu wetland

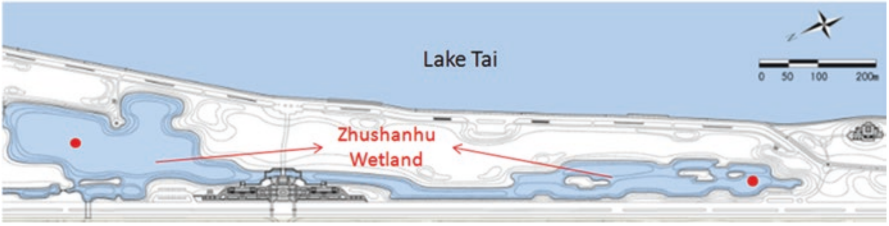

Fig. 3 The shape of the Zhushanhu wetland (red points are water sampling sites)

5.2 *Design Principles*

5.2.1 Design Restoration Steps Based on Brachistochrone Curve

The principles of the brachistochrone curve were applied to the ecological restoration of wetlands. Copying all the principles of the target wetland directly seems straightforward, but it is not actually a scientific method. The ecological restoration of wetlands should be based on the development characteristics of wetland ecosystems. Three steps were set up as follows: the first was reforming basal morphology, the second was plant species selection and configuration and the third was biomass and species management based on food webs.

Fig. 4 The state of the Zhushanhu wetland before ecological restoration

5.2.2 Self-Organization Principle

Self-organization is a process where some form of overall order arises from local interactions between parts of an initially disordered system. The process is spontaneous and does not require control by any external agent. It is often triggered by random fluctuations and amplified by positive feedback. Self-organization has proven useful in biology, from the molecular to ecosystem level (Witzany 2014).

During the Zhushanhu wetland restoration, some of the aquatic animals, such as fish and benthonic animals, were introduced when setting the foundation with the dredged sediment from Taihu. Therefore, additional aquatic animals were not introduced during the first year of ecological restoration. After a 1-year period of self-organization, the food webs would be tested and biomass and species management conducted.

5.2.3 Design Principle of Ecological Landscapes

In many ways, the environmental crisis is an urban design crisis, since several environmental problems have arisen from urban design problems (Van Der Ryn and Cowan 1996). Urban design can have profound impacts upon the environment in many different ways (Cadenasso and Pickett 2008). Unfortunately, in many past approaches, environmental effects were ignored during the urban design stage. Urban design has not been taught in the context of its ecological impact, and as a result many practices in the urban design field have been undertaken using unsustainable design principles (Çelik 2013).

Ecologically designed landscapes are those which use both ecological processes and human values as form-giving elements. According to Çelik (2013), ecological landscape designs fall into four categories: (1) preservation of existing, functioning ecological systems, (2) enhancement or re-establishment of degraded ecological systems, (3) intensification of ecological processes to mitigate potential or existing ecological degradation, and (4) environmental interventions which reduce nonrenewable resource consumption (Mozingo 1997).

Van Der Ryn and Cowan (1996) have noted principles of ecological design in Table 2. Taken together, these five principles provide a strong framework for the integration of ecology and design.

5.3 Engineering Practice with the Near-Natural Method

The engineering practice of Zhushanhu wetland included three steps, namely, reforming basal morphology, plant species selection and configuration and biomass and species management based on the food webs.

5.3.1 Basal Morphology Reforming

To identify a suitable basal morphology, five types of basement structures (Fig. 4) were tested for their effects on nutrient removal efficiencies under simulated laboratory conditions. The results show that basal morphology has significant influences on water flow, particle sedimentation, effective retention time of pollutants and pollutant transition pathway, among other variables (Kong 2015). Different wetland basal morphologies result in differences in the specific surface area of the sediment-water interface, consequently affecting the attachment space of basal biofilm and exchange degree of sediment and water, eventually affecting purification efficiency and availability of nutrients in wetland systems. In addition, the substrate morphology also affects the strength of the light distribution through the substrate, thereby affecting the development and growth of aquatic plants, and thus making the nutrient removal efficiencies of wetland systems highly variable. The total nitrogen removal rates of the five different basements above were, in order, 28.8%, 25.2%, 27.1%, 31.2% and 35.2%. The optimal structure was the multiple

Table 2 Principles of ecological design

Principles	Summary of implication for landscape design
Solutions grow from places	Ecological design grows from an intimate, detailed knowledge of places and their nuances
Make nature visible	Make sure natural cycles and processes are visible to bring the designed environment back to life
Design with nature	Nature's living processes offer opportunities to design using natural cycles, natural waste and regeneration as part of the total design
Ecological accounting informs design	By tracing the environmental impacts of a design, we can discover the more ecologically sound options
Everyone is a designer	Listen to every voice in the design process

Van Der Ryn and Cowan (1996)

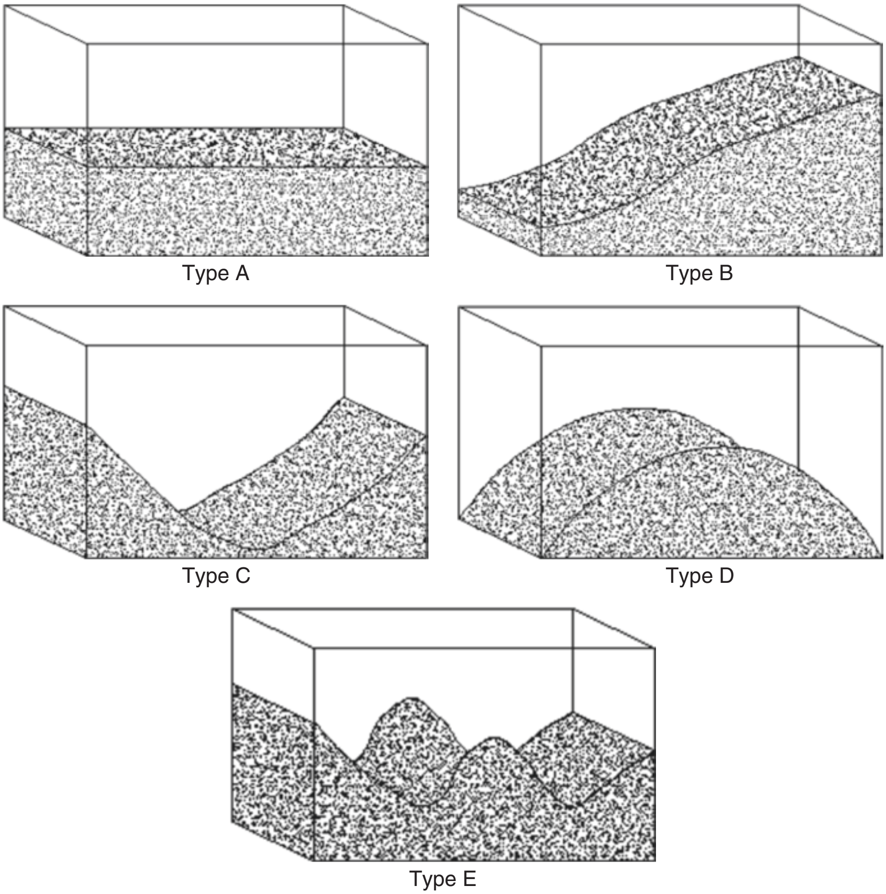

Fig. 5 Five types of basement structures

up-down style (Type E in Fig. 5). Therefore, wetland basal morphology was reformed in the multiple up-down style.

5.3.2 Plant Species Selection and Configuration

Based on the literature reviews and field surveys, a total of 5 vegetation groups, 11 vegetation types and 78 kinds of formations were identified in the local wetlands. Among them, a total of 35 plant species were selected based on their effects on pollution removal and landscape function.

Two kinds of plant configurations were used in the Zhushanhu wetland restoration process (Fig. 6). Type I was designed to prevent soil erosion and increase landscape effects. From terrestrial area to water area, the distribution of plants was as follows: *Metasequoia*, boxwood, *Canna*, *Typha angustifolia* community,

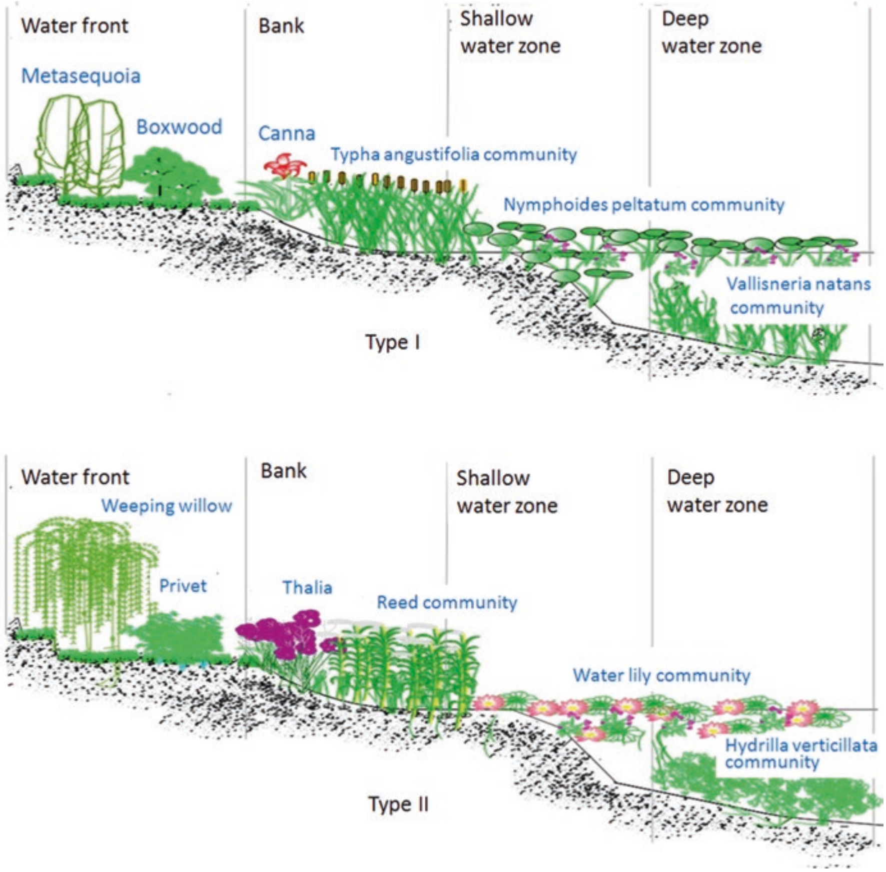

Fig. 6 Plant configurations used in Zhushanhu wetland

Nymphoides peltata community and *Vallisneria natans* community. Type II was used to remove runoff pollution efficiently. Its plant distribution from terrestrial to water area in order was weeping willow, *privet*, *Thalia*, *reed* community, water lily community and *Hydrilla verticillata* community.

5.3.3 Biomass and Species Management Based on Food Webs

Biomass and species management was not conducted until at least 1 year after vegetation restoration. Since sediment was taken directly from Taihu and added to reform the basal morphology of Zhushanhu wetland, some benthonic organisms and fish were also introduced into the Zhushanhu wetland at the same time. No additional fish or benthonic organisms were added by humans.

Fig. 7 Biomass and species management process of Zhushanhu wetland

The EWE (Ecopath with Ecosim) model was used to evaluate the optimal biomass of plants, plankton, benthos, shrimp, crabs, molluscs and fish in the Zhushanhu wetland. According to the EWE model results, the following biomass adjustments were recommended: (1) to harvest submergent plants and emergent plants by 40% and 30%, respectively, (2) to increase the biomass of filter feeders, Cyprinidae fish and omnivorous fish to 1.5 times the current status, (3) to increase the fish biodiversity and (4) to reduce the biomass of shrimp and crabs by 50%. Figure 7 shows the pictures on biomass and species management actions for Zhushanhu wetland.

5.4 Ecological Restoration Effect

5.4.1 Water Quality

Water samples were collected at a depth of 0.5 m and evaluated according to the National Surface Water Environmental Quality Standard (GB3838-2002). Water samples were collected three times: before ecological restoration, during the restoration period and after ecological restoration. The parameters were measured as follows: total phosphorus (TP) using the ammonium molybdate spectrophotometric method and total nitrogen (TN) via the alkaline potassium persulphate digestion-UV spectrophotometric method.

In general, water quality improved from below Class V to Class II based on the National Surface Water Environmental Quality Standard (GB3838-2002) (Fig. 8). TN and TP concentrations were greatly decreased. For example, the concentration of TN in the north section of the Zhushanhu wetland decreased from an average level of 3.32 mg/L before ecological restoration to 1.36 mg/L during ecological restoration and then decreased to approximately 0.92 mg/L after ecological restoration. TN concentrations decreased by 72.3% and 58.9% in the north section and south section, respectively. TP concentrations decreased by 49.6% and 60.7% in the north section and south section, respectively.

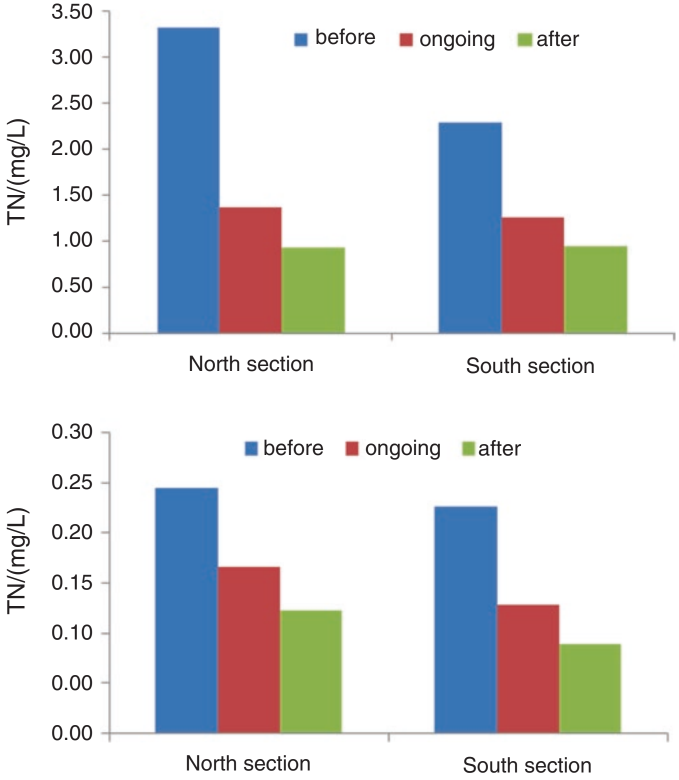

Fig. 8 The concentration changes of TN and TP in different ecological restoration periods

5.4.2 Plant Biodiversity

Three plant surveys were conducted during the same season each year, namely, before ecological restoration, during the restoration period and after ecological restoration. The quadrate method and line intercept method were adopted to survey plants in the Zhushanhu wetland. Plant biodiversity was expressed using the Margalef richness index.

Wetland plant diversity increased significantly; Margalef richness index increased from 1.20 in 2012 to 3.47 in 2014 and to 4.59 in 2015 for the north section and increased from 0.8 in 2012 to 2.17 in 2014 and to 3.75 in 2015 for the south section of the Zhushanhu wetland (Fig. 9).

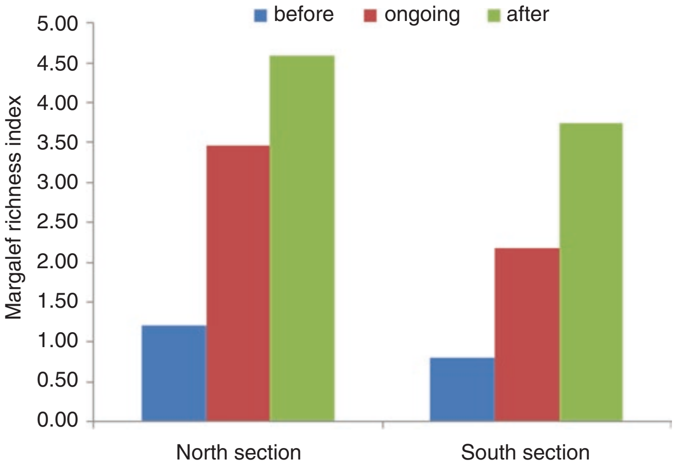

Fig. 9 The change in Margalef richness index in different ecological restoration periods

5.4.3 Ecological Landscape

The community desired a wild wetland park that had a close connection with Taihu. The design strategy for the Zhushanhu wetlands was chosen by the local government to express the traditional architecture style in south China. The surrounding environment was designed to be well integrated with the wetland, with no walls such that people could visit it freely.

The ecological landscape was designed based on the above-mentioned requirements and/or community priorities. Figure 10 shows its landscape effect. The wetland is close to Taihu and only a few hundred metres from the dike of Taihu. An elegant pavilion in the style of traditional architecture in south China is located in the terrestrial area of the Zhushanhu wetland for people to relax or enjoy the scenery. A bicycle path was built around the wetland so that people could conveniently visit the area. The arrangement of plants varies in colour from year to year. Transitional native plantings envelope the bike path, the overlooks and the wetland.

6 Conclusion

Wetland restoration using the near-natural method has proven to be an effective method of constructing ecological cities in practice. Near-natural restoration is both a method and a theory. Its meaning surpasses ecology, embracing a philosophy of ‘harmony between man and nature’ (Da and Guo 2014). Compared with the constructed wetland method, the near-natural method employs fewer artificial measures or facilities, and these artificial measures are temporary. As wetland

Aerial view

Style of traditional architecture in south China

Fig. 10 Landscape effect of the Zhushanhu wetland

ecosystems are restored, these measures will be gradually removed. The ultimate goal of near-natural wetland restoration is to achieve self-sustainability. Additionally, wetland ecological restoration should avoid ‘pseudo-ecological engineering’. Wetland ecological restoration with near-natural methods should follow the brachistochrone curve, the self-organization principle and the design principles of ecological landscapes. The case study of the Zhushanhu wetland ecological restoration demonstrated that restoration using the near-natural method could be more effective, longer lasting and economical than existing methods.

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Urban Flood Prevention

Marc Illgen and Holger Ackermann

Abstract Today's cities face the challenge of climate change adaptation worldwide. In this context, prevention of damage caused by flash floods plays an important role. This requires a cooperative pluvial flood risk management approach, which includes planning, technical, and administrative measures and involves preliminary flood risk analyses. This article outlines the main components of this risk management approach, which has proven its effectiveness in Europe. The recommendations formulated for this purpose are applicable or adaptable to regions with other constraints, such as China, for example.

1 Introduction

Throughout the world, many cities and their citizens have painfully experienced in recent years the dramatic damage that can be caused by pluvial floods. In addition to property damage totaling millions of dollars, these events also involved the loss of human lives (European Environment Agency 2012). The rising relevance of urban flooding is also reflected in the continuously rising costs of the insurance industry to cover the losses due to extreme rainfall and pluvial floods (GDV 2017; Swiss Re 2014, Sörensen and Mobini 2017). In the aftermath of these events, the question always arises as to whether and how the resulting damage could have been avoided or at least mitigated.

Ongoing precaution to prevent pluvial floods is a challenge that must be taken up by cities in the upcoming years and decades – especially in light of climate change and the anticipated increase in heavy rainfall (IPCC 2012; Hoornweg et al. 2011, Emilsson and Sang 2017; Zhou 2014; Tol 2002). This applies above all to cities and metropolises in Europe as well as in Asia and in other regions of the world (Jiang et al. 2018; DWA 2016).

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However, the objective of a forward-looking flood prevention strategy at the municipal level cannot be to control the enormous surface runoff of particularly rare rainfall extremes with the conventional technical drainage structures (Arnbjerg-Nielsen et al. 2013; Charlesworth 2010). Rather, the settlement areas and the infrastructure should be designed in such a way that the remaining risks of flooding, which vary considerably within the city, are acceptable (Illgen 2017; Sušnika et al. 2014; Emilsson and Sang 2017). Such a risk management approach, which covers planning, technical, and organizational measures, is therefore a reasonable concept to better cope with rare and extreme precipitation in urban areas and to reduce resulting damages (DWA 2016; Jha et al. 2012).

2 Pluvial Flood Risk Management

An urban flash flood denotes the flooding of a settlement area resulting from localized torrential rain. Such convective precipitation events mainly occur in Europe during the summer months (DWA 2016, Arnbjerg-Nielsen et al. 2013) and are characterized by enormous quantities of rain over areas of a few square kilometers in a very short period of time. They are often accompanied by thunderstorms and hail. In general, urban flash floods can occur everywhere – even far away from rivers and creeks. Figure 1 illustrates a few pictorial impressions of a local flash flood caused by extreme rainfall. In this example from 2010, approximately 100 mm of rain fell over a period of 2 h.

Flash floods have particular characteristics and occur suddenly, while in neighboring areas there may be only little or no rain (Arnbjerg-Nielsen et al. 2013;

Fig. 1 Local flash flood in an urban area

European Environment Agency 2012; Illgen 2017). In contrast to river floods, no significant warning time is currently possible. Due to the enormous rain intensities, stormwater runoff often far exceeds the hydraulic capacities of public and private drainage facilities and of the local watercourses. As a result, rainwater and sludge flow more or less randomly from agricultural, forestry-related, or other surrounding areas to urban settlements via ditches and roadways. Small drainage ditches, streams, and roads become torrential currents, and the surface water flows uncontrolled through the residential area into low points of the terrain. Land and buildings are rapidly flooded. Buildings, technical equipment, and property assets are destroyed or massively damaged. In addition to the high, solely monetary losses, there can also be an acute danger to life and limb, for example, around critical infrastructures such as electricity installations or underpasses, underground parking garages and tunnels, or in children's and senior citizens' facilities.

In the future, an advanced urban flood prevention that accounts for the local risks of pluvial floods must receive greater attention within municipalities (IPCC 2012; DWA 2016; Jiang et al. 2018). In many cities, active and ongoing precautionary measures against exceptional rainfall have not yet been established or at best are limited to fulfilling the respective design requirements for the public sewer system. To date, the scenario of an extreme rainfall event remains largely unconsidered in municipal planning activities, and the long-sighted prevention against the risks of pluvial flooding is given not enough priority within many municipalities and their administrations. Nevertheless, there are already numerous cities around the world, today, which have addressed the issue intensively and have taken a pioneering role (C40 2016; Engberg 2018; Sušnika et al. 2014; Jiang et al. 2018).

Particularly in the context of the intensive settlement development and the enormous changes with respect to environmental protection in China, pluvial flood prevention, following the paradigm described here, should be integrated into all urban planning at an early stage.

Municipalities – including all of their public and private players – are encouraged to initiate the development of a risk-oriented and integrated flood prevention, to establish it in the municipality, and to implement the according measures over the long term (DWA 2016). The core feature of an effective precaution against flash floods in urban areas is a risk management concept that combines all effective precautionary and coping measures (Fig. 2).

This risk management comprises the identification and assessment of existing risks to precipitation beyond the design level of public drainage systems, as well as the development and implementation of appropriate precautionary measures at the municipal and private levels. Of particular importance are a systematic channeling of surface water within residential areas, extensive retention of surface water on public areas, and property- or object-related flood protection measures (Illgen 2017). Precautionary planning and technical measures against urban flooding are closely interconnected with retention-oriented stormwater management (e.g., sponge city principle), as well as with water-sensitive and climate-adapted urban planning (Davis and Naumann 2017; Zhou 2014; Jha et al. 2012). It is only through consistent implementation of such a risk management concept that damage from

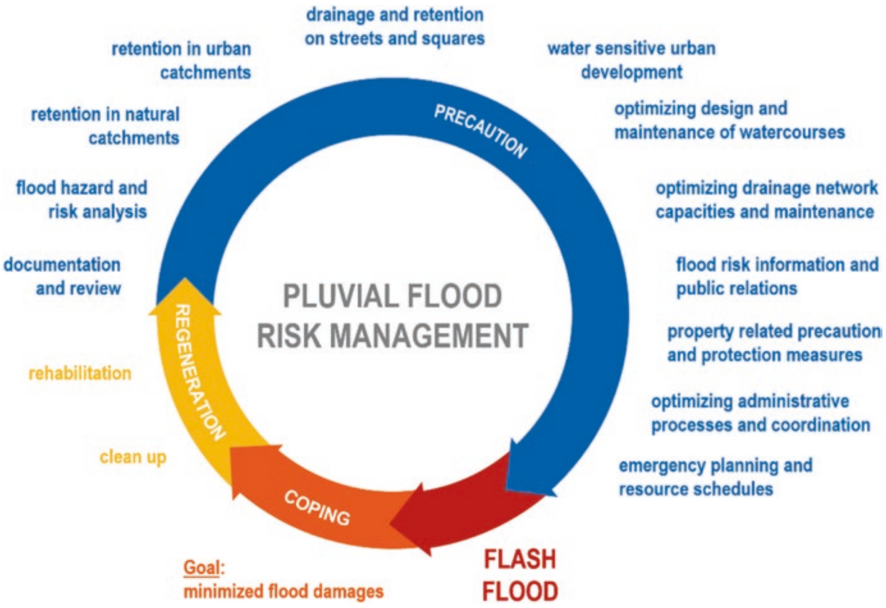


Fig. 2 Pluvial flood risk management cycle and precautionary measures

very rare or extreme rainfall events can be effectively mitigated, limited, or even avoided with adequate economic commitment.

In addition to municipal urban drainage utilities and local policy makers, city planners, road planners, green space planners, building designers, and property owners are called upon to develop and implement effective protective measures. This necessitates intensive communication and exchange among the parties involved and must also include disaster control and local rescue forces (DWA 2016). Urban planning processes and responsibilities must also be adapted and, where necessary, realigned (Hughes et al. 2018).

In order to prevent or mitigate damage due to pluvial flooding, the public sector in particular must provide a substantial contribution in addition to the property owners. This applies in particular to precautionary measures that are directly related to municipal infrastructure and fall within the remit of municipal or regional authorities. In terms of responsibility, the possible precautionary measures can be differentiated as either:

- Relating to infrastructure and under administration of the municipality
- Relating to property and under the responsibility of the property owner

Municipalities are obligated to ensure a defined level of flood protection. By operating a well-designed public drainage system, they provide, together with the estate drainage facilities, a substantial contribution to urban flood protection. However, the feasible protection level has its limits, especially in view of very rare and extreme rainfall events beyond the legal design specifications of the drainage infrastructure (Fig. 3).

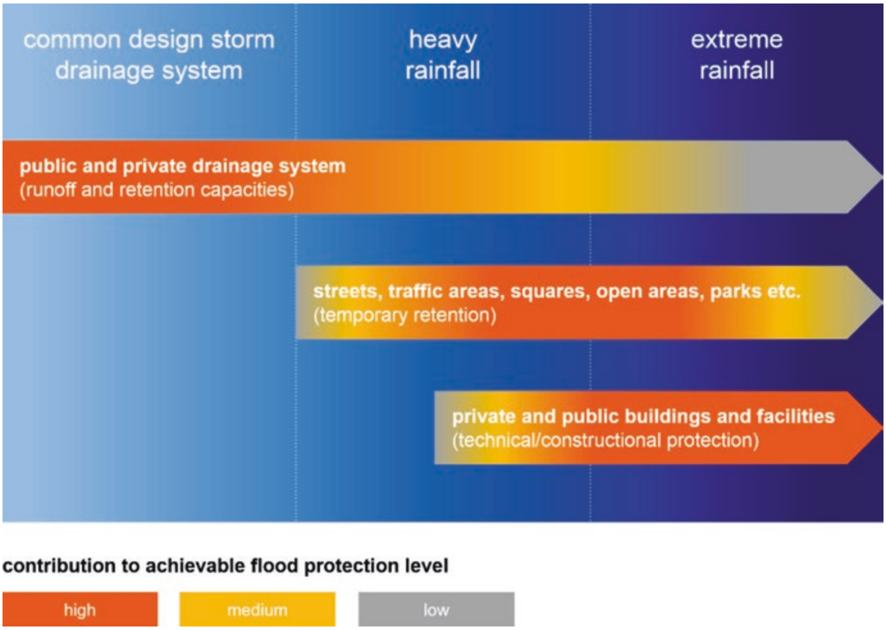


Fig. 3 Elements of urban flood protection and their contribution to the feasible protection level for different storm intensities

One important element of a progressive flood protection strategy is a systematic integration of the possible discharge and retention capacities of roadways and open spaces, which, as urban infrastructure, also lie within the range of responsibilities of the municipality.

In order to limit damage, especially in the case of an extreme rainfall event, the technical protection measures by public and private property owners come to the fore. For an efficient precautionary approach, however, it is necessary that infrastructure and property-related measures are closely aligned and coordinated.

3 Hazard and Risk Analyses

A fundamental requirement for the initiation, development, and implementation of effective precautionary measures and thus for the commencement of a systematic risk management strategy is to identify the critical flood hazard and risk areas. Identification and spatial delineation of existing hazard areas, determination of specific causes of flooding, and the assessment of local flood risks must always take place at the outset of the risk management process in order to attain appropriate planning and technical and/or organizational precautionary measures at both the municipal and private levels (Illgen 2017).

The objective of a systematic risk assessment must be to weigh the locally varying risks in order to define key areas for action and to deploy the available resources as efficiently as possible to minimize risk. A number of approaches can be considered to estimate or to calculate the risk of flooding (Löwe et al. 2017; DWA 2016). These approaches differ in terms of the required data base, the calculation tools used, the validity of the results of the computations, and the costs. Whereas a few years ago it was practically impossible to model pluvial flooding processes in urban areas, today powerful computational tools and high-resolution basic data are available. In total, the risk analyses should help to answer the following questions:

- How is the flooding situation in case of a heavy cloudburst?
- Which areas would be flooded, and where are particularly high water levels to be expected?
- Which buildings and infrastructure would be affected?
- Where would the biggest damages occur?
- Where is the risk of damage acceptable, and where not?
- Where should precautionary measures be considered?

Flood risk is generally composed of two components, the component of flood hazard on the one hand and the component of vulnerability on the other, which can be quantified as damage potential (DWA 2016). Pluvial floods in noncritical regions are assessed differently than floods in areas where a high monetary damage or high danger to life and limb is to be expected. Estimating localized flooding risks therefore consists of three steps that must be taken in sequence: (1) determination of flood hazards, (2) estimation of potential damages, and (3) determination and assessment of the pluvial flood risks as combination of flood hazard and damage potential.

For this purpose, it is advisable to classify the local flood hazard, the estimated damage potential, and the resulting flood risk into categories and assign them to individual buildings, properties, or city sectors. Estimating the (monetary) damage potential is particularly important if the concrete (monetary) benefit for precautionary measures is needed for decision-making.

Quantifying the damage potential is often difficult, especially when nonmonetary damage must be considered. Monetary damage functions, as they are already applied to estimate the effects of river flooding, are to date either not available for pluvial flooding or at best subject to great uncertainties. It is therefore recommended to define categories for the individual risk components that allow a simple qualitative classification (e.g., low, moderate, high).

3.1 Analysis of Flood Hazard

A variety of more or less detailed methodological approaches to analyzing pluvial flood risks is available (DWA 2016; Fuchs and Schmid 2015; Yin et al. 2016). Beside the hydraulic analysis of the frequency and quantity of surcharge and overflow of the drainage system, as it is applied in the context of conventional urban drainage planning, simplified approaches use topographical data and digital terrain models to analyze surface flow paths and ground depressions. These approaches are independent of a particular precipitation load. Advanced approaches consider the flooding processes related to a particular storm event either by simply filling terrain depressions for calculated surface water volumes or by modelling the dynamic runoff and flow processes (2D surface flow/flooding models, dual 1D/2D drainage and flooding models). An overview of the most important approaches is provided below.

3.1.1 GIS-Based Flow Path Analysis

Topography-based flood hazard analysis is based on digital terrain models. Digital elevation data are evaluated using specific tools of geographical information systems (GIS). The required terrain models are now available in many places or can be generated at comparatively little expense (e.g., using airborne laser scanning). In some cases, the resolutions are low (e.g., one elevation point for 10 m × 10 m). In many cases, at least in Germany, resolutions on the order of 2 m × 2 m or better are available and sufficiently precise. With GIS application, it is possible to locate surface flow paths and ground depressions and visualize them in corresponding maps (Fig. 4).

3.1.2 Simplified Flood Computation

Based on topographical analysis, GIS can be applied in an additional step to quantify and visualize water levels for terrain depressions for arbitrary rainfall scenarios. For the determined catchments of the terrain depressions, the surface runoff volume can be estimated based on catchment-specific runoff coefficients and the rain depth of the selected storm scenario. The static filling of individual terrain depressions is

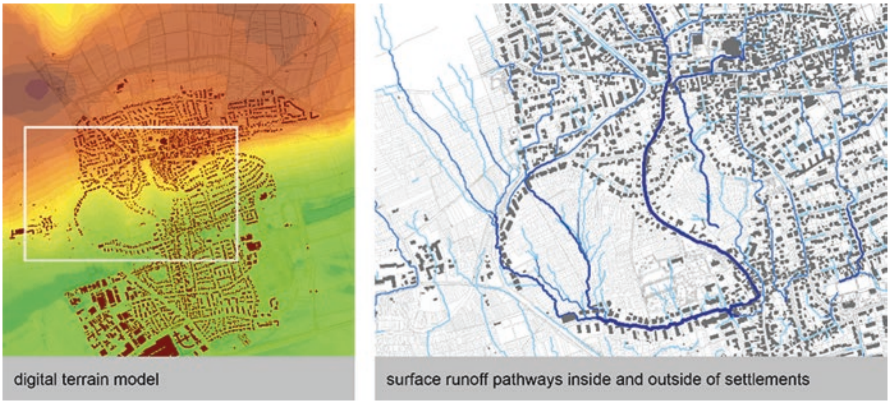


Fig. 4 Results of a topographical analysis based on a digital terrain model

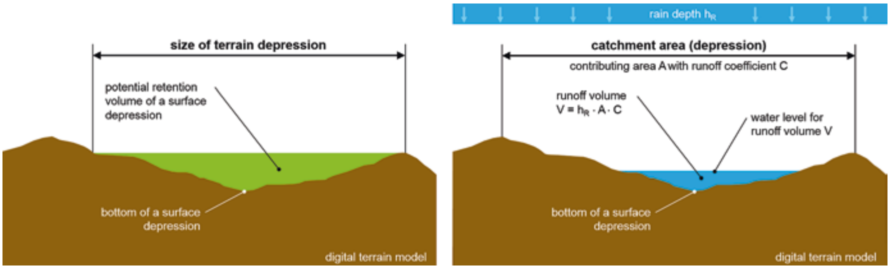


Fig. 5 Potential retention volume of a swale (left) and event-based filling volume and water level

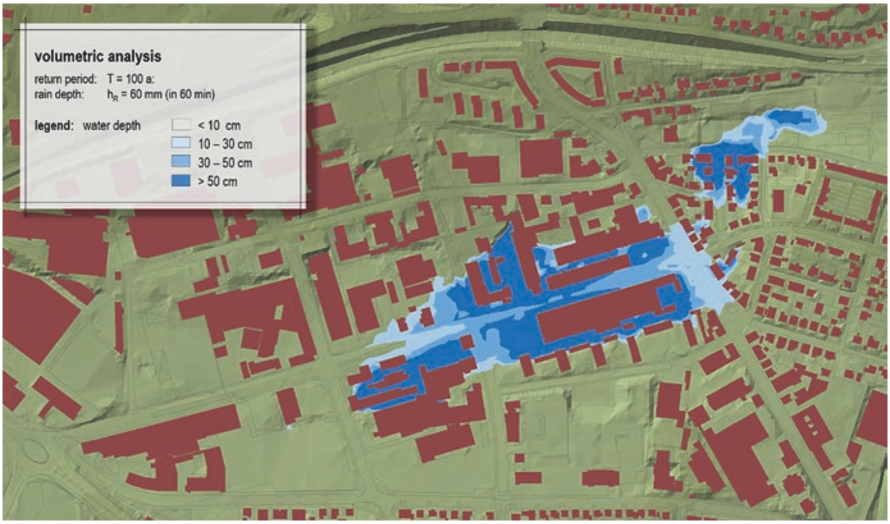


Fig. 6 Example of a flood map based on a volumetric analysis of a digital terrain model

approximated using GIS for the estimated surface runoff volumes by filling the terrain surface from the low points up (Fig. 5). The result is a flood map for a particular storm scenario, which allows the evaluation according to the spatial extent of the flood plain, the estimated water depths, and finally the associated flood risks.

The results of these simplified flooding calculations are considered as a rough approximation of the flooded areas. The water level above the terrain level can be used as one criterion for further assessment. Figure 6 shows a flood map example resulting from this procedure.

By a similar process, the calculated surcharge volume that leaves the urban drainage system can be applied as estimated surface water load if a hydrodynamic calculation of the urban drainage network for a corresponding rainfall event is available. The overflow volumes are then summarized to catchment-specific surface runoff volumes. This approach offers the advantage that the hydraulic capacity and the surcharge condition of the drainage system are taken into account. Otherwise, when estimating the surface runoff volume, these parameters are included only in a vastly simplified manner, for example, by a general reduction of the rain depth in the order of magnitude of the hydraulic capacity of the stormwater network (e.g., 15–30 mm).

Particularities of topography are accounted for in the spatial characteristics of the terrain depressions and the boundaries of the catchment areas. However, this simplified methodology does not explicitly consider the surface flow processes. This also applies to the transfer of excess runoff volumes to surrounding areas when a depression is filled to capacity and overflowing. Precise statements about water levels along the flow paths are also not directly possible. The advantage of the method is that it involves relatively little expense and can be implemented through more or less simple application of GIS tools, but without the use of a hydraulic flow model.

3.1.3 2D Flood Simulations

In addition to the analysis tools based on GIS, today there are also hydraulic simulation programs available that can compute surface runoff and flow processes. These can be coupled with hydraulic drainage network or watercourse models. A simulation of surface flow patterns also requires detailed information about the topography, which is represented in a two-dimensional surface grid. For this, a high-resolution elevation (i.e., digital terrain) model is essential.

2D models for surface runoff simulation only describe flow processes on the terrain surface. In urban areas, runoff usually occurs on the surface and in the drainage network. However, with increasing statistical return period of the considered storm events, the relevance of the drainage system on flood processes decreases. Accordingly, it is sufficient to consider the discharge via the drainage system in simplified form when accounting for larger return periods of 50 or 100 years. This can be done, for example, by a proportional reduction of the rain depth or intensity.

2D surface runoff models are based on the two-dimensional representation of the Navier-Stokes (i.e., shallow water) equations. In contrast to the topographical methods described above and simplified flood calculations, the application of 2D models for simulating surface runoff yields flow patterns that include water depths and lateral flood plain dimensions. These are to be regarded as approximations depending on the resolution of the elevation model used and other assumptions made. They provide a clear picture of the overall flood situation. In addition, possible overflows of sinks due to increased inflows from their direct catchment area and the subsequent activation of further flow paths and sinks can be accurately calculated hydraulically. Furthermore, small water bodies in the area can be included in the calculation if necessary. Figure 7 shows an example of the results of a 2D surface runoff simulation for an urban area.

When creating models, it is recommended to define buildings as non-passable flow barriers in the terrain model. Special attention must be paid to the proper representation of the surface grid along sensitive flow paths. Depending on the quality of the elevation model, manual reprocessing and correction of elevation data are

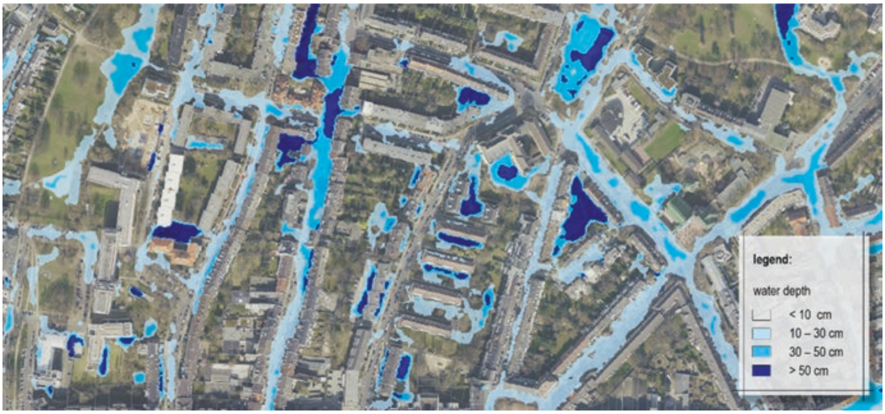


Fig. 7 Example of a flood map based on a 2D surface runoff simulation

generally necessary, in particular around bridges and underpasses but also in many other areas. Preparation of the terrain grid for the runoff simulation (preprocessing) is typically the most expensive step in the process and plays a major role with regard to the quality of the calculation results. This preparation must be undertaken carefully and comprehensively and should include site visits. This also applies to the aforementioned solely GIS-based methods.

If a 2D surface runoff model is coupled with a hydraulic sewer discharge model (1D), even more precise simulation results are possible. This applies in particular to rainfall events in which the public drainage system features a large discharge portion. This is the case, for example, with statistical return periods of up to10–30 years.

The coupled 1D/2D simulation involves a concurrent 1D computation of the flow processes in the drainage system and of the 2D flow processes on the surface (dual drainage). This facilitates the bidirectional exchange of water volumes between the surface and the sewer system within the model. Coupling of the two simulation models takes place at the nodes of the network (manhole, gully, etc.) which act as points of exchange between the drainage system and the surface. In order to accomplish the coupling, these points must be localized and their hydraulic properties defined, and they must be accounted for in both models. An alternative simplification is to distribute the exchange of water over the entire length of each channel.

Both simulation models run simultaneously; as soon as water emerges from the drainage network during overflow, the subsequent flow over the surface is calculated directly in the 2D surface model. If there are manholes and/or road gullies with water levels below ground level in the area of surface flooding, the water can reenter the drainage system. This method is very computationally intensive if small surface elements are included (i.e., at high spatial resolution of the computational grid).

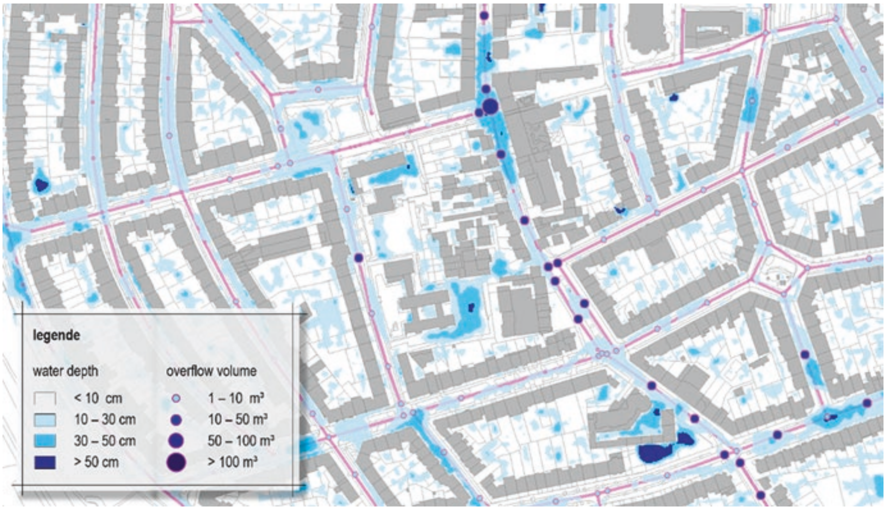


Fig. 8 Example of a flood map based on a dual drainage simulation model (1D/2D)

In addition, some coupled models provide the opportunity for detailed simulation of runoff formation processes using the 2D surface runoff model (e.g., direct irrigation of unpaved open spaces or paved yards and roads). This is especially recommended when considering very heavy or extreme rainfall, in which the estate drainage systems are usually heavily overloaded. In general, these facilities are not a part of all models or at least not included in a detailed manner. The runoff from rooftops, on the other hand, can be directly assigned to the urban drainage system.

The classification into hazard classes can be done with the results of the 2D simulations or the coupled 1D/2D simulations according to the resulting water depths. As additional evaluation criteria, calculated flow velocities can also be used. Figure 8 shows an example of a flood map with water depth based on the application of a dual drainage model (1D/2D).

3.1.4 Evaluation and Classification of Flood Hazards

Depending on the calculation method used, different types of results are obtained (accumulated catchment area, water levels, etc.). On the basis of the results, the catchment can be divided into regions of varying hazard classes in order to approximate and prioritize the spatial variation in terms of flood hazard. The criteria for the categories must be selected with regard to the applied methodology and the local boundary conditions. An example with orientation values is shown in Table 1.

Table 1 Criteria to assess and categorize the flood hazard (example)

Hazard class	Flash flood hazard	Water depth	Catchment area along flow path	Specific retention volume of a swale
1	Low	< 10 cm	< 1 hectare	Aside a swale
2	Moderate	10–30 cm	1–5 hectare	100–500 m^3/hectare
3	High	30–50 cm	5–10 hectare	50–100 m^3/hectare
4	Very high	> 50 cm	> 10 hectare	< 50 m^3/hectare

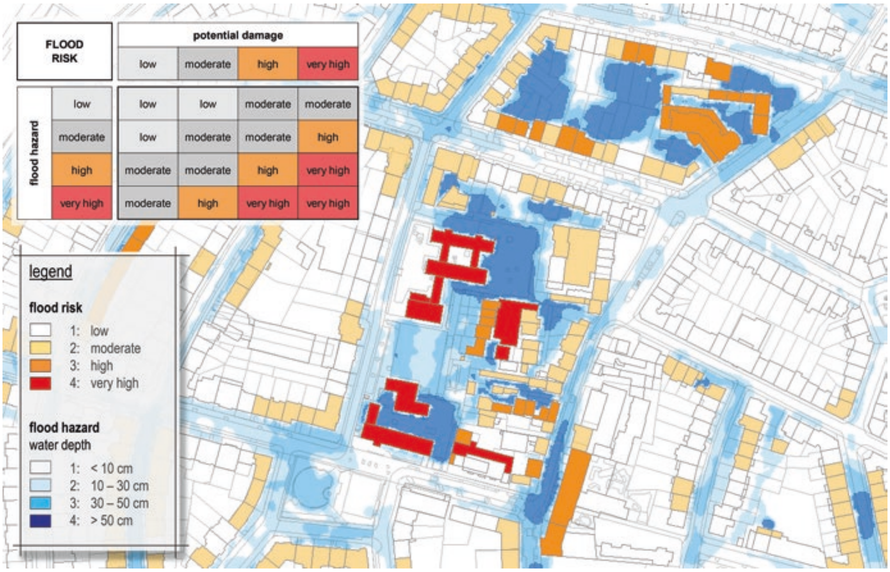
Fig. 9 Example of a simplified flood risk map

3.2 Analysis and Assessment of Pluvial Flood Risks

In order to assess pluvial flood risks, damage potential must be determined and linked to the local flood hazard. Estimating, characterizing, and assessing the damage potential of objects and areas affected by a pluvial flood require an appropriate set of additional data, e.g., geo-referenced data and information regarding:

- The use of buildings and/or properties (e.g., housing, hospital, electricity supply)
- The use of open spaces (e.g., traffic areas, commercial areas, green spaces)
- The structural design of buildings (e.g., with/without basement floors)
- The infrastructure facilities (e.g., subways, tunnels, neuralgic supply facilities)

With these data, varying damage potentials can be defined (e.g., low, moderate, high) and allocated to buildings, properties, or districts. For example, an object-related determination into damage potential classes can be carried out and visualized in corresponding maps. An example is shown in Fig. 9, where a simplified risk



FLOOD RISK		potential damage			
		low	moderate	high	very high
flood hazard	low	low	low	moderate	moderate
	moderate	low	moderate	moderate	high
	high	moderate	moderate	high	very high
	very high	moderate	high	very high	very high

Fig. 10 Example of a systematic flood risk map

map illustrates the flood hazard and the property-related damage potential in combination.

It is also possible to directly assign a risk category to individual buildings and facilities. In this case, the hazard class from the flood calculations is offset against the damage potential class to create a risk class. A corresponding risk matrix must be defined for this purpose. Figure 10 shows an example.

The methods for estimating flood risks presented here require a wealth of geo-referenced data with a high degree of detail. In Germany, for example, these data are largely available nationwide. In other countries, however, this is not the case, so simplified and pragmatic approaches must be chosen or the spatial resolution reduced. This also applies to China, for example, where the development of corresponding geo-based data has only just begun. These efforts should be continued or even intensified.

4 Precautionary Measures

The primary objective of a risk management strategy for pluvial flood prevention in urban areas is to minimize the locally varying flood risk in an economically reasonable manner (Illgen 2017). Hazard and risk considerations are used to identify the existing flood risks due to heavy or extreme rainfall. These considerations provide, among other things, spatially differentiated findings on the flood hazard and the causes of flooding, as well as on the probability and extent of potential flood

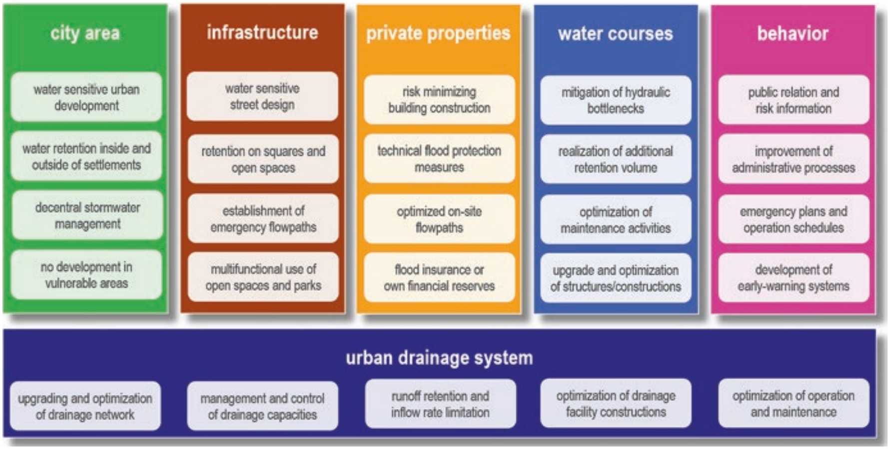


Fig. 11 Major categories of prevention measures

damage (DWA 2016). On this basis, existing risk hotspots can be identified, action requirements derived, and priorities for action determined.

Based on this, suitable precautionary measures can be designed, evaluated in terms of their effectiveness, and finally implemented. They should be described in a master plan, together with the overall risk management strategy, the individual priorities, and a rough time schedule (e.g., The City of Copenhagen 2012). The master plan should also specify the responsibilities, the workflow, and the financial requirements for each measure.

Urban flood prevention is a cross-sectional task and affects various stakeholders. This cross-sectionality is based on the diversity of opportunities for precautionary measures against pluvial flooding (Fig. 11).

The different measures are the responsibility of different authorities and disciplines. They cover infrastructure design, an urban planning, as well as administrative measures (DWA 2016; Illgen 2017). In addition, the citizens and companies of a community are also called upon to contribute toward flood protection by personal precautions. The field of action for local authorities includes, for example, the following measures:

- Broad retention of stormwater in urban areas
- Prevention of inflow from green land, agricultural areas, and forested land from outside of urban areas
- Discharge or storage of unavoidable surface water along roads
- Multiple use of open or green spaces for low-damage retention of surface water
- Appropriate design and operation of public drainage facilities
- Removal of hydraulic bottlenecks and realization of additional retention capacities along creeks and ditches
- Optimization of maintenance activities (drainage system, watercourses, etc.)
- Implementation of a water-sensitive urban development

- Improved alignment of the administrative structure to the task of flood prevention
- Establishment of a coordination unit for interdisciplinary measures

4.1 Infrastructure-Related Precautionary Measures

Precautionary measures relating to infrastructure may be either of a technical or a planning nature (Charlesworth 2010; Davis and Naumann 2017; Gill et al. 2007). Technical measures to prevent or mitigate damage from pluvial floods include, in particular, the design, construction, and operation of technical facilities for the targeted retention or drainage of runoff in the areas of:

- Roads and pathways
- Open and green spaces
- Public drainage systems (sewers)
- Water bodies and drainage ditches
- Green spaces, agricultural areas, and forested land outside the urban area

In the context of water-sensitive urban development, road planning in particular plays an important role (Illgen 2017). Roads are the main runoff paths for surface water in case of torrential storms. Therefore, it is important to understand the importance of road space as a surface discharge element as well as a temporary storage space and to use it as a measure of pluvial flood prevention (Fig. 12). Some excellent examples can also be found, for instance, in the city of Copenhagen (Ramboll Studio Dreiseitl 2018).

Along main flow surface paths, for example, the priority should be given to cross-sectional profiling with raised sides or ramps on footpaths, rather than completely barrier-free road construction. Drainage of the roadway itself generally depends on the local conditions (building development, surface, sewer system, flood risk). If possible, green elements should be integrated which provide both retention and improved aesthetics.

The public drainage system and its storage facilities can also be managed with a targeted flow control system to better exploit the existing storage capacity. Moreover,

Fig. 12 Examples of water-sensitive street design and construction

Fig. 13 Stormwater inlets with three-dimensional screens to avoid blocking

Fig. 14 Urban lawn redesigned as multifunctional retention basin for extreme rainfall

emergency discharge points can be implemented at suitable sites in the drainage system, to discharge water into water bodies, open spaces, or other noncritical areas in exceptional cases (e.g. once every 10–30 years).

Larger inlets to the drainage system should be designed with adequate dimensions and should be equipped with three-dimensional screens. This is particularly important for capturing runoff from outlying, natural or quasi-natural catchments at the residential borders (Fig. 13).

For pluvial flood prevention and, in particular, damage limitation, there is always the option of directing unavoidable surface water specifically to selected areas with lower damage potential and consciously accepting the damage caused there instead of even greater damage in other areas (Fig. 14).

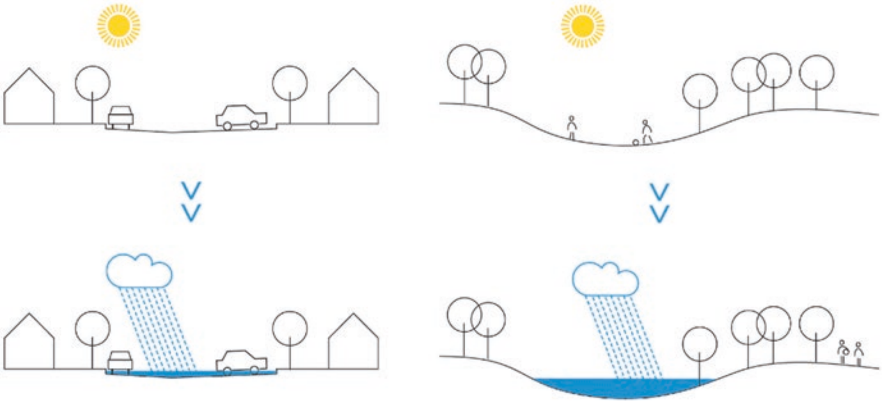


Fig. 15 Principle of a multifunctional urban retention space as a flood precaution measure

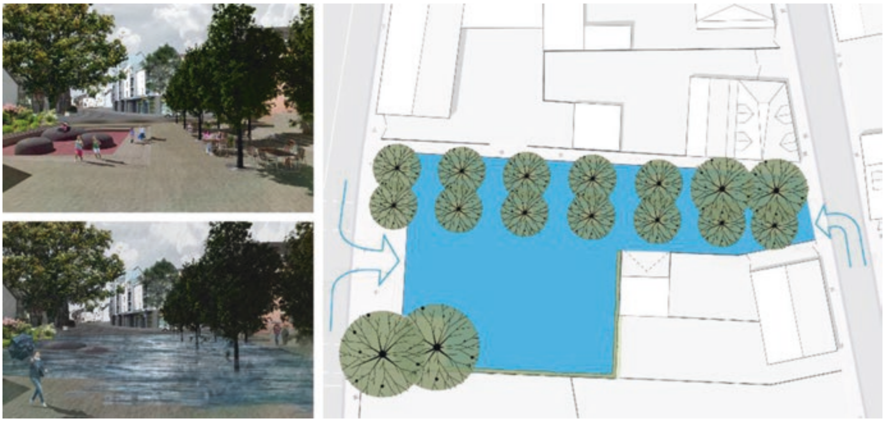


Fig. 16 Multifunctional design of an open space as retention basin for extreme rainfall

As primarily public spaces, these types of multifunctional urban retention areas mostly serve their purpose as traffic areas (roads, parking spaces) or as recreational areas for the population (e.g., green spaces, athletic fields, playgrounds, parks, or squares). In the case of a flash flood, they briefly assume their additional function as a retention space for stormwater (Fig. 15).

Essentially, public green spaces, paved public spaces with no buildings, large public sports facilities, parking lots, ponds, brownfield sites, or undeveloped areas can be suitable for this purpose (Fig. 16). A major advantage of such a multifunctional use of space is the very high cost efficiency. Compared to alternative flood precaution measures, the adapted design of open and green spaces is often associated with relatively low costs.

Multifunctional urban retention areas are useful to improve the management of extreme precipitation events. During a storm event far above the design level of public drainage systems, these areas take up and store surface water. This reduces or even prevents flooding damage elsewhere. It is consciously accepted that in (very) rare cases the main use of the area is temporarily restricted or not possible and that the affected area may have to be cleaned or repaired after the event. However, these restrictions of use are given preference over much more extensive damage to property, higher personal risks, and/or a diffuse distribution of dirt or pollutants in the environment, which would occur elsewhere without this targeted and controlled emergency retention. A multifunctional use of space offers the following advantages:

- Improved protection against flooding with minimal land consumption
- Multiple use of existing or already planned infrastructure
- Avoidance of competition for land or space by combining requirements
- Lower or minimal costs (economic efficiency) and bundling of financial resources
- Simple consideration in redesigns and renovations
- High potential for synergy with other measures of adaptation to climate change (e.g., measures to decrease heat or improve air quality)
- High potential for increasing area value (e.g., design-based or ecologically)

4.2 Property and Building-Related Precautionary Measures

Very heavy rainfall events are always associated with extremely large volumes of surface water within residential areas – regardless if additional measures in infrastructure have been implemented to prevent flooding or not. Protective measures against pluvial flooding on the part of the municipality can only offer a limited degree of protection. Thus, it is also necessary that property owners independently seek property protection to effectively prevent damage to their buildings and contribute to the overall flood protection. Property protection measures are therefore an elementary component of a holistic approach for pluvial flood prevention (Fig. 3).

At the property level, there are also various possibilities for flood prevention (Fig. 11; Illgen 2017). In addition to suitable behavior during a flash flood, technical flood protection measures are vital, especially in already developed areas. This includes, for example, protective elements directly on buildings and facilities as well as in their surroundings. Typical examples at this point are backwater protection devices, raised entrances or light shafts, water- and pressure-tight windows and doors, as well as automatically closing bulkheads or safety gates (Fig. 17). These elements usually act as a last barrier against inflowing water and are of particular importance for the effective flood protection of the property.

Particularly in the case of existing buildings, object protection measures are often considerably more economical than large-scale flood protection measures implemented by the public sector. In general, they can also be implemented more

Fig. 17 Examples of technical and constructive flood protection measures

quickly and thus offer a more rapid approach to flood protection. Whether the corresponding investments are profitable must be assessed by the property owners themselves and with regard to the possible damage (flood risk). Industrial and commercial enterprises are usually affected to a much greater degree; thus, protective measures are particularly worthwhile here.

5 Conclusion and Outlook

Early and ongoing precautionary measures against pluvial flooding must receive greater attention in urban areas in the coming years and decades – particularly in light of climate change and expected increases in storm intensities. This mission is particularly important in cities and metropolitan areas, not only in Europe but in Asia and the rest of the world.

In this context, integrated risk management with regard to extreme rainfall represents a proven solution in Germany and Europe. This strategy comprises planning and technical and administrative measures and is based on a systematic risk analysis with regard to pluvial flooding.

The primary objective of this risk management is to minimize the locally varying flood risks in an economically appropriate manner, by reducing either the flood hazards or the potential damages. Existing flood risks can be identified and prioritized by means of hazard and risk analyses. Digital terrain models, geographic information systems, and hydraulic flow models can be applied to generate hazard and risk maps. On this basis, hotspots of flood risk can be identified, and required actions can be specified. Finally, suitable precautionary measures can be developed, reviewed for effectiveness, and then implemented.

The options for pluvial flood prevention measures are versatile. They are primarily focused on heavy rainfall beyond the design level of urban drainage systems but can be combined very well with measures of general rainwater management (e.g., according to the sponge city principle). In addition to technical protection measures on buildings by the property owners, infrastructural and urban planning measures under the direction of the municipality are especially recommended. They are mainly oriented toward an increased retention of stormwater or surface water. This includes, for example, integrating the requirements of pluvial flood prevention from the outset when planning or redesigning roads, squares, or green spaces and designing them as multifunctional retention areas. In this context, the primary goal should be water-sensitive urban development that also offers better adaptation to other aspects of climate change (e.g., heat reduction, improvement of microclimate).

It is important to understand flood prevention as an interdisciplinary cross-sectional task in which different disciplines, administrative departments, and civil actors must contribute. Pluvial flood risk management can only be successful if it is given sufficient priority in the community and if the management process is well coordinated. This requires intensive communication and exchange between the participants.

The approach offered here for pluvial flood risk management is based on very positive experiences in Germany and Europe. However, the described approaches and recommendations can also be applied to other regions and adapted to the specific local conditions.

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Urban Pipe Assessment Method and Its Application in Two Chinese Cities

Jian'e Zuo, Xiangyang Ye, Xiaoqing Hu, and Zhonghan Yu

Abstract With urbanization in China, the sewer system is increasing in scope, and as a result sewer pipe defects have appeared frequently and caused problems. For example, sewer pipe defects lead to the leakage of wastewater, which may pollute groundwater in northern China. On the other hand, underground water may flow into the sewer pipes in southern China as the underground water level is higher than the sewer pipe (unlike in northern China), which dilutes the inlet wastewater in terms of COD to the wastewater treatment plant, reducing the treatment and operating efficiency. As some large cities in China are gradually being equipped with CCTV devices, the demand for an evaluation method usable by Chinese operators is urgent. Therefore, an objective and comprehensive evaluation system should be established to avoid defects and provides real-time practical suggestions under the current conditions of China. Fuzzy mathematic methods in sewer condition evaluation were utilized to decrease the uncertainty during the evaluation process in some studies, but the reliabilities of the evaluations varied based on different fuzzy methods chosen. Thus, fuzzy mathematic methods were introduced in the whole process of evaluation to eliminate artificial errors and give more objective assessment results. A novel comprehensive sewer condition assessment method was also established.

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1 Sewer Pipes in China and Assessment Using Fuzzy Mathematic Methods

1.1 Sewer Pipes in China

With the rapid urbanization in China, the construction of wastewater treatment facilities is dramatically increasing. More than half of the sewer pipes have been installed in the past 10 years; however, sewer systems receive little attention when compared to other public works (Liu et al. 2011). Although the designed service life of sewer pipes is at least 50 years, the risk of pipe failure caused by pipe defects increases as the time of usage increases. Along with the short average age of sewer pipes in China, related problems have been frequently reported across the country such as road subsidence, sewerage overflow, and wastewater treatment plant failure, among others. To avoid accidents caused by sewer defects, periodical inspection work should be carried out to understand the sewer fitness levels. Effective maintenance and rehabilitation strategies can be undertaken to prolong the lifetime of sewers. Many kinds of technology are now in use to carry out sewer inspection work, for example, closed-circuit television (CCTV), sonar, hand-held cameras, and road surface radar, among others. Among these technologies, CCTV is the most accepted and widespread method (Shehab-Eldeen 2001). Some foreign sewer managing authorities initially established an evaluation system based on CCTV video such as the Water Research Centre (WRC) standard in the UK and the Abwassertechnische Vereinigung (ATV) 149 standard in Germany. Historically, a huge number of sewer pipes in these countries were built using bricks, and thus, the defects are mainly defined using these standards based on brick material. However, China contains relatively few brick sewer pipes, so the existing foreign methods are not suitable for direct application in Chinese cities. As some large cities in China are gradually being equipped with CCTV devices, the demand for an evaluation method usable by Chinese operators is urgent. Some local sewer management authorities developed their own standards by imitating foreign ones. However, problems emerged when these simplified methods encountered various limitations. Their so-called “quantitative” method simply adds the number of defects occurring in the pipe to give a valued index, which varies across several orders of magnitude under different circumstances, making little sense when comparing different pipes. The results of the evaluation should give meaningful instructions to maintenance strategy making. Therefore, there is a need to establish a more objective and more comprehensive evaluation system under the current conditions of China. Fuzzy mathematic methods in sewer condition evaluation were utilized to decrease the uncertainty during the evaluation process in some studies, but the reliabilities of the evaluations varied based on different fuzzy methods chosen (Gua et al. 1994). Thus, fuzzy mathematic methods were introduced in the whole process of evaluation to eliminate artificial errors and give more objective assessment results. A novel comprehensive sewer condition assessment method was also established.

1.2 Assessment Method Based on Fuzzy Mathematic Method

To give the final assessment result of a certain section of pipe quantitatively, three processes should be carried out. First is to record and code every defect occurring in one pipe according to a certain identification standard; second is to classify the degree of each defect into different categories; and third is to consider all the defects in different damage degrees to give an overall result (Low et al. 2011). Aside from the overall assessment result, the tightness, function, and stability of the pipe are also considered in this method to represent the defect effects on different aspects of the pipe features. Tightness indicates the leakage potential and structural change of the pipe. Function mainly represents the transportation ability of the sewerage. Stability shows whether the pipe condition will tend to become worse in the future.

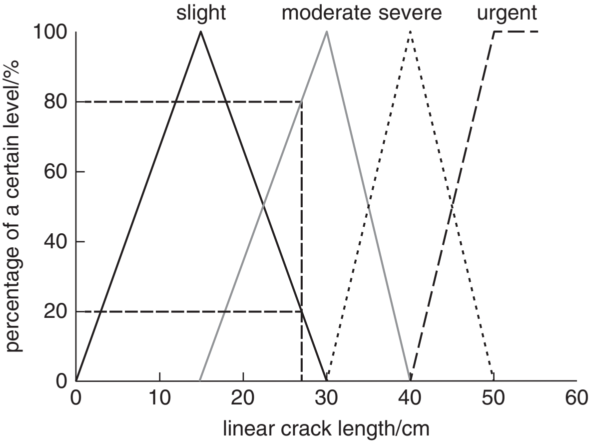
1.2.1 Defect Coding, Identification, and Damage Degree Classification

Based on some preview works using sewer videos in different Chinese cities and other practices from European standards, the defect coding and classification rules were established. In total, 15 types of defects were defined: deformation (D), cracking (C), break/collapse (B), surface corrosion/damage (S), intruding connection (IC), joint damage (JD), displaced joint/opened joint (DJ), unauthorized/misconnected branch (MB), plant roots (R), attached deposits (AD), settled deposits/sedimentation (SD), other obstacles (OO), ingress of soil (IS), groundwater in filtration (I), and sewerage exfiltration (E) [18]. For each defect, an eigenvector was given to describe the damage degree. For example, the percentage of cross-sectional change of a pipe is the eigenvector of the defect deformation. For any currently existing defect classification standard, home and abroad, the level is classified by simply comparing the value of the eigenvector with the level boundary value. In this way, a slight error made by different operators can cause a huge difference in the classification results when the eigenvector value is close to the boundary. For example, a boundary for Level 1 and Level 2 is 60 (cm or % or others). A set of identified values of 59.2 and 60.4 by two operators can put the same defect into different levels. To eliminate this kind of phenomenon, a piecewise function was introduced in this method. The eigenvector value is expressed in a set of piecewise functions. The piecewise functions of some of the defects are shown in Table 1.

Table 1 Record sheet of pipeline video inspections

Location	Upstream inspection well	Downstream inspection well	Material		Video number	
(road name)	GIS	GIS	Diameter	Depth		Defects
Tuangui South Road	*N31.13*	*N31.33*	*Concrete*	*About 0.8 m*	*20,160,428*	*Infiltration*
	E118.23	*E118.28*	*DN800*			*Obstruction*

Fig. 1 Example of a 27 cm crack expressed as a piecewise function



Instead of putting it at one level, the defect class is expressed as a vector R_i, which is the linear combination of four different levels, which are slight, moderate, severe, and urgent.

$$R_i = \left(r_{i-slight}\ r_{i-moderate}\ r_{i-severe}\ r_{i-urgent}\right), \tag{1}$$

where $r_{i\text{-}slight}$, $r_{i\text{-}moderate}$, $r_{i\text{-}severe}$, and $r_{i\text{-}urgent}$ are the portions of a certain defect i categorized as slight, moderate, severe, and urgent degrees, respectively.

For example, a 27 cm crack is the combination of 80% moderate and 20% slight, expressed as (0.2 0.8 0 0), as shown in Fig. 1. The boundary values of each defect can be adjusted according to the feedback of the actual assessment work. Therefore, all the defects with different damage degrees occurring in one pipe can be written as one vector R as follows:

$$R = \begin{pmatrix} r_{\text{Deformation slight}} & r_{\text{Deformation modrate}} & r_{\text{Deformation severe}} & r_{\text{Deformation urgent}} \\ r_{\text{Crack slight}} & r_{\text{Crack modrate}} & r_{\text{Crack severe}} & r_{\text{Crack urgent}} \\ \vdots & \vdots & \vdots & \vdots \\ r_{\text{Root slight}} & r_{\text{Root modrate}} & r_{\text{Root severe}} & r_{\text{Root urgent}} \end{pmatrix} \tag{2}$$

1.2.2 Hierarchical Structure Establishment

Some of the defects mentioned above may affect one or all of the aspects of tightness, function, and stability of the pipe. Simply summing up the scores of the different defects enlarges or covers the contribution of a certain defect. Therefore, the mathematical methods of fuzzy comprehensive evaluation (FCE) and analytical hierarchy process (AHP) are introduced in the assessment process to objectively balance the contributions of the different defects. First, the hierarchical structure of the assessment was established, as shown in Fig. 2.

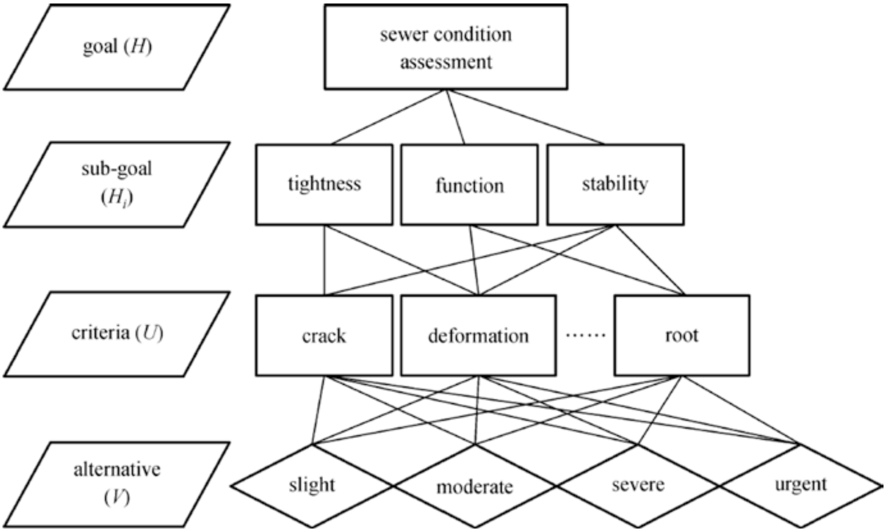


Fig. 2 Hierarchical structure of the assessment process

In our process, the factor set denotes the types of defects:

$$U = \{\text{crack, deformation, …, root}\} \tag{3}$$

The decision set denotes the damage degree of each defect:

$$V = \{\text{slight, moderate, severe, urgent}\} \tag{4}$$

Therefore, the evaluation is the fuzzy mapping f: $U \rightarrow V$, as previously described, that is:

$$f(u_i, v_i) = R \tag{5}$$

1.2.3 Weight of Defects

According to FCE, the final assessment should be the inner product of the weight of defects and the fuzzy mapping R. Let the health index H represent the final results; three subindices H_t, H_f, and H_s denote tightness, function, and stability, respectively.

Therefore,

$$H = A \cdot R, \tag{6}$$

where A is the weight of defects $A = (a_{Deformation}, a_{Crack}, \ldots, a_{Root})$.

Using the pairwise comparison method and the consistency check of AHP, weight A can be calculated. The dimensions and the value of the weight vector *A* vary depending on the type of defect occurring in each pipe. Therefore, the defects that do not occur in a certain section do not “occupy” the weights in the vector. Similarly, weight vector A_t, which concerns all the defects affecting tightness, can be calculated by comparing the related defects, namely, A_f and A_s.

1.2.4 Expression of the Result

The final result is calculated as

$$H = \left(A_t H_t + A_f H_f + A_s H_s\right) \tag{7}$$

After the homogenization process, the overall index *H* always falls into the interval [0, 1] (sometimes larger than 1). The larger the *H* is, the worse the health condition will be. The maintenance and rehabilitation strategy can be made upon the ranking of *H* in the different sections of the sewer pipes. In studying the sewer conditions of Chinese cities, one can simply classify pipes with a good state when $H \in (0, 0.25)$, with moderate problems when $H \in (0.25, 0.5)$, with severe problems when $H \in (0.5, 0.75)$, and with urgent action required when $H \in (0.75, +\infty)$.

After the establishment of the assessment method, it was applied in two Chinese cities, Yixing and Wuxi Cities, in order to test the feasibility and reliability of the method. In addition, assessment methods were adjusted to make them more suitable for sewer pipes in Yixing based on the assessment method introduced above, while further analysis was performed with respect to the properties that may influence the sewer pipes in Wuxi City.

2 Sewer Pipe Inspection in Yixing and Adjustment for the Assessment Method

First, the description of pipeline defects from qualitative method to quantitative method is converted. Quantitative description can intuitively reflect the pipeline situation and provide the basis for pipeline classification management, so it is important to employ quantitative calculation methods for pipeline operation and management.

At present, there are no specific and unified standards for the quantitative method of pipeline defects in China. Some universities and administrations have studied the theory of some quantitative methods for the description of pipeline defects. Thong Soon Low et al. applied fuzzy comprehensive evaluation to quantify pipeline defects. Although these calculation models have advantages in theory, the complex data statistics and mathematical barriers make them inefficient in practical applications and difficult to generalize. They are more used in academic research and in isolated situations. Moreover, the surrounding environment of pipelines and the quality of pipeline construction vary greatly. It is difficult for a model to consider the characteristics in different areas and to consider both internal and external factors.

Therefore, this research cites a quantitative method of drainage pipeline defects established in Yixing Water Special Project, which is applicable in South China.

2.1 Introduction for Yixing

Yixing City is located in southern Jiangsu, the west coast of Tai Hu, and famous for its potteries in China. There are about 681 km of drainage pipe network with infrastructure data in Yixing City, with a service area of 1996.6 km and a service population of 1.07 million covering 11 districts in Yixing City. Most of the drainage pipelines and related facilities in Yixing City are aging. With the expansion of urbanization in recent years, the drainage network has been rapidly built and expanded to form a complex drainage network system. The new and old pipelines in this system are connected in a complicated manner, a phenomenon that is common in many small cities in China.

Over 250 inspection videos of defective pipelines were obtained. These pipelines were surveilled by a local company in 2014, according to the investigation of the national Water Special Project. Initially, pipeline defects were divided into ten types: groundwater infiltration, interface damage, disconnection, dislocation, deformation, collapse, corrosion, breakage, obstructions, and sediment. Then the number of each defect is counted; the result is shown in Fig. 3.

Interface damage, disconnection, and dislocation are each caused by interface problems, resulting in groundwater and soil infiltration, so they are classified as the same type of defect.

Although deformation and collapse are different in terms of visual effects, deformation will eventually lead to collapse. Plastic pipelines are widely used, and

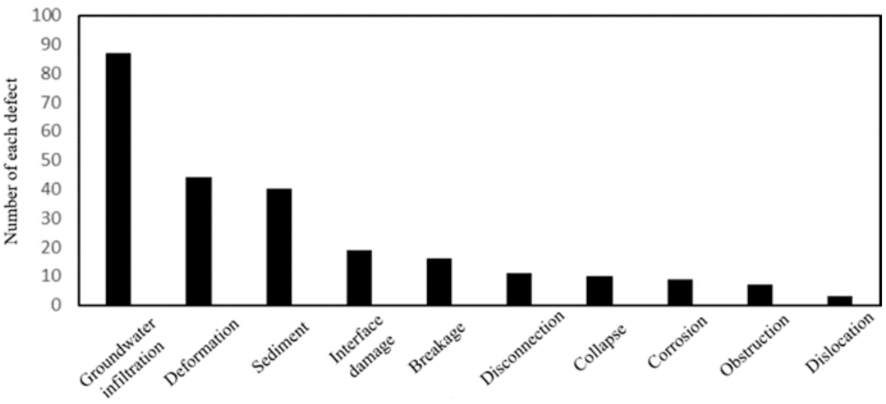


Fig. 3 Statistics of each type of defect found in inspected sewer pipes

sudden collapse of plastic pipelines caused by deformation is a common situation, so deformation and collapse are classified as the same type of defect.

Corrosion and breakage are defects on the inner wall of pipeline. Corrosion mostly occurs in reinforced concrete pipes, and breakage mostly occurs in plastic pipes. The later stage of corrosion is similar to breakage, so corrosion and breakage are classified as the same type of defect.

Pipeline defects are thus divided into five types: groundwater infiltration, interface damage/disconnection/dislocation, deformation/collapse, corrosion/breakage, and obstructions/sediment.

2.2 Establishment of Standardized Inspection Records and Quantitative Method

2.2.1 Inspection Records

Before pipeline defect quantification, pipeline video inspections should be carried out, and standard inspection method established. This standardized inspection method can reduce mismanagement, facilitate the removal of defects, facilitate the quantification of defects, and contribute to the unification of the pipeline defect database systems.

The process of standardized inspection method includes GIS location, QV initial inspection, and CCTV defect site inspection.

Pipeline inspection should ensure that there is less water and silt in the pipeline and the water level is less than 30% of the pipe diameter. If the condition cannot be satisfied, the pipeline should be blocked and cleaned. The operation of QV is simple and does not require a strict condition; thus, QV is utilized first for detecting. If there is no defect, it is recorded as qualified. If a defect is found, the defect location is recorded and filmed. If, using QV, it is difficult to observe or locate defects in some cases, such as cracks, leakage, collapse, interface problems, etc., CCTV should be employed for further inspection and to record the defect type in the pipeline, shown in Table 1.

2.2.2 Extraction of Image of Defects

1. *Groundwater Infiltration*

Definition: Groundwater infiltration is a type of pipeline defects which results in the entry of groundwater into the pipeline. This type of defect is due to the failure of pipeline integrity in the area where the groundwater level is relatively high.

Groundwater infiltration is easily observed in the inspection videos, and it is also the type of defect with the most image data. This type of defect is usually accompanied by other kinds of defects, shown in Fig. 4.

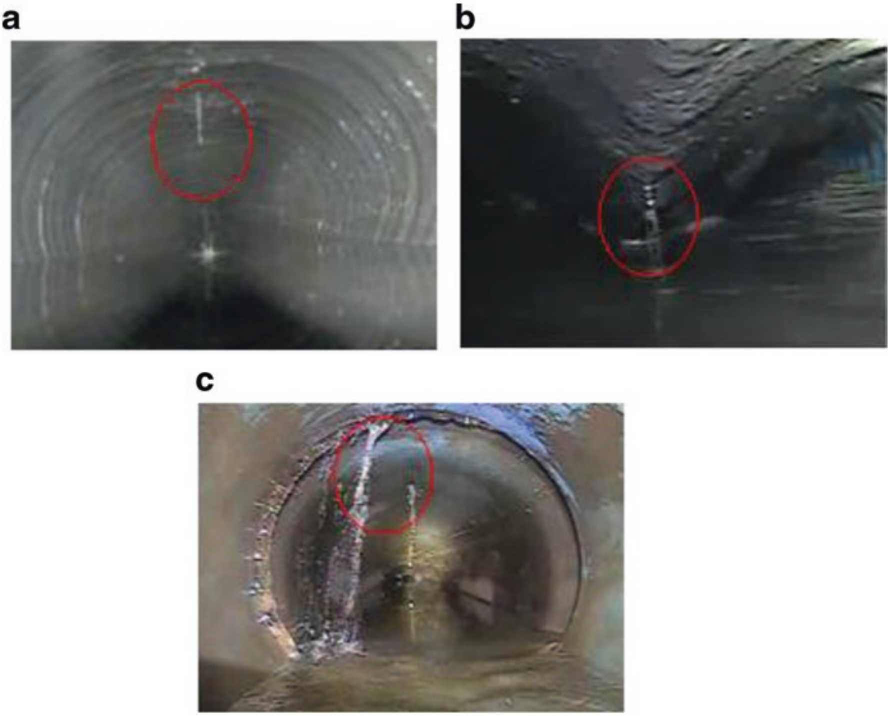


Fig. 4 Groundwater infiltration in sewer pipes. (**a**) Drip infiltration. (**b**) Flow infiltration. (**c**) Splash infiltration

Table 2 Classification of groundwater infiltration

Defect name	Drip infiltration	Flow infiltration	Splash infiltration
Description	Water dripping in through a defect or faulty joint or drain/sewer wall. Not a continuous flow	Water running in through a defect or faulty joint or drain/sewer wall. A continuous flow will be visible	Water entering the pipe “under pressure” through a defect or faulty joint, not necessarily a heavy flow

Groundwater infiltration is divided into three types (Table 2), drip infiltration, flow infiltration, and splash infiltration, according to the severity of the infiltration in the pictures taken from the videos.

2. *Interface Damage/Disconnection/Dislocation*

Definition: The ends of the two connected pipelines are not fully jointed.

This type of defect (Fig. 5) is often related to the previous construction quality and is difficult to repair. The repair of such defect often requires excavation of the ground, affecting the discharge capacity of the pipeline and the ground traffic.

Fig. 5 An example of interface problem

3. *Deformation/Collapse*

Definition: Pipelines are deformed by the external force and will become more affected over time.

If there is no timely maintenance of the deformed pipeline, the collapse of the pipeline will eventually occur, as shown in Fig. 6.

4. *Corrosion/Breakage*

Definition: A kind of defect in pipeline integrity caused by the external forces or the sewage corrosion.

Some of the pipeline breakage is caused by corrosion, but most breakage is caused by uneven stress or sudden impacts, such as damage from road excavation. This kind of defect can cause cracks in the inner wall of the pipeline, as well as cracks in the outer wall, shown in Fig. 7.

5. *Obstruction/Sediment*

Definition: A type of defect, referring to the area of wetted cross section decreasing gradually, including bottom silting, garbage blockage, root invasion, dirt attached to the pipe wall, etc.

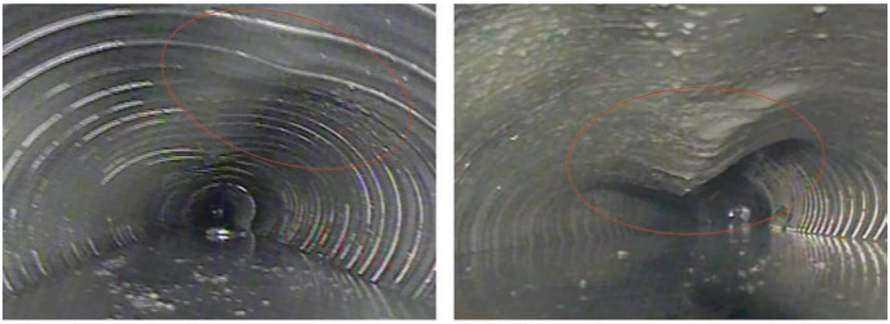
Most of these defects are caused by sediment deposition at the bottom of the pipeline. For such defects, conventional dredging can achieve good results. The defects are shown in Fig. 8.

2.2.3 Quantitative Calculation of Pipeline Defects

1. *Defect Quantification*

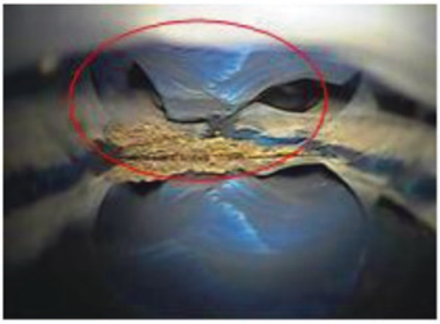
① Groundwater Infiltration

Groundwater infiltration is divided into drip infiltration, flow infiltration, and splash infiltration, according to the severity and nature of the infiltration. Numerical



(a) Deformation less than 10 %

(b) Deformation more than 10 %



(c) Deformation more than 50 %

Fig. 6 Examples of deformation/collapse. (**a**) Deformation less than 10. (**b**) Deformation more than 10%. (**c**) Deformation more than 50%

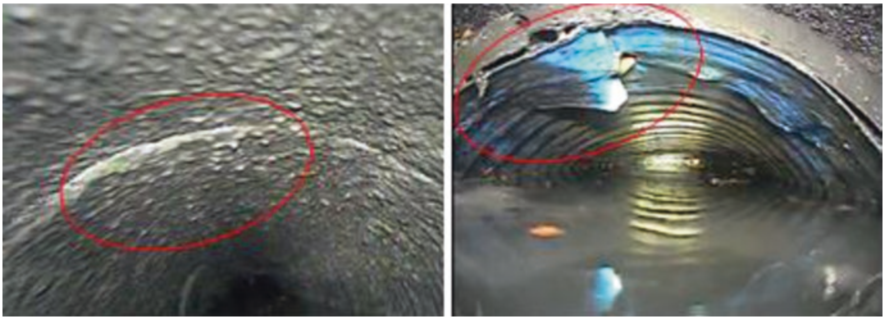


Fig. 7 Examples of corrosion/breakage

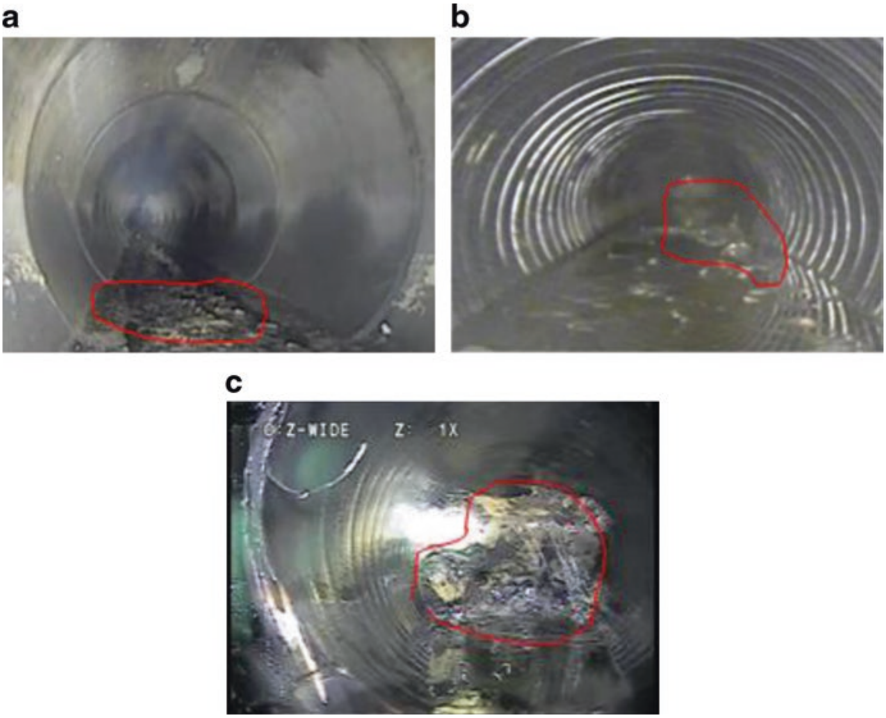


Fig. 8 Examples of obstruction/sediment. (**a**) The ratio of the obstruction/sediment sectional area to the pipe sectional area is less than 30%. (**b**) The ratio of the obstruction/sediment sectional area to the pipe sectional area is more than 30% and less than 50%. (**c**) The ratio of the obstruction/sediment sectional area to the pipe sectional area is more than 50%

Table 3 Classification of groundwater infiltration

Defect name	Drip infiltration	Flow infiltration	Splash infiltration
Range of a_0	(0, 0.3]	(0.3, 0.6]	(0.6, 1]

values are used to quantify the severity of the defects; 0 represents no defects of this kind, and 1 represents a serious splash infiltration. The specific value ranges are shown in Table 3.

② Interface Damage/Disconnection/Dislocation

Similarly, numerical values are used to quantify the severity of the defects. They can be calculated using the following formula.

$$a_1 = s / m \tag{8}$$

where:

s: the vertical length of interface damage/disconnection/dislocation.
m: the thickness of the pipeline wall.
The maximum value of a_1 is 1, which represents a very serious defect.

③ Deformation/Collapse

This kind of defects can be quantified using the following formula.

$$a_2 = \frac{\theta}{360} \times 100\% \tag{9}$$

where

θ: the angle that the deformation/collapse section occupied the circumference of the pipeline

④ Corrosion/Breakage

The degree of corrosion or breakage can be quantified using the following formula.

$$a_3 = C_i / \mathrm{C} \tag{10}$$

where:

C_i: length of corrosion/breakage
C: circumference of the pipeline

⑤ Obstruction/Sediment

This kind of defect can be quantified using the following formula.

$$a_4 = F_i / \mathrm{F} \tag{11}$$

where:

F_i: the obstructions/sediments section area
F: the pipe section area at obstructions/sediments

2. Method of Pipeline Importance Quantification

Considering the complexity of the pipeline defects, a multivariate analysis model was used to calculate the pipeline importance. Ten influence factors were chosen as model input, namely, depth, soil property, groundwater level, ground traffic condition, vegetation, material, age, length, diameter, and hydraulic gradient.

Table 4 shows that professionals can use a ten ordinal value system to evaluate the influence degree of the influence factors. Score 1 represents little influence on the pipeline status, and Score 10 represents great influence. Professionals also should give a comprehensive score for the pipeline general status. Using these scores and

Table 4 Professional score sheet of ten influence factors

Type	Value	Score
Depth	m	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Soil	Excellent, good, poor	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Groundwater level	-m	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Ground traffic	Excellent, good, poor	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Vegetation	Excellent, good, poor	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Material	Excellent, good, poor	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Length	km	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Diameter	m	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Age	-y	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Hydraulic gradient	‰	(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)

Table 5 Classification of soil conditions

Soil condition	Excellent	Good	Poor
Average number of strikes	≥ 300	≥ 100 <300	<100

mathematical methods, the relationship between factors and results and the parameters of the factors in this model are obtained. This model can be used to predict the pipeline general status in the future: more data should create a more accurate model. Most of the ten influence factors can be described using numerical values, such as depth, diameter, and hydraulic gradient. However, soil condition, ground traffic condition, vegetation, and material are described using excellent, good, and poor as qualifiers.

Soil Condition

The soil around the pipeline has a great influence on the pipeline structural stability. Soil settling ability should be studied as it can present the comprehensive soil condition. Soil settling ability can be measured by drilling out detection. Steel rod with standard diameter will be fixed perpendicular to the surface of soil. Then a hammer with standard weight is used to strike the steel rod until it gets into the soil 30 cm. The number of the strikes can present the soil settling ability (Table 5).

Ground Traffic Condition

The structural defects of pipelines are more likely to occur in places where the traffic flow is large, since large traffic flows lead to large pipe load-bearing conditions. Once a pipeline has structural defects, its maintenance will affect the road traffic in turn. The traffic flow is selected to represent the ground traffic condition. Table 6 shows the ground traffic conditions and the ranges of their corresponding traffic flows, while Table 7 shows the division of the pipeline importance.

Table 6 Classification of ground traffic conditions

Traffic flow (vehicles/day)	Excellent	Good	Poor
Important road	<60	[60,600)	≥ 600
Sub-important road	<80	[80,800)	≥ 800
Common road	<100	[100,1000)	≥ 1000

Table 7 Classification of road importance

Importance	Important	Sub-important	Common
Vehicle speed(km/h)	≥ 80	≥ 40	<40
		<80	

Vegetation

The roots of plants will grow larger and larger, gradually invading the drainage pipes and destroying the structural integrity. Therefore the vegetation condition is described by whether there are lawns, shrubs, or trees around the pipes, as shown in Table 8.

Material

The material of the pipelines generally includes concrete, reinforced concrete, plastic, and other material. According to the structural stability, the classification of the material is shown in Table 9.

A model was established to describe the relationship between the influence factors and the pipeline general status after the statistical analysis and evaluation of professionals. An example of the drainage pipeline evaluation in a southern region is given in detail. One hundred professionals provided scores relating to the general status and each factor of the drainage pipeline. The model can be established by counting the score value and assessing the weight of each factor, informing which factor has a more important influence on the general status of the pipeline. And the general status of the drainage pipeline can be predicted by the evaluation of influence factors. The first step of the model establishment is to collect data, as shown in Fig. 9.

The data was fitted and analyzed using Microsoft Excel, and the parameters were obtained as shown in Tables 10, 11, and 12.

The formula of the pipeline importance is obtained using these attributes and parameters, as shown in Table 12.

$$y = 0.345x_1 + 0.221x_2 - 0.157x_3 + 0.253x_4 + 0.156x_5 + 0.042x_6 - 0.352x_7 + 0.008x_8 - 1.624x_9 + 0.045x_{10} \quad (12)$$

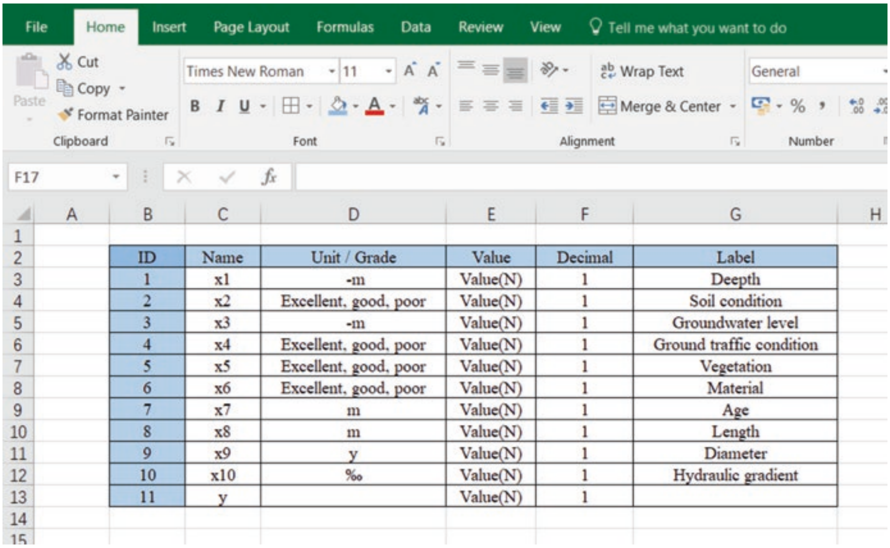
y: pipeline importance index
x_1:depth, (m)
x_2:soil condition, as shown in Table 5
x_3:groundwater level, (m)
x_4:ground traffic condition, as shown in Table 6
x_5: vegetation condition, as shown in Table 8

Table 8 Classification of vegetation condition

	Excellent	Good	Poor
Vegetation condition	No shrub or arbor	No arbor	Large shrub or arbor

Table 9 Classification of material

	Excellent	Good	Poor
Material	Plastic	Reinforced concrete	Concrete



ID	Name	Unit / Grade	Value	Decimal	Label
1	x1	-m	Value(N)	1	Deepth
2	x2	Excellent, good, poor	Value(N)	1	Soil condition
3	x3	-m	Value(N)	1	Groundwater level
4	x4	Excellent, good, poor	Value(N)	1	Ground traffic condition
5	x5	Excellent, good, poor	Value(N)	1	Vegetation
6	x6	Excellent, good, poor	Value(N)	1	Material
7	x7	m	Value(N)	1	Age
8	x8	m	Value(N)	1	Length
9	x9	y	Value(N)	1	Diameter
10	x10	‰	Value(N)	1	Hydraulic gradient
11	y		Value(N)	1	

Fig. 9 Statistics table for influence factors of drainage pipeline

Table 10 Model fitting results

					Statistics of modification					
Model	R	R^2	Adjusted R^2	Standard errors of estimate	R^2 modification	F modification	df1	df2	Sig.F modification	Durbin-Watson
1	0.894	0.88	0.785	0.3970	0.800	52.534	7	92	0.000	2.150

Table 11 Model fitting results

Model	Sum of squares	Df	Mean square	F	Sig
Regression	57.964	7	8.281	52.534	0.000
Residual	14.501	92	0.158		
Total	72.466	99			

Table 12 Model coefficients

Model	Nonstandard coefficient		Standard coefficient	t	Sig.	Colinearity statistics	
	B	Standard error				Tolerance	VIF
Constant	−0.503	0.442		−1.139	0.258		
x1 depth	0.249	0.181	0.345	1.388	0.171	0.028	37.174
x2 soil condition	0.156	0.188	0.221	0.999	0.320	0.146	13.553
x3 groundwater level	0.188	0.036	−0.157	1.743	0.000	0.035	3.528
x4 ground traffic condition	0.345	0.129	0.253	6.853	0.136	0.356	52.321
x5 vegetation	0.120	0.234	0.156	2.637	0.000	0.624	3.485
x6 material	0.433	0.223	0.042	5.367	0.000	0.036	2.739
x7 age	−0.456	0.085	−0.352	7.447	0.749	0.824	1.836
x8 length	0.007	0.085	0.008	2.179	0.457	0.315	3.489
x9 diameter	1.432	0.153	1.624	−3.783	0.626	0.371	15.589
x10 hydraulic gradient	0.192	0.032	−0.045	−1.638	0.289	0.626	1.372

x_6: material, as shown in Table 9
x_7: age, (year)
x_8: length, (m)
x_9: diameter, (m)
x_{10}:hydraulic gradient; (‰)

Multiple regression analysis was used considering six main factors: depth, ground traffic condition, material, age, diameter, and hydraulic gradient. Pipelines were categorized into important pipelines, secondary pipelines, and general pipelines, and a model was established for the pipeline status evaluation.

$$y = 0.345x_1 + 0.253x_4 + 0.042x_6 - 0.352x_7 - 1.624x_9 + 0.045x_{10} \tag{13}$$

where:

y: pipeline importance index
x_1: depth, (m)
x_4: ground traffic condition
x_6: material
x_7: age, (year)
x_9: diameter, (m)
x_{10}: hydraulic gradient, (‰)

3. Comprehensive Formula for Quantifying Pipeline Defects

Considering the defects of the pipeline and the importance of the pipeline, the following formula is utilized:

Table 13 Priority level of pipeline maintenance

Q	Q = 0	$0 \leq Q \leq 0.5$	$0.5 \leq Q \leq 1$	$Q \geq 1$
Grade	No defect	Slight	Medium	Serious
Measure	No measure	Pipelines should be inspected again within 1 year	Pipelines should be repaired within 3 months	Pipelines should be repaired immediately

$$Q = y_i * \sum b_i \tag{14}$$

Q: pipeline comprehensive index
y_i: pipeline importance index
b_i: ith pipeline defect index
$\sum b_i$: pipeline defect index

The pipeline comprehensive index can be obtained by adding up the indices of each pipe section. The maintenance program can be established according to the value of the pipeline comprehensive index, as shown in Table 13.

2.2.4 Pipeline Defect Record Sheet

Data obtained from the above steps can be recorded in a sheet as shown in Table 14.

2.3 Application in Yixing City

A 2-year inspection was carried out using QV and CCTV for select pipelines in Yixing City. The inspections covered 82 roads in Yicheng and Hufu Districts. The distribution of sewage pipes in Yixing City is as shown in Fig. 10.

The red points in Fig. 10 denote the pipelines studied. In total, 436 inspection videos were utilized to study these pipelines, whose total length is about 16.86 km, as shown in Table 15.

Yicheng District is the Old City and located in the center of Yixing. The average age of the pipelines is relatively high, and the pipeline system is complicated. Hufu District is a newer area boosted by tourism, which began constructing drainage systems after 2008. The pipelines in Hufu District are configured in a tree-like hierarchical distribution.

The ages and diameters of the pipelines inspected in these two districts are shown in Fig. 11.

Table 14 Pipeline defect record sheet

Video number		Measuring record	Calculation	
Defect types	(A) Groundwater infiltration	Drip infiltration(0, 0.3)		a_0 =
		Flow infiltration(0.3, 0.6)		
		Splash infiltration(0.6, 1)		
	(B) Interface damage/ disconnection/ dislocation	$a_1 = s/m$	a_1 = s/m =	a_1=
		The vertical length of interface damage/ disconnection/dislocations		
		The thickness of the pipeline wall m		
	(C) Deformation/ collapse	$a_2 = \frac{\theta}{360} \times 100\%$	$a_2 = \frac{\theta}{360} =$	a_2=
		The angle that the deformation/collapse section occupied the circumference of the pipeline θ		
	(D) Corrosion/breakage	$a_3 = C_i/C$	$a_3 = C_i/C$=	a_3=
		The length of the corrosion/breakage C_i=		
		The circumference of the pipeline C =		
	(E) Obstruction/ sediment	$a_4 = F_i/F$	F_i/F=	a_4=
		The obstructions/sediments section area F_i=		
		The pipe section area at obstructions/ sediments F =		

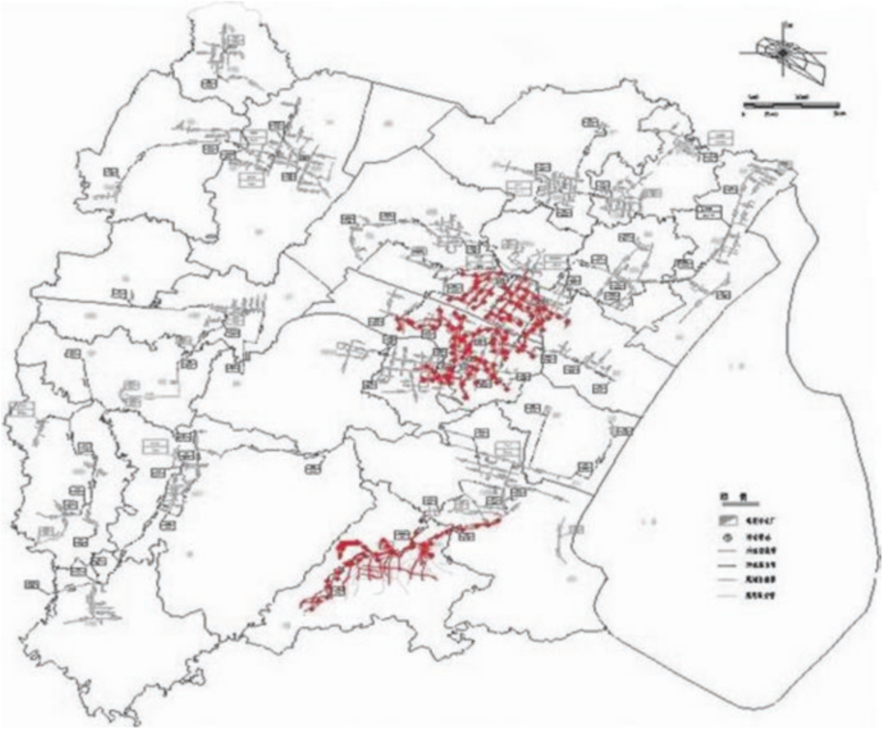


Fig. 10 Pipelines in Yixing City and pipelines inspected in this study

Table 15 Distribution of the inspected pipelines

Area	Road/quantity	Effective pipe section/section	Effective length /m
Yicheng District	62	315	12,650
Hufu District	20	121	4210

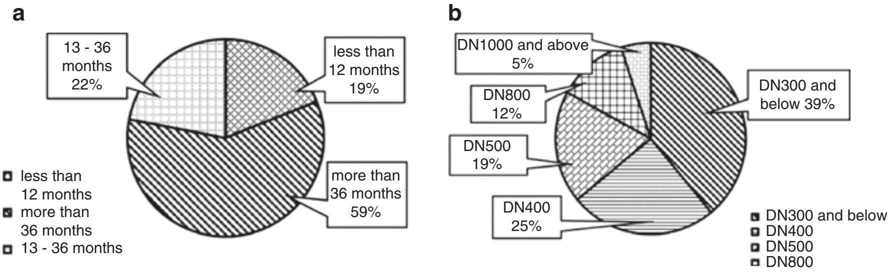


Fig. 11 Ages and diameters of the inspected sewer pipes

Table 16 Amount of each type of defect observed in the inspected pipelines

	Groundwater infiltration	Deformation/ collapse	Interface damage/ disconnection/ dislocation	Corrosion/ breakage	Obstruction/ sediment
Amount	56	21	27	18	11

Table 17 Distribution of the pipeline comprehensive indices

	$Q = 0$	$0 \le Q \le 0.5$	$0.5 \le Q \le 1$	$Q > 1$
Amount of pipe sections	328	63	31	14

Figure 11a shows that 59% of pipelines have a pipe age of more than 3 years and the remaining 41% have been installed within the last 2 years, which indicates a rapid development of the pipeline system. Figure 11b shows that 83% of pipelines have a diameter of 500 mm or less. They can be inspected using pipeline robots when problems arise.

Quantification of Pipeline Defects

Inspection programs were conducted for pipelines in Yixing City, according to the standardized inspection record and the quantitative method described in earlier sections. Data from the 436 pipelines were analyzed, and it was found that there were 133 defects and 108 defective pipelines, with some pipelines having more than one defect. The types and the importance of the defects are shown in Table 16.

The pipeline comprehensive index Q can be obtained using the formula 2–6: the distribution of the indices are shown in Table 17.

Table 17 shows that 14 sewers with serious defects should be repaired immediately, 31 sewers with medium defects should be repaired within 3 months, and 63 sewers with slight defects should be inspected again within 1 year.

2.3.1 Pipeline Dynamic Management Model

Yixing City has built a pipeline management platform based on the geographic information system (GIS) in 2015, as shown in Fig. 12. This platform recorded the basic information of all the main pipelines in Yixing City, such as depth, ground traffic condition, material, age, diameter, elevation. and hydraulic gradient.

This platform is basically a database of infrastructural information (Hu et al. 2010). It can provide quick search results for the basic data of pipelines, but it lacks the data of operations and defects. It does not implement automatic management and cannot provide technical support for the maintenance plan of pipelines.

The following optimizations were undertaken for this platform:

1. Module of the pipeline importance calculation

   The algorithm of $y = 0.345x_1 + 0.253x_4 + 0.042x_6 – 0.352x_7 – 1.624x_9 + 0.045x_{10}$ was developed to grade pipelines according to the value of the pipeline importance index y.
2. Module of the defect quantification

   The pipeline defect index $\sum b_i$ can be obtained by inputting five defect indices of each type in this module.
3. Module of the comprehensive evaluation of the pipeline

   The algorithm of $Q = \sum \gamma b_i$ is introduced in this module. Thus, the pipeline comprehensive index q can be obtained automatically.
4. Module of characterization with color

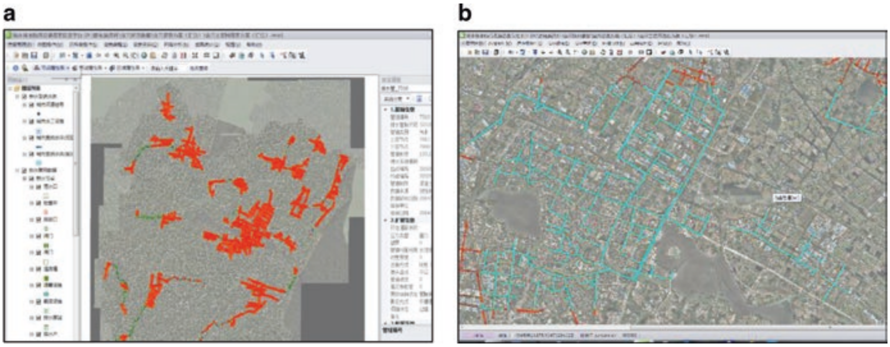


Fig. 12 The GIS platform in Yixing City. (**a**) The distribution of the main pipelines in Yixing City. (**b**) The distribution of pipelines in Yicheng District

Table 18 The comprehensive indices Q and their corresponding color labeling

Range	$Q \geq 1$	$0.5 \leq Q \leq 1$	$0 \leq Q \leq 0.5$	$Q = 0$
Grade	Serious	Medium	Slight	No defect
Color labeling	Red	Orange	Yellow	Green

(a) Search of pipeline information (b) Calculation of pipeline importance

(c) Pipeline defects quantification (d) Quantification results

Fig. 13 Interface of the pipeline evaluation system of Yixing City. (The language of the program operation interface is Chinese as this application was carried out in China.) (**a**) Search of pipeline information. (**b**) Calculation of pipeline importance. (**c**) Pipeline defect quantification. (**d**) Quantification results

Four colors, red, orange, yellow, and green, were used to describe the severity of the defects in a pipeline. The severity can be quantified according to the value of Q. The relationship among them is shown in Table 18.

The optimized user interface is shown in Fig. 13.

A sewer pipe with groundwater infiltration was selected to demonstrate the functions of the optimized platform, as shown in Fig. 14.

The pipeline importance index y = 1 is obtained according to the automatic calculation. The pipeline defect index value $\sum b_i = 0.5$ is obtained, because there is only one defect, namely, flow infiltration, in the pipeline. The pipeline comprehensive index Q is calculated to be 5, and should be marked yellow in the map of GIS, as shown in Fig. 15.

管道基本信息

管段编号：ys32

建设时间：2009.3

上游管井：19

一般管道

下游管井：20

y=1

管网巡查问题记录

报告日期：2017年5月30　　报告人：

问题类型：■ 地下水入渗

地下水入渗

缺陷描述

□ 滴漏

☑ 水流

□ 喷溅

缺陷结果：
b=0.5

管道健康等级

缺陷量化值 0.5

Fig. 14 The interface of the automatic quantification of groundwater infiltration

Fig. 15 The interface of the automatic grading of defective pipelines

Table 19 Pipeline maintenance programs

	Groundwater infiltration	Interface problems	Deformation/ collapse	Corrosion/ breakage	Obstruction/ sediment
Slight	Quick-drying cement	CIPP or excavation	CIPP or excavation	Hot-melt plastic or quick-drying cement	Upstream water-washing or excavation
	Quick-drying glue				
Medium	Hot-melt plastic or quick-drying cement	CIPP or excavation	CIPP or excavation	CIPP or excavation	High-pressure washing or excavation
Serious	CIPP or excavation	CIPP or excavation	CIPP or excavation	CIPP or excavation	High-pressure washing or excavation

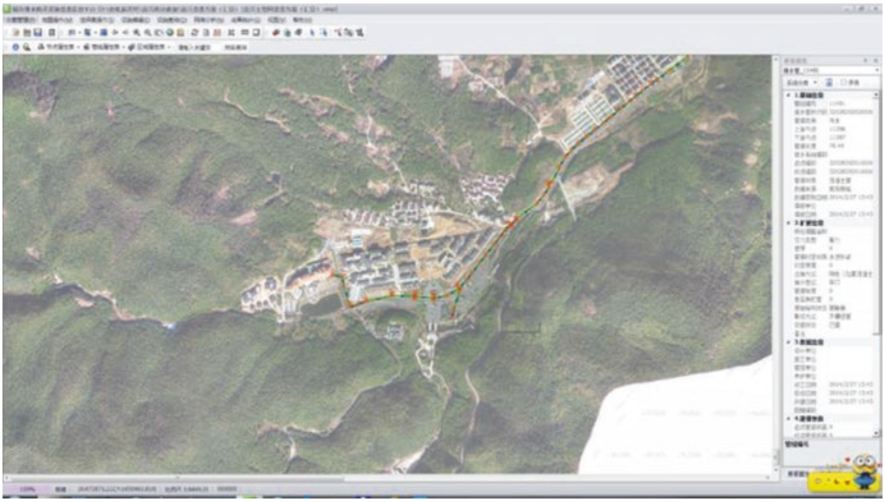


Fig. 16 The interface of the GIS platform

The ultimate task of pipeline operation and management is the pipeline maintenance. The study of the online operation and management mode is aimed to reduce the occurrence of pipeline operation accidents, to enhance the efficiency of the drainage system, and to realize the information-based operation of the drainage system in Yixing City. The authors propose five kinds of maintenance programs aimed at the five types of pipeline defects, as shown in Table 19.

Managers can complete the search of pipeline information easily in this platform, as shown in Fig. 16.

This optimized platform provides functions to calculate the indices, classify the pipelines, and characterize the pipelines with different colors according to their comprehensive indices. Thus, managers can make maintenance plans based on the pipeline colors showed on the platform interface. For example, if a pipeline is marked in red, indicating a badly damaged pipeline, it will be prioritized in the

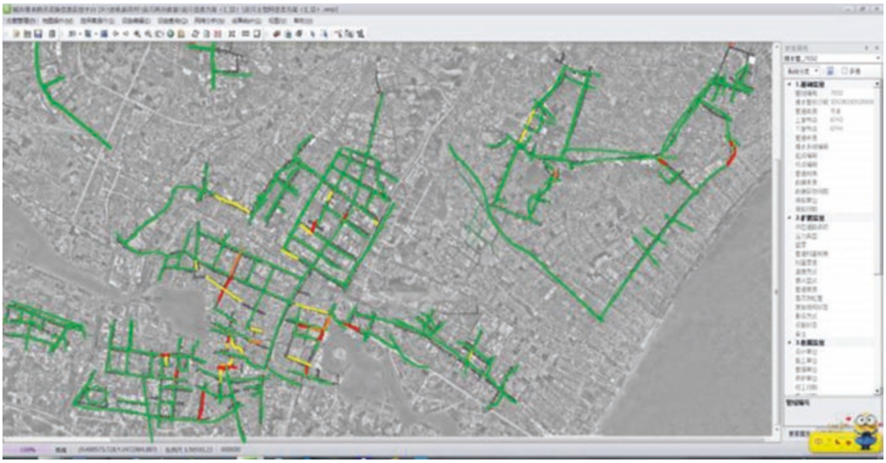


Fig. 17 The interface of the pipeline status warning

maintenance schedule. In general, this platform provides a more reasonable schedule for pipeline maintenance, as shown in Fig. 17.

The online operation and management mode can help managers obtain information of the pipelines quickly and make the maintenance work easier. Managers can conduct the secondary information collection according to the color labeling of the pipelines. This information can then be used to evaluate the accuracy of the pipeline defect assessment and to correct the assessment system. Using this method, the pipeline management capability of this platform can be improved significantly.

At present, many cities in China have established an urban drainage system database based on GIS technology. However, there is not yet a unified standard of data storage including updates, due to the complexity and inconsistency of pipe network conditions countrywide (Wei 2011). Pipeline maintenance plans also should consider the difference among the cities such as locations, climate, and management infrastructure.

3 Sewer Pipe Inspection and Analysis in Wuxi City

Due to uninformed construction practices, lax supervision during construction, and the lack of regular maintenance, sewer pipes tend to be out of order in many cities in China; in the worst cases, injuries have resulted due to accidents. Both the internal and external environments of pipelines are complicated and highly influencing, and many types of defects may occur at different degrees, which makes it difficult to perform thorough analysis based on a few samples. Sewer pipes are influenced externally by the soil environment and internally by sewage, for example. Many external factors can lead to the appearance of the sewer pipe defects. Beyond that, the material, age, relative length, and diameter can also influence the health conditions of sewer pipes. The structural stability of sewer material will be weakened as the pipes age and the defects worsen. As for the sewer pipes with larger diameter and shorter length, their rigidities are relatively high, which means they are unable to deform along with the whole structure and will undergo joint damage and crack defects instead. When this happens, soil around the pipe will flow inward, leading to further deformations from its original position and eventual pipe collapse. Therefore, analyzing how sewer pipe properties affect the sewer pipe condition could provide reasonable guidelines for construction and maintenance of sewer pipes. Thus, sewer pipes were inspected and data collected in Wuxi City to study the sewer pipe defect properties and the sewer system conditions.

Wuxi City is located in the Yangtze River Delta, a region with countless rivers and lakes. The total area of Wuxi City is 4627 km^2, of which the water surface area is 1342 km^2, occupying 29.0% of the total area. Water resources are generally speaking abundant; however, high-quality water sources are few. Water-related environmental problems are gaining prominence as the quantity of wastewater increases continuously; as a result, urban sewage infrastructure has gained importance. As of 2015, the total length of sewer pipes was 1660 km in Wuxi City. The service area is 282 km^2, while the population serviced is 2.2 million, and 95% of the total sewer pipes are part of a separate system. The city consists of six smaller systems. The inspection work was implemented, by which 1043 CCTV inspection images were acquired and a total length of 28,760 meters of sewer pipes were inspected.

3.1 Data Description and Analysis

In this research sewer pipe conditions are described including sewer pipe defect variable sets, sewer pipe performance variable sets, and sewer pipe comprehensive evaluation indices. These data derive from the inspection and assessment of sewer pipes in Wuxi City. The sewer pipe properties include age, diameter, material, relative length, and hydraulic slope, obtained from the database of Wuxi City from 2013 to 2015.

3.1.1 Describing the Data

Sewer pipe defect variable sets include defect classification results of 15 common defects. Defect classes consist of four designations, slight, moderate, severe, and urgent, resulting in the defect class vector R.

Sewer pipe performance variable sets and sewer pipe comprehensive evaluation indices are both calculated according to the assessment method. Tightness, function, and stability are chosen to evaluate the sewer pipes according to their respective impacts. The three subindices are denoted as Ht, Hf, and Hs. The sewer pipe comprehensive evaluation index is calculated using the three subindices and their weights. During the computing process of the fuzzy-based assessment method, the normalization process is applied in order to adjust the range of all index values.

3.1.2 Analysis Methods

To analyze how sewer pipe properties influence defects, sewer pipes are divided into four or five sections according to their relative length, diameter, age, hydraulic slope, and material. Next, the average value of each section is calculated, as well as the occurrence rate of all defects. The calculation results are shown using histograms and scatter diagrams.

To analyze the correlation among all different defects, a Pearson correlation is applied, in which −1 and 1 represent perfect negative and positive linear correlations, respectively. T tests are applied to describe significant differences between the fact and the null hypothesis: 0.05 and 0.001 are the values used to denote significant or extremely significant correlations, respectively.

To study the effect of pipe properties on defect class, performance index and comprehensive evaluation index, the canonical correlation analysis method is applied. By calculating the correlation between two variable sets, the correlation pairs of variables are acquired. These pairs of variables reflect the relationship between two sets of variables as much as possible. Then, the reliable level of the correlations can be tested according to the correlation coefficients and significance levels.

3.2 Interrelations Between Sewer Pipe Properties and Sewer Pipe Conditions

3.2.1 Interrelations Between Single Properties and Sewer Pipe Conditions

According to the assessment based on fuzzy method, there are 15 common defects, including deformation, cracking, break/collapse, surface corrosion/damage, intruding connection, joint damage, displaced join/opened joint, unauthorized/misconnected branch, plant roots, attached deposits, settled deposits/sedimentation, other obstacles, ingress of soil, groundwater infiltration, and sewerage exfiltration. The defect types are too many to analyze; thus, 15 defects are divided into 5 groups, including deformation, internal obstruction, damage/corrosion, joint problem, and leakage. Sewer pipe properties are likewise divided into subgroups according to relative length, diameter, age, hydraulic slope, and material. The occurrence rates of the five groups are calculated. Figures 18, 19, 20, 21, and 22 show how the properties affect the occurrence rate and defect damage class.

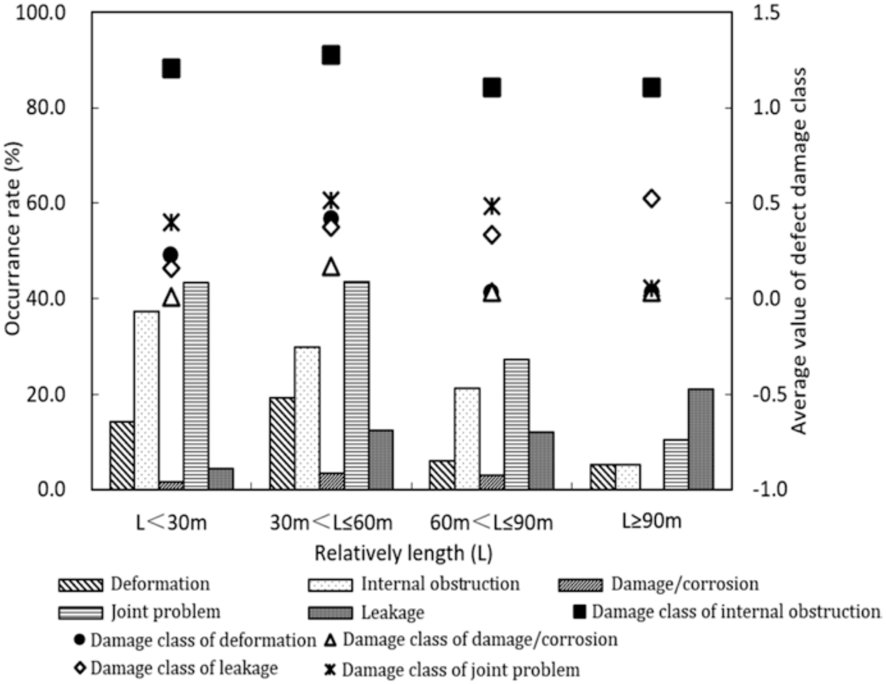


Fig. 18 The defect condition analysis results of different relative lengths

The analysis of the influence of the relative length on sewer pipe defects is shown in Fig. 18. All inspected sewer pipes are divided into four subgroups. Occurrence rates and average values of defect damage class are measured.

Based on Fig. 18, several conclusions may be drawn:

1. The trend of occurrence rate: as the relative length increases, occurrence rates of internal obstruction and joint problem decrease. The occurrence rate of joint problem doesn't change much when the relative length is short. Occurrence rate of leakage increases, while the relative length increases and the trend is very clear. The occurrence rate of deformation and damage/corrosion is first increased and then decreases when the relative length keeps increasing.
2. The trend of defect damage class: the defect class of internal obstruction is significantly higher than other defects, and the results of Figs. 19, 20, 21, and 22 are the same. In Fig. 18, the defect class of deformation and damage/corrosion decreases when the relative length increases in general, but the worst defects occur when the relative length is between 30 and 60 meters. Joint problems increase and then decrease as the relative length increases. The defect class of leakage increases obviously, while the relative length increases, indicating that when the relative length is longer, the leakage is more likely to occur and the leakage class is severe.

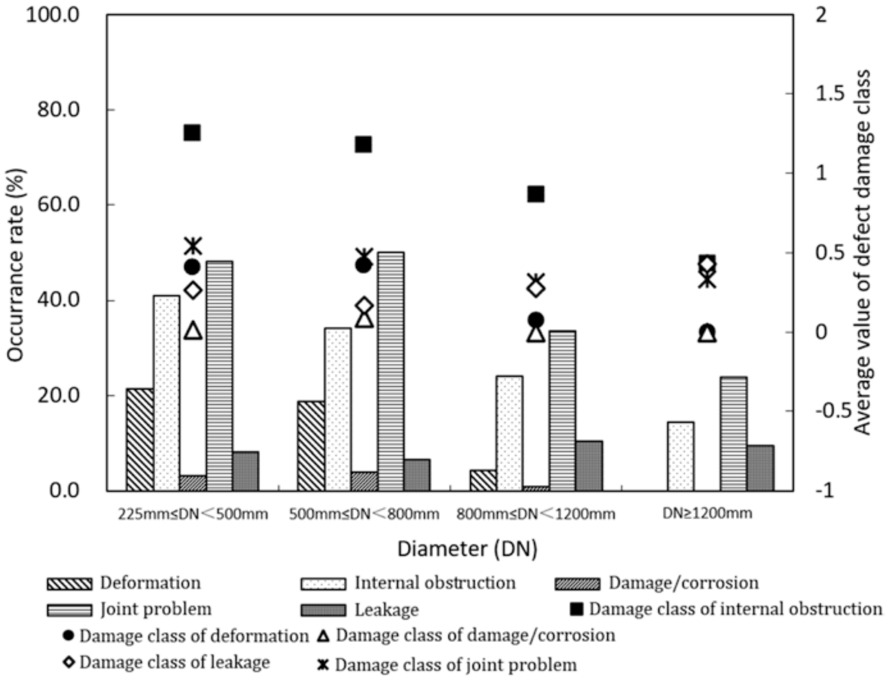


Fig. 19 The defect condition analysis results of different diameters

When analyzing influence of sewer pipe diameter on defects, sewer pipes are divided into four subgroups (expressed as DN): 225 mm ≤ DN < 500 mm, 500 mm ≤ DN < 800 mm, 800 mm ≤ DN < 1200 mm, and DN ≥ 1200 mm. The statistical results are shown as Fig. 19.

Figure 19 indicates that:

1. The trend of occurrence rate: the occurrence rate of deformation, internal obstruction, and joint problems decreases, while the diameter increases and the trend is very clear. The occurrence rate of leakage is nearly constant. Occurrence rate of damage/corrosion decreases as the diameter increases in general.
2. The trend of defect damage class: the defect class average values of internal obstruction and deformation decrease as the diameter increases, indicating that even with low occurrence rates, once defects occur they will be worsen quickly. The defect class of leakage and joint problems first decreases and then increases, while the defect class of damage/corrosion remains almost unchanged.

Figure 20 shows the impact that sewer pipe age has on the different defects. Sewer pipes are divided into three sections based on their ages (0–1 years, 1–3 years, and 3–5 years).

Some trends are visible from Fig. 20:

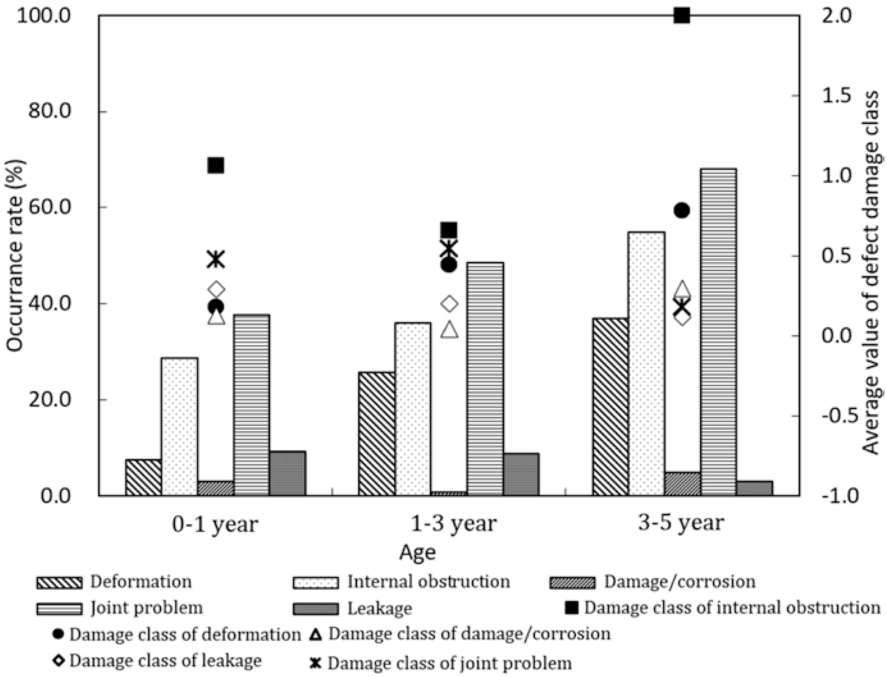


Fig. 20 Defect condition analysis results of different ages

1. The trend of occurrence rate: except leakage, the occurrence rate of the other four defects increases, while the age increases in general. But the occurrence rate of leakage decreases as the age increases; the reason may be that the material influences the leakage to a greater degree: most of the sewer pipes within 0–1 year are plastic, which is more likely to undergo leakage defects.
2. The trend of defect damage class: the defect damage class of deformation increases, while the age increases. The defect damage class of internal obstruction values in subgroup 3–5 years is much higher than the values in the other two sections, which means that as time passes, more obstructions are likely to enter and form in the sewer pipes. The joint problem decreases over time. Considering the occurrence rate of joint problems, it can be concluded that more severe joint problems occurred at an early age, likely caused by incorrect construction. Most joint problems are only discovered during operation and then repaired. New joint problems result from soil settlement, but the deterioration of the joint problems that affected by the environment is very slow, so the average defect damage value is decreased.

Figure 21 shows how the hydraulic slope (i) influences the defect conditions. The sewer pipes are divided into four sections as well: $i < 0.3\%$, $0.3 \leq i < 0.6\%$, $0.6\% \leq i < 1.0\%$, and $i \geq 1.0\%$.

Figure 21 indicates that:

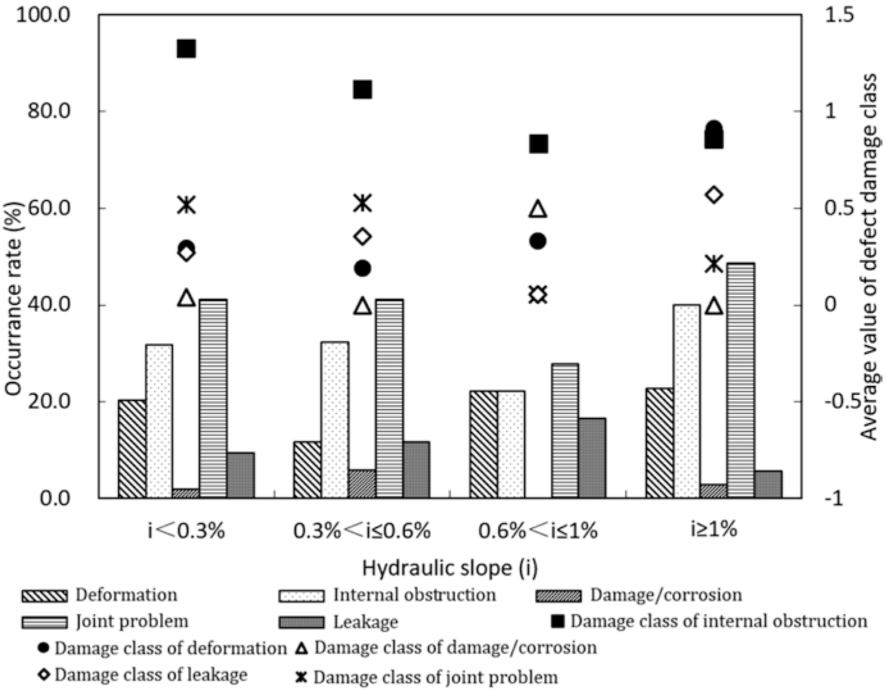


Fig. 21 The defect condition analysis results of different hydraulic slopes

1. The trend of occurrence rate: as the hydraulic slope increases, the occurrence rate of deformation, internal obstruction, and joint problem decreases firstly and then increases; the occurrence rate of damage/corrosion and leakage increases firstly and then decreases. The occurrence rate of deformation is the lowest when: 0.3 < i < 0.6%, while the occurrence rate of internal obstruction, damage/corrosion, and joint problem becomes the lowest when 0.6% < i <1.0%. The occurrence rate of leakage reaches the lowest when i > 1.0%.
2. The trend of defect damage class: the defect damage class of internal obstruction decreases when the hydraulic slope increases. The defect classes of damage/corrosion, joint problem, and leakage don't have clear trends. The defect class of deformation becomes more prevalent with increased hydraulic slope.

In conclusion, most of the trends between relative length, diameter, age, and hydraulic slope and different defect occurrence rates are obvious and could be estimated using general conclusions shown in Table 20. Most of the trends for defect damage classes are variable.

Material results are shown in Fig. 22. Steel pipes rarely are affected by obvious defects, so only four types of material including spheroidal graphite cast iron, reinforced concrete, PVC (polyvinyl chloride), and HDPE (high-density polyethylene) are shown in Fig. 22. Table 21 compares and ranks the occurrence rates.

Based on Fig. 22 and Table 21, it may be concluded that:

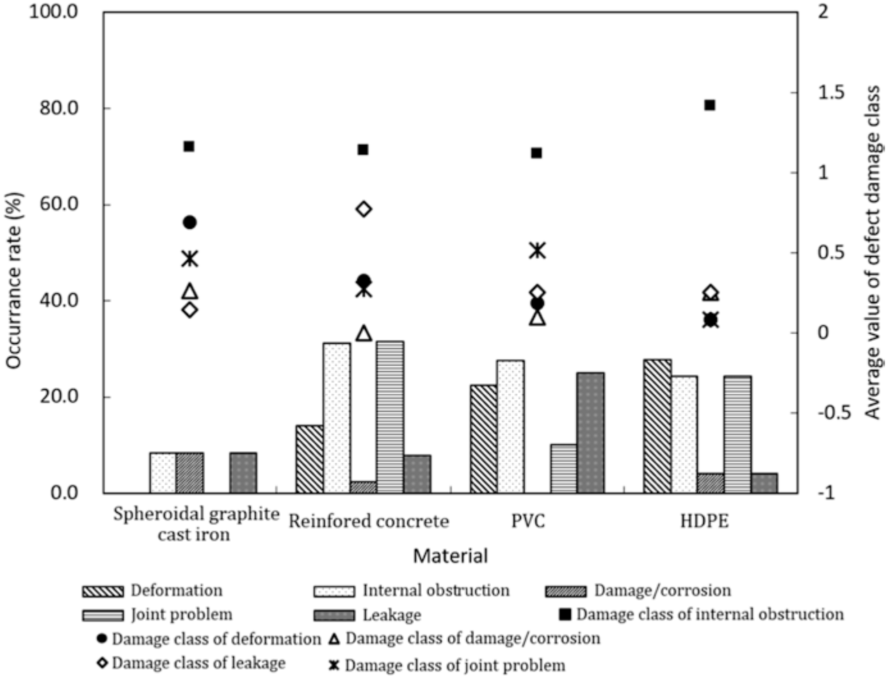


Fig. 22 The defect condition analysis results of different materials

Table 20 Trends between relative length, diameter, age, and hydraulic slope and sewer pipe defect occurrence rates

Property	Deformation	Internal obstruction	Damage/ corrosion	Joint problem	Leakage
Relative length	–	– –	–	–	+
Diameter	– –	– –	– –	– –	×
Age	+ +	+ +	+	+ +	– –
Hydraulic slope	+	+	×	+ +	– –

"– –": trend that decreases one by one; "–": trend that decreases in general; "+ +": trend that increases one by one; "+": trend that increases in general; "×": no obvious trend

1. The trend of occurrence rate: steel pipes are in best condition without obvious defects. Spheroidal graphite cast iron pipes are also in a good condition; its occurrence rate of damage/corrosion is in this case likely highly rated due to small sample size: only 12 sections were inspected. Regarding deformation and leakage, HDPE pipes have the highest occurrence rate of deformation; next are PVC pipes which also have the highest occurrence rate of leakage: about 3–6 times that of other materials. So it can be concluded that deformation and leakage are the most acute sewer pipe defects. As for joint problems, reinforced

Table 21 Occurrence rate ranking of different material pipes

Defect type	Ranking from high to low based on the occurrence rate
Deformation	HDPE>PVC > reinforced concrete>spheroidal graphite cast iron, steel
Internal obstruction	Reinforced concrete>PVC > HDPE>spheroidal graphite cast iron>steel
Damage/corrosion	Spheroidal graphite cast iron> HDPE>reinforced concrete>PVC, steel
Joint problem	Reinforced concrete>HDPE>PVC > spheroidal graphite cast iron, steel
Leakage	PVC > spheroidal graphite cast iron>reinforced concrete>HDPE>steel

concrete and HDPE pipes have the highest occurrence rates, the former due to rigid connections which are prone to open joint defects, while the latter is due to the susceptibility of plastic pipes to deformation and displacement.

2. The trend of defect damage class: the ranking of leakage severity class of five materials is PVC pipes > spheroidal graphite cast iron pipes > reinforced concrete pipes > HDPE pipes > steel pipes, while the defect class value of the middle three type pipes is ranged from 0.14 to 0.25. PVC pipes are still the most vulnerable pipes with a defect class value of 0.76. The rankings of other four pipe defects are equivalent to the occurrence rate rankings.

3.2.2 Interrelations Between Multiproperties and Sewer Pipe Condition

To compare the influences that the different properties have on sewer pipe condition in more details, we divided the sewer pipes into 5–6 sections according to their relative length, diameter, age, hydraulic slope, and material, respectively. The statistical results are shown as Figs. 23 and 24. In the following figures (Figs. 23 and 24), the sewer pipe comprehensive evaluation indices are noted as *H*.

Comparing Fig. 23 (a)–(d), it can be concluded that the data distribution variations of different relative lengths are the most inconsistent with most of the section data dispersedly distributed. In Fig. 23 (b), *H* decreases gradually as the diameter increases in general, from which it can be concluded that sewer pipes with bigger diameter are in a better condition. And as the diameter increases, the data tends to be more centralized, meaning the sewer pipe condition gets more stable and the regularity is more obvious. According to Fig. 23 (c), it was established that the relationship between age and sewer pipe comprehensive evaluation index is very obvious with a trend of decreasing to increasing. This conclusion is similar with other researchers' findings: all correlation curves concerned with age turn to be "tub-shaped." As for Fig. 23 (d), sewer pipe conditions with a hydraulic slope from 0.15% to 1.00% have little difference in general, while the sewer pipe conditions with hydraulic slope less than 0.15% and above 1.00% are unstable and worse in general.

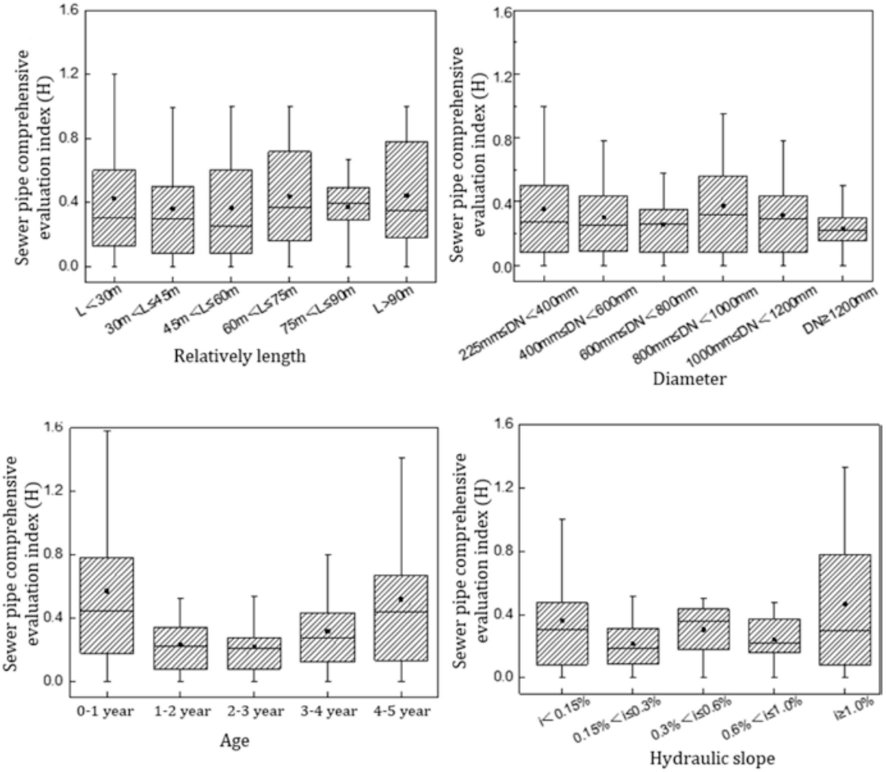


Fig. 23 The statistical results of sewer pipe condition based on different properties

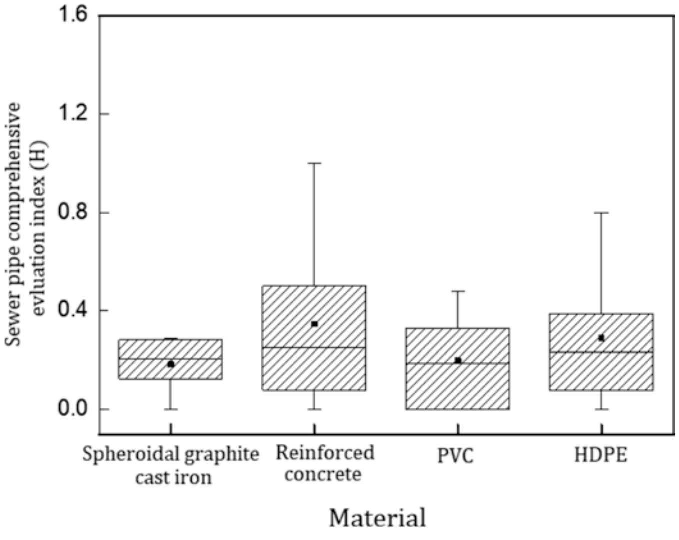


Fig. 24 Statistical results of sewer pipe condition based on different materials

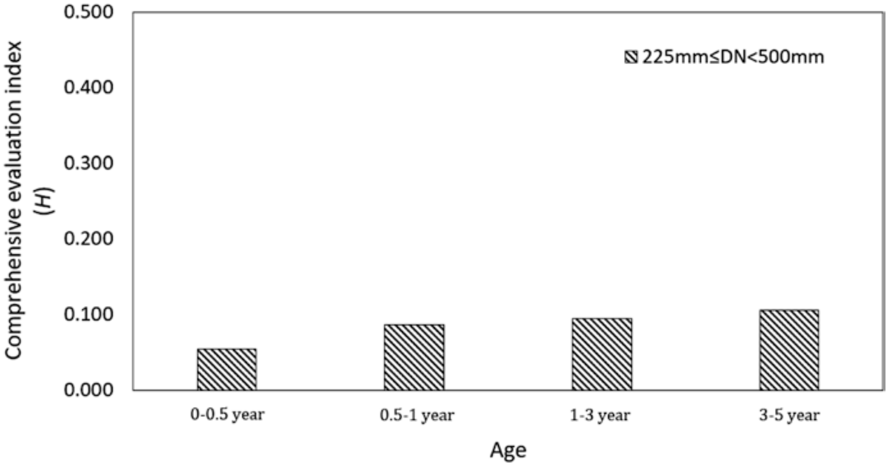


Fig. 25 Comprehensive evaluation indices classified by diameter and age of spheroidal graphite cast iron pipes

In addition to the four properties mentioned above, sewer pipes were categorized into five groups according to their material, including steel, spheroidal graphite cast iron, reinforced concrete, PVC, and HDPE. Among these, all steel pipes inspected were in very good situation without any defects, so the *H* values are all zero. Thus, the other materials are compared in Fig. 24.

According to Fig. 24, spheroidal graphite cast iron pipes are the most stable and are in the best condition, followed by PVC pipes. HDPE pipes have the same box height as PVC pipes, but all the *H* values are higher. Reinforced concrete pipes have the most dispersive distribution, as their conditions are most unstable and are the worst group overall in terms of performance.

As mentioned above, it can be concluded that diameter, age, and material are the main properties which influence the sewer pipe comprehensive condition. However, the comprehensive condition is concerned with all properties; thus, *H* values of different ages and relative lengths are compared based on Fig. 24, as shown in Figs. 25, 26, 27, and 28.

According to Figs. 25, 26, 27, and 28, it can be concluded that:

1. Material is primary influence on the comprehensive evaluation index *H*. Metal pipes are in the best condition, and HDPE pipes are generally in poor condition.
2. There are obvious trends as the age increases. Three material pipes' *H* values increase as their ages increase independent of diameter – except reinforced concrete pipes. As for reinforced concrete pipes, pipes in early age own higher *H* values. This may be caused by the incorrect construction and maintenance after inspection. In general, over time sewer pipe defects are more gradual in nature, and intensity of single events tends to be lower.

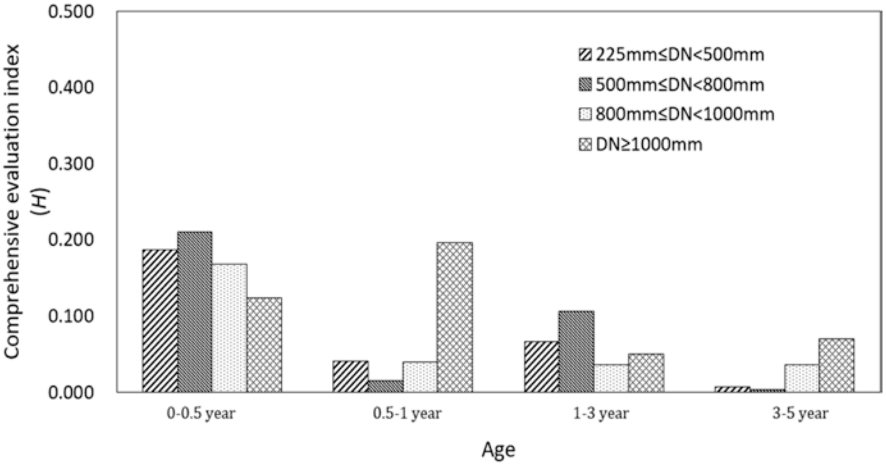


Fig. 26 Comprehensive evaluation indices classified by diameter and age of reinforced concrete pipes

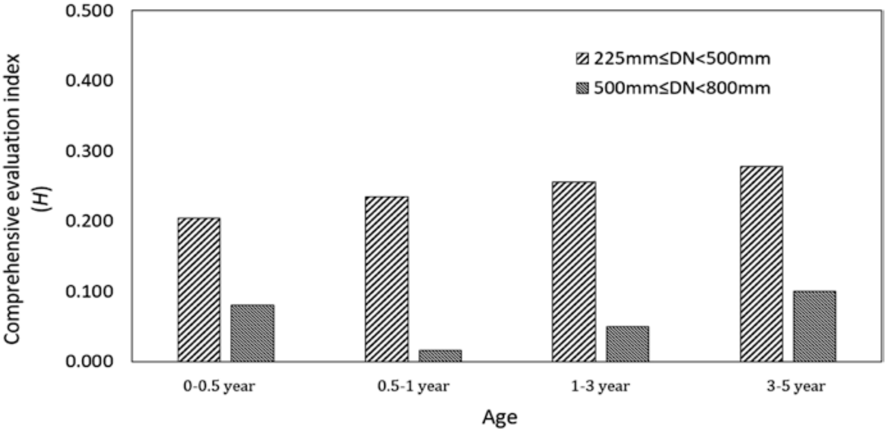


Fig. 27 Comprehensive evaluation indices classified by diameter and age of PVC pipes

3. There are clear laws of diameter which influence sewer pipe condition for HDPE and PVC pipes. Sewer pipes tend to more stable operation as the diameter increases. But this law does not exist in reinforced concrete pipes, indicating that diameter has more significant impacts on plastic pipes. The reason may be that structural stability of plastic pipes is poor and the pipe wall of smaller diameter pipes is also thinner, making them more susceptible to defects.

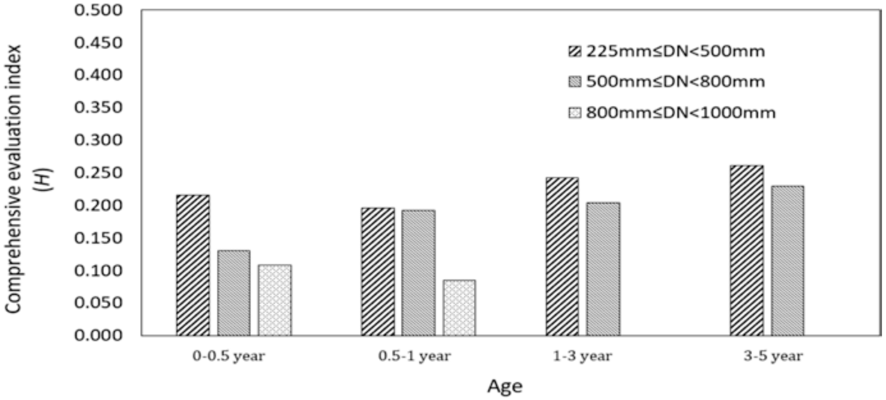


Fig. 28 Comprehensive evaluation indices classified by diameter and age of HDPE pipes

4 Summary

With urbanization in China, the sewer system is increasing in scope, and as a result sewer pipe defects have appeared frequently and caused problems. For example, sewer pipe defects lead to the leakage of wastewater, which may pollute groundwater in northern China. On the other hand, underground water may flow into the sewer pipes in southern China as the underground water level is higher than the sewer pipe (unlike in northern China), which dilutes the inlet wastewater in terms of COD to the wastewater treatment plant, reducing the treatment and operating efficiency. Ongoing inspection and assessment of sewer pipes helps avoid defects and provides real-time practical suggestions. Thus, the inspection, assessment, and analysis of sewer pipe defects, which have until now received little attention, are necessary steps and will be an important research field in the future.

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Part IV

Innovative Technologies and Implementation: Wastewater Disposal

Special Issues of Wastewater Management in China

Max Dohmann

Abstract An orderly wastewater disposal and associated wastewater management are important factors for human health and environmental protection. After a brief description of the development and the current situation of wastewater disposal in China, recommendations are given for future activities. The identified deficits in the operation and maintenance of the sewerage systems are currently a special focus of Chinese wastewater management. In many cities the reduction of external water also plays a role. Other areas of work will include measures for industrial wastewater, wastewater in rural areas, and, in the sense of "sponge city," a different handling of rainwater in urban areas. The "smart cities" targeted in China will also be linked to changes in the conventional centralized wastewater disposal system. In addition, the reinforcement of wastewater recycling has a special significance.

1 Introduction

The development of sanitation facilities and infrastructure for the collection and treatment of sewage water in the past 150 years was essential conditions for global urbanization. Wastewater management ensures the functionality of the entire wastewater infrastructure. The protection of water bodies and water resources through wastewater management is, as (is) well known, one of the most important factors of environmental protection.

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2 Current Challenges for Wastewater Management in China

Since the beginning of this century, measures to improve water protection have been significantly strengthened in China. It is well known that over the last decade China has made enormous improvement in its sanitation service through the construction of municipal wastewater treatment plants. This is reflected in the development of the number and capacity of Chinese sewage treatment plants. In 2000, there were 481 sewage treatment plants in China with a daily capacity of 22 million m^3 of wastewater. In 2016, the plant number was 3910 with a capacity of 167 million m^3, an eight-fold increase from the year 2000 (Pan 2016). Nearly 60% of the sewage plant construction was in urban areas. The wastewater treatment discharge standards in China are divided into several levels. The most stringent grade is Class 1-A; however, most wastewater treatment plants (WWTPs) in China are only required to meet the requirement of the second standard 1-B, according to GB 18918-2002. Meanwhile, the requirements for wastewater treatment have been increased to standard 1A.

In Table 1 the compliance values of Chinese sewage treatment plants are compared with the corresponding German requirements.

In the catchment area of the heavily contaminated Chinese lake shores, lower emission values (exceeding the standard 1A) have been set, which are listed, for example, for the Tai Hu in Table 1 under Standard Tai Hu. It can be seen that the standard 1A and, above all, the Tai Hu standard represent significantly higher requirements than the German emission values. From Table 1 however, it is also clear that a particular challenge in the coming years will be the appropriate high-speed upgrading of existing sewage treatment plants. Further challenges for Chinese sanitation exist in rural areas. In these regions many small decentralized sewage treatment plants and treatment plants for agricultural sewage are necessary. The following treatment rates for China were available at the end of 2010 (Deng and Wheathley 2016):

Cities	77.5%
Counties	60.1%
Villages	<20%

Table 1 Comparison between Chinese and German discharge standards for wastewater treatment plant

	China			Germany
Parameter mg/L	Standard 1B	Standard 2A	Standard Tai Hu	Size range 5
COD	60	50	30	75
BOD5	20	10	6	15
SS	20	10	–	–
TN	20	15	10	13*
NH_4- N	8	5	1.5	10
TP	1	0.5	0.3	1

* without **Norg**

Table 2 Estimates of the share of connection of the population to sanitation facilities in China and Germany (WHO 2015)

			Use of sanitation facilities (percentage of population)		
		Population (in mil.)	Urban	Rural	Total
China	1990	1165	68	40	48
	2015	1402	87	64	76
Germany	1990	80	99	99	99
	2015	82	99	99	99

Large sections of Chinese rural areas have so far no wastewater treatment (Ju 2012). China has 2.79 million villages with 768.8 million inhabitants corresponding to 57% of the Chinese population (Chen 2012). In 2010, the rural area discharge represented about 50% of major water pollutants of the whole country, as 43% of COD, 57% of total nitrogen, and 67% of total phosphorus (MEP 2010). In Table 2, the existing differences between connection rates of the population in urban and rural regions in China are shown. For all Chinese regions, there was a significant increase in sanitation after 1990. But in contrast to Germany, there is a clear need to modernize wastewater facilities in the rural regions.

The treatment of industrial sewage is a critical task of Chinese wastewater management. This applies to both directly discharge and the wastewater treated with domestic wastewater in municipal wastewater treatment plants. The planning of industrial treatment plants as well as of pretreatment plants prior to the discharge of sewage into a municipal sewage system requires a special competence from design institutes. In the absence of sufficient procedural knowledge, planning should be supported by appropriate pilot tests to avoid false investigations.

Municipal wastewater infrastructure, which is part of the wastewater infrastructure with the task of collecting and transporting sewage, was formerly not prioritized in China in contrast to municipal wastewater treatment plants. This has changed since 2014 in connection with the Sponge City program for changing the handling of water and especially of stormwater in urban areas. Since then, special care has been given to these fields, in particular the discharge and storage of stormwater. In several Chinese cities, measures for the operation and maintenance of the existing sewer systems were enacted. Existing combined and separated sewerages remain problematic due to numerous faulty connections or leakages. Therefore, this part of wastewater infrastructure will continue to present a particular challenge for Chinese wastewater management.

3 Improvement of Sewer Systems and Stormwater Facilities

The main motive for the necessary improvements to sewer systems and stormwater facilities in China is a reduction in water pollution. The drainage of wastewater and rainwater in Chinese sewers is based on the principle that wastewater requires treatment and rainwater does not. Accordingly, two basic systems of sewerage, the combined and the separate, were planned in Chinese cities. Due to many faulty connections in cities where areas with combined systems and separated systems exist, the sewers are in urgent need of improvement. Measures for the identification and subsequent elimination of these deficiencies are therefore urgently necessary.

Experience in Europe has shown that rainfall runoff contains different levels of pollutants. In Germany, these runoffs are thus divided into three groups:

- Uncontaminated stormwater from yards in residential areas and roofs in residential and mixed areas (no treatment necessary)
- Slightly contaminated stormwater from roofs in commercial and industrial areas, paved areas with low vehicle traffic, shopping streets, and market places (treatment generally required)
- Highly polluted stormwater from surfaces, which may include hazardous substances, e.g. urine, manure, areas with heavy vehicle traffic, and take-off and landing runways of airports (treatment compulsory)

This means that in cities the treatment of runoff from roads with heavy traffic should be considered. The runoff pollution load simulation for a combined and a separate system in Germany yielded the annual water impacts for COD and NH_4-N as shown in Fig. 1.

It can be seen that the advantages of the separate system with respect to COD and ammonia treatment were not apparent due to the high loads from the separated sewer overflow (SSO). If in urban areas with combined sewer systems it is possible

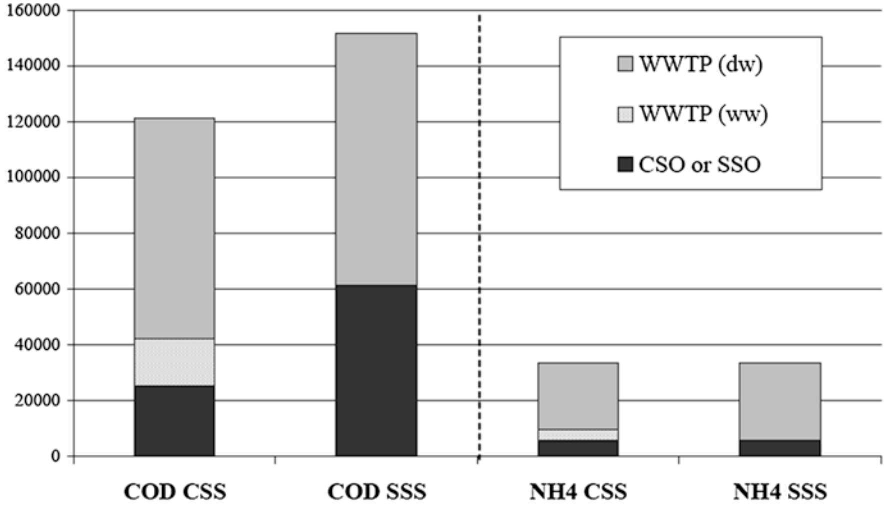

Fig. 1 Annual water pollution (kg/year) for a combined and a separate sewer system in Germany calculated by pollution load simulation (Welker 2008)
WWTP (dw) effluent WWTP dry weather, *WWTP (ww)* WWTP wet weather, *CSO* combined sewer overflow, *SSO* storm sewer outlets, *CSS* combined sewer system**,** *SSS* separated sewer system

to reduce the water pollution from the combined sewer overflows using stormwater tanks, there is no need in China to transition to separate systems.

Based on experience in Germany, there are additional opportunities for Chinese cities to reduce water pollution. These include:

- Modification of conventional combined and separate sewer systems
- Mechanical treatment of stormwater for combined and separate sewer systems
- Advanced treatment of stormwater for combined sewer systems
- Flow control in sewerages

A modification of the combined sewer system means in this case that only highly polluted stormwater is discharged together with wastewater, while not or slightly polluted stormwater is decentrally discharged. (While not or fied separate sewer system, highly polluted stormwater must be treated before it is discharged.) In the modified separated sewer system, the high polluted stormwater must be treated before it is discharged.

The stormwater tanks built in conjunction with the sponge city measures in Chinese cities perform the task of storing a part of wastewater flow at rainfall events in combined sewer systems. After rainfall, the stored wastewater is fed to a wastewater treatment plant. In many cases, it is a good solution to use the tanks additionally for a mechanical treatment of wastewater and thus to contribute to the reduction of water pollution. For an advanced treatment of stormwater, retention soil filters come into question. These have proven their value for the quality of stormwater overflow in combined sewer systems and for the treatment of polluted road runoff in separate systems. Due to large space requirements, the use of retention soil filters is only feasible in the outer reaches of the cities.

Developments and practical experiences have been undertaken in Europe with improved control of the flow and discharge processes in sewerages. This will be also a task for Chinese cities. Particularly effective is an integral control including the wastewater treatment plant and the receiving water. In the future, pollutant-dependent control will gain importance with corresponding measuring equipment.

4 Reduction of Extraneous Water

In the case of the central drainage of urban areas, extraneous water is a concern. This water, which flows into the sewers of a sewage treatment plant, is caused:

- By groundwater penetrating into sewers through leaks
- By drains connected to sewers
- Through incorrectly connected rainwater channels
- By surface water, which is discharged continuously or only in rainy weather in sewers

In Germany, extraneous water comprised 23% of the WWTP inflow to the wastewater treatment plant, a medium-sized fraction (UBA 2015). There is also a consid-

Table 3 Comparison of water quality in different Chinese cities

	Beijing	Qingdao (Jiaohan)	Yingchuan	Guangzhou	Shanghai	Kunming
BOD mg/L	350	300	160	150	44	–
COD mg/L	700	600	350	–	142	210
NH_3-Nmg/L	30	–	40	–	–	–
TN mg/L	–	–	–	35	–	36

erable amount of extraneous water in Chinese sewerages and wastewater treatment plants. So far, however, no corresponding statistical data have been made available. Unpolluted extraneous water causes a dilution of municipal wastewater. For this reason, the concentrations of pollutants of a wastewater plant inflow, especially in the case of dry weather, provide information on the size of the sewage water pollution (Cornel and Wagner 2005).

Table 3 reflects a particularly high inflow of extraneous water in Shanghai and Kunming, but also in Guangzhou and Yingchuan. This is probably associated with high groundwater levels and severe leakages in sewers in these cities.

Extraneous water in sewerages and wastewater treatment plants has various effects on:

- The efficiency of a wastewater system, including stormwater treatment facilities
- The treatment performance of wastewater treatment plants
- The pollution of surface waters
- The costs of wastewater disposal

In the sewer system, extraneous water causes higher flows in the sewers and thus necessitates larger pipe cross sections. In the case of stormwater tanks, the required volume increases as a result of extraneous water. Increased energy costs are incurred for the associated pump stations.

In WWTPs, extraneous water necessitates larger volumes of mechanical treatment facilities. The efficiency of biological treatment is reduced as a result of the wastewater dilution caused by extraneous water and the reduced wastewater temperature. In the highly polluted German sewage treatment plant Starnberg, extensive investigations were carried out on the problems of extraneous water. Figure 2 shows the inflow and outflow concentrations as well as the corresponding loads for different extraneous water fractions of the sewage plant inflows for the parameter total nitrogen (TN).

The TN concentrations in Fig. 2 show the dilution effect caused by the presence of extraneous water. It is remarkable from the point of view of water protection that as the amount of extraneous water increases, the performance decreases and therefore increased loads enter the surface waters. The increase in the proportion of water from 46% to 87% resulted in a doubling of TN discharge as shown in Fig. 2. Similar ratios were obtained for the parameters COD and TP.

It can be seen in Fig. 3 that, with increasing dilution of the sewage plant inlet by extraneous water, the effluent concentration of phosphorus becomes lower.

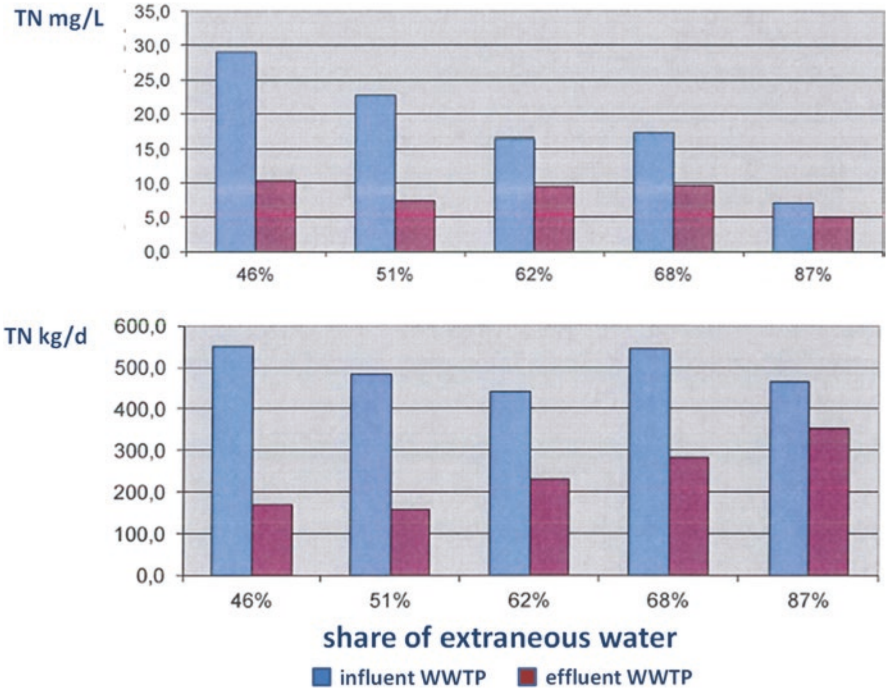

Fig. 2 TN inflow and outflow concentrations and loads of the German WWTP Starnberg for different shares of extraneous water (UBA 2015)

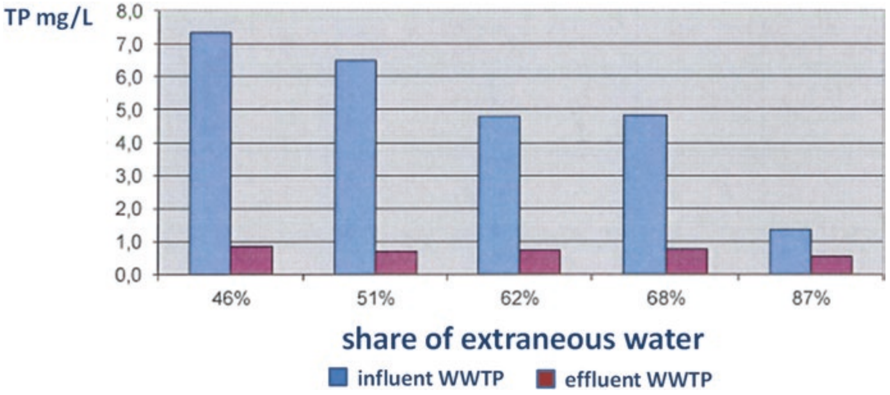

Fig. 3 TP inflow and outflow concentrations of the German WWTP Starnberg for different shares of extraneous water (UBA 2015)

Table 4 TP removal rate of WWTP Starnberg for different shares of extraneous water (Dohmann 2017)

Share of extraneous water in Starnberg WWTP (%)	Phosphorus elimination rate (%)
46	87.9
52	88.4
62	83.4
68	83.0
87	61.5

Requirements which only relate to compliance with effluent concentrations of pollutants would thus be easier to meet under conditions with higher amounts of extraneous water.

In the catchment area of nutrient-contaminated lakes, however, the amount of nutrients introduced must be further limited beyond the recommended nutrient concentration limits. It can be seen from Table 4 that a higher proportion of extraneous water at the Starnberg wastewater treatment plant led to a reduction of phosphorus elimination and thus to higher phosphorus levels in the effluent of the plant.

5 Decentralized or Semi-decentralized Wastewater Management

The expansion of Chinese wastewater infrastructure has in the past decades been concentrated on central urban systems. Central municipal wastewater treatment plants have been developed with an emphasis on urban environmental protection, with rural areas being relatively neglected (Xi et al. 2014). In rural areas, there are three primary sources/types of wastewater, namely domestic wastewater, whose quantity increases steadily due to increasing central water supply and the changes in domestic sanitation, agricultural wastewater from animal husbandry with high nutrient and pesticide loads, and industrial wastewater. Industrial wastewater in rural Chinese areas comes from the numerous Township and Village Enterprises (TVEs) and is discharged to a considerable extent without treatment into waters. The TVEs are associated with a wide range of industries (Yu et al. 2015), such that treatment of these industrial wastewaters requires adapted technical concepts.

It is important that wastewater infrastructure in rural areas is as simple and cost-effective as possible. In Europe and China, a large number of decentralized technical and natural systems for the treatment of sewage water are available. The technical installations are designed modularly. In order to prove the long-term operability of the systems, simple operating data are collected and checked by the authorities.

One problem is the professional qualification of the necessary operating personnel at the WWTPs. Only about half of the available rural treatment plants are under regular operation (Ju 2012). The required improvement in wastewater management

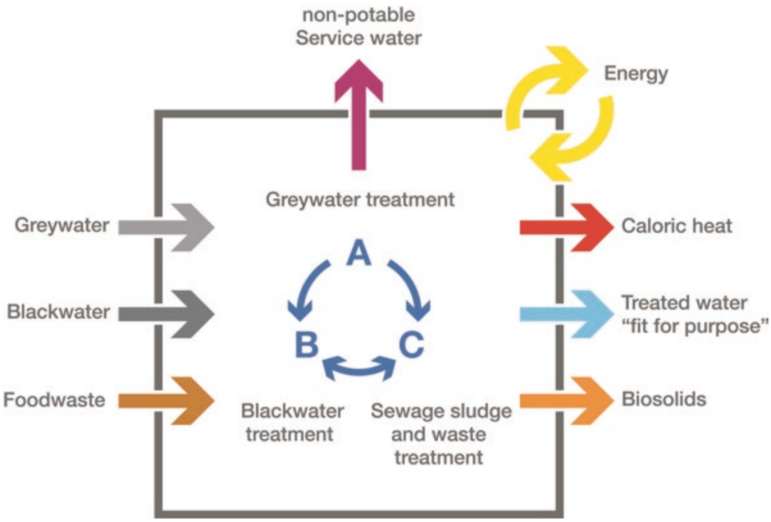

Fig. 4 Mass flow in a semi-central supply and treatment system (Cornel et al. 2017)

therefore means not only a corresponding implementation of the wastewater infrastructure but also the long-term guarantee of a proper operation of the wastewater systems. German experience has shown that professional training and further education for the persons responsible for plant operation is necessary. In China as has been demonstrated in Germany, regular exchange of information between responsible parties is advantageous.

Decentralized sewage systems can also be put to good use in the surrounding areas of cities. Here residential areas are considered for which no sewage system exists. The establishment of resource-oriented disposal systems appears to be viable in such areas. The disadvantages of central sewage systems such as long-term system definition and inflexibility, high costs, and under-use of wastewater constituents can be avoided. Decentralized or semi-centralized resource-oriented wastewater concepts offer under certain conditions an alternative or supplement to centralized wastewater disposal.

A condition for the intended use of resources is a separation of the flows of domestic wastewater. That means feces and urine with toilet flushing water (black water) and other domestic wastewater without feces and urine (gray water).

The resource use of the wastewater is related to:

- The use of purified gray water as service water
- The use of the embedded energy of the black water
- The use of the nutrients of the black water as fertilizer

The semi-centralized treatment of the wastewater can be extended by treating organic waste (kitchen waste) with the black water (Fig. 4).

The advantages of such a resource-oriented disposal concept include (Dai 2016):

- A processing center close to the user terminal saving transport costs and pipeline investment
- An efficient use of water offering 30–50% reduction of fresh water consumption
- Possible self-sufficient operation by co-digestion with sludge and biowaste
- The hygienization and stabilization of organic materials enabling use as fertilizer
- The high integration of facilities, easing construction and management operation

In 2014, the first plant built in Qingdao was commissioned and has demonstrated satisfactory performance.

6 Industrial Wastewater

Water is the solvent for many industrial processes. In China, for 2015, there was an industrial wastewater share of 26.2% and a domestic wastewater share of 73.2% (Xiang 2017). It is, however, to be assumed that the actual share of industrial wastewater is higher, since not all small and medium-sized industrial enterprises are taken into account statistically. If agricultural wastewater is disregarded, industrial wastewater would have a COD share of 25.8% and an NH_4-N share of 13.9% in 2015 compared to domestic wastewater with a share of 74.9% and 86.1%, respectively (Xiang 2017). However, these data do not adequately reflect the environmental impacts of Chinese industrial wastewater due to the varying characteristics and environmental effects of different industrial wastewater sources. While pulp and paper, chemicals, textile, and coal mining industries are considered to be China's biggest polluters, the large outflow of wastewater from power plants is relatively uncontaminated.

The following common characteristics of industrial wastewater are to be mentioned in relation to domestic sewage:

- One-sided composition of the wastewater constituents
- High concentration of individual wastewater constituents
- Strong fluctuations in the concentrations
- Discontinuous wastewater flow and pH fluctuations
- Higher temperatures than in municipal wastewater
- Difficulties in removing wastewater pollution such as coloring or persistent organic substances.

A particular problem is the treatment of industrial wastewater with high organic loads of non- or poorly biodegradable composition. To date, compliance with predetermined maximum concentrations of pollutants in China is often achieved only by diluting industrial wastewater with less contaminated water. As a result, biological

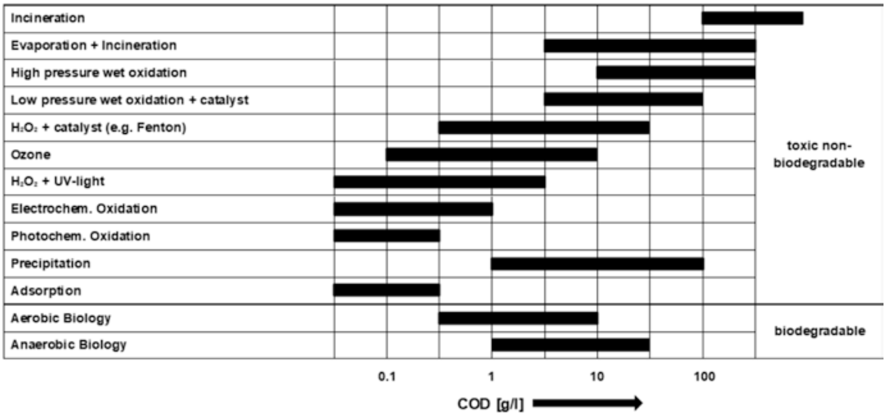

Fig. 5 Process comparison on COD concentration of wastewater (Ulrich 2015)

anaerobic and/or aerobic processes are needed for organic wastewater discharges, and the physical and chemical processes necessary for the elimination of toxic or biologically degradable wastewater constituents are avoided. The background for this purpose is usually economic. Figure 5 shows the relative fields of application of the different wastewater treatment processes for the elimination of COD.

In case of the discharge of industrial wastewater into a municipal wastewater system, it must be ensured that this step does not damage the wastewater system and that the municipal treatment plant can eliminate the pollutant loads of industrial wastewater accordingly in terms of water conservation. This means that different industrial wastewaters must be treated before discharge into a municipal sewage system due to high concentrations of relevant substances. In China, as in Germany, a large portion of industrial wastewater is discharged indirectly, i.e., after treatment together with municipal wastewater in a municipal wastewater treatment plant.

In the case of larger industrial plants with wastewater from different production processes, as in European industrialized countries, a sensible flow separation with appropriately differentiated wastewater treatment should also be carried out. As a result, an improved water recycling and recycling of wastewater constituents is generally possible. The amount of wastewater recycled and reused remains low at only 10% of the wastewater treated (Xu 2016). It is still too often the case that industrial wastewater treatment plants are constructed when far more efficient solutions would be available incorporating the integrated analysis of water, energy and materials balances to identify areas for improvement and investment, in order to achieve best practices and move toward zero discharge (Pan 2016). In recent years, several policies on water recycling have been published in China (Xu 2016). For example, the Water Pollution Prevention and Control Action Plan (State Council 2015) states that by 2020, the usage rate of reclaimed water shall be 20% for water scarce cities and 30% for the Jing-Jin-Ji area. This represents a particular challenge for the planning of new and the addition of existing industrial sewage systems.

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Part V

Urban Water Governance: Overarching and Methodological Aspects

Urban Water Governance in Europe and in China: Key Challenges, Benchmarks and Approaches

Moritz Reese

Abstract Urban water systems will not be developed and managed in a sustainable way unless this is ensured through adequate regulation, organization, and finance, or in short "governance." The following sections of this volume aim to explore the different government arrangements in China and in Germany with a view to identifying options for improvement and governance innovation in and beyond these countries. The present chapter is aimed at providing some groundwork for this comparative assessment including an overview of the major factual challenges and differences of urban water governance in China and Germany, a conceptual frame for comparative assessment, a synthesis of the key benchmarks of "good" and "sustainable" governance, and a brief outlook to the highlights presented in the following contributions.

1 Introduction

In the first section of this volume, a wide array of innovative technical solutions is presented with a particular focus on urban waste water and rainwater management. The engineer's assessment demonstrates that technical options toward sustainable management of urban water flows have been further developed in almost all regards and especially as regards design and maintenance of sewer systems and waste water treatment in both centralized and decentralized systems as well as "sponge city" technologies including multifunctional urban infrastructures. Hence, from a technical point of view, the methods and building blocks for sustainable urban water systems are readily available to a wide extent. However, whether these are actually applied in practice in an effective, cost-efficient, and sustainable manner is barely a technical question but primarily a societal issue and, above all, dependent on governments, policies, and regulations, i.e., *Governance*. As is known, States and municipalities have regularly taken a leading responsibility for the provision of

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urban water infrastructures due to the monopolistic and essential nature of these services. Water services, uses and polluting activities are, today, subject to extensive regulation and administrative management. In order to ensure adequate and fair management of the resource, China and Germany – like most industrialized countries in the world – have deployed a large arsenal of regulatory, organizational, and fiscal policies and instruments. These governance arrangements have essentially contributed to ensuring adequate water services and management in the past. However, in view of persisting implementation gaps and sustainability deficits, it is clear that the governance of urban water management needs further development, too.

Against this backdrop, it is the endeavor of the following sections of this book to provide insight in the governance arrangements in China and Germany and to also facilitate comparative analysis with a view to identifying promising instruments, approaches, and perspectives for further improvements.

When comparing governance approaches, we must, of course, consider that Chinese agglomerations are dealing with different dimensions and scales of water problems then European and German Cities. Both urban expansion and water problems are, in fact, much bigger in the average Chinese agglomeration. Germany has started several decades earlier to develop modern waste water infrastructures and to clean up its surface and groundwaters, whereas China has only recently commenced to tackle its long legacy of unleashed industrial growth and pollution. Moreover, we need to take into account the fundamental political and cultural differences with a highly pluralistic democratic system and a strong rule of law on the German side and a single party system with a – seemingly – weaker adherence to the rule of law and a stronger role of organization, agents, and campaigns on the other hand. These differences make comparative analysis more difficult and necessitate, in any case, a thorough assessment of the local appropriateness of particular instruments and arrangements.

Nevertheless – and as is further demonstrated in this contribution – the general challenges of urban water management are very much alike in every city on the planet, and the same is true with regard to the policy instruments and institutional arrangements governments can resort to. Within this “global tool box” of urban water governance there are also key instruments that are evidently indispensable and therefore deployed in nearly every modern country in the world – for example, waste water pollution and drinking water quality standards. Other instruments are of rather optional and supplementary nature, and, eventually, the challenge is to compose a coherent policy mix that works well both in itself and in the particular administrative and societal settings. In this instrumental perspective, comparative assessments of regulatory, organizational, and fiscal approaches appear very useful and well possible – despite the different backgrounds – when focusing on the more general advantages and requirements of the respective instruments and instrument mixes, while the details of local applicability and appropriateness are rather left to further steps of local analysis. In this instrumental perspective, it is particularly interesting to explore innovative instruments, designs, and policy mixes and to assess the “global” potential of regional innovations in that regard.

The following is aimed at providing some groundwork for such comparative assessment and this includes:

1. An overview of the major factual challenges and differences of urban water governance in China and Germany
2. A conceptual frame for the comparative assessment
3. A synthesis of the key benchmarks of “good” and “sustainable” governance against which instruments and arrangements are to be assessed
4. A brief outlook on the main instruments and governance highlights presented in the following contributions

2 The Factual Challenges and Differences of Urban Water Governance in China and Germany – In a Nutshell

From a bird’s-eye perspective, the main tasks of urban water management are the same across the globe, namely:

- Sufficient water supply for households and production purposes
- Sanitation and sound waste water management
- Adequate rainwater management and flood protection
- Good water quality and healthy aquatic ecosystems
- Integrated management with regard to all above objectives and relevant factors

With regard to the regional level, however, it is apparent that the complexity of all these key tasks of urban water management depends very much on the size, growth rate, and environmental background of the cities in question, and in this regard, most Chinese agglomerations are certainly facing vastly higher pressures than the average German or European city. Moreover, western European and German regions have started several decades earlier to develop modern waste water infrastructures and to clean up their surface and groundwaters, while China is yet facing its long legacy of unleashed industrial growth and pollution. However, the particular intensity of the Chinese water situation does not necessarily mean that entirely different approaches need to be pursued as to technology and governance. Nevertheless, it is important to have in our view the main factual requirements, challenges, and differences related to the abovementioned water tasks before asking further for what this requires in terms of governance.

2.1 Water Safety and Sufficient Water Supply

Providing sufficient freshwater to households and industries is a prior task of urban water management and basically requiring two things: enough freshwater sources and adequate water supply infrastructures. In both regard the situation in China is far more challenging than in Germany and other European regions. In northern and western parts of China, water scarcity is posing major problems, and in order to sustainably balance supply and demand, particular efforts in water saving and reuse are needed in these regions. The eastern and southern regions are relatively water-rich, and in quantitative regards, these areas can well be compared to northern and central European regions. As to quality, however, the Chinese situation is different as vast parts of the available surface and groundwaters are heavily polluted from industrial emissions, urban waste water, and agricultural fertilizers and pesticides. China's Ministry of Water Resources stated in 2017 that more than 80% of the mainland's shallow groundwater is not fit for human consumption because of severe pollution and contamination with heavy metals and toxic organic compounds.[1] Therefore, pollution abatement is apparently the biggest challenge in ensuring sufficient water supply in Chinese agglomerations (see the facts presented by *Dai* and *Qin*[2] in this Volume). In Germany, pollution seemed to be no serious problem in the past, owing to previous achievements regarding waste water management and a long tradition of stringent drinking water protection zones. However, in more recent times, many of the groundwater bodies used for drinking water abstraction are increasingly polluted by nitrate from intensive agricultural fertilization.

With regard to water supply infrastructure, the major objective is to bring sufficient quantities of clean water to the consumers and to accomplish this service at affordable prices. Purity standards for safe drinking water were developed by relevant WHO committees, and these standards are widely implemented in Chinese, European, and German drinking water regulations. As a rule, this requires purification as well as adequately developed and maintained distribution grids from the water works up to the tap. In Chinese agglomerations and particularly in the growing cities of the western and southern parts of the country, implementation of supply standards has made strong progress, and a relatively high penetration rate of around 95% was reached by 2015 (Liu 2015). The major problem, here, is apparently the continuously high pollution of the water resources that is making necessary tremendous purification efforts with high expenses at the cost of the public and the households, respectively. When looking at today's China in total, however, the major problems of water supply do not concern the growing agglomerations where rapid growth and replacement of old structures has also brought with it modern water supply infrastructures. The countryside and rural settlements, instead, are often left far behind in these regard (Liu 2015). A further general challenge seems to consist in the lack of meaningful data and transparency about the actual drinking water quality and safety situation (Liu 2015, p. 4 f.).

In Germany, secure water supply is widely established with 100% penetration rates in both cities and urban areas. Meaningful and trustworthy monitoring data about drinking water quality is regularly available and documenting an area-wide high quality of drinking water. As opposed to most Chinese cities, particular

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[1] See CGTN report of 07 October 2017: https://news.cgtn.com/news/3d49544e3459444e/share_p.html.

[2] Regional Water Policy in China.

infrastructural challenges arise in some German regions from population shrinkage and decreasing water consumption. However, these developments are much more relevant to waste water management than drinking water supply (see below).

2.2 Sanitation and Sound Waste Water Management

Adequate management of waste water from households and industries is necessary with a view to urban sanitation and in order to maintain sufficient quality of the receiving waters for both further usage and healthy aquatic ecology. Waste water management, too, implies huge investments in sewer systems and treatment facilities, and waste water infrastructures are under multiple "sustainability pressures" both in China and Germany (as to Germany see e.g. Reese and Gawel 2018).

However, the development state of waste water infrastructure in Chinese cities is considerably behind as compared to German cities. In Germany, almost 100% of the households are connected to sewer systems and advanced treatment facilities with secondary or even tertiary treatment. In China the development of waste water infrastructures has advanced rapidly in the past years – as is reported in detail by *Dohmann* in this volume. By 2015 an average penetration rate of 75% was reached in the bigger cities (Hu et al. 2014). While China is trying hard to raise this rate, it is yet facing a rapid increase of waste water quantities as a corollary of the ongoing growth of its agglomerations. Between 2000 and 2012, alone, the total waste water discharge has increased by 65% to 68.5 billion tons which is comparable to the annual flow of the Yellow River (Hu et al. 2014). Hence, China still needs to invest huge amounts in the extension and upgrading of its waste water infrastructures. This includes sludge management which is reported to be still poor in most areas (Yang et al. 2015). At the same time, similarly high efforts are needed in order to repair and upgrade existing pipes and installations since maintenance requirements were often neglected and due to many faulty connections in areas with combined and separate sewer systems (see *Dohmann* in this volume). Moreover, further extensive investments are needed with regard to industrial waste water treatment as industrial emissions are still a predominant source of pollution from urban areas (see *Dai* and *Qin*[3] below). With regard to industrial sources, in particular, poor implementation and enforcement of pollution emission standards is widely seen as a major deficiency in China's water management system. As *Lv* and *You* state in their contribution, "although the law provides for several regulatory tools, the discharge of water pollutants is still high in concentration and large in quantity." This is, of course, primarily a governance problem and also owing to the fact that the stakeholders are often not willing or able to implement the required mitigation measures.

In Germany, as mentioned above, the development of urban water infrastructures is long completed in terms of penetration rate and decent treatment technologies. However, similar to the situation in China, large parts of the existing infrastructure

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[3] Regional Water Policy in China.

suffer from serious underinvestment (Dohmann 2014; Grabow and Schneider 2014). It is estimated that the annual amount needed to be spent on the country's sewage infrastructure alone is €8.5 billion (Dohmann 2014, p. 17). Yet, in 2013, the actual investment totalled a mere €4.8 billion (Leptin et al. 2014). Many systems are outdated and in need of replacement. Hence, reform of financing and investment policies is necessary if the infrastructure is to be appropriately maintained and also upgraded in accordance with new challenges and technical developments. Recent demographic changes are entailing a twofold challenge for water infrastructure development. Significant shrinkage is occurring especially in rural areas but also in many urban neighborhoods (Statistisches Bundesamt 2015). Sewage infrastructure in these shrinking areas is increasingly underutilized, resulting in significant inefficiencies and increased costs for operators and users (private households, businesses). As a consequence, possibilities of transformation towards more decentralized solutions are taken into consideration. Secondly, increasing discharge of pharmaceuticals into domestic sewage is receiving growing attention (Tränckner and Koegst 2011; Hillenbrand et al. 2010) together with other – previously neglected – micro-pollutants, and new strategies and technologies are discussed in this regard, too. A key point of this debate is whether to upgrade larger treatment plants with a so-called fourth treatment stage consisting of either active carbon adsorption or ozonation (Pinnekamp 2014, p. 5). Such a technological upgrade is also advocated in view of augmented standards and demands regarding chemical and ecological water quality. In Europe, waste water infrastructures must comply with increasingly stringent water quality standards, largely as a result of the European Union's water policy (see below 2.4). Adversaries, however, point to the high cost and energy demand of these advanced treatment technologies – and the latter points to another seminal challenge, i.e., the need to improve energy efficiency of waste water treatment not least in the face of climate change.

2.3 Rainwater and Urban Flood Risk Management

Management of rainwater and protection against urban flash floods has become increasingly challenging as a consequence of unleashed forms of urban growth. As shown in detail in this volume by *Zhan* and *We*, *Illgen* and *Ackermann*, and *Zhou* et al., urban development in both China and Germany has not sufficiently observed the requirements of water-sensitive development and adequate rainwater absorption, drainage, storage, discharge, percolation, and evaporation capacities. With regard to Chinese cities, the reasons for these particular deficiencies in urban development – also in terms of governance – are comprehensively analyzed by *Zhou* et al. below. As *Zhou* et al. explain, Chinese municipalities have long facilitated excessive sealing of urban spaces since the release of land to developers has constituted the major source of public revenue. At the same time, China's transition framework of building regulations and urban planning laws was not sufficiently prepared to enforce water-sensitive development, and adequate administrative capacities were lacking, accordingly.

The risks of urban flooding resulting from such unsustainable urban development are likely to aggravate as heavy rainfall events are expected to become more frequent and more severe in the wake of climate change. All the more, it is considered necessary to significantly improve rainwater management capacities both in Chinese and German cities. In China this has been prominently expressed through the so-called "sponge city" concept (see below the detailed analysis of *Zhou* et al., as well as *Dai* and *Qin* on the front-running example of Wuhan). The broad variety of technical measures that can be taken to make cities more "waterproof" and eventually become "sponge cities" are depicted by *Illgen* and *Ackermann* in the technical sections of this volume. In their contribution, it is also shown that effective urban flood risk prevention and sponge city development require thorough risk assessments and strong integration of water infrastructure and urban development with a particular view to multifunctional use of transport and green infrastructure as essential elements of the urban drainage systems.

As further described in this volume by *Zhang* and *Che*, *Dai* and *Qin*[4], and *Zhou* et al., extensive campaigns and support initiatives toward sponge city development were launched in China on both the national and the local levels with some cities taking the lead as model cities. Exceptional opportunities for the construction of water-resilient sponge cities exist where urban growth and expansion is yet ongoing or lying ahead, and, today, large urban development projects are often used as model projects for sponge city technologies. In Germany, progress is less dynamic in this regard and mostly limited to small-scale developments and model projects (see *Illgen* and *Ackermann* in this volume).

2.4 Good Water Quality and Healthy Aquatic Ecology

Good quality of surface and groundwater bodies and healthy aquatic ecology are essential objectives of wider water management. With regard to urban management, these aims mainly imply that pollution emissions from households, industries, and rainwater discharge be reduced to an adequate level and that urban water bodies are shaped and maintained in a nature-oriented way. In order to determine concrete objectives as to chemical and ecological water quality, advanced understanding of the ecological conditions, functioning and potentials of the respective water bodies is required. Moreover, the diverse interrelations between ecology and human impacts need to be understood in order to enable efficient, integrated management (see below 2.5).

As indicated above, water quality in and around Chinese agglomerations is still rather poor compared to the average situation in Germany and western Europe. Despite the significant improvements made in recent times, water quality in China's

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[4] Regional Water Policy in China.

agglomerations is still strongly suffering from industrial, municipal, and agricultural pollution. According to statistics from the National Development and Reform Commission (NDRC), around 32.5% of China's seven major river systems and 29.2% of China's major basins did not meet the prevailing water quality standards (grade III and below) in 2015.[5] In Germany, great progress was made in the second half of the past century in reducing industrial and municipal water pollution with regard to most fatal contaminants. However, in more recent times, a large number of further substances regularly found in our waters were identified as persistent, bioaccumulative, and toxic, and the water quality benchmarks were amended accordingly in the European Union's water legislation. By its famous Water Framework Directive, the European Union has also adopted in the year 2000 quite ambitious *ecologic* quality targets that imply ecologic restoration of rivers and lakes to a status as close as possible to pristine conditions. These ambitious quality objectives are challenging urban water management mostly in terms of waste water treatment technology (see above 2.2) but, as the case may be, also with regard to structural encroachments on ecologic water quality, e.g., by dams, locks, harbors, and water power works (see the contribution by *Köck* below).

In China's ongoing transition phase, the ambitions regarding chemical and ecological status are – necessarily – lower as is explained in more detail in the contributions by *Ly* and *You* on China's national governance framework and by *Dai* and *Qin* on regional water policy in China.

2.5 Integrated Water Resource Management

A fifth key task of urban water management results from the complexity of the water systems in both the urban and the wider catchment dimensions. The manifold interrelations between the abovementioned tasks and factors make it necessary to adapt a systemic perspective and develop well-coordinated, integrated approaches. In the more narrow urban perspective, this implies that the still predominant "build-and-supply" paradigm of urban infrastructure development be overcome and water infrastructure be integrated into (water-sensitive) urban development. Urban development needs to take into account the "blue potential" of gray and green infrastructure and develop efficient and resilient multifunctional structures (for details see *Illgens* and *Ackermann* as well as *Zhou* et al. in this volume). As to water supply, integrated management of the entire water cycle is needed with regard to excessive purification costs that could be saved with much less effort to be invested in abating pollution at source. Last but not the least, the urban water systems need to be integrated in the wider catchment perspective, and they need to adequately contribute to a fair sharing and protection of water resources within the basin community. This regularly requires close cooperation across administrative and – as the case may be – also state borders.

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[5] China Environmental Status Bulletin 2016 (32.3).

The immanent need for integrated water resource management (IWRM) approaches has long been acknowledged in the international community of water managers and experts (UNEP 2014) and essentially also in the water policies of China, Europe, and Germany (see below 4.3). However, while the concept is convincing as such, its implementation entails huge challenges in terms of governance as it requires effective coordination of numerous fields of competence and stakeholders and coherent regulation of multiple conflicts.

3 Urban Water Governance in Comparative Assessment: Conceptual Frame

3.1 The Meaning and Importance of Governance

With regard to urban water management, *governmental action* is apparently needed in multiple regards: Public water infrastructures, as we now, cannot adequately be provided by individuals alone and neither can it be entirely entrusted to the markets due to the essential and monopolistic nature of this infrastructure service. Therefore, water infrastructures are regularly directly provided or strongly regulated by State authorities or municipalities (Cosier and Shen 2009, 249). Governments, policies, and regulations are needed to ensure area-wide development, availability, operation, maintenance, and use of sustainable water infrastructures. For this purpose, governments can act as service providers themselves, or they can "delegate" these tasks to private actors and markets and limit themselves to regulation and enforcement of performance standards. Regulations and administrations are also needed to define and enforce common sustainability objectives including sanitation, treatment and pollution standards, water quality objectives, and flood-safety standards in order to properly protect public good and prevent external effects. Moreover, adequate finance of sustainable water infrastructures and uses can be significantly furthered by fiscal support, enforcement of the polluter/user-pays principle, and additional economic incentives like levies, charges, and trading schemes.

In a more schematic perspective, public governance of the urban water cycle is mainly driven by the following "gears" of governance:

1. *Regulation* includes all binding norms and legal requirements applying to relevant water uses and polluting activities, water quality, infrastructures, services, and other factors of sustainable urban water management. Binding regulations seem to be indispensable when it comes to solving environmental conflicts, distributing "scarce" resources and ensuring certain minimum levels of public infrastructure. As indicated above, extensive regulation, e.g., on water quality, pollutant emissions, waste water treatment, and infrastructure exists, today, in most countries on the globe, notwithstanding the fact that level of ambition may, of course, diverge considerably. An immanent part of these regulatory approaches is *enforcement*. The enforcement side of the regulation coin is playing a

particularly important role in countries with weak rule of law and administrative capacities. Regulation is, of course, also used within the further "gears" of water governance.

2. *Organization* includes, in the first place, distribution and coordination of administrative competences both horizontally between branches and vertically between levels of government. It is apparent that clear allocation of tasks and decision-making power as well as effective coordination schemes are of particular importance for the sound management of a resource that touches so many different fields of urban development and hence falls within the claims of multiple policies and competences. Organization also includes allocation of sufficiently educated personnel and equipment needed to fulfill the various public services and enforcement responsibilities. Last not least, in matters of public infrastructure and service provision, the organization issues also extend to the crucial question of whether and to what extent these services should be provided by public monopolies or by private enterprises and under competitive conditions, respectively.
3. *Economics and finance* include adequate funding of public water infrastructure and services and, in particular, implementation of the user and polluter pays principle with regard to both public water services and the environmental cost of water uses and pollution. It is a simple economic rule that (water) resources will not be efficiently used and managed as long as users do not have to pay the full costs of their use. On the other hand, it might also be an aim of public service providers to provide a certain level of water supply, sanitation, and flood protection to all residents at equally affordable prices thus requiring a system of (cross-) subsidization that contradicts the user pays principle. Not only with regard to this particular conflict of sustainable water finance, is it particularly interesting to compare national approaches to the economic issues of urban water management. As is shown in the further contributions to this volume and particularly by *Zhou* and *Bi* as well as *Gawel* and *Bedtke*, a large variety of "economic instruments" have already been implemented or are experimented with in order to generate adequate funds and incentivize sustainable water management.
4. *Information, participation, and awareness-raising* form a further crucial hub of public governance not least in the water sector. Knowledge and awareness among officials, operators, and citizens is often a key precondition for sustainable development of infrastructures and responsible use of (water) resources. Targeted information and awareness raising requires, first of all, an effective monitoring system that continuously provides reliable information about the quality of the urban water resources and services including the drainage systems and flood risks. In order to raise awareness, and achieve broad cooperation amongst stakeholders, it is equally important to apply effective information and participation schemes.

How to best implement these key factors of urban water governance depends, of course, strongly on the institutional, political, economic, and cultural context of the region in question. Profound knowledge of these contextual conditions is an indispensable basis for the development of (more) effective policies, and the local context is, therefore, regularly included in the concept of "governance" for the purpose of both scientific analysis and official assessments. The latest World Bank Development Report "Governance and the Law" of 2017 can be cited as just one prominent example in this regard (World Bank 2017, p. 3):

> The process through which state and non-state actors interact to design and implement policies within a given set of formal and informal rules that shape and are shaped by power. This Report defines power as the ability of groups and individuals to make others act in the interest of those groups and individuals and to bring about specific outcomes. Depending on the context, actors may establish a government as a set of formal state institutions (a term used in the literature to denote organizations and rules) that enforce and implement policies. Also depending on the context, state actors will play a more or less important role with respect to non-state actors such as civil society organizations or business lobbies. In addition, governance takes place at different levels, from international bodies, to national state institutions, to local government agencies, to community or business associations. These dimensions often overlap, creating a complex network of actors and interests.

The World Bank definition delineates a broad *analytical* concept of "governance" and consequently extends to all those informal settings and practices that influence decisionmaking and effectiveness of policies on the ground. This is fully supported also in the context of the research presented in this volume. However, for the purpose of meaningful comparative exchange, this research is primarily focusing on institutional aspects and on the use, design, and combination of particular governance *instruments*, whereas less attention is paid to the societal substructures – as will be further explained below.

3.2 The "Instrumental Focus" of Comparative Governance Analysis

As to urban water governance, the aim of this volume is to assess governance approaches and instruments used in China, Europe, and Germany in order to enable comparative evaluation and identify strength, weaknesses, and opportunities for improvement on both sides. The scope of analysis is determined, in the first place, by the major tasks of urban water management presented above. With regard to each of these major tasks of sustainable urban water management, we can identify a number of "global" governance challenges that equally occur in every city and country on the planet regardless of the different geographical and societal settings, and the same holds true with regard to the instruments and arrangements by which governments respond the these challenges and which are particularly suitable and interesting as subject of comparative analysis. As to the governance responses, too, we are looking at a large "global arsenal" of key instruments and design options that can be used similarly by all responsible governments, be it in China, Germany, or elsewhere. Eventually, these governance solutions need to be tailored to the local situation; national requirements of institutional fit, enforcement, acceptance, and political feasibility may necessitate considerable differences as to the design and mix of instruments. Despite these differentiation needs, there is yet a lot of room for comparative analysis and learning about the "toolbox" of governance instruments and their functioning especially in the following regards:

1. *Global toolbox of urban water governance*. International comparison gives us a comprehensive view on the full range of regulatory, organizational, and fiscal instruments and governance innovations that are used, developed and discussed as means of ensuring sustainable urban water management of instruments. In this sense, it is a primary purpose of comparative assessment to fully apprehend the "global water governance toolbox" and to gather available knowledge and experience on the diversity of governance options and innovations.
2. *Key instruments and optional measures.* Within this full assessment of the water governance toolbox, it appears important to identify those instruments and structural features that form the indispensable core of a sustainable urban water governance regime regardless of the local situation. For example, it appears that a regime of emission thresholds for water pollution from industrial and municipal sources is an indispensable core instrument of (urban) water management that is part of all modern water governance regimes.
3. *Global and local performance of instruments and policy mixes*. The most challenging and interesting part of comparative analysis is about the performance of diverse governance instruments and arrangements in both a general sense and with regard to specific local settings. Performance evaluation includes general effects of a certain instrument/policy design as such and also interaction/alignment of – typical – mixes of instruments and organizational settings.

The above perspectives of comparative analysis do, of course, emphasize an *institutional* and *instrumental* viewpoint and may thus bear a tendency to marginalize other societal, political, and organizational issues that do belong to a broader concept of "governance" but are not easily conceptualized in terms of instrument choice or design. The distribution and coordination of competences could be one of these issues. However, even with regard to these organizational issues, the diverse national approaches can be framed, to some degree, as (lack of adequate) instruments. For example, one can think of the Chinese situation as one of multiple parallel competences where nowadays we find a number of distinct approaches to streamlining and better coordination of decisionmaking - as described by *Lv* and *You* and by *Dai* and *Qin* - which can be typecasted as "instruments" just like organizational solutions and coordination mechanisms in other jurisdictions.

What the instrumental perspective implies, indeed, is a certain degree of "typecasting" or abstraction, respectively, which is needed to enable comparison across jurisdictions. Hence, we can view the "instrumental perspective" as a methodological means of comparative analysis. This methodology, and the abstraction it implies, does, of course, embrace a loss of precision, and it – deliberately – blinds out to a certain degree the questions of "local fit." Of course, it is important to be clear about this limitation of our comparative perspective and to be careful not to cut away important issues of institutional fit and effectiveness that are may well occur in other jurisdictions, too, and should thus be viewed as "global" features of the respective instruments.

4 Criteria of "Good" and "Sustainable" Urban Water Governance as Measures for Comparative Analysis

When assessing different governance approaches and instruments, it is also important to clarify the criteria against which the instruments are evaluated. In this regard we can draw on a large body of official proclamations and guidelines on good and sustainable water governance like, most prominently, the UN Sustainability Goals 16 and 6, Chapter 18 of the Agenda 21, the OECD guidelines on good governance (OECD 2012) and on good water governance (OECD 2015), the World Bank guidelines on good governance and sustainable water management (World Bank 2017), as well as a number of relevant European guidelines and initiatives (European Commission 2017; Council of Europe 2017). Moreover, there is a large strand of literature and research available on the requirements, benchmarks, and concepts of good governance in general and in the urban and water context (e.g., Hellström et al. 2000; Makropoulos et al. 2008; Novotny 2008). In this introductory contribution there is, however, no room for a detailed analysis of all these valuable contributions – which has recently been provided elsewhere (see Reese and Bedtke 2015; Reese and Gawel 2018). What is intended in the following, instead, is to concisely highlight just the most important and widely acknowledged benchmarks of good and sustainable governance of particular relevance to urban water management.

The leading and most general benchmarks of any governance approach are certainly its *effectiveness and efficiency* in view of the pursued objectives (Sects. 4.1 and 4.2). These purely pragmatic measures of adequacy are also mentioned as key criteria in the above cited proclamations on "good governance" and "sustainable governance," and they are doubtlessly of global validity. The same holds true with regard to equally pragmatic requirements of adequate water system management, namely, the need for an *integrated approach* and consistent mix of instruments (Sect. 4.3) and for an *efficient distribution of competences* among government levels (Sect. 4.4). The concepts of *transparency and participation* can also be viewed as rather pragmatic precepts of efficient management notwithstanding the fact that they are also motivated by democratic values (Sect. 4.5). From the particular viewpoint of sustainability, further benchmarks are to be observed such as – most importantly – *long-term and orientation and openness to change* (Sect. 4.6) as well as *knowledge orientation* (Sect. 4.7).

4.1 Effectiveness

Effectiveness is the leading measure of policy/governance evaluation and design (World Bank 2017; OECD 2012; Council of Europe 2017). With regard to policy instruments, effectiveness can be described as their capability to effectuate the intended results in terms of local decisionmaking, individual behavior, or real-world conditions (state of environment, infrastructures, etc.). In general, the effectiveness of policies and regulations is largely determined by the following factors:

- *Clear targets and obligations*: The targets of the governing collective need to be distinct. Vague objectives imply unresolved conflicts and legal insecurity likely to paralyze local implementation.
- *Clear responsibilities*: Targets and obligations need to be clearly addressed to responsible agents. This is particularly important in complex policy fields with multiple actors involved. In such constellations, distribution of tasks and responsibilities should possibly be prescribed or, at least, ensured through procedural safeguards by the governing collective (e.g., national government versus provinces or municipalities) since the governed – local – collectives are often politically unable to effectively regulate the conflicts of burden-sharing.
- *Adequate competences and capacity*: Responsible agencies must also be provided with adequate competences and resources. This implies, in particular, an equally clear delineation of competences between different administrative levels and branches and sufficient legal competence to regulate the relevant individual behavior. Lacking resources and capacities are, of course, further major obstacles to effective implementation.
- *Achievability and timing*: In general, targets and measures need to be realistically set and achievable in view of the limited public and private resources at hand. With regard to complex structural development targets – like transformation to "sponge city" infrastructures, close-loop technologies, or ecological restoration of rivers and lakes – this implies the need for long-termed targets and implementation programs. In order to effectuate such long-termed targets and ensure adequate progress, interim targets need to be determined as essential part of an effective long-term development program.
- *Fiscal support*: In the latter regard, it may be necessary to flank governance arrangements with fiscal instruments and support schemes. Effective sourcing and fiscal arrangements, as is known, are playing a decisive role as drivers of implementation especially with regard to infrastructure policies and other targets involving high public expenditure.
- *Monitoring and transparency*: Meaningful monitoring and "implementation knowledge" are further basic requirements of effective policy enforcement and development. With regard to regulation, this implies the need to provide adequate monitoring obligations and standards as an integral part of the governance arrangement. Again, this must not be left to the "governed" administrations and actors but effectively regulated by the "governing" (preferably global/national) collective.

- *Sanctions and accountability*: Sanctions are an effective means of preventing non-compliant individual behavior. As far as individuals and private actors are addressed, it is, thus, important to flank their obligations with effective sanctions. In order to ensure compliant behavior of organizations, it is particularly important to determine clear internal responsibilities and ensure personal accountability of relevant officers and managers.
- *Incentives*: Policy implementation can be incentivized by fiscal support schemes when these are stringently linked to the fulfillment of targets and obligations. Moreover, a series of "economic instruments" can be applied in order to incentivize compliance with, e.g., water pollution standards and further going efforts to mitigate water use and pollution (see the contributions by Gawel and Bedtke as well as Zhuo and Bi).
- *Acceptance and stakeholder involvement*: Effective implementation of costly development or reclamation policies is the more likely to happen the more this finds acceptance of the local stakeholders and cost bearers. Broad experiences from large-scale infrastructure projects show that acceptance can be strongly supported through meaningful stakeholder participation (see also below 4.5). Stakeholder involvement is also needed in order to reveal particular implementation barriers and opportunities and adapt the implementation programs accordingly.
- *The rule of law and judicial review*: Laws and regulations are key means of public governance, not least in the water sector. Strong obedience to and enforcement of the rule of law is therefore a crucial precondition for effective (water) governance. How strict the rule of law is observed depends, of course, very much on the national constitutional backdrop and its political and judicial system which is not subject to the sector-specific governance review in this volume. However, in order to evaluate the effectiveness of relevant regulation, it is necessary to also consider the provided possibilities of administrative review and access to justice. The standards provided in Article 9 of the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters can be seen as global benchmarks in this respect. The Convention particularly recognizes the role of NGOs as keepers of the public interest in the implementation of environmental laws and obliges its Parties (China is not party to this convention) to grant NGOs access to courts.

As is demonstrated by further contributions to this volume (*Lv and You, Dai abd Qin, Zhou and Bi, Köck*), implementation deficits are playing an important role in water governance both in China and Germany. *Lv* and *You*, for example, conclude in their contribution that "Problems in urban water management in China are less the result of insufficient legislation and rulemaking than the insufficiency in law enforcement." In China, this mainly concerns pollution control, and in this respect, wide implementation gaps are attributed to diffuse competences, lacking capacities, and limited accountability of the responsible officials (*see Lv and You* and *Dai* *and Qin*[6]). As reported in this volume by *Dai* and *Qin*,[7] China has recently taken decisive steps in this direction, and it is going to be interesting to see how these measures will improve the situation. Europe and Germany are also experiencing severe implementation problems, especially with regard to the ambitious water quality and ecological restoration objectives that were adopted by the EU in the year 2000 as part of the European Water Framework Directive (see the contribution by *Köck*). Despite the fact that these targets were formulated as long-term targets and flanked by the obligation to draw up implementation plans (Programs of Measures, Art. 11 WFD), most European countries and Germany, in particular, are still failing to achieve these standards even 3 years after expiry of the regular 2015 implementation deadline. The planning scheme did not work effectively, so far, due to a lack of local transposition into concrete implementation programs and measures. Again, this is mainly because at the implementation level, no sufficient capacities, responsibilities, and public investments were provided (Reese et al. 2018). Lack of judicial control is a further reason for the wide implementation gaps. In Germany and most other EU Member States, water management plans and programs of measures could not be referred to the courts according to restrictive standing limitations. However, very recently, this was changed in Germany by an amendment to the German "Law on Access to Courts in Environmental Matters"[8] which now gives NGOs the right to take action against water management programs of measures on the grounds that the program does not adequately implement the water quality objectives. In China, similar efforts to extend judicial review also to water management issues seem to take place as a consequence of the 2014 revision of the Environmental Protection Law and some more recent interpretations of the Supreme People's Court as *Lv* and *You* indicate in their contribution to this volume.

4.2 Efficiency

The efficiency requirement relates to the – minimization of – costs and adverse side effects of the instrument (mix). Costs can occur on the government side as enforcement costs and also on the side of private actors as costs of implementation, loss of opportunities, and in the form of inefficient allocation. Side effects may occur by shifting impacts from one environmental compartment to another (water to air, waste, soil) or by shifting burdens from one stakeholder to another.

Efficiency gains are regularly associated with so-called "economic-" or "market-based" instruments that make use of individual economic calculus and market mechanisms in order to allocate implementation efforts where they can best serve their purpose. With regard to water management, service charges, waste water

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[6] Regional Water Policy in China.

[7] Regional Water Policy in China.

[8] Umweltrechtsbehelfsgesetz of December 2006, last Amendement 23. August 2017, BGBl. I 3290.

pollution levies, and water abstraction fees are the most common instruments of that kind (see the contributions by *Gawel* and *Bedtke*, *Zhou* and *Bi*, and *Köck* in this volume). As reported by Zhou and Bi, China has also experimented with interregional trading and compensation schemes as means of efficiently sharing watersaving and pollution mitigation efforts between upstream and downstream regions. In this regard, China is pushing ahead policy innovation, and it will be exciting to see whether these novel instruments succeed and eventually qualify for the "global governance toolbox."

A fundamental economic requirement of efficient water management is signified by the "user and polluter pays principle." Only if full costs are charged for all public water services and if polluters are liable for the full environmental cost of pollution will this motivate efficient water use and adequate mitigation efforts. For this reason, the principles of user/polluter pays and full cost recovery were prominently included as leading principles in the EUs' Water Framework Directive (Art. 9 WFD). However, while clear and convincing in theory, this call for full cost attribution – inclusive of environmental costs – is raising complex question as to monetization of environmental costs and implementation in governance practice. *Gawel* and *Bedtke* demonstrate in their contribution how this is currently pursued in Germany through water service charges and levies, and they reveal considerable room for improvement in the design and mix of instruments. *Gawel* and *Bedtke* also point us to the principal tension between the efficiency requirement of full cost recovery and the solidarity aim of providing basic water services to all citizens at affordable prices. As is shown, this solidarity aspect of public water service provision is motivating considerable cross-subsidization, in practice, and eventually leading to inefficient water pricing. As to the Chinese side, it is demonstrated in the contribution by *Song* that Chinese communities are still lacking adequate cost accounting regimes and practices, and, therefore, the needed cost data is simply not available or accessible.

Another important efficiency issue concerns the involvement of private actors in urban water services and infrastructure development. Involvement of private enterprises is regularly motivated by the expectation that these private actors work more efficiently due to their intrinsic economic interest and because of the fact that they are exposed to market competition. However, the long-standing European experience with liberalization policies in the water sector has proven that it is very difficult to actually use these private market forces for the public purposes at hand. A major problem, among others, is owing to the fact that private investors tend to optimize their short-term revenues and hence neglect the needs for maintenance and long-term reinvestment which are, however, of crucial relevance with respect to water infrastructure development. Despite these problems, Chinese cities are currently heavily resorting to so-called public-private partnership (PPP) models as means of engaging private capital for the purpose of water infrastructure development and particularly also sponge city development projects (Zhang et al. 2015). The European experience advises caution in this regard. It shows that the contracts must pay due regard to the long-term costs of operation and maintenance as otherwise these costs are likely to be externalized by private contractors.

Above all, the efficiency requirement is always calling for a coherent, synergetic mix of policy instruments. A prominent question in this regard is about the relation between coercive standards – e.g. pollutant emission standards – and incentivizing economic instruments like levies or emission trading schemes. In principle, the latter can only contribute to more efficient allocation of resources as far as the polluters are free to follow their economic considerations and not constrained by definite global standards. The contributions by *Zhou* and *Bi* and by *Gawel* and *Bedtke* are providing further insights as to how economic and command-and-control instruments are combined in China and in Germany.

Efficient alignment of action must, of course, also be aspired locally and on the level of implementation. In this regard, there is apparent overlap between the efficiency benchmark and the essential need for integration and effective coordination.

4.3 Integrated Management and Effective Coordination: The Decisive Role of Planning Instruments

The particular need for integrated management has already been marked as a major challenge of urban water management in the introductory part of this contribution. As indicated above, integrated management is particularly needed with regard to *water infrastructure and urban development* but also in the wider *catchment perspective* including the various interrelations between urban and rural water management. In terms of governance, integrated solutions are to be ensured by substantive regulation and by adequat forms of organization and coordination.

4.3.1 Substantive Regulation

Integrated management should be demanded by adequate legal obligations. Urban planners and developers should, for example, be urged to develop integrated water infrastructures and, e.g., conduct water-sensitive development, use the multifunctional potential of green and grey infrastructure, and pay regard to equitable and sustainable catchment management. Integration objectives and possibly also standards should be addressed to all relevant sectors and actors including urban planning and development, energy, transport, and agriculture.

4.3.2 Organization and Coordination

Adequate organization and coordination schemes must ensure that all relevant agents are effectively included in the decisionmaking processes and well-coordinated, coherent decisions are taken. Traditional organizational structures often represent old, segmented patterns of sector thinking and thus work against integrated management; therefore, it is expedient to consider structural integration. However, the possibilities of organizational integration are always limited due to the need to establish effective units with clear tasks and competences. Therefore, it is even more important for the governance framework to ensure intensive communication and cooperation between the relevant agencies through formal procedures and committees.

What is required as major governance approach to both substantive inclusion and coordination are adequate forms of *administrative planning*, i.e., a regulated procedure in which all relevant authorities and stakeholders are involved in order to develop well-coordinated integrated solutions. It is widely acknowledged that the complex integration tasks of urban development cannot be effectively fulfilled without adequate planning including a well-regulated consultation and decisionmaking process. Therefore, urban planning laws were developed in nearly all countries in the world including China and Germany. In China – as reported below by *Lv* and *You* – new efforts are made in the frame of the 2015 "Integrated Reform Plan" to strengthen urban spatial planning and also a new form of "all in one plans." With regard to urban water management, the question is, thus, whether coordination and integration is equally ensured by adequate planning regimes. What is essentially needed in that regard is effective inclusion of water issues in the overall urban development planning. This assumes, above all, the existence of advanced urban planning laws that require municipalities to draw up integrated development plans and take due account of the precepts of sustainable water infrastructure. Beyond that, distinct sector planning instruments are needed in order to develop integrated infrastructure and water resource management concepts, in the first place. It is difficult to meet the multiple optimization requirements without proper planning that develops both the internal and external aspects of the infrastructure system in the light of its relationship to urban development and water resources management and that arrives at a well-founded development strategy by involving relevant bodies and other stakeholders. Corresponding specialist planning regulations relating to urban water infrastructure do exist both in China and in Germany but only in rather rudimentary and apparently not sufficiently detailed and effective forms. In China, urban drainage and sewage plans as well as special plans for the prevention of waterlogging are coercively called for in the 2013 "Regulations on Urban Drainage and Sewage Treatment." These urban drainage plans are to be authorized by the people's government and "strictly implemented." The relevant Article 8 also asks for due coordination with urban spatial plans and further relevant development and water management plans, and Article 14 provides that urban planning authorities are to coordinate their planning with the competent drainage authorities. These regulations do provide a basic legal framework for integrated urban waste water planning. However, no participation scheme is included, so far, and it remains to be seen, how these stipulations are implemented locally. In Germany, sector planning regimes for urban waste water management exist only in the regional laws of the German Regional States (Länder) but mostly in rudimentary forms of merely technical planning (Wickel 2015). An upgraded planning system that is clearly geared to sustainability criteria and legally enforced as a basis for effective coordination with wider urban development is therefore considered an important driver of the sustainable orientation of water infrastructure (Wickel 2015).

As to the wider dimension of catchment management, planning laws and instruments were established in the past decades in China and Europa. In both cases, integrated management planning is prescribed by the relevant laws[9] (see also Sect. 5.4 below). In China, however, the water planning regime seems to be yet too weak to overcome the multiple frictions of the highly fragmented organizational arrangement. In Germany, too, considerable problems remain when it comes to transposing the management objectives and river basin plans into concrete local measures and responsibilities (Reese et al. 2018), and interregional cooperation between the regional States of Germany is also often falling short (Reese und Köck 2018). The somewhat disappointing experience made with our previous efforts on integrated water governance underlines the important role of national standards and clear command-and-control obligations as to emission thresholds and polluting activities. For the sake of effectiveness, it seems advisable to further rely on such global standards as safeguards for a minimum level of sustainable water management and to limit the integration exercise to further optimization and to aspects that can only be decided locally. German water law provides further examples of global water management standards, e.g., on ecological river passage, buffer zones, minimum flows, and flood risk.

4.4 Most Effective Level of Action: Subsidiarity

When regulating objectives, standards, and procedures of water management, it needs to be decided what to regulate on which government level (see also *Grambow* et al.). This question arises similarly in federal and in centralized States since centralized States are usually also structured as multilevel polities with provinces and municipalities and in most countries these regional and local levels of government are also equipped with lawmaking institutions and powers – be it by means of devolution (Alberton and Palermo 2013). In the EU, the above question shall be answered according to the principle of "subsidiarity" as stipulated in Article 5 para 3 of the Treaty of the European Union. The subsidiarity principle basically implies a priority of local decisionmaking and combines it with a postulate of effective, functional distribution of decisionmaking powers. It requires higher levels of regulation to exercise controle over all those affairs that cannot effectively be regulated on lower levels. This is usually the case when lower-level decisions can have negative external effects ("spillovers") on other areas, e.g., by allowing water pollution in transboundary rivers, lakes, or groundwater aquifers. Providing a level playing field for relevant markets and enterprises and avoiding competition of regions for the

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[9] See Art. 14 of the Chinese Water Law and § 82 and 83 of the German Federal Water Act as well as Article 11 and 13 of the EU Water Framework Directive.

lowest environmental standard constitutes another major reason for upper-level regulation. Both, the spillover and the level-playing field argument justify central regulation of *minimum* standards but not also full harmonization in the sense that local regulators must not adopt more stringent standards. In accordance with this, Chinese water quality regulation does provide considerable leeway for more stringent local regulation as is pointed out in the contributions below by *Lv* and *You* and *Dai* and *Qin*. The same holds true with regard to EU water regulation in relation to the EU Member States, whereas in Germany – despite the distinct federal structure of the country – the lower levels are not permitted to go beyond national standards. Last but not least, the need for trans-regional coordination of the management of border-crossing resources and public services can also motivate central regulation and coordination schemes, in particular.

4.5 Transparency and Participation

Transparency and stakeholder participation are, today, viewed as an indispensable precept of sustainable governance for several reasons (see SRU 2008, p. 52ff, and also Jonuschat et al. 2007). Firstly, participation is an important means of generating the knowledge needed for effective and sustainable decisionmaking (Bulkeley and Mol 2003). Moreover, stakeholder involvement is widely recognized as an element of democratic decisionmaking and important basis of acceptance (e.g., Mason 1999). In Europe and Germany, existing and potential expanded forms of participation have been discussed in recent years, mainly in connection with problems in acceptance of major infrastructure projects (see Renn et al. 2014 for an overview). However, this debate has only occasionally touched on water infrastructure, perhaps because water infrastructure projects seldom involve construction or environmental impacts on a scale that would attract attention outside the region (Laskowski 2010, p 889 ff.; Laskowski 2012, p. 606 and her contribution to this volume). Nevertheless, the construction and operation of urban water management facilities can undoubtedly have significant adverse impacts on the neighborhood. This is particularly true of sewage treatment plants, but it also applies to reservoirs, drains, and large-scale sewer construction work. In addition, development of water infrastructure systems can also affect the interests of citizens, companies, and associations, for example, through decisions on:

- Which systems plots of land are to be connected to
- Which decentral facilities may be self-built and self-operated
- Which charges and prices are to be levied for water services
- To which extent expensive connections to decentral properties are to be maintained/expanded and potentially co-financed by the community of charge payers
- Which protection standards are to be ensured for regional water bodies
- How secure against extreme events the supply and disposal systems are to be designed

All these aspects confirm that appropriate participation procedures are rightfully acknowledged as important benchmark of sustainable urban water governance. The role of public participation in German water governance is depicted in detail by *Laskowski* below.

4.6 Long-Term Orientation, Precaution, and Openness to Change

Long-term orientation is mentioned as one of the key "Principles of Good Democratic Governance" of the Council of Europe (2017). With the principle of long-term orientation, the council emphasizes the necessity to:

- Take into account the needs of future generations in current policies.
- Take into account the sustainability of the community.
- Internalize all costs and not to transfer problems and tensions, be they environmental, structural, financial, economic or social, to future generations.
- Provide a broad and long-term perspective on the future of the local community along with a sense of what is needed for such development.

These aspects of long-term orientation are particularly relevant when it comes to transforming traditional infrastructures and implementing objectives that imply substantial structural changes with extensive investment – which is obviously the case with urban water infrastructures. In terms of governance, long-term orientation can be facilitated mainly through planning instruments that include mandatory development of long-term perspectives, scenarios, objectives, and trajectories. The latter are also foundations for a precautionary approach in water system development. Precaution, as well, means that possible developments and risks must be assessed as clearly as possible and that supply and disposal systems and usage structures that are capable of meeting changed requirements in the future, or of being adapted, must be developed at an early stage.

However, it is important to acknowledge that long-term developments can never be safely projected or planned ahead. The failure of former planned economy approaches may be taken as an example for the limitations of plan-based governance. Therefore, adequate long-term orientation and precaution also imply openness to change and innovation and readiness to react to unforeseen developments, threats, and opportunities. In accordance with this, governance arrangements and planning instruments, in particular, must be designed in a flexible and reflexive manner, include review schemes, and provide room for innovative solutions. Adequate planning, in this sense, is predominantly a procedural framework that ensures continuous review against both long-term projection and current development. The planning system established under the EU Water Framework Directive – with its cyclic approach and regular review scheme (see above 4.1) – presents an example of such a modern, reflexive planning approach. However, the WFD planning regime does not include a mandatory, regular long-term assessment, and this omission is to be appraised as a lacuna in terms of sustainable governance (Reese 2017).

As regards, in particular, the planning of urban water infrastructures, there are yet no regulated planning instruments in place – neither in Germany nor in China – that ensure long-term assessment and regular review. The lack of adequate sector planning instruments was already mentioned above as a missing driving gear of integration. Moreover, there is also a lacuna in terms of long-term orientation and precaution and even in terms of flexible and innovative infrastructure governance.

Another important aspect of long-term orientation and readiness for change is what can be termed "economic sustainability." Economic sustainability requires that constant attention be paid to making the needed reinvestment and to building up the reserves that are necessary in order to maintain the functionality of the water infrastructure systems and to finance necessary adaptations and innovations. As a consequence, adequate budgetary regulations and fiscal safeguards are to be acknowledged as a further essential component of sustainable governance arrangements.

4.7 Knowledge Orientation

A basic requirement for broad implementation of all the abovementioned objectives of good and sustainable urban water governance is a profound knowledge base that is as extensive as possible and that is continually expanded through research and innovation. The knowledge base should include, firstly, technical knowledge relating to the options for advanced water extraction, treatment and distribution, and wastewater disposal. Secondly, it should cover knowledge of relevant natural and social conditions. This must include reliable projections and detailed knowledge of the driving forces behind climatic and demographic developments and the causal relationships between these developments. Knowledge in predictive situations also involves knowing what we don't know and dealing with this lack of knowledge. When important infrastructure decisions are to be made, uncertainties must be identified and disclosed; different possible courses of development must, if possible, be illustrated by scenarios; and action strategies must be devised that have the prospect of proving successful in all the possible courses of development. Such knowledge is presenting a public good and can merely be generated by individual private actors. In this regard, as well, adequate assessment and planning regimes need to be provided as fundamental components of a sustainable urban water governance regime.

Besides these drivers of local knowledge generation, publicly funded research and development programs are needed on all government levels in order to expand the public knowledge base, and with regard to governance as such, it is also important that innovative solutions are developed and tested. As demonstrated by *Zhou* and *Bi* in this volume, China has taken a clear lead in this regard especially in developing and testing innovative "economic instruments" of water management.

5 Major Governance Approaches, Innovations, and Lessons to Be Learnt in the Key Fields of Urban Water Governance

On the basis of the above benchmarks, a lot can be taken from the following contributions as to instrumental keys, options, and particular shortcomings in the five major fields of urban water management. In the final section of this contribution, I will merely point out some highlights and particularly important perspectives for governance development, respectively. As to the challenge of *integrated management*, we shall leave it at what is highlighted above.

5.1 Water Supply

With regard to the task of providing sufficient water supply, the following institutions/instruments are to be seen as essential means of adequate public governance:

- *Public responsibility* (of the State and the municipalities) to ensure water supply either by public operations or by contracted and adequately regulated private infrastructure and service providers. The European experience has underlined that full liberalization in the sense of "competition in the market" does not present an adequate path toward efficient, equitable, and sustainable water services (see *Gawel* and *Bedtke* in this volume). Privatization by means of contracting out and in the sense of "competition for the market" is a viable option to include private capital, expertize, and efficiency potential. However, well-designed contracts and stringent regulation are needed in order to ensure that the infrastructures are managed sustainably.
- *A right to adequate drinking water supply* has been adopted as a fundamental human right by the UN Assembly in 2010.[10] Such an individual right corresponds to and enforces the general responsibility of the governments. It is evident, however, that a right to water can merely oblige the States to provide a *minimum* level of supply and that wide discretion must be conceded to the relevant communities in determining this minimum level including the impositions in terms of transport and prices. Nevertheless, an individual right to water supply is needed to ensure that the public responsibility is taken serious and can eventually be claimed before the courts.

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[10] Through Resolution 64/292 of 28 July 2010, the United Nations General Assembly explicitly recognized the human right to water and sanitation and acknowledged that clean drinking water and sanitation are essential to the realization of all human rights; see http://www.un.org/waterforlifedecade/human_right_to_water.shtml.

- *Drinking water quality and technical safety standards* are an indispensable safeguard of adequate drinking water supply. In China,[11] Europe,[12] and Germany,[13] drinking water quality standards are in line with or even more stringent than global WHO recommendations (Liu 2015). However, these standards are not effective unless enforced by stringent monitoring and transparency standards.
- *Effective monitoring and transparency standards*: Lacking transparency about the quality of drinking water seems to still be a problem in Chinese cities. As stated in a report by "China Water Risk" and "Chinadialogue" (Liu 2015), "the real status of water safety in each city, town, county or village remains unclear. Official information disclosure on water quality is poor, and the government keeps official tests and monitoring data secret. Although water supply enterprises have been publishing their water quality test data, there is room for improvement in test frequency, the number of published indicators and public interfaces." The German Drinking Water Ordinance includes stringent monitoring requirements and a system of administrative control by the food safety authorities (§§ 18-20a Drinking Water Ordinance), and, most notably, it obliges the operators of the drinking water facilities to actively inform the consumers about the provided drinking water quality and answer any individual request in that regard (see § 21 of the Federal Drinking Water Ordinance).
- *Stringent protection of water abstraction zones*: Fighting pollution and restoring surface and groundwater quality require a multitude of instruments and measures with regard to the various sources of pollution as indicated above (2.4) and treated separately below (5.4). With regard to drinking water resources, Germany has largely relied on "special drinking water protection zones" (Trinkwasserschutzgebiete) as a legal means of protecting groundwaters uses for drinking water supply (§§ 51, 52 of the Federal Water Act). Within these designated areas, polluting activities are banned or restricted including agricultural use of pesticides and fertilizers. The relevant stipulations of the Water Act also provide for adequate compensation in case that previous uses must stand back. Chinese water law, too, requires designation of functional zones including drinking water zones and protection zones (see the contribution by *Lv* and *You*, according to Standards GB/T 50594-2010).
- *Full cost recovery in water pricing* is an important means of incentivizing and facilitating both sustainable water use and water infrastructure development. The requirements and instruments of sustainable water pricing are analyzed in the following by *Song* and *Gao* for the Chinese part and by *Gawel* and *Bedtke* for the German part. As shown by *Song* and *Gao*, Chinese cities are largely lacking adequate accounting schemes as foundations of cost recovery. *Lv* and *You* explain – in Section 6.1 of their contribution – that in China, water resources are still often used at too low prices and that the national Government has proclaimed to change this within its "Integrated Reform Plan for Promoting Ecological

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[11] Standard GB 5749-2006.

[12] Drinking Water Directive 98/83/EC of November 1998, latest amendment October 2015.

[13] Trinkwasserverordnung of 21 May 2001, BGBl. I, S. 99.

Progress of 2015." How to put on the bill external, environmental costs is discussed by *Gawel* and *Bedtke* and *Zhou* and *Bi*. Waste water pollution charges and water abstraction levies are the most relevant instruments in that regard and used both in China and Germany. As to the design of these charges *Gawel* and *Bedtke* (see Section 3.3 of their contribution) explain why it makes sense to raise such levies for residual pollution "below" pollution thresholds as so called "demerit charges."

- *Urban water supply plans including participation*: Adequate formal planning instruments are the only means to overcome incremental "build-and-supply" practices and enable an efficient area-wide development of sustainable supply schemes. Moreover, official supply plans are needed in order to enable meaningful involvement of stakeholders and the public as *Laskowski* points out in her contribution. However, adequate and administrative planning does not exist so far in Germany. In Germany the planning of water supply infrastructure is mainly annexed to urban development plans and projects which is basically perpetuating the tradition of the build-and-supply approach. Municipalities are not obliged to promulgate specialized, systemic and long-term-oriented infrastructure plans (see Wickel 2015).

5.2 Waste Water Management

- *Public responsibility*: Like water supply, urban waste water cannot be adequately managed by individuals and markets, alone, and public hands must therefore be responsible to provide or at least ensure adequate waste water infrastructures and services. Contracting out these services to private firms is, again, a viable way to engage private capital and knowhow. However, contracted services need to be well regulated in order to ensure area-wide provision at affordable prices and sustainable maintenance and reinvestment.
- *Waste water standards* are indispensable keys to effective urban waste water management, and relatively sophisticated standards exist, today, in Germany and in China.[14] The standards of the German Federal Waste Water Ordinance are principally following the concept of "best available technology" (BAT) and include, on that basis, a wide range of specific standards for diverse industries and pollutant emitting activities (see the contribution by *Köck*, Section 5.2). By intervention of the European legislator – as *Köck* shows – the BAT concept has been supplemented by the concept of "integrated pollution control" meaning that the standards are to be set in way that avoids any disproportionate shift of pollution to other pollution paths (air, waste). The Chinese Standard GB 8978-1996 equally regulates specific emission standards for diverse industries and production methods. Other than the German Waste Water Ordinance, the Chinese

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[14] China: Standard GB 8978-1996; Germany: Federal Waste Water Ordinance of 1997, (last amendment March 2017).

Standard differentiates between old and new facilities and also according to the type and state of the receiving water body. In principle, this approach tends to perpetuate the existing water quality and pollution rate, respectively. In this regard the Chinese waste water regulation seems to be less stringent than the German approach. On the other hand, the Chinese approach includes a competence of the provinces to set out more stringent local standards which was used, for example, in the Taihu Lake regions with regard to some parameters (see *Lv & You* in this volume, Section 4.2).

- *Effective control, transparency, and sanctions*: Waste water standards will only effect the intended reduction of pollution when effectively controlled and enforced through sanctions. Administrative permitting forms a first key instrument of administrative oversight in Germany and in China. However, it is even more important to effectively supervise the running activity. This is where China is apparently experiencing major problems, and enforcement deficits are still high. Both *Lv* and *You* and *Dai* and *Qin* refer to the major enforcement gaps in their contributions, and they explain what is currently undertaken by the national government in order to increase accountability of both the relevant officials and the actual polluters. In addition to that, *Zhou* and *Bi* report about very innovative attempts to incentivize eco-friendly corporate behavior through green labeling and credit approaches which go beyond mere compliance and could also serve as example to follow in Germany. In Germany, as it seems, compliance with the laws has never been as big a problem which is probably owing to general differences in the administrative system and a stronger obedience to the rule of law.
- *The role and design of pollution levies*: Levies on waste water pollutant emissions are used in China and in Germany as incentives to comply with applicable standards and – in Germany, in particular – even below these standards as “demerit charges” and means to internalize environmental cost, incentivize further mitigation, and fund compensatory (public) measures for water quality improvement (see *Gawel & Bedtke*, Section 3.3).
- *China’s governance innovations regarding pollution right trading*: As regards economic instruments, China has experimented with different variations of interregional and upstream-downstream trading and compensation in water use and water pollution rights – as explained by *Zhou* and *Bi* and by *Dai* and *Qin* in this volume. As shown in these contributions, the innovative trading schemes are still in an experimental phase, and much can be learned from these experiments also on a global scale. However, one undisputable lesson is that none of these economic instruments is working without effective control and compliance mechanisms.
- *Urban waste water management plans including participation*: As was pointed out in Sect. 4 above, waste water infrastructures – just as water supply grids – can only be developed sustainably, efficiently, and in line with public interest if prepared and guided by an adequate planning instrument that includes thorough assessments and projections, long-term orientation, regular revision and adaptation to change, as well as stakeholder participation. As reported in Sect. 4.3, rudimentary sector planning regimes do exist both in China and Germany, but in both cases, considerable upgrading appears to be needed with regard to, i.e.,

integrative force of the plans, long-term orientation, monitoring standards, and participation.

5.3 Rainwater Management and Flood Prevention – Sponge City Governance

- *State responsibility for adequate public infrastructure*: As is the case with waste water infrastructure, public hands are needed to ensure that urban development and infrastructures are adapted to the requirements of effective rainwater management and flood prevention. This public responsibility includes adequate regulation of "private" rainwater management. As explained in detail by *Illgen* and *Ackermann* in this volume, effective urban drainage cannot be achieved on public ground alone but requires private land owners to ensure "sponginess" of their plots and buildings, too, and necessitates due coordination of public and private parts of the management system. With regard to both public and private grounds, governments are needed to develop and enforce well-coordinated, sustainable infrastructure concepts. This particular coordinative responsibility includes the development and enforcement of integrated urban drainage – or sponge city – concepts and, prior to that, the generation of sufficient flood-management knowledge as such knowledge presents a public good that cannot and will not be provided by individuals.
- *Flood-risk monitoring and mapping*: In order to ensure that the needed knowledge – about local flood risk, projected future precipitation patterns, and management capacities – is actually generated, regularly updated, and made available to the public, it is advisable to set out clear administrative responsibilities, obligations, and standards regarding flood-risk monitoring and mapping. A detailed report on the requirements and state-of-the-art technologies of pluvial flood-risk assessment is provided by *Illgen* and *Ackermann* in this volume. The EU Flood Management Directive[15] presents a good example of how such risk assessment and mapping can be regulated and enforced by the law. However, the Directive is mainly focused on riverine floods and leaves it up to the Member States whether to also apply these instruments to pluvial flood risks. Unfortunately, this has not happened so far in Germany. Instead, the Federal legislator has exempted urban flashfloods caused by sewer overflows from the entire management scheme of the Directive. Nevertheless, the regulation and implementation of the risk-assessment and mapping schemes – as demonstrated in the contribution by *Meyer* and *Schwarze* – can serve as an example also with regard to pluvial flood management. As far as the author is aware, there are no particular risk assessment and mapping requirements in the Chinese law, either. Hence, this appears to be an important gap in the legal framework.

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[15] Directive 2007/60/EC on the assessment and management of flood risks of 26 November 2007.

- *Flood-prevention and water-sensitive development standards*: The development of adequate public drainage and stormwater systems needs to be geared by adequate standards regarding the absorption and attenuation capacity of the municipal drainage system. How such standards are formulated and developed in China is reported in detail by *Zhou* et al. below – who also point to an increasing implementation gap in this regard. Decentralized rainwater management, too, can strongly be enforced by binding standards as to what on-site capacities are to be provided by developers and urban land owners and by development bans on measures that would exacerbate flood risks in flood-prone areas. Of course, it is not easy to define adequate urban drainage standards on a global level as the appropriateness depends strongly on the combination of on-site measures and the surrounding drainage infrastructure. Illustrative examples of development bans and regulations aimed at water-sensitive urban development can be taken from § 78 of the Federal German Water Act. However, these stipulations, too, apply only with regard to riverine flood-risk areas and are not yet extended to pluvial flood risk.
- *Economic incentives by rainwater discharge levies, in particular*: Private initiatives to increase on-site rainwater management capacities and "sponginess" of plots and compounds can be fostered by means of high waste water/rainwater discharge levies charged for all runoff into the public sewer system (see also the contribution by *Gawel* and *Bedtke*, Section 3.4). This approach is, today, widely used in German municipalities. However, the charges are often too low to incentivize more costly measures like green roofs, drainage trenches, or wetland technologies.
- *Integrated and water infrastructure plan including public participation*: Water-sensitive "sponge cities" cannot be effectively developed without a strong planning basis that provides for due coordination of the diverse technical and architectural elements of sponge city systems, expresses these requirements of sustainable rainwater management toward urban developers and spatial planners, and provides a basis for meaningful stakeholder participation. As already mentioned above, a formal, legal anchorage of such water infrastructure planning exists, today, only in some German regional States (Länder). A rather advanced example can be drawn from the Saxonian Water Act (§ 51). As to China, we can refer to the 2013 Regulations on Urban Drainage and Sewage Treatment presented in 5.2, above.

5.4 Water Quality Management

Water quality is, of course, largely dependent on municipal and industrial waste water management and the respective instruments depicted in 5.2 above. However, an array of other sources of pollution and pressures need to be taken into account and managed in view of common quality objective, and this implies particular governance challenges, as outlined in Sect. 2.4. With regard to these challenges, the following instruments and approaches are to be highlighted as key requirements of "good" urban – and area-wide – water governance.

- *Adequate water quality objectives*: A foremost requirement of well-targeted and effective water quality management is the formulation of adequate quality objectives. Such targets should be as clear and ambitious as possible and extend to chemical and ecological quality. However, the targets also need to be feasible and take into account local differences as to existing pressures, uses, and restoration capacities. As can be taken from the reports by *Lv* and *You*, *Dai* and *Qin*, and *Köck*, very different approaches are followed in that regard in China and in the EU (and Germany, respectively). In China, quality standards for surface water – as set out in Standard GB 3838-2002 – are classed and differentiated according to water function zones (see *Lv & You*, section 4.1), meaning that different quality objectives are applied depending on the main functions the water body is designated for. Hence, the quality objectives are adapted to and make wide concessions to the local pressures. The quality objectives refer to general parameters including temperature dissolved oxygen, COD, BOD, pH values, nutrients, and a number of toxic substances. In the EU far more demanding targets were adopted within and under the auspices of the EU Water Framework Directive which basically obliged the EU Member States to achieve "good ecological quality/potential" and "good chemical quality" by 2015 and 2027 at the latest. The chemical status target is supplemented by pollutant thresholds for some 46 priority substances without any differentiation regarding water type or use. The ecological quality target is allowing for only minor deviations from a pristine status in terms of species composition and morphological features. A general exemption is made with regard to artificial and heavily modified water bodies. In these water bodies the ecologic objectives are to be fulfilled only as far as this does not necessarily impede the dominant water uses. Further adaptation to local givens and restraints is enabled on a case-by-case basis through a number of exemptions as provided in Article 4 para 4-7 of the Water Framework Directive. In contrast to the ecological indicators, these exemptions are shaped extremely vague and allow the relevant authorities to apply deadline extensions and to less stringent aims. Currently, these exemptions are excessively used by the relevant agencies, and this increasingly raises doubts about the adequacy of the entire target-and-exemption regime of the WFD. Nevertheless, a lot can be learned from this European experience with regard to definition of global quality and restoration targets. In the meantime, China is carefully exploring the definition of ecological quality targets with regard to selected, particularly valuable water bodies (Meng et al. 2011).
- *Integrated catchment management and planning including participation*: In order to provide for adequate catchment-wide and integrated management of all relevant sources of pollution, the EU has included in its Water Framework Directive the obligation of the Member States to draw up and revise every 6 years river basin management plans and programs of measures that are well-coordinated with regard to transboundary issues and cooperation needs. The scope and content of the programs of measures is regulated in detail in Article 11 of the

Directive, and it follows from these stipulations that the programs are to include all relevant sources and pressures and that they must include efficient combinations of measures. In general, this comes up to the principle requirement of integrated catchment management. However, as indicated in Sect. 4.1, this planning is not effectively implemented on the ground, and what is particularly missing are local implementation plans where concrete measures, responsibilities, and timelines are fixed. The Chinese Water Law, too, obliges the relevant administration to draw up catchment-related, integrated management and also special plans for various specific aspects (Article 14). Similar to the situation in Europe and Germany, however, the actual degree of integration and, most notably, implementation appears yet to be rather poor – which is mainly ascribed to the diffuse distribution of relevant competences among multiple administrations (multi-headed dragon; see the contributions of *Lv* and *You* as well as *Dai* and *Qin*[16]).

- *Emission standards and other global quality benchmarks as minimum level of protection*: Considering the inherent complexity and persisting weak implementation of the integrated approach, it seems advisable – as explained above in Sect. 4.3 – to further and increasingly rely on clear global standards as safeguards for a minimum level of sustainable water management and to limit the integration exercise to further optimization and aspects that can only be decided locally. German water law provides further examples of global water management standards, e.g., on ecological river passage, buffer zones, and minimum flows (see §§ 33, 34, and 38 of the Federal Water Act).

6 Conclusions and Outlook

Above, we have identified major tasks and benchmarks of sustainable urban water governance, and by drawing on the contributions to this volume, we have outlined how these requirements are tackled in terms of institutional arrangements and regulatory instruments. This appraisal is, of course, limited to a cursory review, and much deeper analyses on the specific elements of urban water governance are provided in the following contributions. However, what can be concluded beyond the details is that China has very dynamically developed its governance arrangements in terms of both substantial standards and instruments for better implementation and enforcement. In the face of the ongoing rapid developments, it is difficult to judge whether and in how far these new developments are going to be successful especially in closing the yawning implementation gap. Comparison with the German and European governance system suggests that stringent monitoring, transparency, and public control via judicial review are major stepping stones in this regard that still need to be further developed in China.

However, Europe and Germany are also struggling with severe implementation deficits – albeit on a different level of pressures and ambitions – particularly as

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[16] Regional Water Policy in China.

regards the ambitious water quality objectives of the Water Framework Directive. When it comes to implementing long-term objectives for substantial sustainability transformations, Europe and Germany are apparently facing considerable implementation and governance deficits, too. What we can learn in this regard from both the Chinese and the European experience is that much more attention needs to be paid – also on the national level – to the local implementation level, local responsibilities, implementation planning, and finance. The local governments are often unable to establish effective implementation structures by themselves due to the prevalence of contrary economic interests and competition between regions and cities. Therefore, it must also be seen as a global and national responsibility to enforce effective local governance regimes.

Local governance arrangements and instruments should also be the focus of further comparative review. More efforts should be invested to compare the arrangements of specific cities and regions, and particular attention should be paid to the relation between the national and local level in determining these governance settings. In all these regards, it is, of course, important to widen the view and include experiences beyond the Chinese and European horizon. In this sense, not least, we hope that this volume will contribute to enhanced international exchange.

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Sustainable Water Resource Management in China – Reflections from a Comparative Governance Perspective

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Abstract This article reflects the past years of Sino-German cooperation in water governance. Starting with the challenging task of goal setting, both China and Europe have developed toward a holistic understanding of sustainability by setting emission-immission values, taking resilience into account and introducing bioindicators into legislation. Chinese traditions in health-conscious behavior as well as its new concept of "Beautiful China" link to European efforts of revitalizing rivers also for human health and recreation. Secondly, functional administrative structures are fundamental for legal implementation. Integrality and subsidiarity need to be taken absolutely seriously as decisive factors for success. In European countries it has been proven advantageous that only 1 ministry is primarily responsible for water resource management, whereas China manages its water resources jointly by up to 12 different ministries. As this basic structure remains the same from the national level down to the provinces, it guarantees a more similar overall framework than is the case in most European countries. Thirdly, two innovative tools are introduced that allow a holistic comparison, visualization, and evaluation of different water governance systems: within a comprehensive 3D process, model interactions between different stakeholders are represented. A universal indicator system for water governance is able to obtain measurable values to gauge internal performance of a specific water sector. Lastly, urban systems are chosen to exemplify application considerations.

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1 Opportunities and Limitations of a Comparison Between China and Europe

Years of cooperation between German and Chinese institutions and scientists in the water sector have provided much insight into water resource management in both countries that are worthy of reflection.[1]

How can we begin to comprehend China? It is breathtaking. It is as big as a whole continent, integrating several time zones into one central one. Its climate ranges from subtropical to the near Arctic Circle climate, and its precipitation patterns vary from monsoon by the Pearl River to the Taklamakan Desert along the Tarim River. With a surface area as large as Europe, China has 1.4 billion inhabitants, which is nearly twice as many as Europe. China has one of the oldest cultures of humanity with a wealth of formative history and traditions and has been undergoing profound economic and political changes for several decades. Chinese metropolitan areas as well their infrastructures are growing at enormous speed; the proportion of urban population in China grew from 16% in 1960 to 57% in 2016 and is projected to reach 70% in 2030 (World Bank and Development Research Center of the State Council, the People's Republic of China 2014).[2] With great efficiency, the powerful central government is steering the breathtaking development of the country, especially its infrastructures.

The term "breathtaking" also applies to Europe with its equally long and turbulent history and its diversity of climate and landscapes. Politically, Europe is very unique in the way it combines sovereign states to form a community with common economic and environmental values. Hence, with respect to environmental politics and technologies, a high level of differentiation has emerged. In Europe, highly dynamic developments prevail too; the pursuance of common values within pluralistic societies often evokes Schopenhauer's allegory about the coalition of freezing porcupines. In the European Union, every member state is, in a manner of speaking, a fractal of the universal quest for the most favorable environmental conditions in the interest of the common good; it is precisely this heterogeneity that makes Europe a hub of innovation. The different regions adapt the jointly developed basic standards to their respective natural and legislative boundary conditions, and partly under competitive conditions. This also applies to the environmental sector in particular.

Therefore, the common ground between European countries and China lies at least in the high degree of diversity including the major societal challenges and the political responsibilities this entails.

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[1] The results are from many years of cooperation between the Bavarian State Ministry of the Environment and Consumer Protection (StMUV) and the Chinese Research Academy for Environmental Sciences (CRAES), the Technical University of Munich, and scientists from China (including Tongji University).

[2] See also https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS. Accessed 19 April 2018

Water management tasks have essential similarities all over the world. There is a fundamental congruence that water is the basis of all life and therefore also part of every human activity. Thus, each life is adjusted to the locally predominant water resource, and small changes to the water balance can result in far-reaching consequences. As a gravimetric resource, water always flows downward and connects all life on Earth in an (competitive) upstream-downstream relationship. Water thereby becomes a political resource in China as well as in Europe. Consequently, water management is a fundamental part of state security for every nation, and its organization is a basic component of the state's role to provide "immunization" (Sloterdijk 2009) against threats.

It is therefore meaningful to compare water management between China and Europe, even if the comparisons are always in the eyes of the beholder.[3] Learning with and from each other sounds like a very reasonable task. In analogy to the philosophical perception that awareness of ignorance is as valuable as knowledge itself, not only the successes but also unsolved challenges are instructive within this comparison. Perhaps the most profitable part of the effort to better understand each other is the necessity to understand oneself as an essential prerequisite to any meaningful comparison.

2 Environment Policy and Water Management Goals

Historically, flood protection, irrigation, and hydropower are the traditional human-centered ways of utilizing or managing water. Both in China and Europe, challenges arise due to the strong regional divergences or seasonal fluctuations in water quantity. With industrialization and a growing population, the issue of qualitative tipping points linked to water usage is also becoming more and more important. This leads to a need for a management whose technical/scientific goals could be described as a mixture of qualitative and quantitative indicators and characteristics. In fact, it is a socio-ethical process which in essence consists in the question: What kind of (water) environment do we want? Answering this question is much more challenging than it appears at first glance. The laws and the subordinate standards and norms are the materialization of, ultimately, political, ethical, and morally based guidelines that affect all the needs in our lives, ranging from management through personal living quality to intergenerational responsibilities (from which the precautionary principle is derived, which was notably recognized and codified as a common principle in the first European Union Environment Action Programme in the year 1973 (OJ C112/4)). The development of standards and norms depends on the level of knowledge and expertise but also on social priorities.

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[3] At present, the observers have a European-German-Bavarian focus, while in China, particular observations were conducted in regions like Beijing, Shanghai, Liaoning, Kunming, and the Tarim Basin.

Codified as sustainability, environmental quality as a political objective initially had intuitive-spiritual roots in Europe, which was only recognized later with industrialization, as a direct contribution to individual health.[4] As a result, the first guideline and threshold values for emissions were geared toward protecting human health, later to be extended to precautionary aspects. One fundamental advance in European environmental understanding lies in the methodology of not only considering the emission of substances into the environment but also the resulting effects on protected goods (in our case water) and besides setting emission standards also defining status goals, so-called immission values. As a further fundamental step, environmental quality standards (EQS) have recently been established. These take the resilience of ecosystem into account and no longer rely solely on a human-toxicological assessment. The comprehensive approach to exposure assessment leads to a situation in which, with increasing knowledge, a growing number of substance groups as well as individual compounds will have to be assessed in terms of their toxicity in the aquatic habitat.

The third characteristic of a holistic understanding of sustainability lies in the bioindicators: as the selection and determination of water-related threshold values is apparently difficult and will remain incomplete for the foreseeable future, bioindicators were defined on the immission side with status assessment based on reference conditions. Finally, with the publication of the *Water Framework Directive* (*WFD*) in the year 2000, water body morphology was included in the indicator system, thus introducing a parameter for the description of the biosphere.

All in all, a very sophisticated and differentiated systemic understanding of the environment has been developed in Europe. However, a systematic core problem remains that there is no neutral reference status. Fundamentally, our ecosystems are characterized by continuous changes and evolution (autopoiesis). In addition, as an expression of civilization, we have intentionally altered (cultivated) the landscape extensively and completely transformed it as a defining characteristic of the current era, the Anthropocene. Intentionally or unintentionally, the Anthropocene, at the very latest, has taken our innocence and assigned to us the full responsibility for the functioning of the entire ecosystem. To a certain degree, the path from wilderness through cultivated landscapes to the desired landscape and from hydraulic machinery via cultural technology to integrated water resources management is a reflection of the *Reason of State*.

These anthropogenically transformed systems are still dynamically evolving. In a first approximation, the European environmental legislation has a well-founded, highly conservational or static component, which is only suited to these dynamics to a limited extent. In addition, there is a further challenge in that concentrating on (a selected few and partly low in abundance) indicator types can only partially reflect the stability of the overall system.[5] On the other hand, up till now we still

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[4] Examples are “Canticle of the Sun” from Franz von Assisi and the romantic nature understanding in German literature.

[5] Prof. Dr. Dr. hc Wolfgang Haber: “Nature itself has no standard for species, for the regulation of their growth or decrease.”

aren't able to reliably model the biological interrelations to a point that would allow an accurate prediction regarding the stability of changed and changing and ecosystems. We react legislatively (in line with Hans Jonas' principle of responsibility) by setting precautionary values, which, of course, restrict the uncontrolled and arbitrary use of water resources but also, as a direct consequence, pose a burden for the achievement of economic goals.

Nevertheless, the WFD together with its daughter directives and other European environmental standards has installed a system that can, in principle, address the identified threats. The essence lies in defining "good status" as the objective for *all* water bodies.

A similar development pattern also emerges in China. Since the 1970s, successive legislation and quality standards have been introduced, which focused initially on the emission aspects. The most representative legislation are the Water Pollution and Control Law, the total load control (a revision adopted in 2017 also specifies the concrete responsibilities for implementation and monitoring issues), and the Water Ten Plan on pollution prevention and control and discharge permit management regulations. In the period since 2004, progress has been made due to significantly increasing efforts devoted to immission aspects. This is clearly reflected in legislation related to water function zones, environmental impact assessment, and so-called watershed-based discharge permits. The environmental objectives are no longer exclusively orientated on input values, for example, the number of wastewater treatment plants built in a district within a 5-year plan. In a results-oriented approach, much more attention is payed to water quality targets as benchmarks. While significant successes have been achieved in the field of municipal and especially industrial wastewater treatment, water body morphology has received less attention so far. Furthermore, like in Europe, China is also facing enormous challenges regarding diffuse pollution, especially from agriculture.

Based on similar development experience in Europe, it can be predicted that the enormous investments in sewage systems and wastewater treatment will certainly pay off, with the noticeable improvements in water quality – the black (inorganically polluted) water bodies are getting less. But there are still essential questions left open! With regard to the aquatic, terrestrial, and marine bio-systems, which quality or which environmental services and what degree of resilience does China ultimately wish to achieve? Are the defined goals already enough, or will further integrated steps be taken, like in Europe, to restore the stability of the ecosystem? Judging by what is apparent at this point, the massive nationwide investments have not yet produced the intended improvements, never mind the realization of "good status" by European standards, due to other remaining pressures such as impoundment, water discharge, and transfer and diffuse pollution.

China is also closely observing which routes are taken in other regions, especially Europe and the USA, and is developing its manner of proceeding on this basis. Such developments are, in turn, inspiring for Europe. For example, as a part of the Major Water Program, the measures implemented along several hundred kilometers of the Liao River mainstream have barred any form of land use activity in several hundred-meter-wide buffer zones on both sides of the river and also partially

Fig. 1 Water purifying function area of Laoyu river wetland park (M. Disse)

revitalized the riverbanks. First assessments indicate significant positive effects. There are also very ambitious developments regarding pollution prevention for lakes, where the performances of state-of-the-art wastewater treatment plants are supplemented by the targeted establishment of wetlands. Such areas, designed as clarifiers, serve to remove the nutrients and in some cases also function as excellent recreational spots. One example is the Kunming city-governed wetlands by the Dianchi Lake that reduce nutrient pollution and are also popular with the citizens of Kunming (see Fig. 1 and parallel Bavarian wetland example in Fig. 2).

In view of the dense population, intensive commercial activities, and historic pollution, the task of water resource management in China is clearly demanding. Such tasks typically could not be solved solely through technological and regulatory approaches and objectives. Thus, it is advantageous to take a look at the administrative structures which are critical for their implementation.

3 Administrative Structures

The management of water resources is a fundamental state duty. The way in which this task is performed at the administrative level can serve as an access point for understanding the entire state structure. Sociologists like Wittfogel (1931)[6] even consider the necessity to manage water resources as an origin of the state itself; this applies, at least, to so-called hydraulic societies. Also in modern societies, Anthropocene factors can inevitably lead to a clear prioritization of good water

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[6] Wittfogel developed the theory of hydraulic societies.

Fig. 2 Retention and purifying ponds for urban drainage, city of Nuremberg, Bavaria (R. Manitz)

governance, reflected in, among other things, the development of the UN Millennium Development Goals (MDGs) and the current Sustainable Development Goals (SDGs) and their connection to water. In Europe, this basic understanding is codified in, for example, the WFD, related water laws as well as in principles of management measures. Water management in China has many thousand-year-old traditions and still ranks among the most efficient management systems today, which is well illustrated by the successful development of the rapidly growing urban areas.

In Europe, despite (Or because of?) the heterogeneity and fractionalization through sovereign states, a legislative consolidation process has developed. At the beginning, European Community regulations were formulated in strict directives. At the latest since 2000, the continuous review of European water policies, while under the aegis of EU Commission, was prepared by consulting experts from all member states, and the national implementation was accompanied by a Common Implementation Strategy (CIS) and a comprehensive and absolutely transparent reporting system (WFD CIRCABC Library). This ensures homogenous implementation and allows success rates to be monitored, despite the fact that organizational structures are very different at the national and federal state levels (Fig. 4). It has proved advantageous that only one ministry in a country is primarily responsible for water resource management.

In China, on the other hand, water resources are managed jointly by up to 12 ministries at the national level within a complex system (Fig. 3). This condition of high fractionalization is illustrated in the following organizational chart and is traditionally referred to as the dominion of the "water dragons." The basic structure remains the same from the national level down to the provincial level, thus guaranteeing a more similar overall framework than is the case in European countries. However, here too are some specific features that differ from the meta-structure. In order to fulfill special tasks or achieve certain additional goals, new specific structures with a limited regional scope were established. Some examples are especially worth mentioning, such as the establishment of the Dianchi Administrative Bureau, the Dianchi Lake Protection and Management Committee, and the Liao River Reserve Authority.

What impacts do the different organizational structures have on the performance and success of water resource management (good water governance)? Water, as a resource, requires integrated management approaches simply due to its unique characteristics, diverse functions, and uses. Therefore, the state structures for the water

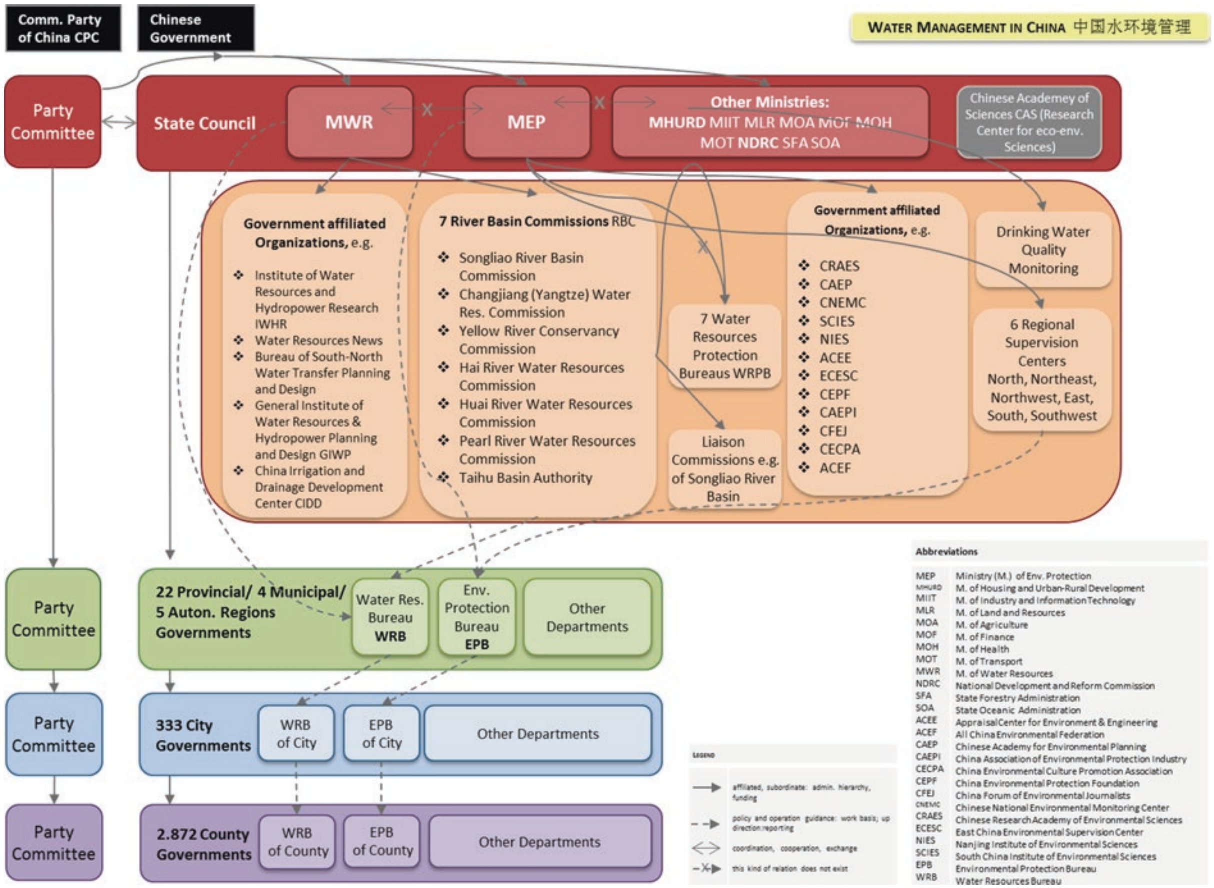

Fig. 3 Administrative structures in the Chinese water sector (Patalong 2013, p. 38)

sector can be expected to demonstrate a certain degree of integrality or offer institutional support for integrated solutions. This integrality can be realized through central governance or, when competences are distributed, with transparency and adequate communication capacity.

3.1 Subsidiarity

The principle of subsidiarity has become established and has proved to be a suitable basis for the cooperation between European member states. The term itself refers to a system in which the organizations are decentralized and tasks, with all their rights and obligations, are allocated at the lowest possible and efficient level. In China, this principle also applies by allowing provincial governments and subordinate authorities to govern freely (with restrictions) within their territories. Especially in the water sector, the introduction of the River Master Plan in December 2016 provided a new instrument to facilitate legal implementation at the regional level, by institutionalizing the allocation of responsibilities for the achievement of specific objectives. An evaluation to assess whether the new instrument really does result in better implementation of regulations is already under preparation.

Nevertheless, as a gravimetric resource, water breaks the hierarchical system of administration and legislation both at national and provincial levels (Drost and Grambow 2016). Thus, contrary to the subsidiary decision-making supremacy, there is also the imperative for cross-border cooperation. In order to do justice to the connecting properties of water, organizational forms such as joint bodies are necessary and should be permanently integrated into existing state structures and the decision-making paths. Such meta-bodies across administrative boundaries have been established both in Europe (in the form of national and international river basin commissions) and in China as river basin communities or commissions.

3.2 Internality

The firm establishment of the subsidiarity principle alone is not yet a guarantee of success! To be more specific, subsidiarity without the corresponding responsibilities and means to execute the designated tasks (technical term: internality) is destined to fail.

Therefore, good implementation concepts are needed for the operational level. One such approach is pursued in the River Master Plan in China mentioned above. The obligations and responsibilities which arise from the subsidiarity principle are fulfilled by the respective authorities and individual persons.

3.3 Innovative Instruments

Due to heterogeneous natural, political, and cultural situations, each of the world's nearly 200 existing water governance systems has its own unique organizational structure and working procedures for handling routine water management tasks.[7] At the same time, every water governance system is designed to fulfill similar fundamental management tasks such as water supply, wastewater treatment, flood protection, monitoring of water quality and quantity, etc. Therefore, it is worth reflecting on holistic institutional frameworks as well as fundamental relationships between the relevant authorities and entities to further improve water management approaches.

Currently, no ready-to-use tools are known that allow a holistic comparison of water governance systems by dynamically representing individual management tasks while also taking into account the way they interact. The SINOWATER project[8] aims to develop such tools.

3.3.1 Description of Structure and Processes of Water Management Tasks

Currently most water governance structures are depicted in two-dimensional organization charts together with abstract descriptions of assigned tasks and responsibilities. The interaction between organizations and management tasks, between hierarchies and sectors or between administrative regions or watershed boundaries, add a third dimension to the individual organizational structures. Furthermore, the model of an active organization is not a "frozen picture" but can be seen as an "engine," a dynamic management process. Therefore, a comprehensive process model could show both structures and processes within, and interaction and dependencies between different players in the field water management, respectively.

The SINOWATER project aims to develop such an integrative 3D water governance model (in short 3D model). This kind of model could significantly facilitate the representation and comparison of water governance systems, e.g., in Europe (or Bavaria) and China.

The following results are shown as the first findings of SINOWATER project.

- *Governance constructs*: At first glance, Chinese organizational structures seem to be very clear, while subordinate or lower hierarchical systems appear as reflective fractals of the national structures. The phenomenon of complex task alloca-

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[7] An in-depth analysis has already been undertaken for about 60 of these water governance systems including countries like India, China, Iran, and Uganda. These studies on institutional arrangements of the water sector were led by the StMUV and mostly carried out in cooperation with TUM.

[8] SINOWATER is a Sino-German cooperation project funded by BMBF aiming at good water governance, management, and innovative technologies for the improvement of the water quality in the Liaohe and Dianchi catchment area.

tion between various ministries is thus partially compensated by a more uniform structure in subordinate areas. However, the underlying problems still tend to occur at all levels. The local institutional comparison has revealed that German water-related governmental organizations have hierarchical structures that allow direct commands, communication, and overall coordination between different authorities (Fig. 4). In China, different organizational hierarchies also exist at different levels of governments. Nevertheless, due to the uneven economic development and population distribution in different administrative regions, internal department structures, management polices, as well as management measures can vary significantly between those regions, which increase the difficulties for general coordination and achieving common goals. On the other hand, in Germany, local administrative regions are more evenly developed, and management mechanisms are more similar. In addition, in China, even within one level of government, various bureaus (the so-called nine dragons) including their subordinate authorities are involved in different water management processes, which results in overlapping responsibilities at different phases and areas of diverse management issues. In contrast, local water management tasks are more integrally governed at each specific administrational or organizational level in Germany. Thus, a certain degree of uniformity can effectively reduce unnecessary duplication of efforts and responsibilities.

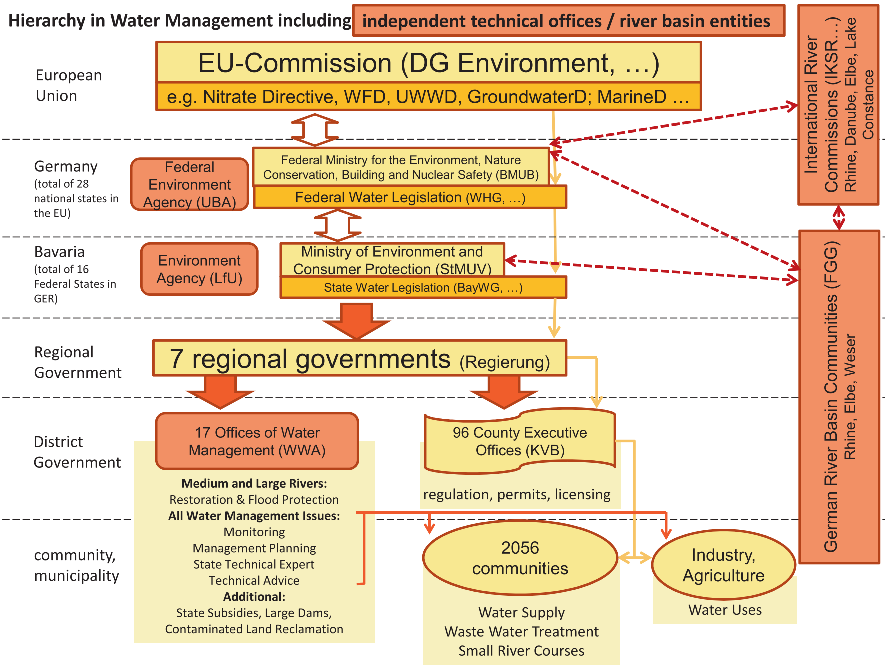

Fig. 4 Hierarchy and responsibilities in water administration in Bavaria as one of the 16 federal states of Germany (own compilation)

- *Responsibility for core management tasks*: As mentioned above, in Germany, the three main water management areas (management, water infrastructure, and hydrology: Fig. 4), including water law, are typically, aggregated within one administrative structure, in as far as they are state duties. In most cases, urban water management tasks are the responsibility of municipalities. In China, the different modes of distributing fundamental water management tasks lead to increased complexity. To be more specific, core tasks of water management in China fall mostly within the responsibilities of city or district governments. Nevertheless, operative facilities such as wastewater treatment plants and water supply enterprises are usually managed separately. Therefore, they could be managed by various state-owned companies, subordinate institutions of governmental bureaus, third-party operation management organizations, etc. Different facilities are established and maintained with varying technical inputs and requirements. In urbanized areas, operative facilities are built with greater treatment capacities, higher technical requirements, and more strict monitoring measures. In contrast, in rural areas they are usually equipped with significantly less treatment capacity, inferior technologies, as well as fewer monitoring requirements.
- *Standards and norms*: It is remarkable that, both, in Germany and China, water management depends on many governmental and nongovernmental organizations. In Germany, technical standards and norms are mostly set by associations and institutions; only in exceptional circumstances are they determined by the state. In contrasts, nontechnical standards (threshold values) are formulated by the state. In China, technical standards and threshold values are both determined by central government, and in addition, under the condition that this does not violate national standards, local governments can establish stricter ones, which apply to their own development and environmental goals.
- *Process description*: Basic administrative processes in Germany are typically specified in detail by laws and standards. The Bavarian water management also uses additional extensive internal descriptive process descriptions and procedural guidelines. In China, these basic processes also exist, but the implementation procedure is partially hampered by unclear competences and jurisdiction. In many cases, several bureaus share the responsibilities for different stages and areas of a particular process. As a result, efforts are duplicated, and there is a lack of adequate communication throughout the whole procedure. In addition, under the current regime of frequent modifications and amendments to laws and regulations, many processes are facing considerable changes. Consequently, it has not been possible to design fully comprehensive processes or develop them to reach their mature stage. Furthermore, due to jurisdictional limitations, numerous processes could only partially realize their intended results and objectives. This is often compensated by introducing additional requirements and restrictions to other relevant processes.

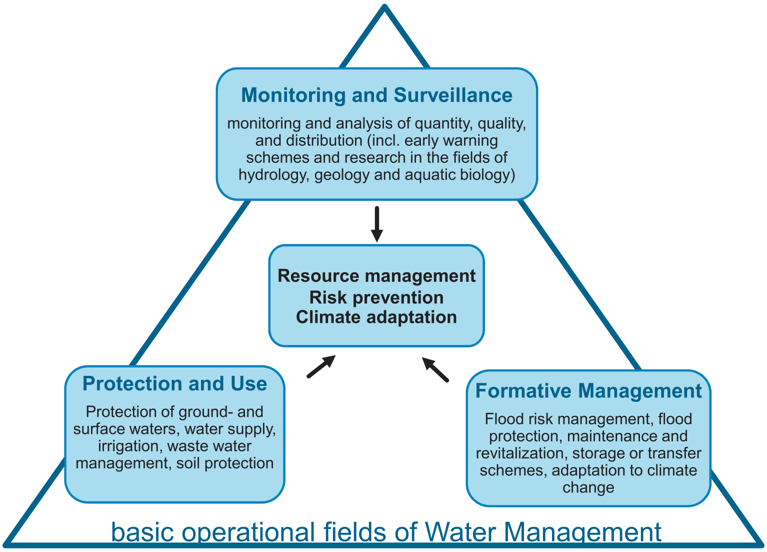

Fig. 5 Every water management has to deal with the three basic issues of management, water infrastructure, and hydrology (Grambow 2013, p 171)

3.3.2 Indicator System

The description of governance structures and processes alone can already serve to identify management deficits and opportunities for improvement in the respective water sector and can lead to helpful recommendations for action. However, the assessment of the actual status is highly dependent on the respective observers and is not standardized. In order to eliminate this systematic error from "pure assessment" and to obtain measurable values to gauge internal performance, a further innovative approach in SINOWATER project was initiated, which aims at developing an improved system of good water governance indicator systems. In addition to the technical indicators (see Fig. 5), indicators for "nontechnical" functionality of the administration will, for the first time, also be included.

Within the EU, technical indicators, including biological ones, are described in detail in numerous guidelines and directives, such as the EU Water Framework Directive, the EU Floods Directive, and the REACH.[9] In China, some of these concepts have also been adopted over the past few years (e.g., the emission-immission principle), and new ways, far from COD or TOC, for the regularly monitored technical indicators together with biological indicators also exist within the framework of "Harmonic China." In this respect, some technical indicators, for example, for water quality, are accessible and well represented both in Europe and China.

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[9] REACH = Registration, Evaluation, Authorization and Restriction of Chemicals

When talking about nontechnical indicators of good water governance the situation is different. These indicators significantly contribute to the review and enhancement of any water management system but are usually unnoticed or given little consideration. Here, there is considerable potential for development worldwide, including in Europe. The term nontechnical indicators refers to, e.g., components of transparency, efficiency, integrality, and administration.

The requirements for such an indicator system are very high, as it must comprehensively and transparently describe a highly complex system while enabling reliable comparisons. The prototype was developed in a problem-oriented and iterative approach; it was accomplished based on good water governance principles and tested for its practical suitability.

The selection and weighting of the indicators are inevitably based on expert assessments. The new index is constructed based on the following criteria: each individual indicator must be precisely formulated, relevant, and practicable. The entire system should also be balanced, not only regarding the content-related focus of the individual components (social, ecological, economic, political priorities of the indicators) but also their characteristics (framework conditions, processes, results). In addition, a balance must be struck between indicators that are purely dependent on data collection and those that reflect the achievement of a specific goal. A representative number of indicators should be identified that cover the most important aspects. At the same time, it must be ensured that data collection is possible with justifiable human and financial efforts.

By definition, indicators are a simplified abstraction of reality, behind which deficits can be hidden by poor choices and high aggregation. Through careful selection, cautious aggregation, and the use of subindices, an attempt is made to convey a clear message which can, nevertheless, be traced back to individual components. A mere value for the entire indicator system (index score), from which it is no longer apparent in which areas improvements are actually needed, is ultimately not very helpful.

Some organizations have already applied similar approaches. In addition to the OECD, there are also examples from Transparency International, the Canadian Government with its Canadian Water Sustainability Index, and UN Habitat with its Urban Governance Index. However, none of these existing indices could meet the requirement of building a comprehensive and universal index, which can cover all dimensions of water governance. In addition, they have only found limited application in practice. In Bavaria, an approach with an indicator-based management instrument is pursued, especially with the application of cost and performance accounting. However, this instrument was only ever intended for internal use and consequently has a very specific problem orientation and setup, making it unsuited for any form of application to other water management systems. For China, using indicators, especially the nontechnical ones, to systematically analyze the water sector is rather a new concept and seems not yet to have been applied. Nevertheless, there is a clear recognition that this focus, in particular, is especially important and can play a key role in helping to eliminate management deficits in the water sector.

4 Considerations for Application for the Example of Urban Systems

4.1 Fundamental Relationships Between Urban Development and Water Management

In the past, both in Europe and China, settlements were preferentially established near to water. Rivers and lakes can function as transportation axes and sources of food and provide revenue (historically also by "road toll") and services such as water supply, waste disposal, and energy production from hydropower. Today, it is still considered desirable to live in places with a view of water surfaces; thus the element water remains closely linked with life and lives. With the development of infrastructures for transportation and water supply, proximity to water courses as a starting and focal point has become significantly less important. To the same extent, the importance of effective water infrastructures for the maintenance of the basal functions of a settlement is growing.

However, four major challenges that determine the relationship between urban development and water still remain: (1) the necessity for urban drainage systems for rainwater discharge and flood protection; (2) water and food supply and thus the protection against drought and water scarcity; from which follows (3) soil degradation through surface sealing and overuse, which, in turn, causes the increasing loss of water landscapes as natural and recreational space in urban areas; (4) finally, the natural phenomena of the Anthropocene, of which climate change is among those most visible.

In the course of urbanization, humankind has already learnt a lot. If we look at the evidence of ancient culture, for example, in Mediterranean or Asian regions, some things obviously had to be developed twice, the knowledge of the interaction with water already having been available, only to fall into oblivion or fail to spread very far over time. Good examples are irrigation, water supply, or drainage systems, which often have their origins in ancient planning. Modern urban planning already has the concept of a water-sensitive city in mind, from the modern-day sanitary systems (the Roman flush toilets), aqueducts, to gardens designed to influence the microclimate or rooftop gardening, the latter being reminiscent of the Hanging Gardens of Babylon.

4.2 Dealing with Path Dependency of Infrastructure

But what is the credo of progress for water infrastructure? Large infrastructure carries a phenomenon within itself: as soon as the decision for an (innovative) system is made, the ties resulting from the commitment to that particular system become stronger with each new investment. The choice of large infrastructure technologies, such as drainage systems, always entails path dependencies and result in a loss of flexibility. Scaling effects point in different directions: small modular freedoms or large-system efficiency. For example, urban drainage through decentralized small wastewater treatment plants can be adjusted more quickly to, for example, changing demographic or climatic boundary conditions. On the other hand, substances can be better eliminated or recovered in centralized large wastewater treatment plants. Or individual flood protection measures function precisely with tailor-made effects, whereas trans-regional protective infrastructures can be operated reliably in a multifunctional manner.

Every effect causes side effects: beyond the initial capital commitment, in the long run, every technical solution remains linked with subsequent costs for operation and maintenance and combined with a "behavioral imprint," for example, with regard to water saving, the establishment of businesses or leisure activities, etc. An indicator that is well suited for system comparison should ideally take into account (long-term) operating costs and competence-building measures while at the same time describing both the extent of resource conservation and the risks that arise from incorrect operation and even include possible side effects for human cultures. Presumably, this "one" indicator will never be found.

In Germany, for example, the vote is still not finally decided regarding the conversion from mixed sewage collection systems to separate systems, which drain water of different qualities separately, on the one hand, and a central wastewater collection and treatment system on the other. In 2010, a historical step was taken with the Water Resources Act, which prescribes separate sewer systems. Nevertheless, concerns remain with regard to this decision: operation costs, safety, increased risks of incorrect connections, questions of flexibility, or improved recycling conditions play a role; ecological advantages and disadvantages are hard to balance.

The holistic approach of European water legislation has resulted in a change of attitude in water administration in Europe. As well as the balance of ecology, usability, and security, it is in particular the inclusion of cost-effectiveness of environmental improvement measures and the simultaneous incorporation of the value of ecosystem services that resulted in the necessity, or even imperative, for a comprehensive higher level assessment that is independent of individual measures or sectors.

Not just the permanent struggle to find the proper ideal conditions (target values) but also the accompanying discussion regarding the best technology is subject to constant changes as the knowledge base evolves.

4.3 What, Ultimately, Is the Purpose of Water Infrastructure and River Basin Management?

Even if a sustainable use of water is successfully achieved, it still remains unclear whether it will provide a comfortable, livable urban environment for human beings in the future. To put it another way, the EC Water Framework Directive may answer the question whether the fish are doing well because the water body has reached good status. But how do we answer the question of how good the lives of the people are who live along this good-quality urban water course? So far, too few indicators are in use that also incorporate life quality of the population. After all, technology and development should not be an end in themselves. Instead, they should serve to improve life (not just to make it more "efficient").

In Europe, it is becoming increasingly apparent that the many river revitalization measures, from those on small river stretches up to large-scale projects like the Isar-Plan in Munich, succeeded in combining management objectives (WFD, flood risk management) with meta-effects linked to improved leisure and recreation, beautiful landscapes, health, positive living environment, and life quality, which may conceivably even represent their primary societal value (European Environment Agency 2016).

Clean water, safe supply and disposal systems, and enjoyment of water landscapes – all of this has a positive effect on human health and well-being. With traditionally health-conscious behavior in China – exercise-oriented and striving for mental harmony – sustainable urban development should be greatly appreciated by the citizens there. The idea of "Beautiful China"[10] is a strong approach that recognizes the significance of landscape as part of life quality. Exchange and dialogue about reflections and developments (eco-city, green city, sponge city, smart city, etc.) promise mutual benefit in Sino-German cooperation in sustainable urban development. If one combines German experience in water management and environmental education with Chinese traditions in natural philosophy, a new understanding of the many issues surrounding water could emerge.

4.4 The Urban Rural Nexus

Urbanization is sometimes a euphemism for rural exodus. This causes deficiency situations in rural areas while also burdening urban development. In Bavaria, the stabilization of rural areas began in the 1950s with the State Development Program. Then, as now, the financial support for major infrastructure, especially water infrastructures, has been essential. China is doing a tremendous amount for urban development, while the development of the urban periphery and rural areas is (still) not a central concern.

The OECD study "Water Governance in Cities 2014" identifies the interrelation between city and countryside as a key issue for a successful water future in metropolitan areas all over the world. Water supply (rural-urban), water quality (urban-rural), and flood protection (rural areas as retention zones for the city) are cited. In cities where there is a serious lack of space, re-densification may still be a reasonable option, even when it is only possible at the expense of the natural water balance. Further urban sprawl, on the other hand, should be avoided at all costs. Strict precautionary resource protection is given emphatic priority over the permanent technical treatment of water resources exposed to contamination.

Agriculture will play an essential role for the outcome of this current development in Europe as well as in China. Diffuse agricultural emissions (nitrate, phosphate, pesticides, erosion) pose a threat for water management which could go as far as all-out failure of the ecosystem. Defining and adhering to strict environmental

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[10] "Beautiful China" is part of the 13th 5-year plan ("We must work to build through tireless efforts, a Beautiful China where the sky is blue, the land is green, and the water runs clear.").

goals which are appropriately formulated are imperative. At the same time, there is a high demand for healthy food. To keep farmers from leaving the villages, they need sound technical and social infrastructure and secured incomes that aren't founded on environmentally damaging action. Investment in a good living environment in rural areas is widespread in Europe; however, there are significant deficiencies in the acceptance of environmental regulations.

4.5 Cognitive Processes and Meeting the Demand for Improvement

An example of the growing visibility of water management is the Chinese "Water Ten" Plan, promulgated in 2015. It includes a "name and shame" ranking of the ten best and worst performing cities in terms of achieving environmental goals, which is initially perceived as a kind of public participation. One way to develop this approach further would be to integrate input from the general public and administration directly into a feedback loop in order to progressively address the environmental challenges.

This approach is followed by the European water legislation reporting cycles, the results of which are fully published. This does not include ranking; however, any inconsistencies or the failure to achieve the objectives is followed up by the EU Commission. At the same time, the CIS documents are regularly supplemented by best practice examples, providing practitioners with a sound basis for self-reflection. In the sewage sector, the best available technology approach, i.e., the elaboration of the best possible solutions, is an integral part of the specification of wastewater treatment requirements.

Our experiences in Europe suggest that it is best to treat successes and failures completely transparently. The primary aim is not to look superficially for "merit" or "guilt," but rather a continuous learning and improvement process, which makes the facts accessible to a broad political discussion. Often, the underlying consideration is: Which world do we want?

5 Conclusion

The fundamental prerequisite for the fulfillment of the UN Human Rights to water is a functional water administration system. Throughout the world, environmental and water experts can learn from each other by sharing their country-specific experiences in order to gain mutual knowledge. One of the positive aspects of globalization is that knowledge is no longer confined to specific regions or countries. In the best case, this can result in a mutually fruitful knowledge network and the transferability of good ideas.

This approach is also pursued by China and Germany. The one universally optimal administrative structure in the water sector does not exist. The analysis of administrative processes using technical and nontechnical indicators with the aid of a (3D) structural model can be an important aid in optimizing national water management in both countries. Examples for this are transparency and public relations, which are well advanced under the legislative umbrella of the EU Water Framework Directive in Germany, or the rapid and efficient implementation of water body protection projects in China (e.g., wetlands).

New ideas can and must be given a try. A good administrative system also requires a certain amount of "error tolerance"; only then can innovations be generated. Increased knowledge can be gained by the establishment and examination of hypothesis; thus, it is always based on incomplete knowledge. Integrated Water Resource Management (IWRM) signifies an all-encompassing "umbrella," which overcomes the barriers of the single-resource-oriented way of thinking. Especially in the critical transition areas between different sub-systems of the environment, but also between sectors and disciplines, thinking has to be innovative and integrating.

Integrality and internality should be taken absolutely seriously and regarded as decisive factors for success. Deficits occur especially where things are not integrally thought through, planned, and executed.

Decision-making systems and analytical instruments can support the achievement of objectives. The 3D structure and process demonstration and indicator systems, for example, can facilitate visualization and evaluation. This also allows meaningful comparisons between different systems.

In the light of human responsibility toward nature, it would be unforgivable to stop thinking about the water management system, questioning it in its established form or trying to understand and improve it.

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Cross-boundary Evolution of Urban Planning and Urban Drainage Towards the Water Sensitive “Sponge City”

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Abstract To counter its high urban pluvial flood vulnerability, China has been promoting Sponge City Development, a critical urban transition that requires cross-boundary evolution, particularly among the urban planning and urban drainage sectors. This article analyzes the relevant causes of high urban pluvial flood vulnerabilities in Chinese cities and the enormous gaps between the status quo and the ambitious targets. To bridge the gaps, a three-tier solution system is proposed and is supported by a broad range of approaches, know-how, techniques, examples, concepts, and policies. Firstly, water-sensitive urban planning can minimize macroscale damage on the local hydrological cycle. For example, it is illustrated here how cities can preserve critical ecological infrastructure effectively while developing resiliently, compactly, and habitably, for example, through spatial development criteria, urban growth boundaries and multifunctional urban poly-centers. Furthermore, implementations of low-impact development (LID) facilities can ameliorate local hydrology and reduce runoff pollution. This research thoroughly analyzes the relevant risks and challenges while customizing solutions, e.g., LID

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planning, based on improved hydrology – hydraulic and water quality simulations, management train, and separated treatment. Lastly, urban sewer system can be improved cost-efficiently via improving top-level designs and also via fully releasing, utilizing, and activating the existing sewer system's drainage and detention potential. Although the lessons and recommendations reviewed here are customized for Chinese cities, they can also be a reference for other fast-developing cities endangered by urban pluvial flooding.

1 Introduction

Due to economic reform, China has been experiencing unprecedented economic growth and rapid urbanization. Till 2016 its urbanization ratio reached 57.35% with 792.98 million urban dwellers living in 656 cities and counties (NBS, 2017). However, its ultra-urbanization in the past decades also caused substantial urban environmental problems, such as severe ecological damage, air pollution, urban climate problems, water deterioration, and water scarcity. Urban pluvial flooding is a notorious threat in particular for most Chinese cities and has led to billions of euros lost on average each year (Yu and Liu 2003; State Flood Control and Drought Relief Headquarters and PRC Ministry of Water Resources 2012). Within the years 2008–2010, pluvial floods swept over 218 Chinese cities (Lv and Zhao 2013).

Future urban pluvial flooding scenarios will be exacerbated due to the impacts of climate change and its synergy with the urban microclimate caused by land sealing. A series of researchers have indicated that climate change will on one hand accelerate China's urbanization via surging the risks for rural populations (Chen et al. 2005; Huang et al. 2007) while on the other hand concentrating urbanization and immigration to Central, Southern, and Eastern China in the middle and long term, due to the predicted worsening climatic and geological disasters in Northern and Western China than the rest of China. However, even Central, Southern, and Eastern China also expect to face serious climate change challenges such as rising sea levels, storm surges, extreme rainfall, flooding, seasonal droughts, and heat waves (Chen et al. 2005; Xu et al. 2005; Zhang et al. 2008; Zhai et al. 2011a; Shi et al. 2012). Furthermore, urban microclimate, esp. UHIE (urban heat island effects) and URIE (urban rain island effects), can escalate extreme weather esp. drought and heavy rainfall (Zhai et al. 2011b). UHIE and URIE together with the nationwide fiercer and more frequent heavy rainfall can intensify urban flooding risks. Hence, it is foreseen that climate change will put more urban populations under the enduring risks of urban stormwater flooding along with greater damages and higher economic losses than before (Weng et al. 2013).

With the advancing urbanization of China, urban infrastructure construction esp. municipal engineering development will continue to thrive. On one hand, large cities need to retrofit and improve their existing infrastructure. On the other hand, a large number of small- and medium-sized cities will experience large-scale urban infrastructure development esp. in water supply and drainage services (Xinhua News Agency 2014).Yet, urban infrastructure construction esp. in medium- and small-sized cities faces serious funding shortages and therefore requires robust and cost-effective solutions in the long term (Koizumi et al. 2008).

This article is targeted at reducing China's urban flooding vulnerabilities and resolves urban planning and urban drainage problems. This article also seeks to explore and customize the state-of-the-art practices and concepts as future-oriented solutions.

2 Materials and Methods

This article is based on a broad range of literature reviews covering major topics such as urbanization, land-use planning, climate change, flood control, urban drainage, politics, administration, and finance. On one hand, we have integrated information from relevant research results, policies, and reports from China and additionally from international experiences. On the other hand, this research article is practice-oriented, thanks to practical inputs from plenty expert interviews, stakeholder workshops, and site visits. Though Chinese cities are the main focus, other fast-developing regions could also refer to the experiences, principles, concepts, and techniques summarized here due to the integrated inputs.

3 Results and Discussions

3.1 Cause Analysis

3.1.1 Low-Efficiency Urban Expansion

The most evident symbol for China's urbanization is the vast land use and land cover changes (LULCC), esp. sealing natural land with impervious surfaces, which has been particularly swift since the year 2000 (Kuang et al. 2013). Massive urban expansion and construction often encroach over farmland and water bodies. For instance, Shanghai has usurped 1158 km^2 of farmland in the last 20 years (Miao et al. 2011), while Wuhan City has preserved only 27 of 147 lakes since 1949 (Di Liu 2009). Such massive construction has also led to the unreasonable positioning and arrangement of urban settlements. The construction of towns and cities is located in many cases in low-lying areas, sometimes even in flood zones without protection (Dai and Cao 2012).

Researchers have acknowledged that increasing imperviousness causes dramatically higher stormwater runoff in addition to higher and earlier peak discharge (Livingston and McCarron 1992; Schueler et al. 1992; Wijesekara et al. 2010; Yang 2013). It is no wonder that most of China's big cities integrated runoff coefficients reach as high as ca.0.4–0.8 (MOHURD 2011). For example, Shanghai, with over 80% imperviousness, has 50–80% precipitation becoming runoff (Wang and Rao 2004).

Moreover, impervious surfaces also damage the urban hydrologic system. The massive LULCC during China's urbanization has not only eliminated lots of water bodies but has also split, blocked, and impaired the natural hydraulic circulation of the remaining urban water systems. These arbitrary disturbances increase the instability of natural water bodies' hydrological processes, impair natural water bodies' ecological security, and therefore aggravate urban water safety problems (Cuo et al. 2008; Liu 2009; Bao 2011; Kuang et al. 2013).

In addition, impervious urban LULCC also exacerbates the flooding pressure through escalating the UHIE and the accompanying URIE. Under URIE, urban areas tend to receive more precipitation than suburbs during flooding seasons but less than suburbs during dry seasons. In any case, URIE makes cities more susceptible to high-intensity rainstorms, therefore aggravating the risk of urban flooding (Zhai et al. 2011b). As Chinese cities feature especially severe UHIE (Tang et al. 2009; Zhai et al. 2011b; National Aeronautics and Space Administration 2013), one can safely infer their strong URIE and hence predominantly high heavy rainfall possibilities.

3.1.2 Infrastructure Planning and Construction

The ultra-rapid urbanization has left Chinese cities with a huge gap between the fast aboveground development and the overdue underground urban infrastructure development, such as the poor-quality urban drainage pipeline system (Koizumi et al. 2008). Nationwide surveys show that even the drainage capacities in provincial cities have about only 1y return period, while more than 70% of all the urban drainage systems have only less than 1y design return periods (IWHR 2013). Such low urban drainage pipeline capacities originate from the following facts:

(a) Though improved, China's urban drainage standards have been set as very low, e.g., ranging between 0.5 and 3y before 2014 and between 2 and 5y since 2014 for ordinary areas (MOHURD 2011, 2014a).
(b) The common application of flow attenuation coefficient for storm sewer design until 2014 made the capacity of a 1y design return period storm sewer in China only equal to a 0.5–0.8y abroad (Gong et al. 2012; MOHURD 2014a).
(c) Local decision-makers tend to adopt the lower limits of the already very low urban drainage standards (IWHR 2013).
(d) The relevant weak monitoring, operation, and maintenance culture excessive sewer misconnections, blockage, and damages. Meanwhile the common "lowest unique bid" and subcontracting during government procurement may not guarantee the due quality either (Robert Rothery 2003; Weisheng et al. 2013; Ye et al. 2013).
(e) Plenty of the urban drainage pipeline systems in Chinese cities are already heavily loaded even in dry seasons, due to the ever-increasing service area and the higher stormwater runoff coefficients.

To sum up, massive LULCC surge Chinese cities' pluvial flood risk via causing higher and more rapid peak discharge and boosting URIE (Di Liu 2009). Meanwhile the vanished natural drainage capacity fails to be compensated under the absence of a robust and systematic drainage system (Wu and Zhai 2012). Consequently, in the event of heavy rainfall, large impervious urban areas intensely escalate and concentrate stormwater runoff in a short time. On one hand, the weak municipal sewer system becomes a bottleneck for transferring floodwaters to the receiving water bodies; on the other hand, the impaired inland water system not only fails to buffer the intense stormwater runoff inflow but also poses an extra flooding risk. Take the typical pluvial flood process in Wuhan City as example: after urbanization, its flooding durations were squeezed from ca. 20 h to ca. 10 h; flood peak occurred 3–4 h earlier, and the flood peak runoff turned significantly higher, severely surging the shock on drainage system (Di Liu 2009). Evidently, should such low-efficiency urbanization development continue, high urban flooding vulnerability will always be an attribute of Chinese cities.

3.1.3 Regulative and Administrative Reasons

A critical driver behind the scenes of massive urban LULCC is the Chinese taxation system and ideology about urbanization. On one hand, local governments heavily depend on releasing land via land market to raise governmental revenue to fund local urban infrastructure and public services (Ding 2007; Koizumi et al. 2008; Wang 2013). By 2008, 60% of all local government finances originated from land-releasing (Wong 2005). On the other hand, sealed land surfaces and high-rise buildings have been for a long time the dominating symbols of urbanization and modernization and critical criteria for evaluating political performances. Local governments have consequently spared no efforts to release more land, to promote "huge" projects, esp. by developing undeveloped land into commercial and residential uses, even at the price of demolishing and replacing existing developments (Koizumi et al. 2008; Li 2012; Wang 2013).

Furthermore, China's broad, complex, and transiting framework of laws, regulations, and standards on urban planning and construction, though contributive, was not fully prepared to helm China's swift urbanization processes. Firstly, the Soviet "population speculation-land use-infrastructure layout" approach dominated China's urban planning for decades and failed to cope with the swift urbanization and sustainability issues (Yu et al. 2011). Secondly, relevant regulations and standards often lose power in practice due to the lack of supportive details and requirements and due to lack of pertinence and justification (Wang 2013). For example, it was not until 2002 and 2005 that China first issued administrative measures (*ban fa*) for urban green lines and urban blue lines (MOHURD 2002, 2005a). However, it is still not rare in practice to destroy the natural green and blue space first and then artificially create "green lines" and "blue lines" for cities, due to the insufficient legislations safeguarding urban natural infrastructures.

Lastly, China's top-down planning decision-making, although it directed the overall trend of its large and rapid urbanization, failed to effectively attend to details (Yin 2008). On one hand, this is caused by the complex, sometimes overlapping sometimes split administrative system, e.g., the fragmented and discontinuous urban river landscape planning, administration, supervision, and maintenance (Bao 2011). On the other hand, the common information silos among various departments and regions put Chinese cities in a vulnerable situation, esp. during emergencies such as heavy rainfall or malfunction of critical infrastructure (Fang 2009).

3.2 China's Countermeasures in Urban Planning and Urban Drainage

The emerging urban environmental problems and the aggravating urban flooding pressures have pushed Chinese authorities to ameliorate the urban planning system and urban drainage system for its new era of urbanization.

China's urban planning system is under transition. At the national scale, a long-term blueprint "the National Major-Function-Oriented-Zoning (NMFOZ)" categorizes different regions as optimized, prioritized, restricted, or prohibited for spatial development (State Council 2010). At the regional scale, central government has plotted urban clusters to develop both coordinately and synergistically. At the city scale, recent years have seen the authorities repeatedly emphasizing enhancing the spatial and environmental quality of urbanization; advocating principles such as compact development, inventory planning, urban expansion control, and natural space protection; constructing the underground infrastructure before the aboveground infrastructure; and enhancing the role of water such as the official slogan "water-oriented city" (State Council 2010). To realize the above principles, urban planning and construction are required to follow the zoning construction (suitable, restricted, or prohibited) and the control boundary lines, such as urban yellow lines (for urban infrastructure, including drainage facilities, flood-control facilities, etc.), urban blue lines (for the prescribed urban surface water bodies), the urban green lines (for various, prescribed urban green spaces), and the urban purple lines (protection scope for historical and cultural blocks and buildings) (State Council 1992; MOHURD 2002, 2003, 2005b, 2005c; State Council 2010; Xinhua News Agency 2014; Jie Fan 2015).

China's urban drainage system is entering a new era as well. Since 2014 the central government requires cities to upgrade from two-level to a three-level urban drainage system. The conventional two-level drainage system comprised only of the municipal-level drainage system with low-return periods (i.e., drainage sewer and pump stations) and the hydraulic-level drainage system with high-return periods (i.e., the flood control system against fluvial flood, ocean tide, torrential flood, and debris flow), leaving a huge drainage gap in between (Huang 2009). The newly founded three-level drainage system introduces a gap-bridging level, i.e., the local flooding prevention and control system, whose design recurrence intervals for megacities, large cities, and smaller cities are correspondingly 50–100 years, 30–50 years, and 20–30 years (MOHURD 2014a). Furthermore, the design standards of the municipal drainage system and the hydraulic drainage system were significantly enhanced. Since 2006, storm sewer design standards were upgraded twice, and the design return period increased from 0.5–3 years to 2–5 years for ordinary urban areas, from 3–5 years to 3–10 years for important downtown areas, and even 10–50 years for downtown underground spaces (MOHURD 2011, 2014a). Meanwhile, the revision of rainfall intensity equations and the abolishment of flow attenuation coefficients since 2014 have led to a giant leap in the practical drainage capacities of storm sewers, for which cities have to gradually catch up (MOHURD 2011, 2014a). Taking a southern city as an example, its 1-year return period storm sewer design for rainfall intensity rose from 33 mm/day to 43 mm/day.

How to realize the newly founded local flooding prevention and control system? Since 2014, China's central government has been strongly promoting "Sponge City," a modern urban stormwater management system that is designed to maintain, restore, and maximize the urban capacity for stormwater infiltration, detention, retention, purification, utilization, and discharge, thereby effectively controlling stormwater runoff (esp. total runoff, peak volume, and peak time) (MOHURD 2014b). The central government encourages cities to regain such functions via flexibly customizing and combining natural and artificial approaches, ranging from protecting the existing ecological system to restoring damaged water bodies and other natural environments and to promoting low-impact development (LID). A Sponge City should comprise the following three interactive and interconnected elemental systems:

(a) LID system: to reduce, decelerate, and treat stormwater runoff via infiltration, storage, regulation, conveyance, interception, and treatment. The LID under China's Sponge City context covers a broad range of facilities, e.g., pervious pavements, green roof, first-flush diversion, perforated pipe, infiltration trench, rain barrels, low-lying green space, bio-retention, grass swale, vegetated filter strips, detention ponds, regulation chambers, retention ponds, stormwater wetlands, infiltration basin, and infiltration wells (MOHURD 2014b).
(b) Drainage sewer system: to collect, transport, and discharge stormwater runoff within its design capacity.
(c) Excess runoff discharge system: comprising retention water bodies, flood way, deep tunnels, etc.

Evidently, the Sponge City campaign will last for decades. Ambitious targets such as reducing the stormwater runoff coefficient to maximum 0.3 should be reached by at least 80% of urban built area by 2030. To facilitate the enforcement, the central government not only assigned batches of pilot cities but also added stormwater runoff control ratios as mandatory control criteria for the urban master plan, the regulatory plans, and the special plans for roads, water, and green space, and set Sponge City as prerequisites of urban planning permission and project construction (State Council 2015).

3.3 Recommendations for Urban Planning and Urban Drainage

3.3.1 Challenges to Solve

The coming decades will witness huge progress to China's urban drainage and urban planning systems if the following challenges and deficiencies can be effectively tackled.

First of all, Sponge City covers various sectors, disciplines, and industries (e.g., urban planning, geology, hydrology, meteorology, civil engineering, landscape planning, ecology, and botany). Its scales range from site to drainage zone, to city, and to watershed. However, due to administrative reasons, most Chinese cities are not ready for such systematic, cross-regional, cross-sector, and cross-profession cooperation yet, not only for the phases of planning but also during the phases of construction, operation, and maintenance. For example, due to lack of cooperation and coordination between different urban sectors, it was not a rare case in the first 3 years of Sponge City Development that the silts from urban greening construction block the freshly finished pervious pavements.

Secondly, China's current experience and talent reserve for Sponge City might be insufficient to achieve the ambitious targets set above in the short term. Despite plenty of LID research and demonstrations in China, there is seldom reliable, long-term operational, and maintenance experience available. Moreover, local practitioners and industries seriously lack LID expertise, since it is often the research institutions that carry out LID projects. As a consequence of the lack of data, experience, and talent, the relevant administrations don't dare yet to compel Sponge City Development in practice; the practice of Sponge City Development can at last differ a lot from the beautiful top-level design as well; despite the national campaign of Sponge City Development, cities rather cautiously demonstrate it in small regions rather than spoil it via large-scale constructions. In the coming years, how successfully researchers, sectors, practitioners, and industries can build up and disseminate relevant experiences will directly influence how well China can cope with the many realistic challenges in the relevant standard making, design, construction, operation, and maintenance issues.

Thirdly, the drainage pipeline sector faces perhaps the trickiest challenge, namely, how to upgrade to higher and stricter drainage standards, and for higher flexibility and resilience toward changes in population, land use, and climate, while causing the least disturbance to urban operations.

Fourthly, a huge challenge is how to deal with the current level of heavy stormwater runoff contamination and hence the risks of siltation and blockage for LID facilities and groundwater contamination.

Lastly, how to persistently finance Sponge City, which requires thousands of billions of RMB investment (Ren 2015)? The central government promotes public-private partnerships (PPP) to bridge the huge financial gap, namely, on the one hand including Sponge City projects into governmental procurement and on the other hand encouraging auxiliary financial support such as loans, bonds, and securities (State Council 2015). However, PPP won't be able to prop up Sponge City smoothly and effectively in the long run, unless the Chinese authorities can coordinate the risks to PPP stakeholders and reasonably reduce the numerous hurdles from laws, regulations, supervision, water tariffs and financial frameworks, etc. (Choi et al. 2010; Cheung and Chan 2011).

3.3.2 How to Enhance Urban Planning

Urban planning and construction is not only the source but also the cure for China's high urban pluvial flood vulnerabilities. Here the authors would like to firstly emphasize solidifying the base, namely, the role and mechanisms of the urban planning system, and then suggest land uses and land cover in detail, i.e., where not to develop and where and how to develop.

Multidisciplinary Urban Planning and Local Water Boards

First of all, urban planning can only direct urbanization and prevent and solve urban environmental problems at the very source, if the approved regulatory plans become statutory and the urban planning sector gets authorized to exercise certain urban planning-related environmental protection on behalf of the environmental sectors (Yin 2008). Moreover, the new era of urbanization, not only featured with Sponge City but also inventory planning, compact development, smart city, etc., requires reducing pressure from the top-down decision-making system and opening urban planning for more independent, multidisciplinary, cross-sector, and multi-stakeholder participations. This means not only to develop harmonized and cooperative sector policies between the urban planning sector, water sector, environmental sector, urban climatic sector, and traffic sector, etc. (Ellis et al. 2002) but also to simplify the know-how of the relevant sectors and research fields, to develop user-friendly toolboxes to enhance the feasibility of multidisciplinary urban planning (Ng 2012). However, the water sector itself needs to become more united, in order to develop a stronger voice in urban development. Despite years of debate around reforming China's dispersed and overlapping water-relevant ministry framework, Chinese cities badly need a better coordinated water sector within the existing framework. Learning from the EU and Singapore (Check 1997; Liefferink et al. 2011; Watson 2014; Hüesker and Moss 2015), it is recommended that each level of Chinese government should form, lead, and coordinate a corresponding level water board comprised of the critical local water stakeholders, e.g., water supply and drainage, flood control, water resource, river and lake administrations, agriculture, and fisheries. An efficient water board requires not only a well-designed network management but also a clear empowerment to coordinate, participate, supervise, and impact the water-related issues throughout urban planning and construction, e.g., ensuring the safety of drainage pipelines during underground construction, restricting the development of low-lying areas, and safeguarding water bodies from development (Check 1997). In this respect, Zhejiang Province is a pioneer by promoting the "Five Water Comprehensive Control Office" (五水共治) to coordinate wastewater treatment, flood control, pluvial flood discharge, water supply security, and water saving (Chun 2015). However, huge potential still exists for Chinese cities to develop effective downscaling, e.g., assuring and authorizing the effective water administration to drainage-zone levels (Check 1997), to introduce and customize bottom-up approaches to the conventional top-down approach (Watson 2014).

Such cross-sector and multidisciplinary cooperation is not only necessary for the urban planning phase but also critical for improving the urban management. In fact, a key for achieving Sponge City Development would be, via multidisciplinary conversation, input, and cooperation, to optimize the construction schedules, to supervise the construction process, and to achieve integrated operation and maintenance for the road, urban landscape, urban drainage infrastructure, and urban water bodies.

Where Not to Develop: Critical Ecological Infrastructure

The biggest lesson for China from the decades of massive urban construction is not about what to develop but rather where not to develop. The urban planning sector needs to take the lead in preserving, restoring, and maintaining urban critical ecological infrastructure (CEI), i.e., the critical natural elements and structures formed by natural green spaces and water bodies, acting as ecological calming buffers between urban zones (Yin 2008; Yu et al. 2011; Lafortezza et al. 2013). When well arranged, CEI brings tremendous benefits to cities, e.g., improving urban resilience against pluvial flooding, maintaining natural water cycles, improving the urban microclimate, and relieving air pollution (Pretty et al. 2007; Forest Research 2010; Lafortezza et al. 2013). Within the context of Chinese urban planning systems, the most practical approach to realize and remedy CEI directs to the urban green lines (UGL) and urban blue lines (UBL), both of which are mandatory for Chinese cities master planning, regulatory planning, and detailed planning. However, the following deficits of the current UGL and UBL need to be solved; otherwise CEI and its beneficial effects cannot be scaled up: on one hand, the passive and affiliated roles of UGL and UBL make them always compromised for other urban special plans, e.g., roads and utility lines. On the other hand, such a high-footprint approach still prevails, as using UBL and UGL for conquering nature rather than working with nature, e.g., landfilling natural rivers somewhere and excavating artificial ponds elsewhere, "building a valid green space but destroying the ecological environment" (Saunders and Yu 2012).

In order to retain and restore more CEI, we recommend the following approaches. Firstly, the urban planning sector needs multidisciplinary cooperation to rectify, identify, classify, and upgrade UGL and UBL according to their CEI potentials and hence to set corresponding protection buffers and protection measures, as well as to initiate relevant guidelines and directives. The core criteria of identifying CEI potentials should include, for instance, soil and water preservation, low maintenance, climate change resilience, ecological diversity, biodiversity, and a low overall carbon footprint. Due to limited urban natural spaces, brownfield restoration will become a major source for CEI development, e.g., restoring abandoned industrial parks into wetland parks (Turenscape 2016). Secondly, as continuity and connectivity can synergize the beneficial effects of CEI, it is recommended to plan CEI as an overall ecological system and to hierarchically connect the different tiers of CEI via spatial planning ranging from site and neighborhood scales to the district and city scales and to the city-region and regional scales (Benedict and McMahon 2002; Weber et al. 2006; Wickham et al. 2010; EEA 2011; Lafortezza et al. 2013). Thereby, even if only for CEI, the scope of urban planning and the relevant land investigation and database development needs to expand from the urban built area and urban plan-to-build area to the whole urban planning area or even to the whole administrative region of a city. In this respect, Shenzhen City undeniably foreruns via enforcing the "basic ecological control line" (基本生态控制线) since 2005 (People's government of Shenzhen 2013; Xiao and Xie 2014; Peng 2014).

As to UGL particularly, it is time to enhance the quality of UGL as solely quantitative control tools (viz., the mandatory criteria of the green rate and the green space per capita) at certain levels connived the unsustainable urban greening mentioned before. Therefore, we recommend that relevant authorities customize obligatory guidelines and eco-design directives to preserve/restore/optimize/create the mature urban green space esp. for the high flood risk areas and ecologically sensitive areas. Particularly, considering the well-proven contributions of urban forests in pluvial flood control and stormwater purification, it is recommended to delineate the critical root zone as protection zone for the preserved trees and native forest remnants and to include more mature trees into preservation lists rather than only for "ancient and famous trees" and over 50-year-old trees (Brabec et al. 2002; Yin 2008; MOHURD 2012; Stone Environmental Inc. 2014). Stakeholders could also use tools like the Urban Forest Effect Model to evaluate the benefits of UGL (Jayasooriya and Ng 2014). As for the artificial landscape, eco-design in comparison with the conventional landscape can significantly enhance the CEI potentials of a landscape, e.g., the multi-advantages of the customized native polyculture over conventional turf (Mark Simmons 2013).

As to UBL, an overall watershed view is highly recommended for the local planning board including esp. the water resource sector and the flood control sector to plan UBL, namely to coordinate and customize short-term, middle-term, and long-term UBL plans for the overall targets of gradually restoring the hydrological network of the local watershed by reconnecting and restoring disturbed rivers while conserving remnant water bodies and undeveloped floodplains and restricting further development of developed riverine floodplains (Ellis et al. 2002; Rong et al. 2009; Liao 2012; Yang and Li 2014).

How to Develop: Urban Built-Up Area

How to make cities more resilient against unending challenges such as climate change, population fluctuation, economy transition, and deteriorating environments and resources? China needs more resilient urban structures, as the severe urban environmental and resource problems have already proven the obsolescence of the extensive, passive economy-driven and population-driven urban construction and expansion. Nowadays compact city is quite often counted as a solution. However, if compact city is merely limited to the pursuit of always higher-density living, it may neither bring a healthier city nor curb urban expansion (Neuman 2005; Wei and Zhang 2012). The authors believe that the way toward urban resilience and sustainable urban spatial development lies in organized, controlled, and moderate decentralization. To put it into a scenario, it is the urban clustering formed ploy centers featured with urban growth boundaries, compact and mixed-land use, and multifunctional and relatively independent urban operation, buffered by traffic routes and ecological land in between (Geng 2008; Chiu. 2012; Xinli et al. 2013; U.S. Department of Energy 2014). Rather than a fixed blueprint, this is a process-oriented direction (Neuman 2005). Hereafter illustrated in details about its spatial development features.

1. Urban Growth Boundary

Urban growth boundary (UGB) is a well-known tool for curbing urban expansion. Despite Chinese central government’s call for UGBs since 2006, the UGB practice of several pilot megacities and large cites failed to substantially control urban expansion due to (1) the deficiencies of the methodologies for setting UGBs, including the commonly adopted constrained cellular automata-based methodologies, (2) the nonenforcement characteristic of UGB, and (3) the incomplete coverage of development permits and hence large amount of unofficial development outside of the UGB (Li 2011; Wan et al. 2013; Long et al. 2015). Therefore, it is recommended to effectively control urban sprawl with UGB as follows. Firstly, authorities should summarize and evaluate the existing UGB experiences and provide clear guidelines for UGB determination. Environmental capacity analysis and flood risk analysis should particularly be taken as mandatory toolbox elements for UGB determination to secure the bottom line of local environmental quality and urban security. Planners can use different levels of environmental quality standards such as surface water quality to infer the corresponding upper limits of population, industrial allocation, construction land, and hence the scales of UGB (Fu et al. 2009). The urban planning sector should integrate flood risk as a mandatory concern and add interacting hydrological risk simulations into its daily toolbox, therefore delineating the high-risk flood zones as construction-limited or even as construction-forbidden areas (van Sebastiaan et al. 2011; Xu et al. 2013). Therefore, it would be promising for determining UGB to develop spatial models that couple Constrained Cellular Automata Model with Green Infrastructure Assessment Model and Soil Conservation Service Model or with hydrologic and hydraulic framework (Li 2011; Xu et al. 2013; Giacomoni et al. 2014). Moreover, Chinese authorities may have to set UGB as mandatory or even statutory requirements for all cities, not only for the megacities and large cities, since small-medium cities and towns will become the major contributors for the growth of construction land (State Council 2016). Furthermore, it is necessary to fully enforce development permits without exception and to strictly monitor land use with technologies such as remote sensing. Meanwhile, cities should be authorized to moderately adjust UGB with sufficient demonstration on the premise of not breaking the critical bottom lines mentioned above.

2. Multifunctional Poly-center with Mixed Land Use

Depending on the scale of the cities, poly-center can refer to multipolar cities and satellite towns. Besides, based on the fragmentation analysis of built-up land, cities can delineate new poly-centers by uniting the construction-land fragments with high defragmentation potentials (Wei and Zhang 2012). Spatial planning for multifunctional poly-centers, beyond the simple high density and intensity of industrial and residential land uses, requires mixed land use, multimodal transportation, and high degrees of accessibility in order to activate urban operation even within small spatial scopes (Neuman 2005). Such multiple urban function allocation largely depends upon the political and economic decisions, housing policies, employment-decentralization, and industrial allocations which are beyond the context of this article (Gilli 2009). But in order to ease such transitions, China's urban planning sector should soon revise its still mutually exclusive land classification system for more compatibility capacities (Yin 2008).

Urban open spaces are particularly great sites for multifunctional planning. When well designed with integrated approaches and multidisciplinary involvement, they can safely augment the urban stormwater detention and retention capacity without using extra land, hence significantly reducing the peak runoff and protecting surface water via reducing CSOs and stormwater tank overflow (Fu et al. 2009; Michael et al. 2011). There are many such examples worldwide, such as the SMART tunnel in Kuala Lumpur and the squares, streets, parks, and even playgrounds also used for stormwater detention in Hamburg and Rotterdam (Kannapiran 2005). However, this also poses more requirements of the upstream stormwater management processes for sure.

3. Space Development Criteria

The interpretations of compact city, which are based on the idea against urban sprawl, have gradually evolved over years. Researchers have gradually agreed that compact city rather than fixed blueprints is the evolving process toward more efficient and habitable urban land uses. Namely, construction density and intensity, including the population density, building density, traffic density, plot ratio, etc., should be neither too low due to the efficiency nor too high due to the habitability (Neuman 2005; Yan et al. 2013; Martilli 2014). Despite the will from Chinese authorities for more compact land use, the existing construction density indexes are criticized as incomplete, unspecific, lacking of technical proof, susceptible to changes, and lacking of enforcement (Zhou and Zou 2004; Ban et al. 2007; Yin

2008). The mandatory construction density and intensity control criteria as required by the national codes include construction land area, population capacity, land-use type, plot ratio, building height, green rate, green space allocation, and underground space development layout (Ministry of Construction 2002, 2005). However, only few mandatory construction density limits are available in the national codes, e.g., for residential areas, maximum building density of 30% and minimum plot ratio of 1.0. Consequently, urban construction compactness in practice is out of control along with the tremendous extensive land use. For example, in campus cities and development zones, there are plenty of hyper-dense urban areas afflicted with poor habitability, overloaded drainage infrastructure, and hence high risk of pluvial flooding. Such construction density disorder results in not only the wasting of land resource and land sealing but also urban decay (Geng 2008). Therefore, we recommend updating the construction density indexes as follows:

(a) To add an open space ratio as another mandatory criteria to form a three-dimensional construction density index combination including plot ratio, site coverage, building height, and open space ratio, which can effectively describe urban density and simulate the possible urban morphologies (Haupt et al. 2004; Dong 2012). As urban open space offers a great platform for various multifunctional stormwater controls (US NAP 2009), the open space ratio will be another important Sponge City criterion in addition to the plot ratio and low-lying green space ratio.

(b) We also suggest that the central authority specifies the lower and upper limits for the various development density and intensity criteria of the different land uses at the different urban zones of various scales of cities that are located in different climatic zones. They should provide basic revision formulas for the local cities to further customize the development density and intensity limits according to the coefficient factors such as plot area, traffic capacity, runoff control, and the distance to CEI. One can find density zoning experience from the forerunner Chinese cities such as Shanghai, Guangzhou, and Shenzhen (Zhou and Zou 2004; People's government of Shenzhen 2014). As for the existing hyper-compact urban areas, local government should focus on its step-by-step redevelopment toward safer and better environments and higher resource and energy efficiency, instead of even higher construction densities (Geng 2008).

3.3.3 How to Realize Low-Impact Development

Sponge City Development opens a huge platform and market for LID facilities in China. However, China must overcome the following challenges to implement LID effectively. Firstly, there is a lack of high-resolution data that are crucial for LID planning such as land use, land cover, geologic and hydraulic data, empirical cost, and performance data. Secondly, the stormwater runoff of most Chinese cities can be heavily contaminated and poses a high risk of causing a fast defect of LID units and of groundwater pollution. For example, Beijing roof runoff (COD 123–328 mg/L) was even more contaminated than German road runoff (COD 582 mg/L) (Che et al. 2003). Thirdly, uneven rainfall distribution and limited urban land resources make it difficult to search for cost-effective scales and placements of LID units. We therefore suggest the following routes for the coming age of LID implementations:

Firstly, cities should accelerate the relevant monitoring and high-resolution database construction and sharing. Cities can meanwhile customize local stormwater management models such as SWMM for the LID selection, placement, and assessment with limited data as follows: (1) Carry out LID on several high-resolution, well-gauged urban catchments; calibrate and validate each high-resolution model. (2) Regionalize the model for large-scale low-resolution urban areas with reasonable efforts including surface discretization and processing the high-resolution models calibrated parameter sets. Such regionalized low-resolution models can accurately simulate runoff volume although they tend to over-simulate peak runoff (Krebs et al. 2014).

Secondly, effective pollution prevention measures can significantly reduce the contamination load and hence increase the life span of LID facilities, e.g. enhancing urban waste management; public education; disconnecting stormwater hotspots from LID facilities; controlling the application of fertilizers and pesticides especially nearby LID infiltration facilities, for example, via slow-release fertilizer, maximum dosing limits, fertilizer-free zones and fertilizer-free seasons (EP Florida 2015); and limiting toxic construction material such as galvanized roofing materials (Foerster 1996; Clark et al. 2008).

Thirdly, LID design should follow the stormwater management process (also called as treatment train), selectively combining LID units in series to reduce the overall land use of LID and the effectiveness of both runoff control and runoff pollution control (Liu et al. 2015a). A full LID management process includes source control, site control, regional control, and conveyance control in between, each comprised of various possible LID units with different functions such as stormwater absorption, pretreatment, filtration, infiltration, detention, storage, retention, conveyance, treatment, etc. (susdrain, 2012; MPCA 2015b). Optimal combinations can be found by evaluating project targets, site conditions, the runoff reduction and pollutant removal performance of various LID units, and other critical concerns of stakeholders such as amenity, ecological service, and costs. There are various tools developed to assist with the selection of a management train, such as the runoff quality scoring system in Germany (DWA 2007), the Minimal Impact Design Standards (MIDS) Calculator in Minnesota (MPCA 2015a), and various models such as SWMM, SUSTAIN, MUSIC, and L-THIA LID in the USA and Australia (Jayasooriya and Ng 2014; Liu et al. 2015b). In order to control stormwater runoff as close to the source as possible, source control is of primary importance, namely, to reduce runoff formation and to separate differently contaminated runoff. The coming years will see huge growth of green roof and pervious pavements in Chinese cities due to the authorities demands for an increase in perviousness. Yet, green roofs and pervious pavement are no universal cure and need to be taken with precautions, e.g., allowing pervious pavements only for low-traffic load roads to avoid pavement deformation and groundwater pollution and selecting extensive/intensive green roofs according to local climate and the site water balance. Separating differently contaminated runoff at the source can significantly enhance the cost-effectiveness of runoff control via avoiding treating large amount of low-concentrated mixed runoff (Ellis et al. 2002). For example, the management trains of roof runoff and road runoff should have as few overlaps as possible. Since the first-flush concentration of most runoff pollutants is within a short-time period, it is highly recommended for Chinese cities to customize the split-flow control volume according to the local land use and runoff pollution load and to divert first flush to wastewater sewer or separate treatment facilities. For instance, the split-flow volume in Beijing is recommended for the first 1–3 mm rainfall for roof runoff, 4–5 mm for neighborhood runoff, and 6–8 mm for downtown road runoff (Che et al. 2007). Another critical concern for designing a LID treatment train is to base LID processes on the pollutant particle sizes (Wong et al. 2002). As most of the runoff pollutants are adsorbed to suspended solids (Gooré Bi et al. 2015), TSS removal facilities and designs can significantly reduce the pollutant load and increase the lifespan of LID, such as a vortex separator, vegetation buffers, forebays, and design for sufficient hydraulic residence time.

Sufficient support and attention should be invested upon improving stormwater management modeling. China's current local stormwater models still have huge upgrading potential in terms of accuracy, water quality simulation, universal applicability, and user experience (Wu et al. 2010). Yet, even the universal model SWMM, which is a sophisticated, common tool for Chinese researchers and designers, also has many gaps to fill, e.g., to accurately address a broad range of the LID practices rather than only for green roofs, rain gardens, infiltration, and bio-retention practices (Jayasooriya and Ng 2014). It must be able to simulate the outflow-inflow connection between the LID practices to simulate the distribution of pervious surface's runoff to LID practices in a single sub-catchment (Rosa et al. 2015). China's Sponge City Development will accelerate the trend of LID simulations, such as to promote stakeholder participation, cyber infrastructure, web-based models, model coupling, real-time monitoring and modeling, etc.

Lastly, the following factors will also decide the success or failure of LID practices. A prerequisite is the sustaining funding and management mechanisms. We recommend officially assigning LID practices such as stormwater utility, to clearly define the ownership-duty-and-benefit distribution and balance among the LID facilities, storm sewer pipelines, wastewater sewers, and treatment facilities, to adopt stormwater runoff discharge fees, to allocate funding from the municipal finance according to multi-services of LID practices, and to explore various tax and insurance incentives for the LID campaign. Moreover, proper maintenance of LID is crucial but also seems difficult and tedious for local municipalities. Therefore, it is worthwhile for Chinese cities to customize clear LID operation and maintenance guidelines, to issue maintenance certificates to certified companies, and to implement mandatory and regular third-party inspections (Michael et al. 2011). LID authorities should also never overlook the risk management of stormwater reuse and should regulate the reuse application, reuse scale, and reuse treatment to minimize the risk of public infection, particularly considering the relatively highly contaminated stormwater runoff quality and the high population density in Chinese cities.

3.3.4 How to Upgrade the Sewer System?

Recent central government policies clearly point out the development trend of the conventional urban drainage system (including drainage pipelines, pump stations, and drainage ditches), namely, increased drainage pipeline design standards, separated sewer systems, utility tunnels, deep tunnels, and digital management. Admittedly, these new era urban drainage infrastructures, if properly carried out, will improve the urban drainage capability. However, it can take decades to complete such a national infrastructure revolution due to the enormous investment requirement, the limitations from built urban space, and conflicts with urban operations. However, the most urgent, practical, and cost-efficient solutions should be to fully utilize the drainage capacity and storage capacity of existing drainage infrastructure. It is not rare for Chinese cities to have a significant amount of silted or damaged drainage pipelines and drainage ditches and hence huge loss of its drainage and storage capacities. The direct causes for such avoidable losses include a massive number of illicit sewer connections (i.e., storm sewers often convey combined wastewater), poor site management of construction sites (i.e., a lot sand and silt flow into drainage pipelines), and illegal wastewater dumping (especially oily wastewater discharge from restaurants and slurry discharge from construction sites) (Huang et al. 2007; Li et al. 2014; Wang 2014). The indirect causes can originate from the sewer design, construction, pipeline material, engineering supervision, quality control, and operation and maintenance (O&M). Most Chinese cities have not yet developed scientific, systematic, and stable O&M mechanisms for drainage pipelines. The sewer O&M approaches still feature low efficiency, high labor intensity, high risk potential, and low technology (e.g., sewer dredging mainly depends on human labor), due to a lack of attention and finance. The following approaches are recommended to fully activate the drainage and storage capacity of conventional drainage infrastructure.

First of all, the relevant top-level designs should be improved and made more explicit to reduce, avoid, and remedy the problems damaging the drainage infrastructure's capacity as mentioned above. Contributing efforts would be to develop explicit national technical guidelines, standards, and liability mechanisms to direct and regulate the relevant survey, consensus, design, construction, materials, engineering supervision, operation, and maintenance and to develop a training-certification-supervision system for the relevant practitioners (Xue and Song 2014). The conventional drainage infrastructure will benefit from more attention, support, and organization via a more efficient institutional setting with a clear duty-power-finance structure for integrating drainage infrastructure, wastewater treatment plants, and flood control. The top-level financing design should esp. consider the long-term, stable finance for regular and qualified drainage infrastructure operation and maintenance. Some of the other critical top-level design efforts include to effectively forbid the "lowest unique bid" behaviors, to prioritize and advance drainage infrastructure planning before land trade with developers in order to gain sufficient time and support for the qualified planning and reliable construction of drainage infrastructure (Ellis et al. 2002), to promote full-scale coverage of connection permission for public drainage pipelines, to enhance the monitoring and punishment of illegal wastewater dumping, to enhance construction site management criteria, etc.

Furthermore, the conventional drainage system can release, utilize, and activate its drainage and storage capacity via a three-step innovation and improvement, in order to reduce the costly burden of building inline or offline tanks, tunnels, and basins. Firstly, fitting hydrodynamic sewer self-cleaning technologies into drainage infrastructures can release the capacity inhabited by silt. Such self-cleaning facilities, based on a preset hydrodynamic mechanism, automatically detain upstream stormwater or wastewater and form an adequate flush wave from the impounded water to remove silt. With neither intensive labor nor external powers, self-cleaning sewers can create an easy and approachable physical sewer base for other critical sewer O&M tasks, such as online monitoring, video inspection, and trenchless repair. Secondly, urban drainage infrastructure can further exert its inline storage potential via embedding flow control technology such as weirs and vortex valves. Flow control devices restrict the flow rate from its upstream sewer to its downstream sewer, utilizing the otherwise unused volume of the upstream drainage pipeline, storage tank, and road space, attenuating peak flow, and protecting downstream drainage and treatment facilities (Richard et al. 1994; Andoh et al. 2009).

Lastly, to fully activate the capacity of the whole drainage network, measures to increase its connectivity, flexibility, and resilience are necessary. To increase the drainage network connectivity, it is recommended to add connection pipes to increase the drainage pipeline density esp. for high flood risk urban catchments (Peng et al. 2015). The enhancement of sewer network flexibility and resilience depends on the promotion of decentralized systems, flexible design alternatives, and smart sewer technologies. Therefore, new constructions and infrastructure retrofits should prioritize the decentralized system at the planning phase over the conventional centralized system, due to the prior's integrated advantages in terms of flexibility, sustainability, and security (Dong et al. 2012). At the early design phase, designers need to select local suitable flexible design alternatives rather than the conventional rigid design, such as the "robust design, phased design, modular design, modular/component platform design, and design for remanufacturing" (Spiller et al. 2015). Intelligent sewer technologies, including smart metering, smart control (smart valves, pumps), intelligent processing and analysis, and decision-making tools, can fully activate the overall capacity of drainage network by allotting drainage water among the differently loaded drainage pipelines. However, modern intelligent sewer technologies are still only viable for developed cities due to the relatively expensive investment requirement.

4 Conclusions

Decades of massive urban construction not only wins China high urbanization and economy growth but also causes severe urban environmental problems, particularly the widespread high urban pluvial flood vulnerabilities. Since 2014, China has been promoting Sponge City Development 海绵城市建设, a Chinese version of Water Sensitive Cities, to alleviate this high urban pluvial flood problem and meanwhile to improve the urban water system.

The causes for Chinese cities' high urban pluvial flood risk are a complicated cluster, which is related to several urban sectors and various urban development phases, especially urban planning; the planning, construction, operation and maintenance of drainage infrastructure; the relevant regulations and administrations of water bodies and green infrastructure. This review analyzes the causes and classifies the complicated causes into the following three categories:

Firstly, the low-efficiency urban expansion, which is featured with massive growth of impervious land use and land covers, caused higher and more intensive stormwater runoff, severely damaged urban hydrologic system, and escalated urban heat island effects and urban rain island effects.

Secondly, the planning, construction, and maintenance of urban drainage infrastructure severely lag behind the overground development. Urban drainage infrastructure becomes a bottleneck of drainage, due to the following reasons: low drainage standards; use of flow attenuation coefficient; common "lowest unique bid"; weak engineering supervision; poor operation and maintenance; excessive sewer misconnections, blockage, and damages; ever-increasing service area and high runoff coefficient; and low water tariff and high dependence on governmental subsidies.

Last but not the least are the regulative and administrative reasons. For example, both the taxation mechanism and the political fever for a sealed urban image encouraged local governments' overdependence on land releasing. Moreover, the relevant laws, regulations, and standards on urban planning and construction are not cutting-edge and agile enough for China's very swift urbanization, such as the insufficient legislations and shallow enforcements for safeguarding urban natural infrastructure. Also necessary to mention are the typical problems of top-down planning decision system: the complex, sometimes overlapping sometimes split administrative system and their information silos.

As analyzed in this article, Chinese authorities have started series of countermeasures in the urban planning sector and urban drainage sector. Sponge City Development, as one of the most systematic evolution, set series of ambitious targets yet needs to solve the following challenges and problems: from cross-boundary cooperation experience to the capacity of relevant talents, to the not well-separated drainage system, to the power distribution, to more efficient administration, to long-term finance, to effective legislation, etc.

Just as the high urban pluvial flood vulnerabilities are caused systematically, it requires also cross-boundary efforts, evolution, and cooperation to develop into a water-sensitive, climate change-resilient Sponge City. We customize for Chinese cities series of recommendations for their urban planning, low-impact development and urban sewer system. Here briefly summarizes some of the key points.

There is a lot that urban planning sector can improve to avoid and to solve the urban pluvial flood problems and urban water system problems from the beginning:

Firstly, in order to keep urban construction relatively in control, the authority should authorize and support the urban planning sector to exert the function of environmental and ecological protection. Particularly the dispersed water sectors should get better streamlined, coordinated, and integrated and actively participate in all the phases of urban planning and construction, to protect and to optimize the urban water system from the very beginning.

A most preliminary concern of urban planning should be to firstly preserve the valuable critical ecological infrastructures free from development. The urban green lines and urban blue lines of current urban planning system, if well enforced, can serve this means, if only the multidisciplinary contributions can be introduced to rectify, identify, classify, and upgrade the urban green lines and urban blue lines according to their potentials of critical ecological infrastructures.

While planning for urban developed land, we think, cities can gain more climate change resilience via organized, controlled, and moderate urban decentralization and clustering, formed ploy centers featured with urban growth boundaries, compact and mixed-land use, and multifunctional and relatively independent urban operation, buffered by traffic routes and ecological land in between.

In order to curb urban fragmentation, we recommend Chinese authorities to fully promote urban growth boundary and strictly enforce the development permits nationwide. Yet more efforts still need to be invested in developing methodologies for scientifically setting urban boundaries, considering, for example, not only environmental capacities but also flood risks.

It is also recommended to revise China's still mutually exclusive land classification system for more compatibility capacities, so that to encourage more multifunctional and mixed land use of urban area. This can activate cities efficiently. For example, multifunctional open spaces, if properly designed, can safely augment the urban stormwater detention and retention capacity without using extra land.

Compact city development can at the source limit urban imperviousness and the impacts on hydrological cycle. To balance between land use efficiency and habitability, we recommend the central authority to specify the lower and upper limits for the various development density and intensity criteria accordingly and to form a three-dimensional construction density index combination including plot ratio, site coverage, building height, and open space ratio.

Low-impact development, as core element of China Sponge City Development, can very well connect the urban planning sector and the drainage sector. We firstly analyzed the challenges for LID, such as lack of high-resolution data, heavy stormwater runoff contamination, uneven rainfall distribution, limited urban land resources, and critical gaps in modelling. Based on that this technical review customized recommendations about how to accelerate relevant monitoring and high-resolution database construction and sharing, how to customize local stormwater management models, how to effectively prevent stormwater runoff pollution and hence to increase the life span of LID facilities, and how to customize stormwater management process. Besides, we also listed some critical points to improve the stormwater management simulation tools and shared some insights about sustaining, funding, and management mechanisms for LID.

As to the sewer system, the most urgent, practical, and cost-efficient solutions should be to fully utilize the drainage capacity and storage capacity of existing drainage infrastructure.

Hereto this article customized recommendations for improving the relevant top-level design, in such as national technical guidelines, standards and liability mechanisms, more efficient institutional setting, long-term reliable financing design, prohibition of "lowest unique bid," and prioritization of drainage infrastructure before land trade.

Technically, this technical review described a three-step innovation and improvements to release, utilize, and activate the drainage and storage capacity of sewer system: to fit hydrodynamic sewer self-cleaning technologies into drainage infrastructures, to embed flow-control technology such as weirs and vortex valves, and to promote measures for enhancing sewer connectivity, flexibility, and resilience, such as connection pipes, decentralized systems, flexible design alternative, and smart sewer technologies.

In its first 3 years, 2015–2017 Sponge City Development has been taking over more expectations, not only urban pluvial flood control but also improvement of the whole urban water environment. For both expectations, this decades-long national mega project and evolution requires mind-opening cross-boundary evolution and cooperation especially among urban planning, drainage system, and urban natural infrastructure. This review, based on the past lessons and cutting-edge trends, summarizes the relevant causes and recommendations and serves as an introduction for the beginning of this cross-boundary evolution. In the coming years, China's Sponge City Development will bring the world lots of technical and administrational innovations and breakthrough and lively demonstrate how to evolve toward water-sensitive cities with cross-boundary efforts.

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Part VI

Urban Water Governance: Regulatory and Organizational Framework

China's National Governance Framework for Urban Water Resource Management

Zhongmei Lv and Mingqing You

Abstract China has serious problems in urban water resource management, which have profound social, economic, and political implications in China. It is necessary to analyze political and governmental policies, legal rules, technical standards, authorities and responsibilities of governmental agencies, and other issues related to the urban water resource management. The constitutional basis for urban water management mainly lies in the ownership and the division of governmental powers. The CPC and the legislative bodies, executive bodies, and judicial bodies of the government all have authorities and make rules for urban water management. Rules may take the form of national or local legislation, administrative regulations or rules, or technical standards. Relevant regulatory agencies mainly include the Ministry of Ecology and Environment, the Ministry of Water Resources, and similar local agencies. Planning and functional zoning, administrative permits, and technical standards are key regulatory tools for urban water management. The CPC and the government have adopted some important measures to improve urban water management.

1 Introduction

China has serious problems in urban water resource management, including water shortage, water pollution, and disrupted aquatic ecosystem. Both surface water and underground water have these problems. These problems are interrelated and may reinforce each other: the water pollution reduces the quantity of water available for use, the shortage of water reduces the environmental carrying capacity and deteriorates water pollution, and the disruption of aquatic ecosystem reduces the carrying

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capacity for water pollutants. These problems have profound social, economic, and political implications in China.

Urban water resource management is part of environmental governance but also has some unique features. An understanding of the general environmental law is useful for the understanding of urban water resource management, and the discussion of urban water resource management may also help understand the general environmental law.

This paper analyzes political and governmental policies, legal rules, technical standards, authorities and responsibilities of governmental agencies, and other issues related to the urban water resource management.

2 Overview of the Constitutional Basis, Sources of Rules, and Regulatory Agencies for Urban Water Management

2.1 Constitutional Basis of Urban Water Management

The constitutional basis for urban water management mainly lies in the ownership and the division of governmental powers.

As to the ownership, the state ownership generally applies to the urban water resources as well as the land and aquatic ecosystem of urban waters, with minor exceptions. According to Article 9 of the Constitution of the People's Republic of China, water flow and other natural resources are owned by the State. The Water Law reiterates the state ownership of water resources. According to Article 2 and Article 3 of the Water Law, water resources are owned by the State, both surface water and underground water. However, the same Article 3 provides that the water in the ponds owned by rural collective economic entities and the reservoirs constructed and managed by rural collective economic entities is owned by respective rural collective economic entities. Nevertheless, this exception does not apply to urban water. In sum, urban water resources are owned by the State. The situation for land is more complicated. Article 10 of the Constitution provides that land in cities are owned by the State, while land in the rural and suburban areas is owned by collectives except for those portions which belong to the State in accordance with the law. Because of the rapid urbanization in the past decades, some rural and suburban areas close to cities have been urbanized but are still owned by collective economic entities. This may lead to some complicated matters for urban water management, for example, the infrastructure for urban water management.

The State has the responsibility to manage urban waters. This responsibility is part of the State's responsibility in environmental protection, as provided by Article 26 of the Constitution. This article provides that the State protects and improves the living environmental and ecological environment as well as prevents and controls pollution and other public hazards. The State performs this responsibility mainly through its executive/administrative branch. The executive/administrative branch is also called the government. In China, the government has five levels. At the highest is the central government. At the second level are provinces, municipalities directly under the central government (Beijing, Tianjin, Shanghai, and Chongqing), and autonomous regions. At the third level are cities, prefectures, and the like. At the fourth level are the counties and districts of cities. At the fifth level are townships and the like. Each government at or above the county level has various branches. The management of urban waters falls into the responsibilities of more than one administrative agency. For example, at the national level, the Ministry of Ecology and Environment (MEE) (formerly the Ministry of Environmental Protection, MEP), the Ministry of Housing and Urban-Rural Development (MOHURD), and the Ministry of Water Resources (MWR) all have some authorities and responsibilities. Vertically, there is no clear division of power among different levels of government as to environmental protection matters, including urban water management. Therefore, all levels of government have authorities and responsibilities in urban water management. The governments established various administrative agencies to perform duties related to urban water management. This paper will further discuss the authorities and responsibilities of the relevant administrative agencies later.

The congresses have the power to pass legislations and oversee the work of the executive/administrative branch. The National People's Congress (NPC) is the highest legislative body. The revision of the Legislation Law of the People's Republic of China enlarges the number of local congresses with legislative powers. According to Article 72 of the 2015 revised Legislation Law, all congresses of cities which are subdivided into districts have the power to adopt local legislations on urban development and environmental protection. No matter with or without legislative power, the national congress and local congresses have the power to oversee the work of executive/administrative branch on urban water management. Compared with the past, the congress plays a more active and stronger role in environmental protection. Article 27 of the 2014 revised Environmental Protection Law provides that governments at or above the county level shall report environmental quality and the progress on and achievement of environmental protection goals to the plenary meeting or standing committee of the corresponding people's congress, shall report major environmental incidents to the standing committee of the corresponding people's congress in a timely manner, and shall accept supervision according to the law. Some local legislations contain similar provisions before the revision of the Environmental Protection Law in April 2014. Such provisions require the government to be more accountable and make moderate modification to the horizontal relationships among the people's congress, the executive branch, and the judicial branch (You 2015).

The courts hear cases, the same as the courts of other countries. A recent development is the public interest lawsuits for environmental protection and the protection of consumer rights. The 2012 and 2017 revisions of the Civil Procedure Law formally introduced public interest litigation into China and conferred the standing to initiate public interest cases to non-governmental organizations (NGOs) and the people's procuratorate. The 2014 revised Environmental Protection Law clarifies the qualifications of NGOs to bring public interest lawsuits for environmental protection. The Supreme People's Court also adopted judicial interpretations on the handling of public interest lawsuits. Because of these developments, the court may have a more active role in urban water management.

In addition to public interest cases, the more traditional role of the procuratorate system headed by the Supreme People's Procuratorate is to bring public prosecution against the criminal suspects. Since the pollution of urban water environment may constitute crimes, the procuratorate's role in the prosecution of crimes is quite important for the protection of urban waters.

A unique feature of the Chinese constitutional law is the role of the Communist Party of China (CPC). The preamble to the Constitution provides for the leadership role of the CPC. Article 2 (2) of the Constitution further provides that CPC's leadership is the most inherent feature of the socialism with Chinese characteristics. In reality, the CPC indeed has a dominant role in governmental work and economic development, including urban water management. For each governmental agency, there is a parallel CPC committee or branch headed by a CPC secretary.

2.2 Sources of Authorities/Rules for Urban Water Management

Being the leading political party, the CPC has a dominant position in the formulation of governmental policies, lawmaking, and law enforcement at both the national and local levels. Therefore, it is necessary to examine CPC's policies on environmental protection, particularly those related to urban water resource management.

The highest source of law in China is the Constitution. Under the Constitution, the NPC and its standing committee adopt laws. The State Council, the central government of China, has the authorities to adopt administrative regulations under the Constitution and laws adopted by the NPC or the NPC Standing Committee. Ministries and commissions under the State Council have the power to adopt administrative rules or other normative documents. Such rules and normative documents are lower in authority than administrative regulations adopted by the State Council.

Among the laws adopted by the NPC or its standing committee, the most relevant to urban water resource management are the Environmental Protection Law of the People's Republic of China (EPL), the Water Law of the People's Republic of China (Water Law), and the Law of the People's Republic of China on the Prevention and Control of Water Pollution (Water Pollution Control Law). Some other laws are also relevant, for example, the Law of the People's Republic of China on Urban-Rural Planning (Urban-Rural Planning Law) and the Law of the People's Republic of China on Flood Control (Flood Control Law). The EPL was first adopted in 1979 for trial implementation, formally adopted in 1989, and revised in April 2014. The Water Law was adopted by the NPC Standing Committee in January 1988 and revised in August 2002. The Water Pollution Control Law was first adopted in 1984 and was revised in 1996, 2008, and 2017.

Technical standards form a sui generis source of rules. Although there are disputes as to their nature in the bodies of rules, they play a vital role in environmental protection in general and urban water management in particular. National technical standards related to urban water management are mainly formulated by MWR, MEE (formerly MEP), MOHURD, and the National Health Commission (formerly the National Health and Family Planning Commission).

2.3 Overview of Regulatory Agencies

The government takes the overall responsibilities for urban water management. Each level of government establishes some administrative agencies to exercise some authorities and perform some responsibilities. Local governments generally establish administrative agencies corresponding to administrative agencies of the central government or higher government. The result is a high level of homogeneity among the central government and local governments in the establishment of administrative agencies relevant to urban water management. This paper will only discuss the relevant administrative agencies at the national level. At the national level, the MWR, MEE, and MOHURD are closely related to urban water management, though other administrative agencies also have some relevant authorities.

The MWR is the number one administrative agency for water resources, including the urban water management. It is responsible for water resource development, flood control, and various other matters. For urban water resource management, the MWR is responsible for rivers, lakes, river banks, and water extraction. It also has some authorities over the discharge of wastewater and domestic sewage.

The MEE is the most important administrative agency for environmental protection. Its authority over urban water management is mainly on the control of water pollutants flowing into urban waters. It also has some responsibilities on urban aquatic ecosystem.

The MOHURD has authorities over infrastructure related to urban water management, including sewage pipes and sewage treatment facilities.

The authorities and responsibilities of these administrative agencies may overlap or have gaps. Some issues related to urban water management may fall into the authorities of more than one administrative agency but may also not be the responsibility of any. If that is the case, the government needs to coordinate with the relevant administrative agencies.

3 Planning and Functional Zoning of Urban Waters

The utilization of water resources is subject to governmental plans. The law provides authorities, procedures, and other requirements on the making of various types of governmental plans on water use.

Governmental plans for water are to balance different needs and harmonize different interests. According to Article 4 of the Water Law of the People's Republic of China, the use of water should harmonize the domestic needs, industrial and agricultural needs, and the ecological needs. However, the water resources may be insufficient to meet all these needs. In this case, the domestic use should be first ensured, while agricultural needs, industrial needs, navigation needs, and other needs are also taken into consideration. Article 21 of the Water Law provides that adequate consideration should be given to the water needs of the ecosystem in arid or semiarid areas. Currently the ecological demand for water is given much more attention now than in the past. Nevertheless, domestic needs are still the top priority for cities and towns.

The government adopts different types of plans on the allocation of water resources, including the allocation of water resources for urbanized areas. In terms of duration, water resource plans can be classified into long-, medium-, or short-term plans. These plans provide guidance to urban water management.

The function zoning of surface water embodies the primary use of each part of surface water. It is both the differentiation of use and also the differentiation of protection requirements. It is a tool to allocate water resource as well as a tool for controlling water pollution. This paper discusses the implication of water function zoning on the allocation of water resources in this paragraph and will discuss the implication on water pollution control in other parts. The water function zoning is provided in Article 32 of the Water Law, specified by the rules on the management of water function zones issued by the MWR, and further specified by a national standard entitled the standard for water function zoning (GB/T 50594-2010). According to the primary use, or "dominant function" in the term of the standard for water function zoning, surface water is classified into four types of function zones: protection zones, buffer zones, development and utilization zones, and reserve zones. The development and utilization function zone is further classified into seven secondary function zones: drinking water function zone, industrial water function zone, agricultural water function zone, fishery water function zone, scenery and recreational water function zone, transition water function zone, and pollutant discharge control water function zone. Surface water in urbanized areas generally falls into the development and utilization zones, more specifically, drinking water function zones, industrial water function zones, scenery and recreational water function zones, and pollutant discharge control water function zones.

4 Administrative Permits

The administrative permit is an important regulatory tool for the government to manage urban waters. The following are some important administrative permits related to urban waters administered by the administrative agencies in charge of water resources:

1. Water extraction permit. Water extraction permit is required for drawing water directly from rivers, lakes, or underground, and water resource fees should also be paid. Only large-scale industrial entities and water supply companies can get a water extraction permit. Other users need to buy water from water supply companies. In many northern dry areas, it is illegal to dig well and extract water without governmental approval.
2. Approval for water use plan. A user needs to submit a water use plan for governmental approval if the amount of water it uses exceeds a certain amount. Other users are exempted, including households and small businesses.
3. Approvals for river-related construction projects. Construction projects over the river, under the riverbed, or on the banks may affect flood control and the safety of banks and dams or have other effects on the river. Administrative permits are required for these projects.
4. Approval for occupying lakes. Sometimes it may be necessary to temporarily occupy the lake, for example, for the construction of buildings. However, the allowed occupation of lakes is usually temporary. The administrative permits set a time limit and the licensee needs to remove all obstacles and restitute the lake before the end of the allowed period. However, the licensee may apply for a renewal and extension.

The environmental protection agencies also administer some administrative permits related to urban waters, notably the water pollutant discharge permit. This permit sets forth the name, concentration, quantity, and other attributes of water pollutants. However, the water pollutant discharge permit is not fully applied in China yet, though this requirement was introduced for some time.

Furthermore, other administrative agencies also administer some important permits related to urban water management. For example, the site selection and detailed construction plans need to be approved by the administrative agencies for housing and urban-rural development. The construction plans should meet the infrastructural requirements on urban water management.

5 Technical Standards

Technical standards related to urban water management generally fall into four categories: environmental quality standards for water, water pollutant discharge standards, technical standards on construction projects, and technical standards on drinking water. At the national level, the environmental quality standards for water and water pollutant discharge standards are environmental standards and fall into the authority of the MEE. The MEE has the authority to make national environmental quality standards and national pollutant discharge standards. Governments of provinces, municipalities directly under the central government, and autonomous regions have the authorities to adopt local environmental quality standards and local pollutant discharge standards. The local environmental quality standards should be

Table 1 Environmental quality standards for surface water

Category	Main suitable functions
Category I	River sources and national reserves
Category II	Class one protected area for concentrated household drinking water, habitat of rare aquatic species, spawning sites of fish and shrimp, and the feeding ground of young fish
Category III	Class two protected area for concentrated household drinking water, winter habitat of fish and shrimp, migration channel, fish farming, and swimming
Category IV	General industrial needs and non-swimming recreational use
Category V	Agricultural use and scenery

Source: Environmental quality standards for surface water (GB 3838-2002)

more stringent than the corresponding national standards. Technical standards on construction projects are issued by the MOHURD, though some of them are drafted by the MWR. The technical standards on drinking water are issued by the National Health Commission and its predecessors.

5.1 Water Quality Standards for Water

Currently, there are five environmental quality standards for water at the national level: the Environmental Quality Standard for Surface Water (GB 3838-2002), the Sea Water Quality Standard (GB 3097-1997), the Quality Standard for Ground Water (GB/T 14848-93), and Water Quality Standard for Fisheries (GB 11607-89).

Among the five standards, the Environmental Quality Standard for Surface Water is the most important for urban waters. Technically, this standard classified surface water into five categories: from Category I to Category V. However, some water bodies may be even worse than Category V. Therefore, this standard in fact classifies water bodies into six categories, the lowest category being the category worse than Category V. The classification is based on the main functions that the water is suitable for (Table 1).

On the other hand, the function zoning also implies the water quality to meet. For example, water of Category II is suitable for class one protected areas for concentrated household drinking water, which also means class one protected areas for concentrated household drinking water should meet the requirements of Category II.

The responsibility to meet the water quality standards lies with local governments. Local governments need to enforce the law directly or through their various governmental agencies to make the water meet the applicable standards. The local governments also need to coordinate with their various branches of governmental agencies.

5.2 Water Pollutant Discharge Standards

Water pollutant discharge standards form an important type of environmental standards. Those standards generally require that the discharged wastewater should not exceed certain limits in terms of concentration, acidity, or temperature. To prevent intentional dilution to meet the concentration requirements, those standards generally provide for the benchmark quantity of wastewater.

Water pollutant discharge standards are set according to different industries and even different production methods. For instance, currently there are six pollutant discharge standards for the pharmaceutical industries: fermentation production, chemical synthesis production, and other production methods. If there is no discharge standard specifically for an industry, then the Integrated Wastewater Discharge Standard (GB 8978-1996) should apply.

Generally speaking, each water pollutant discharge standard further differentiates the current facilities and new facilities and provides different requirements. The requirements for current facilities are lower than those for new facilities. However, the water pollutant discharge standards only allow a limited period of transition time for current facilities. After that time limit, even the current facilities need to meet the requirements for new facilities.

Some water pollutant discharge standards differentiate requirements according to the water body that receives the pollutants. For example, the Integrated Wastewater Discharge Standard (GB 8978-1996) sets for different requirements according to the grades of the water body receiving the wastewater. The highest requirements are for wastewater discharge to Category III surface water or Category II seawater, the mediate requirements are for wastewater discharge to Category IV and Category V surface water or Category III seawater, and the lowest requirements are for wastewater discharge to Category II municipal sewage treatment facilities.

Some water pollutant discharge standards provide for special discharge limits, which are even more stringent than the requirements for new facilities. The special discharge limits are only applicable to some areas, not the whole country. For example, the Discharge Standard of Water Pollutants for Pharmaceutical Industry (Chemical Synthesis Products Category) (GB 21904-2008) provides that certain places of the Taihu Lake catchment are subject to the special discharge limits.

5.3 Technical Standards on Construction Projects

Buildings and other infrastructure are key to urban water management, so a large number of standards were issued. Standards under this category are quite many, including those related to water supply, sewage pipelines and sewage treatment facilities, eliminating or reducing wastewater, anti-flood facilities, and many others. Some of them have much implication in environmental protection and urban water management.

5.4 Technical Standards on Drinking Water

The current technical standard on drinking water is the Standards for Drinking Water Quality (GB5749-2006), which was issued in 2006 to replace the 1985 standard. It covers 106 items related to the quality of drinking water.

6 Problems in the Current Urban Water Management

In the past decades, China took much effort in urban water management. The main achievements are in the sewage treatment and flood control. However, urban water management is still insufficient, particularly in the following aspects.

6.1 Control of Water Pollution

The control of water pollution in cities and towns mainly includes controlling pollutant discharge, removing pollutants from the water, and increasing the carrying capacity with ecological measures. Although the law provides for several regulatory tools, the discharge of water pollutants is still high in concentration and large in quantity. The result is the deterioration of water quality and aquatic ecosystems of some urban lakes and rivers crossing or adjacent to cities.

6.2 Problems in Real Estate and Infrastructure Development

China witnessed a rapid urbanization in the past three decades. Urbanization puts a big demand of land for buildings and other infrastructure works. Most of the demand was met with farmland, but urban lakes and rivers were also occupied. Compared with farmland, in fact it is cheaper to convert lakes and rivers for real estate development because the compensation and transaction costs are much less. For this reason, many urban lakes shrank or even disappeared, and rivers became narrower. Some real estate projects and infrastructure projects took insufficient consideration of water management and led to some lock-in difficulties in urban management. However, some recent changes in real estate and infrastructure development may help urban water management. On the one hand, the development for commercial condominiums slows down because of the market and governmental control. On the other hand, many cities put or divert more investment to public interest infrastructure projects, including the cleaning up of urban lakes and rivers and restoring their aquatic ecosystems, and the development of construction projects under the notion of sponge cities.

6.3 Insufficient Water Supply

Some Chinese cities naturally lack sufficient water, but for most cities, the insufficiency in water supply is the result of irrational urbanization and water pollution. Currently many northern cities do not have sufficient surface water and heavily rely on underground water. The transfer of water from Yangtze River to northern cities may ease the problems to a certain degree but at a very high cost. For southern cities, the insufficiency in water supply is mainly the result of water pollution.

7 Ever Strong Political Will on Urban Water Resource Management

Problems in urban water management in China are less the result of insufficient legislation and rulemaking than the insufficiency in law enforcement. For many years, the enforcement was weak because local governmental and political leaders put priorities on economic development. The political will, particularly the political will of local governmental and political leaders, to enforce the law and standards is vital to urban water management. The CPC's attitudes and policies on urban water management changed significantly over time. Urban water management is a key infrastructure for cities and towns and naturally attracts CPC's attention. However, the attention was much more to water supply and sewage treatment, and much less to the urban aquatic ecosystem. Now, CPC pays more and more attention to urban aquatic ecosystem than ever. This change is part of the overall change of CPC's policies toward environmental protection.

Currently, the CPC treats environmental protection as a prioritized issue in its political agenda. This is a significant change after a period of neglect or under-evaluation of the environment. The current notion on environmental protection is "ecological civilization." The CPC called for setting ecological civilization as the prioritized task and fully integrating ecological civilization into the development of economy, politics, culture, and society in the 18th National Congress of the CPC held in November 2012 (Hu 2012). The CPC also revised its Constitution to incorporate the notion of ecological civilization in the same CPC national congress. Finally, the 2018 revised Constitution incorporated the notion of ecological civilization in its preamble.

Under the banner of ecological civilization, the CPC also adopted some more specific policies on environmental protection. The following are some of the most important ones.

7.1 *The Integrated Reform Plan for Promoting Ecological Progress*

The CPC Central Committee and the State Council published the Integrated Reform Plan for Promoting Ecological Progress on September 21, 2015 (CPC Central Committee & State Council 2015). The document proposes to reform the legal regimes for environmental protection and sustainable development in eight aspects.

The first reform aspect is unifying the system for determining and registering ownership of natural resources. The Constitution of the People's Republic of China provides that China owns all natural resources except for the land owned by rural collective entities. The Property Law of the People's Republic of China reiterates this rule and provides for the registration of ownership. However, the actual situation is far more complicated than the simple declaration of ownership of natural resources. Natural resources are in fact utilized lawfully or unlawfully, with or without governmental approval. Governments at different levels have different authorities, responsibilities, and economic incentives related to natural resources. Considered in this context, the determination and registration of ownership do not simply mean registration but imply the reallocation of political and economic incentives among different levels of the government. Clear ownership and governmental authorities are conducive to governmental performance as well as to development of the market economy.

The second aspect is establishing a system for the development and protection of territorial space. This is mainly to be accomplished through the differentiation of territorial space and the corresponding differentiation of development. Specific rules cover the functional zoning system, the national park system, and the differentiated regulation of differentiated space.

The third is establishing a planning system for territorial space. The Chinese government stresses the use of governmental plans to regulate social and economic life, which is part of the heritage of the past planned economy. The most authoritative governmental plan is the national five-year plan, which is drafted by the State Council and approved by the NPC. Under the five-year plan, local governments at different levels and different administrative branches have their respective plans. Several plans are related to the environment and natural resources but may potentially contradict each other. The Integrated Reform Plan calls for spatial plans and all-in-one plans. The spatial plans are at the national, provincial, and municipal or county level. The all-in-one plans are for the municipal and county levels: a plan covering all issues so that different administrative branches will not conflict with each other because of the conflicts among plans. The Integrated Reform Plan also calls for the innovation of methodology for making spatial plans at the municipal or county level, including more public participation.

The fourth aspect of the Integrated Reform Plan is improving the systems for total resource management and comprehensive resource conservation. The purpose is to strengthen natural resource management, improve the efficiency of the use of natural resources, and develop a "circular economy."

The fifth is improving the system for payment-based resource consumption and compensating conservation and protection efforts. In China, some natural resources are used at low prices or no price. The Integrated Reform Plan calls for accelerating price reform for natural resources and their products and improving the payment-based resource use for land, mineral resources, sea, and offshore islands. For those environmental factors that cannot be subject to property rights, it calls for the reform of resource and environmental taxes and fees, ecological compensation, and funds for ecological protection and restoration. It also calls for creating a restoration system for farmland, grasslands, rivers, and lakes.

The sixth reform aspect is establishing an effective system for environmental governance. The environmental governance envisioned in the Integrated Reform Plan includes administrative permits for pollutant emissions, mechanisms for cooperation within a region in pollution prevention and control, systems and mechanisms for rural environmental governance, public disclosure of environmental information, liability for ecological and environmental damage, and an effective administrative system for environmental protection.

The seventh reform is improving the market system for environmental governance and ecological conservation. The Integrated Reform Plan calls for fostering market entities for environmental remediation and ecological conservation. Additionally, it calls for promoting the trading of administrative permits related to environment and natural resources, such as energy-use rights, carbon emission rights, pollutant discharge rights, and water rights. It also urges the establishment of a green finance system and a unified system for green products.

The eighth reform aspect is improving the performance evaluation and accountability for ecological conservation. Arguably, this is the most important part of the Integrated Reform Plan because it is designed to incentivize local CPC and governmental leaders, who have a vital role in local economic development and environmental protection. It calls for holding local CPC and governmental leaders accountable – for life – for ecological and environmental damages. Toward this end, it is necessary to set targets for ecological conservation, establish monitoring and early-warning mechanisms for environmental and resource carrying capacity, create balance sheets for natural resource assets, and audit outgoing officials' management of natural resource assets.

These reform aspects are well envisioned, but a big question is how they will be implemented. Some of the reforms had been advocated in the past and even provided for in past legislation. Approaches to implement the reforms include strengthening leadership; launching pilot or explorative projects; imposing stricter supervision, laws, and regulations; and utilizing mass media. Among those approaches, strengthening the leadership is the most important. The policy document discussed below, issued a month before the Integrated Reform Plan, specifically addresses the accountability of local CPC and governmental leaders.

7.2 Measures for Accountability of CPC and Governmental Leaders for Ecological Environment Damage

In August 2015, the CPC General Office and the General Office of the State Council issued and published the Measures on Accountability of Leading Officials of CPC and Government for Ecological Environment Damage (for Trial Implementation). A striking feature of this policy document is that it is applicable to both governmental leaders and CPC leaders. In China, at each level or branch of the government, there is a parallel committee or branch of the CPC headed by a CPC secretary. CPC leaders have considerable power in decision-making for economic development and environmental protection. However, most legal rules on environmental protection are inapplicable to CPC leaders unless they acted in the capacity of governmental officials in addition to their roles as CPC leaders. Taking into account this fact, and to incentivize self-discipline, the CPC made its leading officials at various levels also accountable for environmental damages.

Local governmental and CPC leaders are key to the implementation of national policies. The Measures on Accountability are expected to strengthen an important policy transmission channel in China. The policy document specifically lists the situations for which the key leaders of local CPC committee and local governments should be held accountable, the situations for which responsible members of the group of leading officials of the local CPC committee and local government should be held accountable, and the situations for which members of the group of leaders of administrative branches should be held accountable. The document also lists certain violations for which CPC leaders or governmental leaders should be held accountable if they use their influence to commit the violations. Disciplinary punishments include censure, an order to make a public apology, demotion, removal from office, and forced resignation, and are in addition to possible criminal penalties.

7.3 Restructuring the Environmental Monitoring, Supervision, and Law Enforcement Teams

At local levels, each Environmental Protection Bureau (EPB) has subsidiary and supporting teams, particularly for environmental monitoring and for environmental inspection. The environmental monitoring team is responsible for monitoring pollutant discharge and environmental quality. The environmental inspection team is responsible for ascertaining compliance, investigating violations, and imposing administrative punishments. Some environmental inspection teams also allocate the total allowable discharge of key pollutants and collect pollutant discharge fees.

One concern over environmental monitoring and inspection is that these teams are not in a position to resist local protectionism because they are subsidiaries of local EPBs. Partly because of this factor, the CPC proposed that the environmental monitoring team and inspection team should be directly under the EPB at the provincial level (CPC Central Committee 2015). That is to say, EPBs at the county and municipal levels would no longer have their own monitoring teams and inspection teams. The purpose was to make environmental monitoring and inspection more independent and to incur less interference from the local government and polluters.

Some provinces, municipalities directly under the central government, and autonomous regions have completed the restructuring of environmental monitoring, supervision, and enforcement team. However, this may lead to some implications. Environmental inspection is one of the most important duties of local EPBs. If EPBs at the county and municipal levels are deprived of their inspection teams, how can they carry out their work? Besides, even if all inspection personnel are directly under the provincial EPB, can they really resist local interference? There is still much to be done to make the reform more specific and better address these concerns. If this reform is carried out and achieves its goals, it will contribute greatly to law enforcement and make local CPC leaders and governmental leaders more accountable for environmental protection.

The Integrated Reform Plan, the Measures for Accountability, and the restructuring of environmental monitoring and inspection teams are the three most important policies on environmental protection. Reading them together with other important documents helps one understand the development of Chinese environmental policies. The importance of the Integrated Reform Plan is that it makes the reform of environmental policies more specific. The significance of the Measures for Accountability is that it provides methods for reducing obstacles in the policy transmission channel and translating policies into action. The purpose of restructuring the environmental monitoring and inspection teams is to make them more effective. Many efforts are still needed to implement these reforms.

8 Concluding Remarks

Urban water management will continue to a big issue for China. China has developed a relatively comprehensive legal rules and technical standards related to urban water management. The current problems in urban water management are mainly the result of weak enforcement. The stronger political will for environmental protection may bring a change to the behavior of local governments and may contribute to urban water management. The notions of sponge cities may be a future trend for the urban water management.

Appendix: List of National Environmental Standards (As of 31 March 2018)

Quality standard for water environment

Code	Name	Release date	Effective date
GB 3838-2002	Environmental quality standards for surface water	2002-04-28	2002-06-01
GB 3097-1997	Seawater quality standard	1997-12-03	1998-07-01
GB/T 14848-93	Quality standard for ground water	1993-12-30	1994-10-01
GB 5084-92	Standards for irrigation water quality	1992-01-04	1992-10-01
GB 11607-89	Water quality standard for fisheries	1989-08-12	1990-03-01

Water pollutant discharge standards

Code	Name	Release Date	Effective Date
GB 3552-2018	Discharge standard for water pollutants from ships	2018-01-16	2018-07-01
GB 31572-2015	Emission standard of pollutants for synthetic resin industry	2015-04-16	2015-07-01
GB 31570-2015	Emission standard of pollutants for petroleum refining industry	2015-04-16	2015-07-01
GB 31574-2015	Emission standards of pollutants for secondary copper, aluminum, lead, and zinc industry	2015-04-16	2015-07-01
GB 31573-2015	Emission standards of pollutants for inorganic chemical industry	2015-04-16	2015-07-01
GB 30484-2013	Emission standard of pollutants for battery industry	2013-12-27	2014-03-01
GB 30486-2013	Discharge standard of water pollutants for leather and fur making industry	2013-12-27	2014-03-01
GB 13458-2013	Discharge standard of water pollutants for ammonia industry	2013-03-14	2013-07-01
GB 19430-2013	Effluent standards of water pollutants for citric acid industry	2013-03-14	2013-07-01
GB 28938-2012	Discharge standards of water pollutants for bast and leaf fibers textile industry	2012-10-19	2013-01-01
GB 28937-2012	Discharge standards of water pollutants for woolen textile industry	2012-10-19	2013-01-01
GB 28936-2012	Discharge standards of water pollutants for reeling industry	2012-10-19	2013-01-01
GB 4287-2012	Discharge standards of water pollutants for dyeing and finishing of textile industry	2012-10-19	2013-01-01
GB 16171-2012	Emission standard of pollutants for coking chemical industry	2012-06-27	2012-10-01
GB 28666-2012	Emission standard of pollutants for ferroalloy smelt industry	2012-06-27	2012-10-01
GB 13456-2012	Discharge standard of water pollutants for iron and steel industry	2012-06-27	2012-10-01

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GB 28661-2012	Emission standard of pollutants for mining and mineral processing industry	2012-06-27	2012-10-01
GB 14470.3-2011	Effluent standards of water pollutants for ammunition loading industry	2011-04-29	2012-01-01
GB 27632-2011	Emission standard of pollutants for rubber products industry	2011-10-27	2012-01-01
GB 27631-2011	Discharge standard of water pollutants for fermentation alcohol and distilled spirits industry	2011-10-27	2012-01-01
GB 26877-2011	Discharge standard of water pollutants for motor vehicle maintenance and repair	2011-07-29	2012-01-01
GB 26452-2011	Discharge standard of pollutants for vanadium industry	2011-04-02	2011-10-01
GB 15580-2011	Discharge standard of water pollutants for phosphate fertilizer industry	2011-04-02	2011-10-01
GB 26451-2011	Emission standards of pollutants from rare earth industry	2011-01-24	2011-10-01
GB 26132-2010	Emission standard of pollutants for sulfuric acid industry	2010-12-30	2011-03-01
GB 26131-2010	Emission standard of pollutants for nitric acid industry	2010-12-30	2011-03-01
HJ 594-2010	Water quality: determination of the total amount of the developing agent and their oxides (iodine-starch method)	2010-10-21	2011-01-01
GB 25468-2010	Emission standard of pollutants for magnesium and titanium industry	2010-09-27	2010-10-01
GB 25467-2010	Emission standard of pollutants for copper, nickel, and cobalt industry	2010-09-27	2010-10-01
GB 25466-2010	Emission standard of pollutants for lead and zinc industry	2010-09-27	2010-10-01
GB 25465-2010	Emission standard of pollutants for aluminum industry	2010-09-27	2010-10-01
GB 25464-2010	Emission standard of pollutants for ceramics industry	2010-09-27	2010-10-01
GB 25463-2010	Discharge standard of water pollutants for printing ink industry	2010-09-27	2010-10-01
GB 25462-2010	Discharge standard of water pollutants for yeast industry	2010-09-27	2010-10-01
GB 25461-2010	Discharge standard of water pollutants for starch industry	2010-09-27	2010-10-01
GB 21909-2008	Discharge standard of water pollutants for sugar industry	2008-06-25	2008-08-01
GB 21908-2008	Discharge standard of water pollutants for pharmaceutical industry Mixing/compounding and formulation category	2008-06-25	2008-08-01
GB 21907-2008	Discharge standards of water pollutants for pharmaceutical industry Biopharmaceutical category	2008-06-25	2008-08-01

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GB 21906-2008	Discharge standard of water pollutants for pharmaceutical industry Chinese traditional medicine category	2008-06-25	2008-08-01
GB 21905-2008	Discharge standard of water pollutants for pharmaceutical industry Extraction products category	2008-06-25	2008-08-01
GB 21904-2008	Discharge standards of water pollutants for pharmaceutical industry Chemical synthesis products category	2008-06-25	2008-08-01
GB 21903-2008	Discharge standards of water pollutants for pharmaceutical industry Fermentation products category	2008-06-25	2008-08-01
GB 21902-2008	Emission standard of pollutants for synthetic leather and artificial leather industry	2008-06-25	2008-08-01
GB 21900-2008	Emission standard of pollutants for electroplating	2008-06-25	2008-08-01
GB 21901-2008	Discharge standard of water pollutants for down industry	2008-06-25	2008-08-01
GB 3544-2008	Discharge standard of water pollutants for pulp and paper industry	2008-06-25	2008-08-01
GB 21523-2008	Effluent standards of pollutants for heterocyclic pesticide industry	2008-04-02	2008-07-01
GB 20425-2006	The discharge standard of water pollutants for sapogenin industry	2006-09-01	2007-01-01
GB 20426-2006	Emission standard for pollutants from coal industry	2006-09-01	2006-10-01
GB 18466-2005	Discharge standard of water pollutants for medical organization	2005-07-27	2006-01-01
GB 19821-2005	Discharge standard of pollutants for beer industry	2005-07-18	2006-01-01
GB 19431-2004	The discharge standard of pollutants for monosodium glutamate industry	2004-01-18	2004-04-01
GB 14470.1-2002	Discharge standard for water pollutants from ordnance industry	2002-11-18	2003-07-01
	Powder and explosive		
GB 14470.2-2002	Discharge standard for water pollutants from ordnance industry	2002-11-18	2003-07-01
	Initiating explosive material and relative composition		
GB 18918-2002	Discharge standard of pollutants for municipal wastewater treatment plant	2002-12-24	2003-07-01
GB 18596-2001	Discharge standard of pollutants for livestock and poultry breeding	2001-12-28	2003-01-01
GB 18486-2001	Standard for pollution control of sewage marine disposal engineering	2001-11-12	2002-01-01
GB 8978-1996	Integrated wastewater discharge standard	1996-10-04	1998-01-01
GB 15581-95	Discharge standard of water pollutants for caustic alkali and polyvinyl chloride industry	1995-06-12	1996-07-01

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GB 14374-93	Discharge standard of water pollutant and standard of analytical method for space propellant	1993-05-22	1993-12-01
GB 13457-92	Discharge standard of water pollutants for meat packing industry	1992-05-18	1992-07-01
GB 4914-85	Effluent standards for oil-bearing wastewater from offshore petroleum development industry	1985-01-18	1985-08-01
GB 4286-84	Emission standards for pollutants from shipbuilding industry	1984-05-18	1985-03-01

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Regional Water Policy in China – Problems and Approaches in the Taihu und Wuhan Regions

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Abstract This contribution depicts the governance arrangements for water resource management in the regions of the Tai Lake Basin and in the city of Wuhan. As to the Tai Lake Basin, the focus is on pollution control. It is shown that sustainable, integrated water management is strongly impeded by high fragmentation of the administrative competences and that adequate organizational integration and effective coordination instruments are lacking. The city of Wuhan is presented as an advanced example regarding the implementation of the "Sponge City" concept. It is shown that Wuhan has managed to establish a more integrated administrative arrangement for the purpose of water infrastructure development and a complex structure of objectives, standards, and responsibilities for the advancement of the Sponge City project. In order to place these examples of regional water governance into the wider national picture, we firstly provide a brief overview of the factual and institutional backdrop in China.

1 Water Resources in China

There are about 50,000 rivers with an area larger than 100 km^2 in China, among which more than 1500 rivers cover an area larger than 1000 km^2. Most rivers are distributed over the eastern and southern part of China. The total basin area of the rivers flowing into the sea accounts for 2/3 of the total area of Chinese territory, and the remaining 1/3 belongs to the inland river basins (FAO 2016). Seven river basins are considered as the major basins in China: the Yangtze River Basin, Yellow River

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Basin, Hai River Basin, Pearl (Zhujiang) River Basin, Huai River Basin, Songhua River Basin, and Liao River Basin. There are seven River Basin Commissions located in those seven river basins respectively, except Songhua River Basin and Liao River Basin share one commission which named Songliao River Commission. The seventh Commission, i.e., Tai Lake Basin Authority, is stationed in Tai Lake Basin which is a sub-basin of the Yangtze River Basin.

2 Institutional Arrangement of Water Resource Management in China

2.1 Water-Related Authorities and Responsibilities

China's institutional framework for water resource management is often referred to as a "multi-headed dragon" as a number of Ministries are involved. Taking the national level as an example, there are more than 40 departments directly governed under the State Council, among which at least eight are related to water management. The Ministry of Agriculture is responsible for irrigation, fishery environmental water, and nonpoint source pollution control, the Ministry of Health manages the national drinking water safety, while other departments are responsible for different aspects of water use: the Ministry of Transport concerns inland navigation, the Ministry of Housing and Urban-Rural Development is responsible for the construction and management of water supply projects and drainage and sewage disposal projects, the State Forestry Administration protects soil erosion, while the National Development and Reform Commission cooperates with other departments while the comprehensive river basin plans are made (Dai 2012).

Among these departments the Ministry of Water Resources and the Ministry of Environmental Protection play the most important roles. The former is responsible for water resource management with the focus of water quantity management and hydraulic projects across the country; it delegates the management to seven River Basin Commissions which are responsible for the daily administration of water resource management within their own jurisdictions. The Ministry of Environmental Protection is responsible for water quality and the prevention and treatment of water pollution over the country. Corresponding to the distribution of powers between these two Ministries, the local water resource authorities and environmental protection agencies have the same responsibilities within their own prefectures (Dai 2012).

2.2 Legal Framework of Water Resource Management

The Chinese legal system is primarily based on the Civil Law model; the prime source of law is statutes. The National People's Congress is the highest-level legislative body, which is empowered by the Constitution (Article 58). The National People's Congress enacts and amends fundamental national statutes, for example, the establishment, organization, and responsibilities of the National People's Congress, the people's governments, the people's courts, etc. (Ferris and Zhang 2002). The other basic national statutes, like the Environmental Protection Law, the Water Law, the Water Pollution Prevention and Control Law, and so forth, are enacted and amended by the Standing Committee of the National People's Congress (Dai 2015b).

The State Council, as the direct executive authority of the National People's Congress, issues decisions in accordance with the Constitution and other laws. For example, in order to further indicate the implementation of the 1988 version of the Water Law in 2000, the State Council issued detailed rules for the implementation of the Water Pollution Prevention and Control Law. In the meantime, as the highest administrative organ, the State Council also approves and promulgates national administrative regulations (Ferris and Zhang 2002). For example, the Regulation on the Administration of the License for Water Drawing and the Levy of Water Resource Fees is a regulation issued for strengthening water resource management and protection by the State Council.

The Ministries which are directly governed by the State Council have the legal right to make "ministerial regulations" within their areas of competence (Ferris and Zhang 2002) and within the scope of implementing national law, administrative regulations, and decisions or orders issued by the State Council (Article 71). For example, measures for the administration of water abstraction licensing are guidelines issued by the Ministry of Water Resources for implementing the regulation on water drawing licenses and the water resource fee addressed above.

At the provincial level, the provincial people's congresses (and their standing committees) may issue local regulations provided they do not contravene the Constitution, the applicable national statutes, and administrative and ministerial regulations. The provincial people's governments may also issue local regulations provided that they do not contravene any regulations issued by the provincial people's congresses (Ferris and Zhang 2002). The administrative structures in the 34 provinces (including municipalities and autonomous regions) within the country are similar to the central level as the political structure of China is unitary (Dai 2015b).

Since the Open and Reform Policy in 1978, China has promulgated a series of laws and regulations to regulate water management. They cover almost every aspect of water management from strategic planning and water quantity management to water quality control (Peng 2010).

Besides the National People's Congress and the State Council, the Communist Party of China is another principal actor in the field of China's water resources management. It has a profound influence on both the National People's Congress and the State Council. Party policies sometimes are more efficient than formal law.

3 Water Quality Management in Tai Lake Basin: Pollution Control

3.1 Water Challenges in Tai Lake Basin

Tai Lake is the third largest freshwater lake in China. Tai Lake Basin is the subbasin of the Yangtze River Basin, occupies an area of some 36,500 km^2, and extends across multiple jurisdictions: Jiangsu Province (52.6%.), Zhejiang Province (32.8%), Shanghai Municipality (14%), and Anhui Province (0.6%). As one of the most developed regions in China, with only 0.4% of the land territory but 4.4% of the population, the Tai Lake area produced 10.3% of GDP; per capita GDP in this region was 2.4 times more than the national average in 2012 (Bureau of Taihu Lake Basin Ministry of Water Resources 2011). The lake connects seven large cities across East China, including Shanghai and Hangzhou, which have a population of 23.8 million and 8.8 million, respectively.

Water pollution is the biggest challenge in Tai Lake Basin. The entire lake has suffered from eutrophication since 1993, the most serious crisis coming in 2007 when dozens of centimeter-thick algal blooms covered the entire lake and tap water turned yellow and was foul-smelling. Trans-provincial water pollution problems are persistent issues in this watershed as it extends across three provinces and one municipality (Dai 2014).

The following factors contribute to water pollution in Tai Lake Basin:

- *Industrial development* is the most important contributor. According to the Water Environment Comprehensive Management Plan for the Tai Lake Basin, there are some 2.10 million industries in the Comprehensive Treatment Region of the lake. Of this total, around 1.04 million are in Jiangsu Province and 1.06 million in Zhejiang Province; 0.56 million of these industries belong to the six major pollution industries (textile industry, manufacture of paper and paper products, petroleum processing and coking and nuclear fuel processing industry, manufacture of raw chemical materials and chemical products, manufacture of medicines, and manufacture of chemical fibers), which also contribute significantly to the economic development in the region (Dai 2014).
- *Diffuse source water pollution* is another main contributor to water pollution in the Tai Lake Basin. If the total nitrogen (TN) and the total phosphorus (TP) – two main pollutants in diffuse agricultural pollution – had not been included in the evaluation of the water quality, most of the surface water in Lake Tai would have reached Class III. However, when the TN and TP are taken into account, the

water quality drops to a level worse than Class V, especially in Jiangsu Province. This diffuse pollution is attributed to agriculture – 40 percent of which originates from aquaculture since the lake is most famous for hairy crab and its "three whites": white shrimp, whitefish, and whitebait (Dai 2014). Land-based agriculture also has been a major contributor to water pollution as farmers, fearful of counterfeit chemicals and paper-thin profit margins, regularly over-apply chemical fertilizer and pesticides (Tai and Ellis 2011).

- *Municipal wastewater discharge* has largely increased in the regions as a result of the tremendous population growth. According to a Nanjing Agricultural University study, between 20 and 30 percent of eutrophication in Tai lake is attributed to municipal sewage. Hans Paerl of the Institute for Marine Sciences at the University of North Carolina estimates that 50 percent of the nitrogen in the lake originates in municipal wastewater (Tai and Ellis 2011). This is not surprising given that 33.5 million people live in the area surrounding the lake. There are 127 functioning sewage treatment plants around the Tai Lake Basin, with a combined capacity to treat three million tons of sewage water everyday (Tai and Ellis 2011).

3.2 The Institutional Arrangements of Water Pollution Control in Tai Lake Basin

According to the Water Law, China shall manage water resource by integrating river basin management with administrative management. The fact that multiple causes and transregional nature of water pollution in Tai Lake Basin makes for a great challenge in terms of integrated water resource management in the region. There are several factors involved in the integrated management in Tai Lake Basin, i.e., the Tai Lake Basin Authority, the East China Environmental Supervision Centre, and three main provincial-level governments (Jiangsu, Zhejiang, and Shanghai).

The *Tai Lake Basin Authority* was set up by the Ministry of Water Resources in 1984 to perform water resources coordination and management in the Tai Lake Basin. Its main tasks include:

1. Supervision of the implementation of the Water Law and the law on conservation of water and soil.
2. Water resources development strategy and long- and mid-term planning.
3. Overall water resources management.
4. Overall management of the rivers, lakes, estuaries, and wetlands.
5. Flood control management.
6. Resolution of conflicts among the provinces and municipality.
7. Measures on conservation of water and soil.
8. Review of relevant feasibility studies and design reports.
9. Management of relevant water resources engineering works.
10. Guidance to relevant work in rural and urban water resources management.

However, when it comes to water pollution control, its function is very limited. The *Water Resources Protection Bureau* of Tai Lake Basin, which is jointly guided by the Ministry of Water Resources and the Ministry of Environmental Protection, performs the responsibility of monitoring water quality in trans-administrative areas and reporting to the Tai Lake Basin Authority. However, neither the Water Resources Protection Bureau nor the Tai Lake Basin Authority has the legal power to regulate polluting activities or punish the polluters. These institutions can only provide the monitoring data to the Ministry of Environmental Protection and relevant local governments in the Basin. Ironically, the local governments often rely on their own monitoring data, and therefore, the data provided by the Water Resources Protection Bureau is not always taken into account by the local governments. Arguably, such parallel monitoring creates a great deal of administrative resource waste (Dai 2015a).

The former *Ministry of Environmental Protection* (merged into the Ministry of Ecology and Environment in 2018) was the sector administration responsible for water quality and the prevention and treatment of water pollution. The *East China Environmental Supervision* is a regional agency of the Ministry of Environmental Protection in Tai Lake Basin, established in 2002. This agency is vested with the authority to supervise and inspect the enforcement of national environmental laws and regulations on behalf of the Ministry of Environmental Protection. It focuses on major cross-provincial and river basin issues of environmental protection and emergency events. However, it can neither take any substantial environmental administrative decision – to regulate, reward, or punish – by itself nor mediate as an independent actor between the Ministry of Environmental Protection and the provincial governments. It is not allowed to take any significant action without prior approval of the Ministry of Environmental Protection, and it has no substantial competence as to the environmental issues under investigation by the Ministry of Environmental Protection. Furthermore, it is not allowed to interfere with the environmental protection duties of provincial governments or their responsible departments. As a consequence, it seems very much like a regional information-gathering and consultative agency of the Ministry of the Environmental Protection (Huan 2011).

According to the laws and administrative regulations, the relevant departments of local governments above the county level are in charge of the administration of environmental protection issues in their respective administrative regions. In the case of Tai Lake Basin, three main governments of Jiangsu, Zhejiang, and Shanghai take care of water quality of Tai Lake Basin in their own administrative regions, respectively. The internal institutional arrangements of these governments are not much different from the State Council. This means that, in common with the State Council, a number of sectors are involved in the water resource management within these regional governments, and on this regional level, we find, again, the so-called multi-headed dragon. Although water quality is the main responsibility of environmental protection departments, cooperation with other departments is, of course, necessary as water quality is inseparable from other water issues such as water quantity, irrigation, and sanitation, etc. All in all, the fragmentation of competences is high and has been identified to be the primary weak point in China's institutional arrangement by previous research (Dai 2015c). The lack of effective coordinating mechanisms has produced multiple conflicting policies and is a major reason for poor results in both national and regional water management.

Effective coordination is also missing with regard to interregional water conflicts which typically occur in catchments like in Tai Lake Basin where waters are shared by several administrative regions. Local governments tend to be inward-looking and regard each other as economic competitors since the Open and Reform Policy in 1978. This is why local governments tend to exploit their local environmental resources and national safeguards are needed in order to ensure sustainable cooperation and a "level playing field" in terms of environmental protection. However, in this regard the Chinese system provides only few formal mechanisms for inter-jurisdictional cooperation or interest-bargaining between administrative units (Moore 2014). As mentioned above, in the case of water pollution control in the Tai Lake Basin, the Tai Lake Basin Authority is not provided with substantial powers to regulate interregional water issues and curb trans-administrative pollution. Instead, local governments are still playing the main role in water pollution control.

Altogether, the abovementioned institutions are creating a complicated governance system for the Tai Lake Basin. However, the central government has long been aware of this, and many efforts therefore have been made to improve the administrative arrangements as will be reported in the following section.

3.3 Legal, Policy, and Project Instruments in Tai Lake Basin

The following legal, policy, and project instruments have been adopted in order to streamline the governance system and provide better policy coordination:

- *Organizing joint meetings*. In order to control water pollution in the basin, an interprovincial/ministerial joint meeting mechanism was set up by the National Development and Reform Commission in 2008; it has taken place six times up to date. Its round of participants may include parties from the regions around the lake and the entire basin. The tasks of the joint meetings may include studying and discussing key issues of water management; coordinating management activities among regions, departments, and agencies; and strengthening joint enforcement and supervision (Shen and Min 2016). The joint meetings provide institutional support to address the water problems at the basin level; however, they do not imply organizational changes.
- *Setting uniform quality standards in trans-administrative areas*. Quality standards have significant importance as a means of environmental regulation and providing the abovementioned level playing field as a safeguard against contra-environmental competition. In order to enforce this important instrument, a circuit issued by the Ministry of Environmental Protection requires that neighboring provinces shall implement the same water quality standards in their border regions. The provinces involved shall negotiate and make a joint decision. If this

fails, the Ministry of Environmental Protection is competent to set the standards (Ministry of Environmental Protection 2008).

- *Total pollution load control*. Tai Lake Basin Authority is responsible for establishing – together with the water departments of the governments of Jiangsu, Zhejiang, and Shanghai – the pollutant carrying capacity of the lakes and watercourses in the Tai Lake Basin and to put forward suggestions as to restrictions of the total pollutant discharge to the above departments. These departments, on the basis of the national water quality objectives, give full consideration to the suggestions, make plans for the reduction and control of total discharge of major water pollutants, and assign the control to all cities and counties in the Tai Lake Basin. The Ministry of Environmental Protection will then evaluate the relevant governments based on the accomplishment of the assigned quotas. This system of total pollution load control is not only a means to control and reduce water pollution in the basin but also provides a useful tool to divide and evaluate responsibilities between the relevant provinces.
- *Eco-compensation program*. To control diffuse pollution in Tai Lake Basin, the State Council introduced a special regulation (2011) requiring the local governments to take measures such as “constructing an ecological protection forest within a 500-metre area around the shoreline of the lake, a 1,500-metre area around the drinking water source protection zones, and within a 200-metre area along both of the river banks of the shore of the lake” (State Council 2011). It also requires the local county governments to “provide subsidies for farmers whose income has decreased or whose expenditure has increased due to efforts for the reduction of pesticide and fertilizer use” (Dai 2014). This instrument however has not shown immediate effectiveness due to the fact that the diffuse polluting sources in the region are complex, i.e., besides the excessive pesticides and fertilizer usage, intensive aquaculture and domestic sewage also contributed greatly to the pollution. They are, however, not totally covered by this program. Furthermore, existing research has shown that the compensation amount from the government is usually not sufficient to cover the potential loss of the targeted farmers (State Council 2008).
- *Adjusting industrial structure*. Jiangsu, Zhejiang Province, and Shanghai have upgraded their industrial structure since 2008 when the “General Planning of Integrated Water Environment Management in Tai Lake Basin” was issued by the State Council. The emission standards of 13 main industries and paper industries in this region are set stricter than in other regions in view of the serious industrial pollution in the Basin. Jiangsu Province has supported environmental-friendly industries as its strategic emerging industries, which have a total yield of 1.4 trillion Chinese Yuan in 2010 (State Council 2008). However, since these emerging industries are at an early stage of development, the heavily polluting industries such as textiles, chemicals, and metallurgic industry still play the main role, and therefore, industrial water pollution in Tai Lake Basin is still pressing.
- *Water transfer from the Yangtze River to Tai Lake*. Using the Yangtze River water to improve water quality and to reduce the risk of algal blooms in Tai Lake is a project initiated by the state in 2002. The transfer of freshwater from

a comparatively clean source to a more polluted water body is pursued as an effective emergency countermeasure to enhance water exchange, dilute polluted water, and improve water quality. Since 2007, around 5.3 billion cubic meters freshwater have been transferred into Tai Lake from Yangtze River in order to prevent water scarcity in the Lake and maintain the regional water cycle (State Council 2008). However, the effects of this water transfer on nutrient concentration are still debated.

- *Public participation*. Jiangsu Province has initiated environmental roundtable meetings since 2006. Participants were from four cities in the trial period, covering major industries such as chemical, dyeing, power generation, and manufacturing. Although the roundtable meetings could not solve all the environmental issues, they did provide communication platforms for stakeholders and opportunities for the public to engage in dialogues with the government, corporations, experts, and media. However, this roundtable mechanism could only play a limited role in the basin scope as it has only taken place within one administrative region but not at the basin level.

3.4 Section Summary

Water pollution is the main challenge in water management and governance in the Tai Lake Basin and mainly caused by industrial, agricultural, and domestic pollution. The existing governance structure seems insufficient to deal with the multiple and transregional causes mainly because of the high – vertical and horizontal – fragmentation of competences and a lack of effective coordination mechanisms. Some new institutional arrangements have been established in more recent times by either the central government or the local agencies in order to enable better coordination and cooperation of the involved agencies and regions. According to the General Planning, significant achievements have been made in controlling the water pollution especially in industrial sources in the basin, too. However, the water pollution situation remains critical as heavily polluting industries still play a main role in the region, and diffuse pollution becomes more serious (State Council 2008).

4 Urban Water Resource Management in Wuhan: Sponge City Program

4.1 Water Challenges in Wuhan

Wuhan is the capital city of Hubei Province, with a population of just under 8.5 million. It is located in Central China, where Yangtze River and Han River intersect. The urban core is divided into three parts by the Yangtze River and the Han River:

Wuchang, Hankou, and Han Yang. The city occupies a land area of 8500 square km^2, most of which is plain and decorated with hills and a great number of lakes and pools (the water surface area in total was 2117 square km^2 according to the statistics in 2014). The city enjoys the reputation of the "River Town" and the "City of Hundreds Lakes." The abundant water resources have created many development opportunities for Wuhan, but also brought many problems, such as waterlogging issues in the city and water pollution from the urbanization and economic activities (Dai et al. 2017).

The expansion of Wuhan and the expected effects of climate change are increasing the risk of floods in the city. Due to rapid urbanization, the natural wetland area in Wuhan decreased by 18.71 and 50.3% from 1987 to 2005, respectively (Cheng and Zhou 2015; Xu et al. 2010), although the lake surface increased slightly afterward. Wuhan is located in a floodplain area (Jianghan Plain). According to the Asian Development Bank, a weather trend for Wuhan is seeing a significant increase in precipitation due to the climate change. However, Wuhan has yet to take the more frequent and severe climate change impacts, especially increased precipitation, in the planning and design of its urban drainage and flood control program (Asian Development Bank 2013).

Water pollution is also a considerable issue in Wuhan. According to the municipal Water Resource Bureau, 4 out of 11 rivers did not meet the prescribed standards of water quality in 2014 (Yu and Yu 2015). The reasons were that these river areas were historically designed as "discharge control areas" with intensified drain outlets. Incompletely treated industrial and domestic sewage is discharged to the Yangtze River and Han River via these areas. Besides point source pollution, nonpoint source pollution is also serious in Wuhan since the new district invests heavily in agriculture with heavy use of pesticides and fertilizers (Dai et al. 2017).

Wuhan is also vulnerable to water supply shortage. The city is among the few fortunate cities in China that currently have adequate water resource, with 100% coming from the Yangtze River and the Han River. However, climate change has led to runoff reduction in the Yangtze River catchment, and the watershed of the Han River catchment has been experiencing higher frequencies of consecutive years of drought (Asian Development Bank 2013). The city, with its total reliance on these two rivers, is actually vulnerable due to the climate change in terms of water supply.

In the light of the existing issues – flooding, pollution, and water supply shortage risks – the municipal government of Wuhan has decided to build a "Sponge City" (discuss below), and it gives first priority to waterlogging and nonpoint source pollution control supplemented by rainwater collection and reuse.

Table 1 Water-related organizations and their functions before 1998

Name of organizations	Functions and responsibilities
The Wuhan Water Conservancy Bureau	Rural water conservancy construction in the municipal area including reservoir, pumping-station, irrigation, water-soil conservation, embankment in the rural area
The Wuhan Flood Control Headquarters	Flood control and embankment construction in the urban area
The Wuhan Public Utilities Bureau	Water supply, the protection of potable water sources
The Wuhan Municipal Infrastructure Bureau	Urban rain and sewage water drainage and their relevant facility construction, waterlogging mitigation
The Wuhan Mineral Resources Bureau	Groundwater management

Source: Du (2010), p.84

4.2 Institutional Structure and Policy of Water Management in Wuhan

The institutional structure of water management in Wuhan had experienced a large transformation from 1998 to 2001. Before 2001, it was highly fragmented similar to the situation in the Tai Lake region. The turning point happened in 1998 when the central government put forward a new guideline on the water control of the Yangtze River which includes increasing land for reforestation, returning farmland for forestry, resettling people out of river courses to new areas, returning farmland to lakes and rivers, reinforcing main embankments, and dredging the main river courses. These guidelines also required more cooperation among different organizations at the local level. In this context, Wuhan water management initiated institutional reforms in 1998, and its reorganization was finished in 2001 (Du 2010) (Table 1).

The *Wuhan Water Affairs Bureau* was established in 2001; it took over the responsibilities of four former organizations: the Wuhan Water Conservancy Bureau, the Wuhan Flood Control Headquarters, the Wuhan Public Utilities Bureau, and the Wuhan Municipal Infrastructure Bureau. The main task of the Wuhan Water Affairs Bureau is to manage the water resource in Wuhan City in a holistic manner. Therefore, it is in charge of the city's water supply, drainage, and sewage treatment as well as the management of the city's rivers, dikes, lakes, and reservoirs. The water conservancy work in rural areas and the organization and coordination of farmland water conservancy construction are also within the responsibilities of the Water Affairs Bureau. However, water quality issues remain in the competence of the environmental protection sectors.

The *Wuhan Lake Protection Regulation*, issued in 2002, was revised in 2015. The Regulation requires a joint meeting mechanism to protect the lakes in Wuhan and allocates responsibilities to different sectors. As to the use and protection of the lakes, the Regulation proclaims that "the planning shall be unified, the management shall be regulated by law, the treatment shall be integrated, and the usage shall be based on scientific evidence." This Regulation also establishes an eco-compensation mechanism which provides compensation for people who must sacrifice their benefits from the legal usage of the lake, for example, by giving up the fishing farms. It also encourages the public to participate in the lake protection activities. The Regulation is playing an important role in water management in Wuhan.

Another important regional regulation is the "Wuhan Water Resource Protection Regulation" of 2011. This Regulation is the first local regulation to correspond to the national requirement of "Three Red Lines" (cap control) in 2011, i.e., a red line of water resource development and use, a red line of water use efficiency, and a red line of the total amount of pollutant emissions into rivers and lakes. To implement these Three Red Lines, the Regulation established a new responsibility system, which requires the government officials to take personal responsibility for the implementation. As a part of this system, their performance will be evaluated and administrative sanctions may be imposed if they fail to implement the regulations or to complete the assigned tasks appropriately.

4.3 Sponge City Program

The "Sponge City Program" (SCP) is a new program launched by China's central government. The Sponge City concept is aimed at substantially improving the cities' capability to manage rainwater and prevent flooding in a sustainable manner. It includes integrated appliances of diverse technologies and multifunctional infrastructures for effective drainage, storage, evaporation, treatment, and reuse of rainwater as is discussed in detail in the technical part of this volume. Today, the central Chinese government attaches great importance to the SCP. In order to foster implementation of Sponge City technologies, it issued a "Guiding Opinion" earlier in 2015, which urges cities "to comprehensively take various measures to minimize the influence of urban development and construction on ecological environment via the construction of sponge cities." A major target is to consume and use 70% of rainfall locally. Besides this target, the Opinion sets out the timelines for implementation, i.e., over 20% of urban built-up area should achieve the target requirements by 2020 and over 80% by 2030 (State Council 2015).

Wuhan is one of the pilot cities approved by the central government. When initiating the local SCP, the government of Wuhan, as stated above, gives priority to the issues of waterlogging and nonpoint source pollution prevention and control, and supplemented by rainwater collection and reusing. Specifically, the city will focus on improving toward "sponginess residential districts, public buildings, green infrastructures and roads, building sewerage pipelines and pumping stations, repairing the ecological water systems, and establishing a special monitoring platforms for the SCP" (Dai et al. 2017).

The municipal government of Wuhan, based on compulsory standards, laid down five targets for the SCP in two demonstration areas at the current stage, i.e., Qingshan District and Sixin District. The municipality aims that, by the end of 2017:

- Management of rainwater will achieve the national advanced level.
- Water quality of the city will be effectively improved.
- Anti-waterlogging standards and management level will be enhanced.
- The ecological system of the city will be effectively protected.
- The entire process management of the SCP, i.e., source control, process management, and end-of-pipe treatment, will be established.

All these five targets are supplemented by technical standards in a special implementation plan issued by the municipality. This plan also allocates the responsibilities of the related departments (see Table 2).

Besides allocating the responsibilities, the municipality also provides technical and institutional support for the SCP. For example, it issued the Wuhan Technical Guidelines for the SCP Planning including the preparation of work, special research, and technical constancy of the SCP construction as well as the establishment of two monitoring platforms for the SCP in demonstrative areas. In order to enhance the cooperation and collaboration between the related departments, the municipal government set up a "Headquarter of Pilot Project for Construction of Sponge City in Wuhan," the office of which is attached to the Water Affairs Bureau of Wuhan City. It also provides a coordination platform as a forum to discuss the "major policies and import decisions of the SCP" ("Implementation Plan on Pilots of Sponge City Program in Wuhan City" of 2016). Moreover, the district governments where the SCP demonstrative areas are located are required to set up Task Forces to coordinate and implement the pilot construction of the SCP (Dai et al. 2017).

The municipal government planned to invest 16.3 billion RMB in total in 455 pilot SCP projects within the two demonstrative areas during the year 2015 to 2017. Besides the subsidies from the central government, the municipal government is required to invest 400 million RMB, and the district governments where the pilot projects are located are required to invest no less than 100 million RMB ("Implementation Plan on Pilots of Sponge City Program in Wuhan City" of 2016; see Dai et al. 2017).

The municipal government established a subsidy policy for nongovernmental investment of SCP construction taking October 1, 2015, as a reference time. The investor who initiated the SCP project by social capital before October 1 will get 30% of the total investment amount as the governmental subsidy and 15% if after the time. The government encourages the PPP model of investment and promotes the participation of the social capital via various means, for example, using government purchase of services to repay the loan of local government financing platforms (act as a vehicle to provide off-balance sheet quasi-fiscal support for local governments) and taking advantage of the national supporting polices of SCP to get long-term loan from the bank. Furthermore, the Municipal Planning Bureau and the

Table 2 Responsibilities allocation of SCP in Wuhan

Departments	Responsibilities
Water Affairs Bureau	Daily administrative work of the Wuhan Headquarter of Pilot Project for Construction of Sponge City
Municipal Construction Commission	Comprehensive coordination, supervision on the process management of the pilot SCP
Municipal Development and Reform Commission	Researching on investment channels and mechanisms, integrating the pilot SCP into investment planning of the municipal infrastructure construction, coordinating with other departments
Municipal Planning Bureau	Integrating the pilot SCP into municipal urban and rural planning, coordinating with other departments
Municipal Finance Bureau	Coordinating with the Water Resource Bureau on drafting the SCP funding management methods and the measures of sanctions and incentives
Municipal Gardening and Forestry Bureau	Researching and drafting technical standards of landscaping and greening on pilot SCP
Municipal Department of Environmental Protection	Monitoring and bulletining the water quality of the SCP pilot areas
Municipal Meteorological Bureau	Establishing the platform of storm monitoring and early warning, collecting relevant information in pilot areas
Municipal City Management Committee and Housing Management Bureau	Specifying the management responsibilities of public buildings, roads, and residential districts in SCP pilot areas
Municipal Supervision Bureau	Monitoring the performance of other departments on the implementation of SCP regulations and assigning responsibilities according to law
Legal Office of Municipal Government	Coordinating with Water Resource Bureau to issue SCP-related regulations
Commission for Assessment of Municipal Government	Managing process and performance evaluation in the SCP pilot areas
Pilot Projects District Government	Implementing the SCP-related tasks and regulations in their corresponding administrative areas
Municipal Propaganda Department	Social propaganda and public opinions report

Source: Adopted from Dai et al. (2017)

Municipal Gardening and Forestry Bureau are required to give financial priority to the SCP when reviewing and approving the city planning (Dai et al. 2017).

The government encourages research on theory and application of the construction technology of the SCP and set up “Wuhan Sponge City Construction Technology Alliance” for technology research and extension. Furthermore, the governments at all administrative levels of Wuhan City (more specifically, the Department of Propaganda) are responsible for enlarging the publicity of the SCP, which aim to deepen the public understanding and encourage the public participation of the SCP.

One risk of the SCP is that it requires massive infrastructure investment; it requires an investment of 100 million to 150 million RMB for each square kilometer under development (Wei 2015). This large amount of required funding will pose great challenges to Wuhan. For example, the city has planned to invest 16.3 billion RMB into its SCP, besides the direct financial support from governments, i.e., 500 million RMB from the central government, 400 million from the municipal government, and 200 million RMB from the (two) district governments, respectively; there is still around a 500 million gap, which needs to raise the social capital.

4.4 Section Summary

Water management in Wuhan gives high priority to waterlogging, storm-water management, water pollution, and water shortage. In order to facilitate integrated management and development of the urban water systems Wuhan Municipality has allocated the responsibilities for SCP implementation to many different departments. However, the success of the SCP still depends on cooperation between the various departments (Dai et al. 2017).

Wuhan has strongly committed to implement the Sponge City concept in order to its waterlogging and pollution issues under the guidance of the national Sponge City Program (SCP). The municipality has issued special regulations and provided various means of institutional and financial support for the project. It is however hard to evaluate the effectiveness of these efforts since the project is still not yet finished.

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German Water Protection Law with a Particular Focus on Waste Water Management

Wolfgang Köck

Abstract This contribution provides an overview about the German water protection law and about the legal strategies and instruments for water management. The analysis also includes the legal European approaches to water management and their relevance for the German legislation. The report emphasises the legal framework for waste water disposal which is laying down in federal and Länder law.

1 Introduction

The German Federal Water Act (*Gesetz zur Ordnung des Wasserrechts/Wasserhaushaltsgesetz*, WHG) integrates aspects of water management, water protection and flood protection/prevention. It contains regulations on the management of water resources (surface waters, groundwater, coastal waters), on the protection of waters against pollution, on the public tasks of (drinking) water supply and on the treatment of waste water as well as flood protection. It lays down competences, empowers the executive to establish certain concretising arrangements in the form of ordinances, grants powers to intervene to the competent authorities, establishes obligations as well as requirements and prohibitions and provides legal instruments for action.

Historically, water legislation in Germany has always been a matter of the Federal states (*Länder*) so that all Federal states have their own water legislation. Over the last decades, however, the competences of the Federation (*Bund*) have grown significantly (see B. below) so that a strong trend towards standardisation is noticeable. Requirements under European law intended to protect water (see D. below) contributed to this trend of standardisation.

The following report focuses on waste water regulations (G. to H.) but places them within the context of German water legislation in general (E. and F.) and considers the division of powers and responsibilities between the Federation and the

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Federal states (B. and C.) as well as European regulations, which now have considerable impact on German water legislation (D.).

2 The Division of Legislative Competences Between the Federation and the Federal States in the Field of Water Legislation

2.1 Historical: The Framework Competence of the Federation

Until the so-called federalism reform, i.e. the 2006 reform of the German Basic Law (*Grundgesetz*, GG) that changed the division of competences between the Federation and Federal states, the Federation only had limited legislative powers in the legislative field of water (= protection and management of water resources). It was only allowed setting a general framework but apart was dependent on the Federal states to legally concretize and implement its framework regulations. This complex and time-consuming legislative technique had become a problem given the increasing Europeanisation of water legislation, because the implementation of European legislation required legislation not only at the Federal level but also at the level of all 16 Federal states.

2.2 After the Reform of the Federal System: Concurrent Competences of the Federation but Limited Rights to Enact Laws at Variance on Part of the Federal States

By being granted concurrent powers, the Federal legislator was given the possibility of regulating the subject matter of water comprehensively. There is no longer any need for water legislation at the state level as far as the Federation has made use of its powers comprehensively. However, the Federation's increase in competence in the field of water management was only achieved by a constitutional compromise. This compromise is based on the fact that, following the reform of federalism, the Basic Law grants the Federal states limited rights to enact legislation at variance in the area of the management and protection of water resources (Article 72(3)(5) GG), i.e. the Federal states may adopt regulations which contradict Federal provisions (Degenhart 2010). However, this right to enact laws at variance is not comprehensive but restricted: Art. 72(3)(5) GG excludes 'regulations related to materials or facilities'. The latter fall into the core competences of the Federation and thus do not allow for deviation (Ginzky and Rechenberg 2006; Gawel et al. 2011). So far, the Federal states have used the right to enact laws at variance only to a very limited extent or in very specific areas so that the basic concept of Federal law is not affected.

The Federation made use of its new legislative competences by revising the Federal Water Act (*Wasserhaushaltsgesetz*, WHG) in 2009. The new Federal Water

Act now contains directly applicable regulations, which replace current state regulations. The Federal Water Act, however, does not regulate all aspects of water management and protection but also contains references to state law, authorises the Federal states and also entails gaps so that state water legislations, which in the meantime have almost completely been adapted to the new legal situation, will continue to exert significant influence in future—beyond any possible enacting of regulations at variance.

2.3 Federal Waste Water Legislation as a Regulation that Does Not Allow Deviation by the Federal States

Since regulations related to materials or facilities are excluded from the derogation rights of the Federal states, the latter may only issue regulations in this area, if the Federation has not yet used its competence conclusively.

‘Related’ to materials or facilities are all regulations that address the effects of materials or facilities on the water balance, e.g. the introduction of substances. (preamble, see Bundestagsdrucksache 16/813)

Accordingly, regulations under waste water legislation belong to in particular such materials and facility-related regulations. Hence, the Federal legislator’s concept of waste water legislation cannot be changed by the Federal states. Whether it can be supplemented depends on whether Federal law is ‘conclusive’ or whether it has left regulatory leeway to the Federal states.

3 The Division of Enforcement Competences Between the Federation and the Federal States

According to Art. 83 GG, the Federal states principally execute Federal laws within their own responsibility. Although the Federation also has its own administrative bodies, specialised administrations are still very much concentrated at the state level. Accordingly, Federal regulations are implemented by state authorities. Federal authorities are included in the implementation of statutory provisions only to the extent that they are involved in the ‘Bund/Länder-Arbeitsgemeinschaft Wasser’ (LAWA; Federation/Federal State Working Group Water). In this working group, basic procedures for the implementation of legal provisions are coordinated, current enforcement problems are discussed, and (nonbinding) guidelines for the implementation of legal provisions are developed.

The Federal Government exercises oversight to ensure that Federal laws are executed by the Federal states (Art. 84(3) GG). However, the Federal Government does not have any authority to issue directives in the field of water management. If the Federal Government takes the view that a Federal state does not implement Federal law properly, and the deficiencies are not remedied by the respective state, the Federal Government may submit an application to the Federal Council (*Bundesrat*) to determine a violation of Federal law (Article 84(4) GG). However, this procedure has not yet been used in the field of water management—as far as is apparent.

4 European Legal Requirements for Waste Water Legislation

The European Union has established a number of water-related regulations, which, however, are mostly of a very specific nature. The most important requirements under European law, particularly with regard to the handling of waste water, are elaborated in more detail below.

EU legislation takes precedence over the legislation of the Member States (priority of European law). The EU Member States are legally obliged to transpose European legal requirements into their respective national law.

4.1 Water Framework Directive (WFD)

With the WFD of 2000, the EU created a uniform legal framework for the management of waters aiming to achieve certain water status objectives. A quality-oriented (immission-related) approach is characteristic of the WFD (Epiney 2013): Art. 4 WFD stipulates that surface waters (including transitional and coastal waters) and groundwater must be managed in such a way as to maintain a good water status[1] or to reach the latter by the end of 2015. What determines a good water status is, for example, specified in the Annexes to the WFD (Annex V WFD) but also in so-called daughter directives, such as the Directive on Environmental Quality Standards or 'priority substances' (Directive 2008/105/EC amended by Directive 2013/39/EU) or the Groundwater Directive (Directive 2006/118/EC). Under strict conditions, the WFD allows the extension of deadlines for achieving objectives (Art. 4(4) WFD) and the definition of less stringent (Art. 4(5) WFD) or deviating objectives (Art. 4(7) WFD), respectively.

The EU Water Framework Directive does not limit itself to setting quality targets but also defines management-independent obligations, such as the obligation to respect the principle of recovery of the costs of water services, including environmental and resource costs (Art. 9 WFD),[2] as well as the obligation to apply the so-called combined

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[1] Here, a distinction is made between the chemical and the ecological status of surface waters and coastal waters. For groundwater bodies, the WFD differentiates the chemical and the quantitative status.

[2] It is controversial whether Art. 9 WFD solely serves to achieve the environmental objectives outlined in Art. 4 WFD or whether it has management-independent functions beyond; for more details, see Gawel et al. 2014a.

approach, i.e. to take account of the emission standards of certain other provisions under European law (Art. 10 WFD), irrespective of whether these emission standards are necessary for achieving good water status. Notwithstanding the existing water quality, emission standards that must be adhered to also include emission-related requirements set out in the Council Directive on Urban Waste Water Treatment (Article 10(2)(c) WFD), which are particularly important for residential water management.

Regarding quality-oriented management, the WFD requires the Member States to conduct water management at the level of river basin districts, which have be determined according to hydrological criteria—accordingly, they do not necessarily coincide with state territory—and to allocate the respective water bodies to the corresponding river basin districts (Art. 3(1) WFD). Within a river basin district, all management, protection and improvement measures must be spatially and substantially coordinated (Art. 3(4) WFD) (Köck 2013), and river basin-related management plans and programmes of measures must be established (Art. 11 and 13 WFD) (Faßbender 2014; Raschke 2014). The WFD explicitly also states that the Member States have to determine in each river basin district those water bodies that are currently and in future required for drinking water supply (Art. 7 WFD). The programmes of measures have to meet specific substantial requirements (basic and possibly supplementary measures, Art. 11(3) and (4) WFD). For example, measures have to be established for achieving and safeguarding the requirements for drinking water (Art. 11(3)(d)), and for point source discharges that can cause pollution, approval requirements must be laid down (Art. 11(3)(g)). Such measures usually require action by the legislator and are not to be legitimised solely by the plan and plan-providing authority (Köck 2013). The WFD also breaks new ground in the field of public participation by determining that the public is to be involved in the planning of objectives and measures (Art. 14 WFD). The Directive expressly requires the Member States to promote the active participation of interested parties in the establishing, reviewing and amending of management plans (Art. 14(1) WFD).

The objectives and tasks of the WFD pose major challenges (BMU 2010a; European Commission 2012; European Commission 2014; Holzwarth 2005; Köck 2009; Köck 2012; Durner 2010; Reinhardt 2013) to EU Member States and Germany in particular, which —if at all— can only be mastered if extensive use is made of the possibilities of derogating. The WFD affects water supply and waste water disposal in numerous ways.

4.2 Directive on the Treatment of Urban Waste Water (Directive 91/271/EEC)

In the 1990s, Directive 91/271/EEC on the Treatment of Urban Waste Water of 21 May 1991 was the most extensive water protection Directive. It established requirements for the collection, treatment and discharge of domestic and industrial waste water thereby also taking run-off rain water into account. The requirements include, among others, the obligation for all ‘agglomerations’ to collect domestic and industrial waste water by means of a collection system and treat it, respectively, within a particular period of time (i.e. the end of 2000 or 2005 respectively); the implementation process takes the size of the respective settlement (‘population equivalent’) into account and moves from smaller to larger settlements. In addition to physical or chemical treatment (‘primary treatment’), biological treatment (‘secondary treatment’) is mandatory, which has to meet certain standards (Annex I, Part B) and prescribes concentration values (emission ceilings) for certain parameters. Only for less sensitive areas, the Directive deems a primary treatment sufficient under certain conditions (Art. 6). To be identified by the Member States by the end of 1993, waste water treatment in ‘sensitive areas’ needs to meet standards that exceed secondary treatment (Art. 5(2)). The Directive also established requirements for the reuse of sludge (Art. 14) and for industrial waste water (Art. 13) not subject to municipal waste water treatment plants. From a formal point of view, the Directive establishes authorisation requirements for the discharge of waste water into water bodies (Art. 11). In Germany, the requirements of the Urban Waste Water Directive were only transposed into national law by the 1997 Waste Water Ordinance (*Abwasserverordnung*)—4 years later than stipulated by European law. This was not only due to differing views on the requirements of implementing European into national law (ECJ 1996 C-297/95) but also to substantial problems in adapting national standards to the new European conception (Breuer 2003a). The requirements of the Urban Waste Water Directive are still applicable in the European law and have not been replaced by the Water Framework Directive.

4.3 Industrial Emissions Directive (Directive 2010/75/EU)

The 2010 Industrial Emissions (IE) Directive (Directive 2010/75/EU) further advanced the 1996 Directive on Integrated Pollution Prevention and Control (IPPC) (Directive 96/61/EC revised by Directive 2008/1/EC). The Directive introduces environmental requirements for the construction and operation of industrial plants in specific sectors and of specific sizes (all installations subject to the obligations of the Directive are listed in an annex). It pursues the aim of an integrated prevention and reduction of environmental pollution caused by such plants, using the so-called BAT standard (best available techniques), which must be determined in a complex process. All emissions from industrial plants are recorded, i.e. emissions that are released into the air as well as emissions that enter water and soil. The BAT standard is intended to ensure that the prevention and reduction process is integrated, that is, that there is no shift in pollution from one environmental medium to another but that the overall best ‘environmental performance’ is achieved.

Germany struggled to implement the IPPC Directive as the predecessor of the Industrial Emissions Directive, since Germany pursued a different concept, namely, the concept of the normative concretisation of emission standards by establishing emission limits for installation-related emissions into air and water. Accordingly, in the negotiations on the IPPC Directive, Germany emphasised the fact that the concept of normative concretisation (as opposed to a case-by-case approach) is also anchored in the IPPC Directive and the IE Directive, respectively. These negotiations were successful. Germany can therefore continue to apply the concept of normative concretisation (i.e. sector-specific general-abstract standardisation as opposed to establish standards in an individual case) for so-called IPPC systems. For waste water emissions, this means that Germany can use the standards of the Waste Water Ordinance as starting point for IPPC installations. This approach makes implementation considerably easier, because the Waste Water Ordinance establishes concrete standards for a large number of industrial sectors—so that standards no longer have to be decided on a case-by-case basis.

5 The Development of Water Protection Legislation in Germany

5.1 Management Rules Under Public Law

The WHG has established a management system under public law, which in principle subjects all water use (with the exception of minor use—'common utilisation') to a permission granted (Arts. 8, 68 WHG). The Act lists as use, among other things, the abstraction and draining off of water from surface waters, the damming and lowering of surface waters, the introduction of substances into waters and the abstraction and channelling and draining off of groundwater (Art. 9(1)(1), (2), (4) and (5) WHG). The approval of such uses is at the management discretion of the state (Art. 12(2) WHG). In the application of its water management discretion, the competent authority shall comply with the management objectives laid down by European water protection legislation, in particular the Water Framework Directive (Art. 12 in conjunction with Art. 3(10) and Arts. 27, 44, 47 WHG). Water management must therefore be carried out in such a way that a good status of the water can be achieved within certain time limits (requirement of improvement)[3] and, in any case, no significant deterioration of the existing state occurs (prohibition of deterioration).[4] The management discretion is usually exercised by means of the management planning and the programme of measures required under European law (Arts. 82 et seq. WHG). These plans prepare, among other things, individual decisions at the implementation level. Only if a management problem has not been addressed by a management plan, now required by the European Commission, management discretion is exercised at the level of the concrete individual decision—as has been customary practice (Hasche 2005; Köck et al. 2010).

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[3] In the case of significantly altered water bodies, management is less demanding; here, it is sufficient to gear the management in such a way as to achieve a 'good ecological potential'.

[4] For the interpretation of the prohibition of deterioration (ECJ 2015 C-461/13; Franzius 2015)

5.2 The Compliance with Emission Standards as a Minimum Requirement for a Waste Water Discharge Permit ('German Precautionary Concept in Water Legislation')

In addition to the management requirements (see 1. above), the WHG requires that a permit for discharging waste water into a waterbody (direct discharge) may only be granted, if the quantity and the harmfulness of the waste water are kept as low as possible when applying state-of-the-art technology (Art. 57(1)(1) WHG). How the state-of-the-art is defined, and how it is to be distinguished from other standards, is outlined in Sect. 7.2 in more detail.

The Act authorises the Federal Government to lay down requirements for the discharge of waste water, which correspond to the technical state-of-the-art (concept of so-called normative concretisation). This has been done by the Federal Government through the so-called Waste Water Ordinance, which currently sets emission standards for 57 different economic sectors (Umweltbundesamt 2010). The sector-specific definitions of pollution standards and the resulting emission standards for direct dischargers ('point sources') are a very important reason for the fact that the chemical quality of water bodies in many areas is now considered to be good. Germany has not changed this policy even under the Water Framework Directive but demands state-of-the-art pollution levels as minimum requirement from any waste water discharger, regardless of whether a good water status has already been achieved or not. The European Water Framework Directive took account of the German concept in so far as it adopted the so-called combined approach (quality-oriented river basin management, on the one hand—emission-oriented point source regulation, on the other) (see Art. 10 WFD).

5.3 Quality Objectives (Immission Standards): The Impact of the WFD

It has already been pointed out that the so-called quality-oriented (immission-related) approach has been introduced into German law by the European WFD: surface waters (including the transitional and coastal waters) and groundwater bodies are to be managed in their respective river basin districts in such a way that a good state of the waters[5] is maintained or will be achieved by the end of 2015. Only severely altered or artificial water bodies are subject to less stringent targets. The same applies when exceptional conditions exist (Art. 4(5) and (7) WFD).

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[5] With regard to surface and coastal waters, a distinction is made between the chemical and ecological status. For groundwater bodies, the WFD differentiates the chemical and the quantitative status.

With regard to the good status of all surface waters, the WFD distinguishes between their chemical and ecological status, regarding groundwater between the chemical and quantitative status.

Quality objectives need to be concretised in order to ensure uniform action by the competent authorities in river basin districts. At the European level, for surface waters (Directive 2008/105/EC of 24) and for groundwater (Directive 2006/118/EC), limits have been defined for priority substances by means of so-called daughter directives and have now been transposed into national legislation (Groundwater Ordinance of 16 November 2010; Laskowski 2011). For further pollutants, limits have been established at the national level in Germany.[6] This means that concrete normative requirements (usually limit values) are available, which the competent authorities need to take as yardstick for their action, in particular with regard to the chemical water status.

Unlike a good chemical status, a good ecological status cannot be determined by European-wide quantified limits but requires applying at the river basin level the complex reference and classification system of Annex V of the WFD. In order to ensure a similar course of action across river basin districts, an EU-wide 'intercalibration process' has been launched under the so-called CIS process (CIS = common implementation strategy), the purpose of which is to ensure consistency among the status classes of the respective water body typology (CIS-Hintergrundpapier 2015). For the specific pollutants listed under Point 1.1.1 in Annex V of the WFD—which are registered if they were discharged in significant quantities and are significant for the ecological status—it is in principle not planned to set European-wide limits, because these pollutants are not necessarily of particular relevance European-wide but rather for the respective river basin. For these specific pollutants that are of relevance to river basins, national environmental quality standards are therefore to be defined by the Member States themselves (Kern 2010). This has happened in Germany at the state level.[7]

6 Important Control Instruments in German Water Protection Legislation

6.1 Approval Requirements for the Use of Water

The most important control instrument in German water management and water protection legislation is the compulsory approval of water use. Water may only be used (beyond minor use) if an official permission has been granted. Giving the

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[6] The Groundwater Directive obliges the Member States to set their own limits for eight specifically listed additional pollutants. Germany met this obligation (Umweltbundesamt 2011).

[7] See, e.g. the state of Hesse: statutory ordinance for the implementation of the Water Framework directive, Annex 4 (GVBl. I 2005: 382). Annex 4 contains environmental quality standards for more than 130 substances.

respective authorisation is at the water management discretion of the competent authority. The management discretion is fundamentally shaped by management plans (see 5. below).

6.2 Waste Water Levy and Water Abstraction Charge

In addition to the regulatory requirements, a uniform waste water levy has been charged for more than 30 years in accordance with the Waste Water Levy Act (Abwasserabgabengesetz – AbwAG 2005 BGBl. I: 114). The waste water levy depends on the harmfulness of the waste water (Art. 3(1) AbwAG), which is assessed on the basis of certain parameters,[8] and its concrete amount is principally determined on the basis of the discharge permit ('permit solution') (Art. 4(1) AbwAG).

The waste water levy is an instrument motivated by environmental economics and based on the polluter pays principle; it allows to charge a polluter for the economic resource costs of waste water discharge. It is based on the economic concept of 'demeritorisation', i.e. charging in the interest of a general reduction in utilisation without a defined target, and is levied for the residual pollution, which remains in spite of the adherence to pollution levels stipulated by regulatory provisions (Gawel et al. 2014b). In addition to its basic goal of demeritoring, the waste water levy also pursues other purposes. For many years, the support of regulatory implementation was key (Breuer 2003b), because the direct discharger, which is liable to pay, can halve its financial burden if it complies with regulatory requirements, that is to say waste water treatment according to the state-of-the-art (Art. 9(5) AbwAG). In the interim, this specific steering function has lost its significance as a result of a wide range of investments in waste water treatment; thus, interested parties demand nowadays to abolish the levy since its goal had allegedly been attained (Nisipeanu 2006). However, such demands ignore the basic concept of the waste water levy. At present, there is intensive discussion about a revision of the waste water levy (Palm et al. 2013). A recent research report commissioned by the Federal Environmental Agency (UBA) provides important arguments for such an endeavour and supports the strengthening of the levy's steering function (Gawel et al. 2014). The levy revenue is allocated to the Federal states and is designated to be used for tasks of water protection.

Under state legislation, a water abstraction charge is levied for the abstraction of groundwater and surface water in 11 of the 16 Federal states (Gawel et al. 2011).[9] The Federal Constitutional Court regarded the levying of this charge as constitutional, because the abstraction of water involves a special partaking in a common good whose benefits are capable of being levied (BVerfGE 93, 319: 345; Gawel

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[8] Art. 3 AbwAG lists oxidisable substances, phosphorus, nitrogen, organic halogen compounds, certain metals (mercury, cadmium, chromium, nickel, lead, copper) and toxicity to fish eggs.

[9] At present there is no abstraction charge in Bavaria, Hesse, Rhineland-Palatinate, Saxony-Anhalt and Thuringia.

et al. 2011). The charge revenue is used for payments to the agricultural sector in order to compensate for the financial losses resulting from the particularly restricted agriculture in water protection areas.

Both levies, the waste water levy and the water abstraction charge imposed on the basis of state legislation, must not be confused with the collection of charges for drinking water and waste water. The latter are levied for a concrete supply or disposal service and are oriented at the economic costs of service provision (see for more details Part I. below).

7 Waste Water Legislation

7.1 The Concept of Waste Water in German Water Protection Legislation

Under Federal law, the term ‘waste water’ is defined by the German Federal Water Act (WHG). Art. 54(1) WHG states:

> Waste water is
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> 1. water changed in its properties by its domestic, commercial, agricultural or other use in addition to the water (foul water) that runs off with the former during dry weather, as well as
> 2. the water that after precipitation runs off from built-up areas or sealed surfaces (run-off rainwater).
>
> Dirty water from installations for the treatment, storage and disposal of waste shall also be considered as waste water.

According to German law, therefore, waste water is not only dirty water but also run-off rainwater (‘storm water’), as far as it gathers on built-up and sealed surfaces, e.g. roads (e.g. via gutters or rainwater canals), and runs off. With the inclusion of run-off rainwater, the legislator reacted, among other things, to the problem that rainwater carries a considerable amount of pollutants acquired on building roofs and roads.

For run-off rainwater, Art. 55 WHG stipulates that it should be allowed to seep away locally, to trickle away or to be lead into a body of water directly or via sewers without it being mixed with contaminated water, in so far as this violates neither water legislation nor other provisions of public law or water management. If run-off rainwater mixes with waste water in the sewage system, it needs to undergo treatment before it is lead into a body of water.

7.2 The Basics of German Waste Water Legislation

In addition to the management provisions and, in particular, the general provisions for the granting of user authorisations (Art. 12 WHG), the WHG requires that a permission for discharging waste water into water bodies (direct discharge) is only admissible, if the amount and harmfulness of the respective waste water is kept as low as is possible given that state-of-the art technology (= German BAT-standard) is used (Art. 57(1)(1) WHG) and given that waste water treatment plants are installed and operated to ensure compliance with these requirements (Art. 57(1)(3) WHG). Art. 60 WHG requires furthermore that waste water treatment plants are to be constructed, operated and maintained in such a way that the requirements for waste water disposal are met. As far as waste water treatment plants requiring authorisation are concerned, they must also satisfy the technological state-of-the-art. For facilities not subject to authorisation, they must be constructed, operated and maintained in accordance with commonly accepted technical rules (Art. 60(1) WHG).

The 'state-of-the-art' (BAT) is defined in Art. 3(11) WHG as 'the state of development of advanced processes, establishments or modes of operation which is deemed to indicate the practical suitability of a particular technique for restricting emission […] altogether'. Annex 1 to the WHG also contains criteria intended to help determine what the respective state-of-the-art is.[10] With the reference to the-state-of-the-art and its implementation in emission limits, the legislation on waste water has been consistently adopting a precautionary approach[11]—one of the great achievements of German water legislation—since 1996 (Köck 2012; Ruchay 1988).

With its 'state-of-the-art' standard (BAT standard), the German waste water legislation exceeds European legislation, which has so far applied BAT obligations only to the scope of the IPPC Directive (now: Industrial Emissions Directive). The normative concretisation of such a state-of-the-art requirement in the Waste Water Ordinance (AbwV) is legally not constitutive, because the state-of-the-art can also be determined in the individual case. However, since the Waste Management Ordinance states what the legally binding state-of-the-art for waste water sources is (Czychowski and Reinhardt 2014), effective enforcement depends on the further development of administrative concretisations in the AbwV.

A state-of-the-art (BAT) exists when technical solutions have been tested 'in experimental and pilot plants to such an extent that it guarantees a sound operation at the technical level and at the large scale' (Feldhaus 1981: 165, 169). A treatment method for waste water that is technically advanced in such a way that its practical use can be regarded as safe but that is exorbitantly costly given its contribution to improve water quality/environmental pollution is not 'state-of-the-art' in the legal sense.[12] A complete cost-benefit analysis of the respective treatment technology is

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[10] The list of criteria is based on European law and derives from the Industrial Emission Directive. Annex 1 of the WHG states: 'When determining the state-of-the-art, the following criteria in particular shall be taken into account, with due consideration for the fact that the benefits of potential measures are proportionate to the input, together with the principles of prevention and precaution, each with reference to installations of a certain kind: […]'. Subsequently, 13 different criteria are listed, among others, 'comparable procedures, equipment and operating methods which have been successfully tested under operating conditions'.

[11] See the sixth WHG (BGBl. 1996 I: 1690). The fifth WHG amending law of 1986 already included such approaches but used the state-of-the-art only partially and not comprehensively as a yardstick (Breuer 2003b).

[12] See also Annex 1 (ad Art 3(11)) to the WHG, which explicitly refers to considerations about the 'proportionality between costs and benefits of possible measures'.

legally not necessary, since state-of-the-art requirements do not presuppose an absolutely positive cost-benefit balance, but a relative assessment based on the cost-effectiveness of the waste water treatment procedure. Before this backdrop, state-of-the-art waste water treatment is always a precautionary measure, the costs of which may not be disproportionate to the benefit of the treatment measures.

Whether cost-effectiveness is given is anyway subject to executive discretion—in any case, if the powers to concretise under Art. 57(2) in conjunction with Art. 23(1)(3) WHG are used.

The Federal Government as regulatory authority can issue concrete requirements on the basis of the-state-of-the-art in the form of technical specifications or emission specifications. Reduction rate requirements are also an admissible means of concretisation. Before the backdrop of the principle of proportionality, it must be borne in mind that a specific technical specification involves a stronger intervention than the definition of an emission standard or a reduction rate, since a technical specification does not permit to choose a respective means.[13] Monitoring requirements depend on the chosen concretising concept (technical specifications or emission specifications). In the case of technical specifications, it is possible to work with assumptions about treatment performance or residual contamination assuming that the respective technology is installed, properly used and maintained periodically.

7.3 The Standards of Waste Water Disposal in German Waste Water Legislation

7.3.1 The Concept of the Waste Water Ordinance: Setting Emission Standards and Treatment Standards for Different Sources of Waste Water

The WHG authorises the Federal Government to lay down specific requirements for the discharge of waste water that meet the-state-of-the-art (Art. 57(2) in conjunction with Art. 23(1)(3) WHG). The Federal Government used these powers in the Waste Water Ordinance (AbwV) (BGBl. 2004: I: 1108, ber.: 2625; as last amended by Article 6 of the Implementing Directive on industrial emissions BGBl. 2013 I: 973) which contains general requirements (Art. 3 AbwV), analytical and measuring procedures (Art. 4 AbwV and Annex 1) and specific emission standards for different sources of waste water in its 57 annexes.[14]

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[13] It is a common opinion that a means chosen by a state norm or by a legislative act is only required if the purpose of the means is not to be achieved by another, equally effective means which does not, or less, restrict the law in question (Sodan and Ziekow 2012).

[14] The appendices range from the sources of domestic and urban waste water (Annex 1) to very different industrial sources, such as brown coal briquette production (Annex 2), milk processing (Annex 3), fish processing (Annex 7) or breweries (Annex 11).

Applying to all waste water sources, the general requirements include unless otherwise specified in the specific annexes the obligation that the requirements may not be achieved by processes which, contrary to the-state-of-the-art, cause pollution to other environmental media (Art. 3(2) AbwV) and that required concentration limits may not be achieved by dilution contrary to the-state-of-the-art (Art. 3(3) AbwV). Art. 3(5) AbwV also states that for waste water for which requirements have been established for the site of its occurrence, a blending of respective waste water streams is only permissible, if these requirements are met. Such requirements can be found in the waste water-related regulations of the annexes to the Waste Water Ordinance. To the extent that waste water is to be introduced into public waste water plants and requirements related to the source area of the waste water have already been established both for the site of its origin and before its blending with other waste water in the respective annex,[15] a so-called indirect discharger permit is required that allows preventive checks of whether these requirements are met (Art. 58(1)(1) WHG).[16] By dint of ordinance, the conditions can be stipulated under which authorisation may be waived, and a mere notification procedure may be sufficient (Art. 58(1)(2) WHG). At the Federal level, these powers have not been used so far so that, according to Art. 23(2) WHG, the Federal states are authorised to enact respective regulations. However, based on previous state ordinances for indirect discharging or state legislation, the Federal states have in part developed other regulatory approaches, such as Saxony, which takes as starting point the fictitious approval and considers indirect discharger permits as granted under certain conditions (Art. 53 SächsWG).

In addition to indirect discharging requirements, which are intended to help ensure that problematic waste water[17] entering public sewage systems is pretreated in a certain way, Annex 1 of the Waste Water Treatment Ordinance is of particular importance for the waste water treatment in municipalities. Annex 1 lays down the requirements for domestic and urban waste water and specifies specific emission limits for chemical oxygen demand (COD), the biochemical oxygen demand in a 5 day-period (BOD5), ammonium nitrogen (NH4-N), nitrogen total (Nges) as well as phosphorus total (Pges) for the site waste water is discharged into a water body; for waste water treatment plants of size category 1–2, only parameters for COD and

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[15] Exemplary are, for instance, Annex 13 (wood fibre boards), Annex 18 (sugar production), Annex 19 (pulp production) or Annex 20 (processing of animal by-products).

[16] Based on the concept of legal framework provisions, the old Federal Water Act gave the Federal states the responsibility to regulate waste water discharges into public sewage systems (Art. 7a(4) WHG old version). In most states, approval requirements exist for the discharge of waste water into public waste water treatment plants and in NRW also for the discharge of waste water into private waste water treatment plants. Even today, in most states, regulations for indirect discharges remain in place—either in the form of special indirect discharge ordinances (Baden-Württemberg, Berlin, Brandenburg, Hesse, Mecklenburg-Vorpommern, Saxony-Anhalt, Thuringia), in state water or waste water acts (Bavaria, Lower Saxony, North Rhine-Westphalia, Rhineland-Palatinate, Saarland, Saxony, Schleswig-Holstein, Hamburg) or in communal drainage legislation (Bremen).

[17] For the substantive reasons of the requirements for direct dischargers (Nisipeanu 2004)

BOD5 are established; for sewage treatment plants of size category 3, additional parameters for NH4-N have been introduced.

Annex 1 applies to waste water which mainly originates from households or similar facilities (e.g. office buildings, hospitals, restaurants) and also to other waste water collected in sewer systems or treated in river waste water treatment plants (Annex 1, Part A AbwV). Industrial waste water is also part of the field of urban waste water, when it is collected in sewage systems provided that the harmfulness of the waste water can be treated by means of biological treatment processes with the same effect as in the case of domestic waste water (Annex 1, Part A no 3 AbwV).

In addition to provisions for the treatment of domestic and urban waste water, the Waste Water Ordinance also contains provisions for 56 other industrial sectors, so that the licencing and monitoring authorities can refer to specific standards for approving and monitoring procedures easing implementation. If, on the other hand, a waste water source does not fall within the scope of application of one of the 57 listed waste water sources, the necessary waste water treatment according to the state-of-the-art must be determined in the individual case.

7.3.2 The Obligation to Observe the State-of-the-Art When Setting Emission Standards

As already outlined in part G.2., the Federal Government is obliged to observe the state-of-the-art in determining requirements on the quantity and harmfulness of waste water. The state-of-the-art is also defined in part G.2. The 'state-of-the-art' obligation for the treatment of waste water exists in Germany since 1986. It replaced a previous provision in force since 1976, which made waste water treatment subject to commonly accepted technical rules. By referring to 'commonly accepted technical rules', a lower technical standard is implied; since 'commonly accepted' are only those technical rules that have already been tried and tested in practice and have been adopted by the vast majority of practitioners (BVerfGE 1978 49, 89: 135 et seq.). The 'state-of-the-art', on the other hand, is a much more ambitious standard, since it refers to 'advanced procedures' that, however, have to have already passed a practice test.

Commonly accepted technical rules are nowadays only of significance in the construction, operation and maintenance of waste water facilities (Art. 60 WHG).

Whether the Federal Government has observed the 'state-of-the-art' or 'commonly accepted technical rules' in establishing requirements can be subject to judicial review.

7.3.3 The Significance of Technical Standards in Waste Water Legislation

Technical standards are standards which usually have been developed by private organisations for the purpose of standardising procedures and products. Technical standards are not legal norms; they can only become legally binding, if the legislator refers to a technical standard in legislation (parliamentary statute or ordinance). In addition, technical standards may provide orientation for legislation. This is especially the case when the law imposes requirements according to ‘commonly accepted technical rules’ but does not specify concretising regulations. In such a situation, technical standards, such as the technical guidelines of waste water associations like the DWA (*Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall*) or the DVGW (*Deutsche Vereinigung für das Gas- und Wasserfach*), become increasingly important, because they are potentially appropriate to indicate what ‘commonly accepted technical rules’ are.

German waste water legislation refers to technical standards in several respects. In the AbwV, reference is made to certain DIN-standards, DIN EN-standards and DIN EN ISO-standards for analytical and measurement methods referred to in Art. 4 AbwV. These standards are the standards of national (DIN), European (EN) and international (ISO) standardisation organisations. However, in Art. 60 WHG, the legislator refers to commonly accepted technical rules for certain waste water plants but does not establish any further concretising rules so that the guidelines of the DWA, DVGW and other trade associations are to be considered in order to develop concrete requirements.

The statutory reference to technical standards that have been developed by standardisation organisations or trade associations, the German study of environmental law sees as an example of the cooperation principle in environmental law. It disburdens the legislator of the task to establish detailed regulations; but the legislator must point to a respective technical standard when it wishes to refer to them. This reference must always be static, i.e. refer to a specific technical standard at a certain point in time, and must not be applied dynamically, i.e. include all further developments of this technical standard. If there are no such clear references, the technical regulations—as already mentioned—only work as guidelines.

7.3.4 Obligation to Dispose of Waste Water in Accordance with Tasks Allocated Under Länder Law

According to Art. 56 WHG, waste water disposal is the responsibility of those legal persons under public law who are obliged to do so under state legislation. In the state water acts, this task is (see, e.g. § 50 SächsWassG) usually delegated to municipalities or established special purpose associations under public law (see, for instance, Art. 51 SächsWassG), which develop waste water disposal concepts for their disposal area having to take into account the river basin-related management plans (see, for instance, Art. 51 SächsWassG).

Art. 56 WHG authorises the Federal states to determine the conditions under which others are responsible to meet the obligation to discharge waste water. State water legislation regularly excludes waste water that has been allowed to be discharged into a water body under water legislation from the public obligation to dispose waste water (see, for instance, Art. 50(3)(4) SächsWassG). That is to say, whoever discharges its waste water directly into a water body and has a permit which can only be obtained if waste water treatment according to the-state-of-the-art has been demonstrated does not have to leave its waste water to the municipalities for disposal. The same applies to rainwater which can be used or seep away on the site on which it occurs (Art. 50 (3)(2) SächsWassG).

The municipal ordinances decreed by the Federal states allow the municipalities or special purpose associations obliged to dispose waste water to mandate compulsory connection to and usage of public sewers on the basis of statutes (Art. 24(1)(2) BayGemO; Art. 11 GemO B.-W.; Art. 9 GemO NRW; Art. 14 SächsGemO), whereby Art. 55(1)(2) WHG determines that the public good can also be satisfied by disposing domestic waste water via decentralised facilities. The municipalities therefore need to examine whether compulsory connection and usage correspond to the public good or whether, in individual cases, decentralised solutions are permissible (Laskowski 2012).

Looking at the waste water management structures in Germany, central water supply and waste water disposal facilities dominate: 99 per cent of households in Germany are connected to the public water supply and 95 per cent of households are connected to sewers and municipal waste water treatment plants (BMU 2010). It remains to be seen whether decentralised solutions will gain in importance under the pressure of demographic changes. Even today, in the sparsely populated parts of the Federal territory, the question is not only about whether the municipality needs to dispose centrally or decentrally, respectively, but also about the conditions under which individuals have the right to resist compulsory connection and usage and to seek more cost-effective individual (decentralised) solutions (Laskowski 2012).

The municipality or special purpose associations obliged to dispose waste water are permitted to use third parties to fulfil their obligations, i.e. to commission private companies (Art 56(sent. 3) WHG). However, the guarantee responsibility remains with the authority obliged to dispose waste water, i.e. it must ensure that the tasks are properly performed. In most cases, municipalities establish their own public utility companies (*Eigenbetriebe*) for this purpose, which are under municipal management.

7.4 Interim Conclusion: Waste Water Legislation in German Federalism

In Germany, waste water legislation is exhaustively regulated by Federal law. The Federal legislator left only a few regulatory areas to the Federal states. This applies in particular to the question of who is obliged to dispose of waste water and which obligations individual households are under for the transfer of waste water.

In Germany, centralised disposal structures dominate, i.e. waste water is centrally collected by municipalities or special purpose associations, respectively, forwarded, treated and discharged into water bodies in a treated state. Decentralised waste water treatment plants that are not connected to sewers concern only 5% of households.

Waste water legislation is essentially independent of various forms of water uses, that is, the stipulated duties apply independent of the water statuses in the individual parts of river catchment areas and are therefore part of a precautionary strategy for water protection.

8 The Financing of Waste Water Disposal

The financing of waste water disposal is usually regulated by the municipal tax laws of the Federal states (Kommunalabgabengesetze). They stipulate that in order to fulfil their obligation to dispose waste water, municipalities are allowed to levy charges from those who have to leave their waste water to the municipality (so-called charges for the use of the public sewer system and for the construction and operation of waste water treatment plants). The charges must be such as to cover the costs of sewer operations including maintenance costs and the costs of waste water treatment in waste water plants. Charges are usually based on a mixed calculation, which split all costs among all users.

Insofar as waste water treatment has been delegated to private companies, which do not operate as public utility companies, services are priced. Since waste water disposal (just as drinking water supply) is a so-called natural monopoly, prices are subject to regulatory oversight under antitrust legislation to ensure that the monopoly cannot be exploited at the expense of the users.

9 Summary

1. In Germany, the Federation has comprehensive legislative competences in the field of water resources (= management of water in qualitative and quantitative terms: water management and protection against water pollution) since the 2006 federalism reform, and it used it by revising the Federal Water Act (*Wasserhaushaltsgesetz*) in 2009. However, and also since the 2006 federalism reform, the Federal states may also deviate from Federal law and adopt their own regulations. However, this does not apply to all matters of water law. Regulations related to materials or facilities, e.g. regulations on waste water treatment, are not allowed to deviate. This ensures under constitutional law that these matters are regulated consistently throughout the entire Federal territory. In the regulatory areas that do not allow deviations, the states are also prohibited to adopt further (stricter environmental) regulations.

   The Federal Water Act contains a series of provisions that empowers the Federal Government to issue statutory ordinances like, for instance, in the field of waste water legislation. This allows the Federation to issue very detailed regulations.

2. German water legislation is now significantly influenced by European water legislation. The most important standards for water protection under European law are the Water Framework Directive (2000) with it's "daughter directives" on Quality norms for surface water (2008/2013) and on groundwater (2006), the Directive on Urban Waste Water Treatment (1991), the Drinking Water Directive (1998) and the Industrial Emissions Directive (2010).
3. Federal regulations under water legislation (statutory law and subordinate legislation) are implemented by the Federal states as their own matter. The states with their administrative bodies are responsible for enforcement. At the state level, administrative regulations are adopted intended to steer enforcement. Coordination between the Federation and the Federal States about a common interpretation of certain rules takes place in the 'Bund/Länder-Arbeitsgemeinschaft Wasser' (LAWA). However, this body does not take binding decisions but issues recommendations.
4. German water legislation is characterised (1) by a public law management system, (2) by a special precautionary strategy for the discharge of waste water (emission principle) and (3) by (very demanding) quality targets for surface water and groundwater (triggered by European legislation) (immission principle).

    1. (1) The management system under public law ensures that the state decides on access to the use of water. Property does not entitle to the use of water. Any substantial use of water requires state approval. This is important in order to ensure that all enjoy a fair share of water resources in the interest of the common good.
    2. (2) The waste water-related precautionary regime stipulates that the discharge of waste water into a water body is only permitted, if waste water treatment is carried out according to the state-of-the-art (BAT-standard; emission principle). This is a minimum requirement, which must always be met regardless of the status of the respective water body (see no. 6 below).
    3. (3) The statutory definition of quality objectives provides the water management authorities with guidelines for their management. All utilisation processes must be managed in such a way that quality objectives are achieved in due time (immission principle). The objectives are essentially specified by European law and are subject to an adaptation process, in particular via so-called 'daughter' directives of the WFD, such as the 'Priority Substances' Directive or the Groundwater Directive. Only under special legal conditions, deadlines may be extended, objectives reduced, or exceptions permitted.
    4. German water legislation possesses a variety of different legal instruments to manage water use. The most important control instrument is that the use of waters needs permission. In addition, important are the authorisation of state governments to designate water protection areas, legal use restrictions and prohibitions as well as taxation instruments for the management of water use (waste water charge) and for levying the benefits of water use (water abstraction charge). The use of control instruments is conceptually prepared in the

water management planning. The plans are to be developed at the level of river basin districts and need to be amended regularly.

5. In terms of water protection, the most important area of German water legislation is the waste water legislation. According to German law, waste water is not only dirty water but also rainwater (storm water) as far as it comes from the area of built-up or fixed surfaces, is collected and discharged. The ‘pride’ of German waste water legislation is the obligation that all waste water discharges into surface waters must comply with the state-of-the-art for treatment procedures (German BAT-standard). Permits for discharging waste water are revocable at any time. A ‘state-of-the-art’ is to be expected, when technical solutions have been tested in experimental facilities and pilot plants to such an extent that a faultless operation on the technical and industrial scale is guaranteed, while also achieving cost effectiveness. To ensure that the state-of-the-art does not have to be determined in the individual case, German waste water legislation pursues a concept of normative concretisation. The Waste Water Ordinance of the Federal Government has set emission standards, in particular emission limits, for 57 different industrial waste water sectors. This facilitates the work of water authorities, because waste water permits are then easier to issue and can also be designed in a legally certain and efficient manner. The successes of German water protection policy are due in particular to this very effective regulation of so-called point sources.
6. German waste water legislation also encompasses a waste water charge, which is levied against so-called direct dischargers, i.e. against those who have a discharge permit for waste water. The levy is calculated on the basis of the discharge permit taking into account the scale of the respective pollution load. It is intended to compensate for the residual pollution, which still remains despite waste water treatment. In the early years of levying the waste water charge, it was in particular used as an incentive for the accelerated conversion to better treatment technologies, since the levy was reduced by half if the discharger complied with all technical standards required by the respective regulation. However, this specific incentive has nowadays become insignificant. At present, the introduction of a so-called forth treatment stage for micro pollutants is discussed in Germany. In such a context, the incentive mechanism of the levy could become effective again.
7. In Germany, municipalities or special purpose associations under public law, respectively, are responsible for waste water disposal. Through the means of compulsory connection and usage, waste water associations ensure that households and all industrial enterprises that do not have a discharge permit lead their waste water into the sewer of the special purpose association. Insofar as industrial enterprises lead their waste water into the sewer, the special purpose association may issue requirements for the treatment of the waste water as far as the waste water needs such a pretreatment in order to be processed by the waste water treatment plant of the special purpose association. Purpose associations finance waste water disposal by charging for the use of

sewers and for waste water treatment. Since special purpose associations have to pay the waste water levy to the respective Federal state, it may split the cost of the levy among the users of the sewers. The levy is calculated on a break-even basis. Waste water associations are non-profit organisations; they are not allowed to make any financial profits, only to cover their costs.

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Information, Participation and Public Control in Water Management & Water Infrastructure Development: the European and German Perspective

Silke R. Laskowski

Abstract Water governance across Europe is mainly affected by the European Union Water Framework Directive 2000/60/EC (WFD), the key legislative instrument to protect and manage European water resources. The WFD requires EU member states to produce and implement river basin management plans, which are to be designed and updated via participatory processes. According to Article 14 WFD, all interested stakeholders shall be actively involved in order to push the effectiveness of the environmental impact of the WFD. However, 18 years after the WFD's entry into force, 50% of EU waters are still lagging behind the "good status" objective of the Directive. Therefore, implementation shortcomings call for a greater focus on the principles of good water governance, which shall apply to water-related policy areas such as agriculture as well. Ensuring availability and sustainable management of water and sanitation for all is a necessary condition for ending poverty and hunger, improving quality of life and achieving most of the other ambitious goals proposed in the 2030 UN Agenda for Sustainable Development, especially goal 6 (clean water and sanitation).

1 Introduction

Water is among the most threatened resources and the most necessary for humankind and the planet's ecosystems (especially groundwater and major basins), biodiversity and climate. Its proper governance and management is essential, integrating urban and rural areas to achieve sustainable development (food, energy, health, economic activities, urban development, education, gender), human well-being and human rights. Against this background, the idea of public participation has been increasingly integrated into the international and European agenda on natural resource protection and sustainability over the past decades (Razzaque 2009). Public

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participation in water management and infrastructure development concerns the relations between the general public and public interest groups that advocate around ecological issues like water protection on the one hand and national water administration authorities that are in charge of water protection and management on the other hand. Since 2000, when the European Water Framework Directive 2000/60/EC (WFD) entered into force, the legal framework for water protection, water management and public participation has changed in EU member states. Since then water administration authorities have to manage rivers, lakes and groundwater in order to achieve "good status" of all water bodies by 2015 – at the latest by 2027 – which is the main goal of the EU Directive (Article 4 WFD). In this connection, new participation rights of the European public were established in Article 14 WFD, which formalizes and strengthens the public's position. Apart from this, the idea of participation is known on the local level in Germany where municipalities are traditionally in charge of public water supply and wastewater disposal. In this respect, local authorities plan and decide on infrastructure development on the grounds of regional planning law, which includes the aspect of public participation as well, but the basic understanding is different from the WFD. The traditional focus is more on supporting administrative action and less on participation as a democratic means of controlling the accomplishment of tasks of administrative bodies by the local public.

This article will give an overview of different models of participation in European and German law. Moreover it will identify the implications of the WFD for municipalities' water planning regimes and its impact on "good water governance" with regard to the Sustainable Development Goals (SDG) of the 2030 UN Agenda for Sustainable Development (ASD)[1], especially SDG 6, which aims to ensure access to water and sanitation for all. Progress in water management is a pivotal contribution to the global success of most SDGs of the 2030 ASD. Achieving the water targets listed in SDG 6 is crucial for the success of the ASD as a whole.

2 European Perspective: Public Participation According to Article 14 WFD

The European Union's WFD states that all river basins in Europe should be managed using a River Basin Management Plan. The public should be involved in creating this plan, in addition to other established stakeholders including private companies, conservation organizations, farmers, utilities and local government. Therefore water governance across Europe is primarily affected by the WFD and its daughter directives: the 2008/105/EC Environmental Quality Standards Directive[2] amended

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[1] UN resolution adopted by the General Assembly on 25 September 2015, 70/1 Transforming our world: the 2030 Agenda for Sustainable Development, A/Res/70/1.

[2] Official Journal L 348, 24/11/2008, p. 84.

by the 2013/39/EU Directive[3], which contains the latest amendment of the list of priority substances (surface water), and the Groundwater Directive 2006/118/EC[4] amended by Directive 2014/80/EC[5]; these are the key legislative instruments for the protection and sustainable use of European freshwater resources. The WFD changed water management in all member states of the European Union fundamentally, putting aquatic ecology at the base of management decisions, complemented by a participatory planning approach (Newig and Koontz 2014). The legal approach is based on the guiding principle that "water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such".[6]

2.1 Water Management

The key instrument of the WFD is *river basin management*: member states have to identify river basins within their territory and to assign them to "river basin districts" (Article 3 WFD). For the river basin districts, the states have to establish "river basin management plans" (Article 13 WFD) and "programs of measures" (Article 11 WFD).

The aim of river basin management under the WFD is to achieve a "good status" of all surface and groundwater bodies in the European Union until 2015 – exceptionally until 2021, but in any case no later than 2027 (Article 4.4 WFD) (see Albrecht 2013). Specifically, the WFD's goals are to:

- Prevent any further deterioration of the status of waters – decisive is the current "status quo" of a water body[7].
- Achieve good ecological and chemical status for all surface water bodies (rivers, lakes, transitional waters and coastal waters, Article 2 WFD).
- Achieve good quantitative and chemical status for groundwater and progressively reduce pollution from a range of substances that are classified in the WFD as presenting significant risks, referred to as "priority substances". These include pesticides, heavy metals and other organic pollutants.

In addition, *coordinated management* within river basins pursuant to Article 3 WFD is an important element of the Directive, and the member states' water industry has

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[3] Official Journal L 226, 24/03/2013, p. 1.

[4] Official Journal L 372, 27/12/2006, p. 19.

[5] Official Journal L 182, 21/06/2014, p. 52.

[6] First recital in the preamble of the Directive 2000/60/EC

[7] European Court of Justice (ECJ), Judgment of the Court (Grand Chamber), 1 July 2015, Case C-461/13 ("Obligation of the Member States not to authorize a project that may cause a deterioration of the status of a body of surface water"); see http://curia.europa.eu.

adapted to this principle.[8] In the past, in Germany, management was based primarily on the political boundaries of regional and local authorities. Therefore, prior to the WFD's entry into force, there was very little uniform management of river basins apart from the work carried out by the water associations and river basin-related planning of certain sub-tasks, such as wastewater disposal (Köck 2015).

2.2 Public Participation

Article 14 of the WFD provides for public participation in the course of the implementation of the Directive and the establishment of the management plans. Of particular note is the *new participatory approach* in Article 14 WFD, which requires that *river basin management plans* are to be designed and updated via *participatory processes*. According to Article 14 WFD, all interested stakeholders shall be actively involved early on in order to push the effectiveness of the environmental impact of the WFD. Article 14 WFD states:

1. Member States shall encourage the active involvement of all interested parties in the implementation of this Directive, in particular in the production, review and updating of the river basin management plans. Member States shall ensure that, for each river basin district, they publish and make available for comments to the public, including users:

(1) a timetable and work program for the production of the plan, including a statement of the consultation measures to be taken, at least 3 years before the beginning of the period to which the plan refers;
(2) an interim overview of the significant water management issues identified in the river basin, at least 2 years before the beginning of the period to which the plan refers;
(3) draft copies of the river basin management plan, at least 1 year before the beginning of the period to which the plan refers.

On request, access shall be given to background documents and information used for the development of the draft river basin management plan.

2. Member States shall allow at least six months to comment in writing on those documents in order to allow active involvement and consultation.
3. Paragraphs 1 and 2 shall apply equally to updated river basin management plans.

In particular, Article 14 WFD provides for more transparency of administrative action. In this respect, public participation has been introduced as a tool to improve eco-sustainable resource management and promote stakeholder engagement and more democratic decision-making – a key element of good water governance.[9]

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[8] With regard to *international river basins*, responsibility for coordination should be shared between the participating states. A management plan is to be prepared for each national and international river basin district. Where non-member states are affected, member states should at least aim to achieve a single management plan.

[9] See also OECD (2015). The 12 "must do" principles on water governance were signed by 35 OECD member countries (including all EU member states) and 5 non-member countries, including the People's Republic of China.

Public participation according to Article 14 WFD covers public information and consultation. It calls on member states to promote the active involvement of all interested parties and to inform and consult the general public. This applies, firstly, to the preparation and subsequent updating of management plans. To this end, the timetables and work programmes for the preparation of management plans and an overview of the key water management issues in the river basins have to be published in due time. Later on, the draft management plan has to be published for consultation purposes. Furthermore, upon request, background information and documents must be made available by the competent authorities. The general public should be given an opportunity to submit written opinions at all three stages. The participatory process aims for transparence of the planning process, identification of conflicts and early solutions, enhanced acceptance of the plans, trust between the authorities and those affected by the measures, as well as all other interested stakeholders (see also Boisson de Chazournes 2013). All member states should take Article 14 WFD seriously. As the *EU Court of Justice* emphasized in 2006, Article 14 "is intended to confer on individuals and interested parties a right to be actively involved in the implementation of the directive and, in particular, in the production, review and updating of the river basin management plans".[10]

The *management plan* and the *programme of measures* must be updated at six-yearly intervals. It thus becomes a control mechanism for those involved in river basin management – for competent authorities as well as for the interested public, finally also for the *European Commission*. However, 18 years after the WFD's entry into force, 50% of EU waters are still lagging behind the "good status" objective of the Directive (European Commission 2015).[11] Therefore implementation shortcomings call for a greater focus on the *principles of good water governance* which particularly imply public participation and shall apply to water-related policy areas as agriculture as well. In this regard, *good water governance* would – at the international level – help implement UN Agenda 2030 Sustainable Development Goal (SDG) 6, which aims to ensure access to water and sanitation for all, and furthermore SDG 2, which aims to end food insecurity through sustainable agriculture.

3 German Perspective: Public Participation in Light of EU Law

The legal implementation of the WFD in 2009 into the German *Federal Water Act*, FWA (*Wasserhaushaltsgesetz*- WHG – of 31 July 2009 (BGBl. 2009 I p. 2585), last amended by law of 18 July 2017 (BGBl. 2017 I p. 2771); primary implementation by WHG 2002 was just framework law, due to former German Constitution which

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[10] EUCJ, Case C-32/05 (Commission vs. Grand Duchy of Luxembourg), 30 November 2006, para 80

[11] This report was published in accordance with Article 18.4 of the WFD by the Commission on 9 March 2015.

was changed in 2006 ("federalism reform") and enables fully regulation since then), established new management instruments (§ 82, § 83 FWA implementing Article 11, Article 13 WFD) and led to a consolidation of the idea of public participation in terms of Article 14 WFD (§ 83 (4) and § 85 FWA, see below 3.2). Strong planning instruments combined with strong public participation rights under the WFD and their implementation into member states' law seemed to be promising: by the end of 2009, *River Basin Management Plans* (RBMPs) and *Programs of Measures* had been established for all German river basin districts, and the implementation of the measures was underway. The second RBMPs (2015–2021) were adopted on 22 December 2015 (European Commission 2018).

But the outcome is rather dissatisfying so far. In 2017, the *German Environment Agency (Umweltbundesamt*, UBA) published a report that shows the current status quo of water bodies in Germany (2015/2016) (UBA 2017a, b). However, unexpectedly, the current status is worse than assumed: just 8.2% of all surface water bodies exhibit "good" or "very good ecological status – because of nutrient contamination by industrial agriculture and insufficient structure of water bodies (missing natural habits); also the "chemical status" is overall "not good" – in other words "bad", because of harmful substances like mercury. Therefore, it is assumed that only 18% of all surface water bodies in Germany will reach "good ecological status" by 2021. Regarding the status of groundwater bodies, the report shows that due to excessive nitrate pollution, only 64% of groundwater bodies (used as the main drinking water resource) have "good chemical status". The "quantitative status" is good for 96% of groundwater bodies (UBA 2017a, b). This gives rise to the question of whether better water governance is needed (alike Voulvoulis et al. 2017). In order to answer this question, a closer examination of the legal interplay between water management and public participation may be helpful.

3.1 Water Management

Germany's current *river basin district management plans* were adopted in late 2015 following extensive consultation with water users, various interest groups and interested members of the general public; they were submitted to the European Commission on 22 March 2016.[12] In conjunction with the *programmes of measures*, these plans constitute a water body management framework for the coming years. The plans also provide a binding basis for the relevant authorities in 16 German states and serve as orientation for the general public and water protection and user interest groups. These days, several measures are either in the planning or in the implementation phase. The member states are required to report on their progress in

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[12] For further information, see *EU Commission*, Environment, http://ec.europa.eu/environment/water/participation/map_mc/countries/germany_en.htm. Accessed 2 April 2018.

the implementation of measures at the end of 2018. The third and final management plans and programmes of measures in compliance with the WFD will come into effect in 2021 (2021–2027) (UBA 2016). At the administrative level, *coordination committees* (in terms of Article 3 WFD) have been set up in the relevant river basins which operate on either an informal or a more or less formalized basis (e.g. treaty, administrative agreement), involving the competent administrations (ministries of environment of the German states). The committees are involving the water administrations of neighbouring member states as well, in order to achieve agreements early on and avoid differences of opinion.

Prior to the implementation of the WFD *water resources management*, Germany had a strong tradition of state water policy and governance among the Länder with administrative rather than natural boundaries. Administrative powers were, and still are, clearly divided between the federal government, which sets the binding standards for planning and management through legislation (i.e. the Federal Water Act), and the Länder, which have primary responsibility for water policy (administration). Despite this, *river basin management* was a recognized approach in Germany but mainly practiced in informal administrative initiatives. A joint working group of the Länder (and later the Federal Ministry of the Environment), called LAWA (*Länderarbeitsgemeinschaft Wasser*), was formed in 1956 and produced guidance documents for the harmonization of management of cross-state water resources. LAWA acted as an important coordinating body, providing guidelines for common procedures among the Länder and thus opting for a coordination-based concept over independent river basin authorities. Though this model provided close cooperation among Länder within RBDs, it was common for Länder to develop their own, separate contribution to a joint RBMP. The transposition of the WFD into German law in 2002 indeed instituted a new river basin planning regime, but it did not result in a consequent shift from the status quo, which still remained based on pre-existing administrative structures (see above) (Jager et al. 2016).

3.2 Public Participation

The new participatory approach in Article 14 WFD emphasizes that the general public shall play a major role in the process of implementing the WFD. The idea behind it: including the general public not only raises public awareness of environmental issues and water body status at the local, regional and national levels; it also improves planning and measures quality by public control (see above).

Though the idea of public participation in Germany had become a central principle of public policy-making, the German and the European models of participation are different. The established procedures for public participation in water resources planning in Germany prior to WFD implementation centred around formalized consultation with the public and affected stakeholders and provided only

Basic Forms of Public Participation in Germany

Many forms of participation have been known and tested since the 1970s and 1980s. Most of them emerged from city and regional planning projects. One example is the Federal Building Code (FBC), upon which the local planning process is formulated. Citizens generally have access to the development and implementation of the preparatory land-use plan (Flächennutzungsplan) and the legally binding land-use plan (Bebauungsplan). Participation in urban land-use planning takes place in two stages: the first stage of public participation provides for the public to be informed at the earliest possible date through public advertisement of the general aims and purposes of the plan and of alternative proposals for the reorganization or development of the planning area and of the foreseeable impacts of the plan. At this point, members of the public are to be given the opportunity to express their views and to gain further clarification. The municipality shall obtain comments and opinions also from public authorities and from other public agencies affected by the land-use planning (e.g. Federal and Länder agencies, chambers of industry, churches, environmental associations, etc.). Once all comments have been collected, the municipality elaborates the draft plan. The public but also public authorities and other public agencies have the opportunity to offer recommendations and make objections regarding the plan, which are then to be taken into account in the ensuing weighting of interests. The preparatory land-use plan must be submitted to the superior administrative authority for approval (Section 6 (1) Federal Building Code). This authorization has to be published. The plan is only binding on the municipality. The legally binding land-use plan is formally adopted by the municipal council and has the legal status of a by-law. It is legally binding on the administration and the general public. Formal public participation (Sections 3 (2) and 4 (2) FBC) is needed in the second stage of public participation. The drafts of land-use plans with the accompanying explanatory report are to be put on public display for a period of 1 month. The place and times at which plans may be inspected are to be made public at least 1 week in advance in the manner customary in the municipality (e.g. official gazette, newspaper).

While the main accent in Germany was put on the administrative action and discretion, the European model emphasizes transparency via broad access to administrative documents (“information”) in order to enable the public to understand and to control administrative water planning and measures.

Hence, water management structures in Germany and the WFD’s catchment management requirements showed misfits because effective public involvement was of low priority – the new European approach of public participation was rather considered “alien to traditional water management practices” (Moss 2004; see also Jager et al. 2016).

Article 14 WFD was implemented by § 84 (4) and § 85 FWA. § 85 FWA, which implements Article 14 (1) sentence 1 WFD, uses the term "promoting the active participation of interested bodies", similar to the wording of Article 14 (1) s. 1, but without concretization of the term "promoting". The open and unclear wording of Article 14 WFD and § 85 FWA is not helpful for strengthening effective public participation in reality.

As WFD implementation is primarily a federal state responsibility, there is no overarching framework or common procedure for *participatory river basin management planning*. Neither the amended Federal Water Act of 2002 nor the LAWA established special rules or harmonizing requirements. Nevertheless, a *two-tier system of participation* is rather common among the Länder:

- On the state level advisory boards, affiliated to the respective environmental ministries, were established in 12 of the 16 Länder. Despite their diverse compositions, these boards generally serve as an information platform on WFD implementation procedures.
- On the local subbasin level, *stakeholder involvement in planning* varies widely, ranging from active cooperation (e.g. in "water forums") to relatively restricted information and consultation procedures. In most instances, the subbasin level consists of organized stakeholders that are involved in these procedures rather than the general public (Jager et al. 2016).

More helpful are the specifications under Directive 2001/42/EC which are additionally valid: in the run-up to preparations or modifications of *management plans* and *programmes of measures* according to the WFD, additional requirements concerning public participation stated by the European *Strategic Environmental Assessment Directive* 2001/42/EC have to be considered. The Assessment Directive is a directive in the field of environmental protection, evaluating all those plans and programmes which can produce environmental effects. According to *Directive 2001/42/EC*, the assessment can be applied to plans and programmes edited in different areas, among others ("agriculture, forestry, fisheries, energy, etc.") also "water management". In this regard, especially environmental protection organizations that belong to the "public affected" or the "public having an interest in" (Article 5 Para. 4 Directive 2001/42/EC) – referring to the terms of the *Aarhus Convention*[13] – become relevant. The German Federal Act implementing the Assessment Directive (Gesetz über die Umweltverträglichkeitsprüfung – UVPG – in the version of publication of 24 February 2010 (BGBl. 2010 I p. 94), last amended by law of 8 September 2017 (BGBl. 2017 I p. 3370), correction BGBl. 2018 I p. 472) stipulates the conditions of public participation much more clearly than the Federal Water Act and orders in regard to "strategic environmental impact assessments" which are compulsorily for "plans and programmes" like water manage-

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[13] The United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters was adopted on 25 June 1998 in the Danish city of Aarhus (Århus) at the Fourth Ministerial Conference as part of the "Environment for Europe" process, download http://www.unece.org/fileadmin/DAM/env/pp/documents/cep43e.pdf. It entered into force on 30 October 2001. For recent updates and the follow-up process, see the UNECE Convention website.

ment programmes (§ 82, § 45h FWA) a hearing for consultations in order to discuss, in particular, the arguments of environmental associations (§ 35 (1) No. 1 UVPG in connection with Annex 5 No. 1.4 (§ 82 FWA), No. 1.9 (§ 45h FWA) UVPG).

3.3 Management and Public Participation in Public Water and Sewage Systems

Responsibility for implementing the measures under the WFD is not only connected to the coordination committees and ministries of German states but also to municipalities which are in charge of public water services like water supply and sewage disposal. A closer look at public wastewater disposal reveals that it may affect the quality of surface water bodies and groundwater. Furthermore, regarding the target achievements of the WFD, 96.1% of the German population is linked to the public sewage system; 10 billion cubic metres of waste water per annum is treated in 9307 public sewage treatment plants (2013) (Federal Statistical Office of Germany 2015). In general, municipalities are responsible for wastewater treatment facilities. Almost 100% of public waste water is treated in sewage works going through three purification stages:

- A mechanical stage
- A biological stage without elimination of nutrients such as nitrogen and phosphates
- An additional biological purification stage with specific nutrient elimination

In Germany, it is not permitted to discharge untreated waste water into rivers and lakes, regardless of whether it originates from private households, trade or large-scale industry. Article 57 of the Federal Water Act (FWA) stipulates that pollutants contained in drainage water must be reduced in line with the best available technology. Though past efforts were successful in reducing pollution by wastewater discharge, there is still a problem with the removal of heavy metals. Therefore contamination from rainfall via public storm sewers has to be reduced by municipalities in order to prevent its discharge into surface water bodies (UBA 2017a, b).

The current *river basin management plans* (RBMPs) and *programmes of measures* (2016–2021) emphasize the importance of sewage disposal for reaching the goals of the WFD. Therefore, sewage disposal has been incorporated into the programmes of measures in order to further reduce pollution.[14]

This also has an impact on the question of public participation. Though the idea of water management and public participation regarding wastewater disposal is not completely new to the German water law system, the importance of public participation is. In the FWA of 1957, certain types of water plans were regulated, e.g. the

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[14] For further information about the contents of current RBMPs and Programmes of Measures, see *WasserBlick, Bund/Länder Informations- und Kommunikationsplattform,* http://www.wasserblick.net/servlet/is/156054/Bund/Länder. Accessed 2 April 2018.

wastewater disposal scheme (§ 18a WHG old version), which was cancelled in the FWA 2002. Nevertheless, a few Länder still adhere to that regulation, e.g. Mecklenburg-West Pomerania (§ 40.3 Mecklenburg-West Pomerania Water Law), Saxony-Anhalt (§ 80 Saxony-Anhalt Water Law), Saarland (§ 42 Saarland Water Law) and the Free and Hanseatic City of Hamburg (§ 3 Hamburg Sewage Law in connection with No. 1.1 Attachment 3 of Hamburg Environmental Impact Assessment Act). This is legal as long as the wastewater disposal scheme fits into the superior European planning law of the WFD. However, the wastewater disposal plan was not very effective in the past. One reason for this might be the lack of inclusion of the general public in the preliminary stages leading to the preparation of wastewater disposal schemes. This has to some extent changed. The above-mentioned Länder laws show a tendency to involve at least environmental and conservation organizations. In this regard, Hamburg shows a most consistent law which includes the general public as well – with reference to the European Directive 2001/42/EC on Strategic Environmental Assessment (see above 3.2) which requires effective public participation and is relevant to public participation in connection with the preparation and subsequent updating of management plans according to the WFD.

4 Conclusions and Outlook

The WFD sets serious targets for water quality across the EU, and also ambitious procedural prescriptions, regarding river basin management and participatory planning. In this regard, the WFD can be modelled as a European concept of "good water governance". The assumption was that these procedural requirements would help achieve the substantive goals of the Directive by 2015 or 2021 or at the very latest by 2027. But recent reports by the European Commission show that there is a lack of implementation of effective measures (especially the field of "industrial agriculture" was excluded) – therefore all member states failed to reach the goals in 2015 and will probably fail to achieve the goals by 2021 (see above).

This does not mean that the WFD's concept of "good water governance" is wrong – but it does have to be optimized. Though the idea of participation in the WFD was a pragmatic one – a tool to achieve the environmental goals of the Directive – the increasing involvement of non-state actors has led to a paradigm change, a shift from the traditional expert-led governing paradigm. It might be useful to examine from a comparative perspective not only the procedural and planning adaptations that have taken place but also the different participatory models of river basin management across the member states. Thus the most effective models of participatory governance and integrated water resources management could be identified and implemented in the EU. This could lead to "better water management" in the EU and increase the likelihood of achieving the substantive goals of the FWD at least by 2027. And it could contribute to achieving SDG 6 of the UN Agenda 2030 as well.

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Part VII

Urban Water Governance: Economics and Finance

Economic Policies of Water Pollution Control in the Taihu Lake Basin, China

Yuanchun Zhou and Jun Bi

Abstract In order to control water pollution of Tai Lake Basin, the Chinese government has implemented a series of economic, technological, and industrial policies during the past decades. This study aims to present the achievements and challenges of water pollution control in the Tai Lake Basin, focusing on the economic policies, such as pollution levy, green credit, ecological compensation, compensated use of pollution discharge rights and pollution discharge rights trading, and environmental pollution liability insurance. The results of this study indicate that China has made great progress of policy design and implementation, especially in Tai Lake Basin. These policies have prevented the deterioration of water quality in Tai Lake. At the same time, further improvements of their implementation are still needed in the future.

1 Background of Tai Lake Basin

During the past three and a half decades, China has made significant achievements of economic development, from a typical poor developing country to the world's second largest economy. However, the rapid economic development has significant environmental costs. For example, for the water quality, 36.9% of monitoring sections reported were worse than Grade III (not suitable for drinking), and the primary water pollutants were chemical oxygen demand, total phosphorus, and 5-day biochemical oxygen demand (Ministry of Environmental Protection 2016). In order to control environment pollution and degradation, China has enacted environmental

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protection laws and regulations, including compulsory ones and economic ones in national and local level (Zhu et al. 2015; Zhang and Wen 2008).

The Tai Lake Basin is the third largest freshwater lake in China, located in the southern Yangtze River Delta in Eastern China. Population density in the region is high, about nine times of the national average. 53% of the basin is located in Jiangsu province, with 33% in the Zhejiang province and 14% in the Municipality of Shanghai. Tai Lake Basin is a typical transboundary basin in China and is one of the most developed regions in China. Because of the rapid economic growth and urbanization progress around the Lake, water pollution problem is very serious. The explosion of incident of cyanobacteria in Tai Lake has caused water supply crisis in Wuxi City in 2007 and estimated to cost several percent of GDP (Wang et al. 2010) (Fig. 1).

In order to control the water pollution, Tai Lake Basin has implemented more stringent local environmental protection policies on the basis of the national policies. The ecological environment has been improved since 2007. The intensity of cyanobacteria has weakened, but there are still some gaps to achieve the national governance target in 2020, concentration of total phosphorus and nitrogen are still high, the average water quality continues in mild eutrophication status (Xinhuanet 2017) (Fig. 2).

Besides compulsory policies, many economic policies are innovated and implemented in Tai Lake Basin, which was firstly implemented in the region and then expanded to the whole country, like environmental performance rating and compensation use of pollution emission right. Economic policies are very important for pollution control because it can change the behavior of related stakeholders through market signals rather than explicit directives regarding pollution control levels or

Fig. 1 Location of Tai Lake Basin. (Source: Yuanchun Zhou)

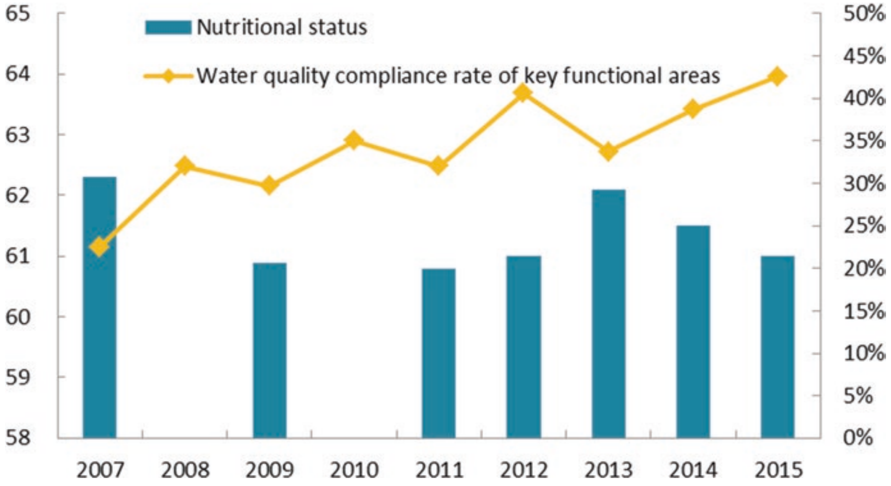

Fig. 2 Water quality of Tai Lake. (Source: Compiled by the authors, data was extracted from Tai Lake Authority 2016, p. 3)

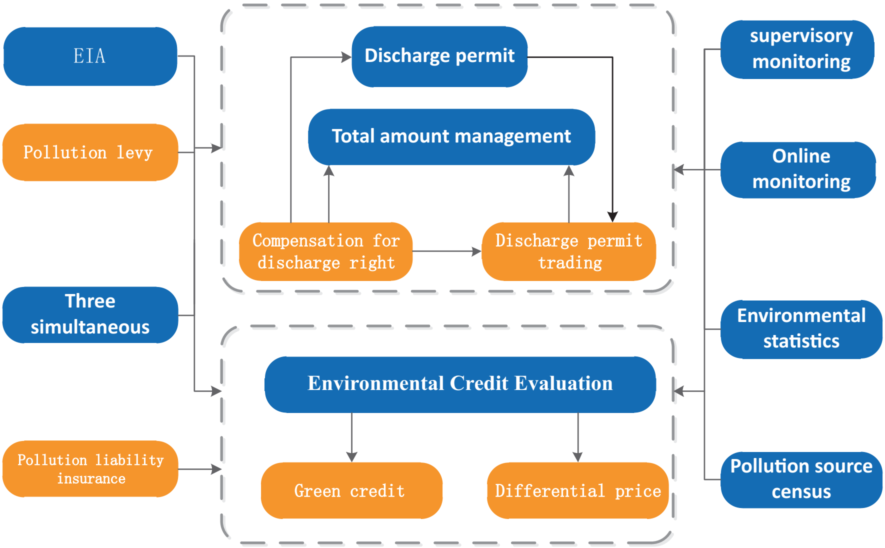

Fig. 3 Main environmental management policies in Tai Lake Basin. (Source: Compiled by the authors)

methods (Maeler and Vincent 2003). At the same time, these economic policies are closely related to other policies, such as environmental impact assessment, total load management, and other control systems. The figure below shows that different policies have very close relationship with each other. For example, firms only can apply for discharge right after their environmental impact assessment has been proved by the government, and after they pay for their discharge right, they can get their discharge permit in Tai Lake Basin (Fig. 3).

2 Enterprise Environmental Credit Evaluation

Environmental credit evaluation policy in Tai Lake Basin is generated from the environmental information rating and disclosure policy in China. This policy is designed to provide the social stakeholders with more understandable environmental performance information, to attract more concerns of the society which can exert more pressures on the laggard enterprises or offer more incentives for the good ones with lower cost (Liu et al. 2010). With the support of the World Bank, China's Ministry of Environmental Protection (previous China State Environmental Protection Administration, SEPA) has carried out pilot projects in Zhenjiang, Jiangsu province, and Hohhot, Inner Mongolia, from 1999. The Chinese national government learned lessons from the pilot program and expanded it to the other regions. In the document "National Planning of Pollution Prevention and Control 2003–2005," SEPA has set up its goal to implement rating and disclosure program based on the experience of Jiangsu province to build up new environmental management instruments, other than compulsory and economic ones. And in 2013, Jiangsu province has further developed this policy and put firms' environmental performance into social credit system. Jiangsu also developed environmental protection credit system construction plan in 2016 (Environmental Protection Department of Jiangsu Province and Jiangsu province social credit system construction leading group 2016).

Industrial firms' environmental credits were evaluated based on 3 categories and 21 indicators: pollution control, environmental management, and social impact. Then firms were ranked into five different colors based on their environmental credit. Black and red denote inferior performances, yellow denotes the compliance with national regulations but failure in certain aspects, and blue and green denote superior performances. The environmental performance rating and disclosure program has been proved to be effectively providing incentives for firm's continuous environmental improvement in China (Liu et al. 2010; Wang et al. 2004). The number of firms that has been evaluated increased from 1059 in 2001 to 26,569 in 2015 in Jiangsu province.

The environmental credit evaluated by the government is an important data source for the implementation of other policies. Jiangsu province has combined the credit policy with insurance policy, permit policy, green credit policy, pollution levy policy, and so on. For example, if a firm has not applied for a discharge permit, its total score will be deducted 20 points. And if the firm has been ranked as black, it will not be able to borrow money from the banks.

3 Pollution Levy

Pollution levy policy is recognized as one of the firstly developed main environmental management schemes in China. The idea of charging pollution was formally adopted by the central government in 1978 and has been stated as "the levy should be imposed on pollution discharges which exceed national pollution discharge standards, based on quantity and concentration of discharges and levy fee schedules established by the State Council" in "Trial Environmental Protection Law" which was enacted in 1979. Since then, China has gradually developed its pollution levy system to a charge on pollution, and almost all the counties and cities have implemented the levy system by now (Wang and Wheeler 2000; Wang and Wheeler 2005). In order to implement the levy policies, the central government has designed related policies, including charging rate setting, collection, collection and use of discharge fees, and so on.

When the levy system was first designed – and until 1993 – levies were only charged for pollution discharges exceeding the legal discharge thresholds. In 1993, this was changed, and since then firms are legally required to pay a per unit fee on specific pollution loads of their discharge also below the legal thresholds. The central government set a minimum rate on specific pollutants, which served as a baseline for local governments' rate setting. Local governments can also charge additional fees for other forms of pollution beyond those that are specified centrally (Wang et al. 2004; Maung et al. 2016). However, an entity that discharges multiple pollutants will not be charged for all these pollutants. Instead, the levy is charged only on the "worst-case" pollutant, which is the pollutant incurring the highest levy liability, from each source (Jiang and McKibbin 2002).

The polluters are required to provide information to the local environmental authorities, including their discharge and other related economic and production information. Based on this information, the environmental authorities can calculate the fee they need to pay. Hence, the information firms provided need to be verified by the local environmental authorities to make sure the accuracy of fee. The local environmental authorities check polluters' reports in several ways, including consistency with material balance models, historical data from the facility, online monitoring, and surprise inspections. When the data are verified by the environmental authorities, they are used for levy calculation manual. Firms pay penalties for false reporting and/or noncooperation with the government inspections. Polluters also need to pay fee in time and otherwise will be fined. At the same time, the amount of pollution discharge cannot exceed authorized permits, and the concentration of effluent must comply with prevailing discharge standards. Otherwise, levy rate of pollutants will increase 1–2 times.

In order to strengthen the prevention and control of water pollution in the Tai Lake Basin, Jiangsu province has set up more striker pollution levy standard. In 2007, the fee was increased from 0.7 yuan to 0.9 yuan per pollution equivalent. In 2010, sewage discharge fee in Tai Lake Basin has increased from 0.9 yuan to 1.4 yuan per pollution equivalent in Jiangsu. With the stricter regulation in Tai Lake Basin, the discharge fee reaches 4.2 yuan per pollution equivalent during 2016 to 2017 and will reach 5.6 yuan per pollution equivalent in 2018 (Environmental Protection Department of Jiangsu Province et al. 2015). From the figure below, we can see that levy rate in Jiangsu is much higher than the national level (Fig. 4).

The levy system has been criticized although it has made great contribution to pollution control in China. Some authors believe that it even provides disincentives

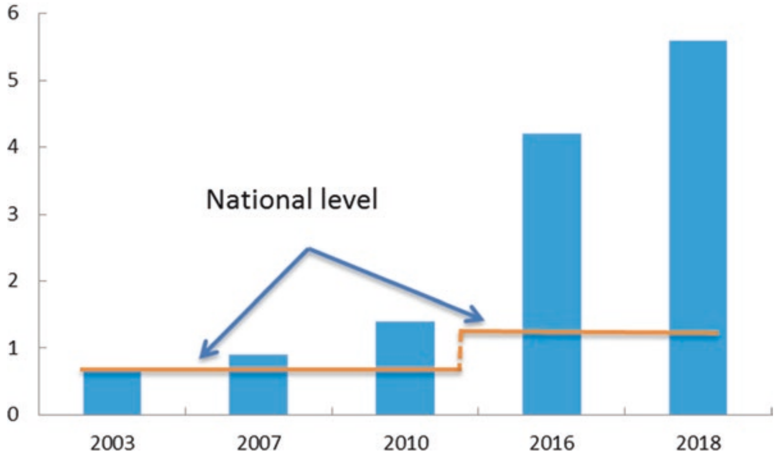

Fig. 4 Pollution charge standard in Jiangsu province (yuan/pollution equivalent). (Source: compiled by the authors)

to pollution control because of the decreasing block levy rates for water pollutants (Jin and Lin 2014). It is also widely believed that the current levy rate is less than the marginal abatement cost and hence insufficient to encourage polluters to reduce their pollution discharge (Jiang and McKibbin 2002). Moreover, the strictness of enforcement is thought to vary widely, so firms in different regions face very different penalties for polluting (Wang and Wheeler 2000; Wang and Wheeler 2005).

4 Green Credit

The main purpose of green credit is to make use of the potential of the financial sector to respond to environmental and social challenges through financial instruments and thereby incentivize more adequate and sustainable behavior (Aizawa and Yang 2010). In 1995, the People's Bank of China (PBOC) published its "Notice on Implementation of Credit Policy and Strengthening of Environmental Protection Works," which requested financial institutions to implement national environmental protection policy in credit activities. In 2007, the Ministry of Environmental Protection (MEP), the China Banking Regulatory Commission (CBRC), and the Peoples' Bank of China required Chinese banks to withhold credit to enterprises that belch pollutants or devour energy and natural resources and to extend credit to green projects on preferential terms (Aizawa and Yang 2010). In 2012, a "Green Credit Guideline" was issued by the CBRC (China Banking Regulatory Commission 2012). The purpose of the guideline is "encouraging banking institutions to, by focusing on green credit, actively adjust credit structures, effectively fend off environmental and social risks, better serve the real economy, and boost the transformation of an economic growth mode and adjustment of economic structures" (Guo 2014, p. 71). In 2013, CBRC issued

"Opinions on Implementing Green Credit," requiring banking institutions to establish statistical systems and to improve evaluation systems of green credit businesses. Based on the central government's policy, Jiangsu province has also further developed related policies, including the "Notice of Jiangsu Province on the Implementation of Green Credit Policy" and on "Further Improving Information Sharing and Notice of Jiangsu Province on Jointly Establishing a Mechanism to Share Information of Environmental Trustworthiness in Jiangsu Province."

Banks are the main players of the green credit scheme. Both the central government and local governments ask the banks to implement green credit regulations to protect the environment. They can increase the support to a green, low-carbon, and recycling economy, prevent environmental and social risks, and improve environmental and social performances when they implement the policy (China Banking Regulatory Commission 2012). For the banks, potential financial risk of firm's environmental performance is their main focus. This is because polluters are facing increasing regulatory risks in China today. In a worst-case scenario, if a polluting company is compulsorily shut down by the regulator, then banks will not get any payback, and the loan will be nonperforming (Guo 2014). In order to promote banks' implementation of green credit policy, CBRC issued "Key Evaluation Indexes of Green Credit Implementation" to supervise banks' implementation of "green credit" in December 2014. Banks have to provide self-assessment report based on the index. This report can reflect how a bank follows the guideline and integrates green credit policy into its review process; regulators can reward the active banks and put more pressure on the less active ones.

In order to help banks to get information about firms' environmental performance, the CBRC issued "The Guideline for Green Credit," which encourages banks to assess and categorize a client's environmental risk levels, and it also offers suggestions regarding internal system construction and management processes (Hu and Li 2015). What's more, the government also established environmental information sharing mechanism between different departments and banks. The color list of firms provided by the local environmental protection bureaus is a convenient tool for banks as they try to carry out the green credit policy.

At the local level, the Jiangsu province has developed green credit policy since 2000 and has made many achievements. A "one ticket veto" principle was used in Jiangsu province for clients whose environmental credit was rated as "black." In 2016, banks in Wuxi refused to loans of a total amount of about 900 million yuan on the grounds that the applicants' environmental performance didn't meet the allowance requirements. By the end of 2016, 33 banks (44 banks of green credit monitoring statistics) had established specialized agencies to perform the green credit system or related credit policies. Thirty-eight banks have implemented the green credit veto system; 24 banks set up green credit positions and introduced green credit information into the existing credit management systems. Moreover, green credit has already been adopted in 13 banks' performance evaluation index system (China Environment News. 2017).[1]

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[1] http://www.jshb.gov.cn/sjb/xxgk/hbxy/201703/t20170331_393228.html

Despite the successful implementation of green credit policy in China, there are still challenges, which impede its future development (Research group of Dazhou branch of the people's Bank of Chinese 2017).

Information about firms' environmental performance is insufficient, which makes it difficult for banks to evaluate how green the clients actually are. Although the environmental credit policy in Tai Lake Basin is better implemented compared to other regions, the information is still not enough for banks. According to the official selection criteria, only those firms' whose discharge of major pollutants has reached 80% of the total discharge in the area are evaluated by the government as to their environmental performance (Environmental Protection Department of Jiangsu Province and Social Credit System Construction Leading Group Office of Jiangsu Province 2013). Hence, the banks have not officially evaluated information on the environmental performance of other firms. Instead, the banks require the firms to provide an assessment document about their environmental performance, but it's hard for them to verify the reliability of such documents.

Most banks are not capable of effectively implementing the green credit policy due to lacking capacities. The staffs are usually trained as financiers or accountants, and they lack knowledge and capacity to handle environmental affairs. When it comes to environmental criteria such as carbon emission and COD (chemical oxygen demand), they will get confused. In some global banks, environmental specialists are hired to analyze environmental and social risks. However, Chinese banks have few talents like these, and they have to train their staff to know more about the environment, but this takes time (Zhang et al. 2011).

5 Ecological Compensation

Ecological compensation in China has often been used interchangeably with the international term "payment for ecosystem services." The main purpose of this policy is to balance the economic interests and environmental benefits of the relevant stakeholders (Liu et al. 2008). Ecological compensation in China is defined in both narrow and broad terms (Dai 2014). The narrow definition refers to rewards for protecting the environment and natural resources, and the broad definition covers not only rewards but also environmental pollution charges. In China, ecological compensation was initiated in the 1990s solely to address the ecological benefits of forests. The "Decision Regarding Strengthening Environmental Protection" issued by the State Council in 2005 stated that "the government should improve ecological compensation policy, and develop an ecological compensation mechanism as soon as possible (…)." Since then, many policies have been developed in China. An "Ecological Compensation Ordinance" was initiated for drafting in April 2010, including forest, grassland, wetland, resource exploitation, marine, watershed, and ecological functional zones. The General Office of the State Council of China has issued the "Opinions of the General Office of the State Council on Improving the Compensation Mechanism for Ecological Protection" in 2016 to further promote ecological compensation developments. Local governments have adopted flexible policies and measures based on local characteristics. For example, Suzhou has developed an "Ecological Compensation Ordinance of Suzhou City" based on the abovementioned national policy documents.

The Tai Lake Basin encompasses many provinces and cities, a complex terrain, and dense river network. In order to realize a good ecological environment in this area, pollution control and ecological restoration policies should be carried out from the perspective of the whole basin. In this perspective, the establishment of ecological compensation systems appears as an effective means to coordinate regional interests. Ecological compensation with regard to water environmental protection can be applied in many forms, including interprovincial offsets, compensation between the administrative regions of the province, and even compensation between different areas of a city. Under the national framework, the Tai Lake Basin has actively explored the development of an ecological compensation system and achieved important progress in this regard. Besides compensation between governments, compensations between governments and farmers and between governments and industry were also applied in Jiangsu province (Luo et al. 2011; see also the contribution by Dai and Qin on eco-compensation in this volume), while tradable water rights, transfer of development opportunities or benefits, and restructuring or consolidation of public financial expenditures related to the environment are the main types of compensation applied in Zhejiang province (Liu et al. 2008).

At the beginning of implementation of the policy, a one-way compensation scheme was applied in Jiangsu province. Upper basin reaches were required to compensate for pollution brought to downstream areas as far as this pollution transfer exceeded a certain compensation criterion. However, the river networks of Tai Lake Basin are proved to be too complicated for such a simple upstream-downstream compensation scheme because of the uncertainty surrounding flow direction and disturbance due to external conditions. In this setting, identifying the responsible polluters is difficult, and habitat loss is difficult to calculate and attribute to certain upstream polluters (Xie et al. 2013). Therefore, in 2014 Jiangsu province issued the "Measures for the Implementation of Jiangsu Province Regional Compensation (Trial)" and changed the scheme from one-side compensation to two-side compensation. According to this approach, the lower reach has to compensate the upstream area as far as the upper reach makes positive contributions to pollution control beyond the compensation baseline thus helping the lower reaches of the region to reduce their burden of pollution. Otherwise, the upper reach has to pay compensation to the lower reach. Through the establishment of this two-side compensation mechanism, the division between the upper and lower reaches is clear. However, there are still challenges in designing and implementing this ecological compensation mechanism, such as technical issues and legislative and policy support (Luo et al. 2011; Liu et al. 2017; Wang et al. 2016).

The compensation baseline needs to be designed in accordance with the actual situation in Tai Lake. The revised ecological compensation method currently refers to the high permanganate index, ammonia nitrogen, and total phosphorus within the range of the whole province's compensation section. However, the main problem in

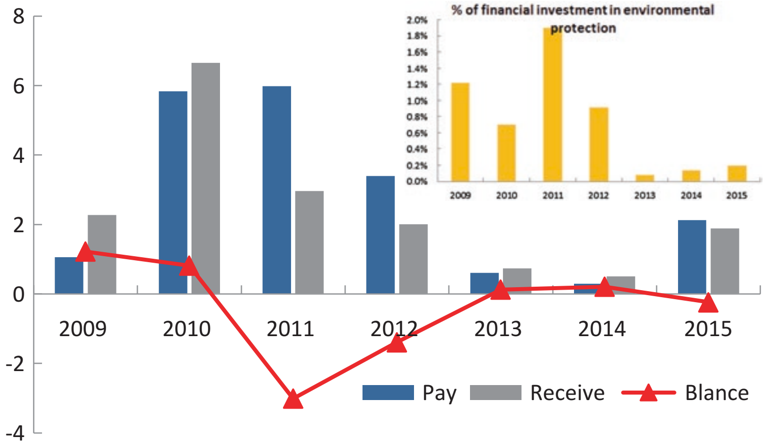

Fig. 5 Eco-compensation of Changzhou, Jiangsu province (million yuan). (Data source: local Environmental Protection Bureau)

Tai Lake today is total phosphorus and total nitrogen. In 2016, 8 of 15 major rivers flowing into Tai Lake did not meet the national regulatory requirements of total phosphorus and total nitrogen (Tai Lake Authority 2016). Despite this, the current ecological compensation does not include total nitrogen in ecological compensation assessment factor.

Moreover, the current standard of ecological compensation does not include value compensation for the water ecosystem services and thus cannot motivate stakeholders in this regard. Taking the ecological compensation funds in Changzhou as an example, the proportion of ecological compensation for financial investment is too low, accounting for less than 1% of the financial investment on environmental protection in some years. It is, of course, unlikely that such a low proportion will motivate the local government to take additional efforts (Fig. 5).

6 Compensated Use of Pollution Emission Rights and Emission Trading System

The approach of “compensated use of pollution emission rights” aims to take pollution emission right as a means to encourage firms to reduce their pollution. As a basis, all firms discharging pollutants into the water are obliged to acquire and surrender equivalent pollutant emission rights. Generally, all existing firms were given the opportunity to buy pollution allowances according to their permitted annual discharge from the government. All new, retrofitted, and expanded projects (firms) must buy the rights they need within the market. The initial amount of allowances offered to previously existing polluters is usually set by a rather complicated method based on different data sources, such as the environmental impact assessments

(EIA), historical emission, and so on. In addition, local environmental authorities also have the right to adjust the amount of allocated permits according to new environmental regulations, such as the new target of emission control or effluent emission standards (Zhang et al. 2016).

The emission trading system is regarded as a cost-effective economic instrument that helps to meet a set of predetermined environmental quality standards with relatively lower costs compared to "command and control" approaches (Hung and Shaw 2005). Firms can sell their allowance after they buy allowance from the government (compensated use of pollution discharge rights) or other firms. Through trading between different participants, firms will be driven to reduce pollution voluntarily with more information about abatement cost of measures, while governments often have imperfect information and find it more costly to implement and administer a "command and control" approach (Zhang et al. 2013). This is why "command and control" approaches usually lead to inefficient results and the reason why such marketbased mechanism are widely used in the US, Europe, and other countries (Zhang et al. 2017), in the fields of air pollutants and greenhouse gases emissions.

China started a pilot emission trading system in 11 cities in 1991, including Baotou, Shanghai, and so on. During the 10th Five-Year Plan period, emission trading was promoted by the central government to facilitate and improve the total amount control of the major pollutants. But more attention was paid on air pollutants rather than water pollutants. During the 11th Five-Year Plan, water pollution emission trading pilot work has made a great progress. In 2007, the Ministry of Environmental Protection and the Ministry of Finance initiated a pilot water pollution trading program in the Tai Lake Basin. In the 12th Five-Year Plan period, the policy has been rapidly promoted nationally. More than half of the provinces have carried out emission trading pilot work. The central government has done a lot of work on policy orientation, division of responsibilities, allocation method design and management, cost management, implementation of security measures of the system design, and so on in order to guide and regulate local emission trading pilots. The General Office of the State Council of China has launched a program for "Further Advancing the Pilot Work for the Paid Use and Trading of Emission Rights" to guide the further improvement of emission trading market in China (Fig. 6).

The main players in the trading market are governments and firms. Firms can trade with governments or other firms certified by environmental authorities. Local environmental authorities can repurchase residual allowances from closed, bankrupted, or relocated firms at a certain price. And they can also sell those allowances to new firms. Firms can find buyer/seller with the help of local environmental authorities. By trading emission allowances in the market, the private sector can reduce its control costs and increase its profits, and national average abatement costs can be effectively reduced (Wang et al. 2008). There is even more innovation in the Tai Lake Basin. For example, emission right can also be used for leasing and mortgage. Firms can use emission right to borrow money from banks.

Although there are many advantages of trading system as compared to "command and control" approaches, some important issues of this policy still need to be

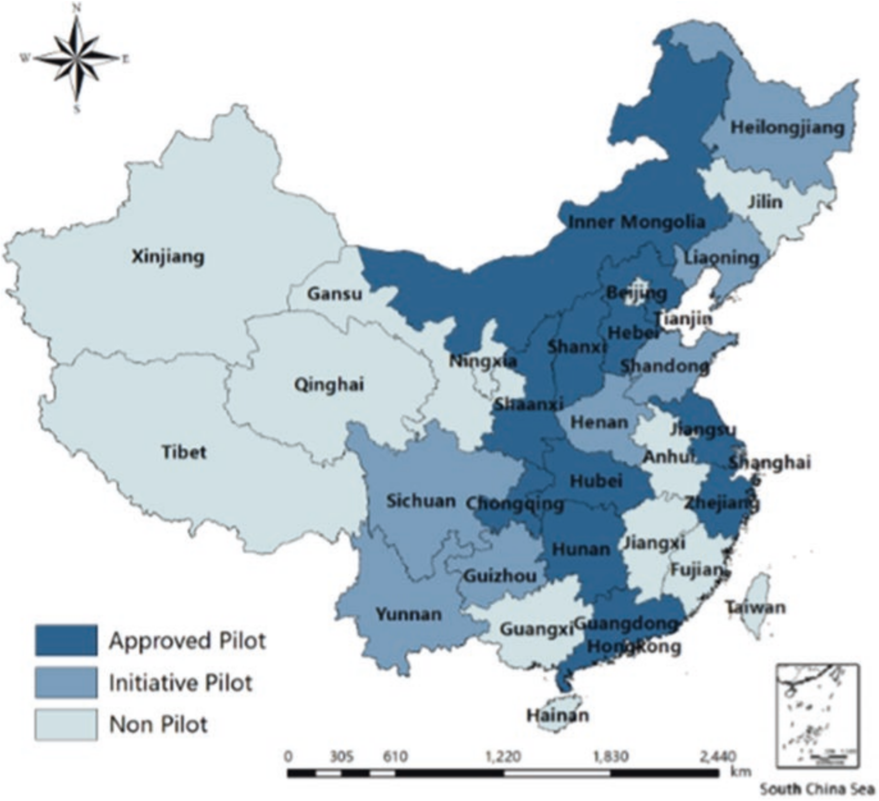

Fig. 6 Emission trading pilots in China 2017. (Source: Compiled by the authors)

considered. For instance, its overall impact on water quality needs to be further studied. Water pollutants (such as COD) trading is much more complicated than air pollutants (such as CO_2), because the water pollutants are nonuniformly mixed pollutants. This means that the extent and spatial pattern of the damage to the environment depend not only upon the level of emissions but also upon the locations and transfer characteristics of the emissions. The potential risk of spatial "hot spots" is well recognized by researchers (Hung and Shaw 2005; Obropta et al. 2008). A case study in Tai Lake Basin shows that a simply designed tradable discharge permit system without trading ratios has the potential to decrease water quality in some locations (Zhang et al. 2013).

At present, the legal basis of the emission rights and trading policy is still insufficient (Zhang et al. 2016; Wang et al. 2008). Existing guidance points out that firms pay money to obtain emission rights to be recognized in the form of pollution permits. However, there is no clear legal basis for the allocation and use of emission rights. The newly revised "Environmental Protection Law" does not make it clear that – and in how far – the environment may be dealt with as a kind of economic, tradable resource, and neither does it clarify the nature of emission rights.

Although in current water pollution control law and the air pollution control act, the total amount of pollution and emission permits is mentioned as a steering criterion, but there are no specific national laws and regulations on such emission rights and their allocation. Hence, regulatory procedures, illegal liability, and other issues are not resolved, so far.

Above all, the role of the government is not clear. The government plays an important role in the process of emission trading, e.g., in determining regional environmental capacity, initial allocation of emission rights, establishment of the auction market, collection of transaction information, pollution monitoring, and revision and improvement of relevant laws and standards. However, at present, from the national level to the local level, policy documents suggest that local governments reserve and sell emission rights, which make the local government one of the main players of emission trading market. Hence, local governments and firms may fight for interests, and on the local level, it seems rather easy to disrupt the market as local government is not only responsible for the formulation of rules but also the executor (Wang et al. 2008).

7 Environmental Pollution Liability Insurance

Environmental pollution liability insurance is a market-oriented solution aimed to reduce operational costs of enterprises, decrease government spending, and promote rapid economic development (Pu et al. 2017). It was firstly developed in the 1960s in industrialized countries, especially in the USA, France, and Germany, and was introduced to China in the 1990s. In China, the main drivers of liability insurance are increasingly frequent environmental pollution incidents and risks on the one hand and an increasing openness to experiment with new market-based approaches to managing environmental risks on the other hand (He et al. 2012). The main goals of pollution insurance include ensuring that the pollution victims can be compensated, even if the company that caused the environmental disaster goes bankrupt; protecting individual companies from bankruptcy if the company causes serious disaster; and mitigating environmental risks by incentivizing polluters to invest in risk reduction and prevention measures through lower premiums (Feng et al. 2014a, b).

In 2006, the Chinese government decided to promote environmental insurance strongly. In 2007, “The Guidelines on Environmental Pollution Liability Insurance” (The Guidelines) were issued by the Ministry of Environmental Protection (MEP) and the Insurance Regulation Committee (IRC). Furthermore, pollution insurance was encouraged and supported as an important economic instrument for energy savings, emissions reduction, and environmental protection in other state council regulations issued between 2007 and 2011. At the same time, technical support was steadily being developed by the government. Recommended calculation methods for environmental pollution damage costs were announced in 2011. These methodology guidelines formed part of the technical support structure for pollution insurance.

In 2008, the government started the national trial applications of pollution insurance in several cities and provinces, and insurance schemes were established in more than 30 provinces and cities by 2016, including heavy industry, heavy metals, printing and dyeing, chemical, and other industries. Local governments in China developed their own strategies in the trial application of pollution insurance based on national guidelines. In most trial application areas, environmental protection authorities and Insurance Supervision Bureau (ISB) became the main departments responsible for pollution insurance promotion and issuance of local guidelines. Insurance companies submit their pollution insurance products to an Insurance Regulation Committee (IRC) in order to receive a permit to enter the pollution insurance market and then further develop their business under the supervision of Insurance Supervision Bureaus (ISB) (Feng et al. 2014b; Yang et al. 2017).

In Jiangsu province, the operation mode of environmental pollution insurance is depicted in Fig. 7. The government, insurance companies, and polluting companies are the key stakeholders in the pollution insurance market. The insurance company and polluting companies are administrated by the local government. Polluting companies are pushed by the environmental protection bureaus to buy pollution insurance from insurance companies. Insurance companies provide more service to attract firms to buy insurance. For example, insurance companies provide a team of environmental experts to assess the particular environmental risks of the firms and issue environmental risk report to the firms and government. Firms can take this as a reference and take measures to improve environmental management and reduce environmental risks. The environmental protection bureaus may, in accordance with these reports, urge firms to solve the problems and reduce environmental risk. After signing the insurance contract, the insurance company will send experts to provide professional risk exploration and training services to the individual firms every year and thus help firms to eliminate environmental hazards. With the development of third-party services in China, insurance companies are gradually turning to third-party service companies in risk assessment and daily inspection of polluting firms (Fig. 7).

Jiangsu province has taken various measures to encourage firms to subscribe to these insurance schemes. Although the insurance policy is voluntary for firms, the government has some means to encourage polluters in high-risk industries to buy pollution insurance. For example, the "environmental credits" (see above section "Enterprise Environmental Credit Evaluation") of 26,569 firms were evaluated in 2016. These enterprises account for 85% of the total amount of pollution discharge, and they are also most important sources of environmental risk. To encourage these high environmental risk enterprises to join the liability insurance, Jiangsu province has set up a special campaign to include insurance into environmental credit evaluation. As a part of this campaign, firms can get five additional credit points if they hold adequate environmental insurance. This is particularly relevant for those enterprises whose evaluation scores are in the crossing point. If they lose five points, credit rating will fall down.

Nevertheless, there are still some challenges for the development of pollution liability insurance. The absence of a national law weakens the legal basis of pollution insurance, and technical support for pollution insurance remains weak, as no unified standard for risk assessment and loss compensation exists, so far. Current

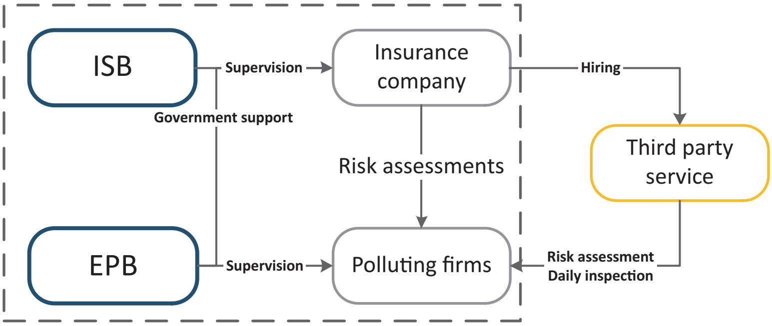

Fig. 7 Operation mode of environmental pollution insurance. (Source: compiled by the authors)

pollution insurance products have limited risk coverage, high premium rates, and low loss ratios, which make them fairly unattractive to polluters (Feng et al. 2014a, b). Meanwhile, pollution insurance is still fairly new to China, and therefore, the government, the insurance companies, and especially the polluting industrial companies have limited knowledge of this type of insurance instrument. Hence, low awareness of environmental and social liabilities is still leading to a limited demand for pollution insurance products (Feng et al. 2014b, Liu and Chik 2012).

8 Other Economic Policies

8.1 Differential Price of Electricity and Water

In order to further encourage polluters to improve their environmental behavior, Jiangsu province has implemented differential price of electricity and water since 2015. Based on environmental credit rating results, wastewater treatment fees for those polluters with black environmental credit were increased by 1 yuan/t and by 0.6 yuan/t for red ones (Department of Finance of Jiangsu Province et al. 2016). At the same time, electricity price for those polluters with black environmental credit was raised by 0.1 yuan/kwh and increases 0.05 yuan/kwh for red ones (Bureau of Commodity Price of Jiangsu Province and Environmental Protection Department of Jiangsu Province 2015).

The Water Supply and Conservation Management Department is responsible for the collection of the city's heavy polluting enterprises' differentiated sewage treatment fee. Provincial power grid enterprises should provide the heavy polluting enterprises' power consumption data and collect electricity charges according to the amount of electricity and increased price. All of the money collected from the heavy polluting enterprises has to be turned over to a special financial account. The Environmental Protection Department evaluates the enterprises' environmental credit every year, and if the enterprises' environmental performance has improved, any increase of the sewage treatment fee and electricity price shall be stopped.

8.2 Environmental Tax

Environmental tax, also called ecological tax and green tax, is regarded as a shift of tax burden toward polluting activities and the use of natural resources (Bosquet 2000). In China, environmental tax has been discussed for many years. The 12th Five-Year Plan of China has clearly stated that "We should actively push forward the reform of environmental protection tax and fees, select the taxable items with heavy tasks and mature technical standards, levy environmental protection tax, and gradually expand the scope of tax collection." In 2016, the Environmental Protection Tax Law was formally adopted and will be implemented as of 1 January 2018 (after implementation of the sewage charges will not be levied). The reform involves imposing a tax on air pollutants, water pollutants, solid waste, and noise. Considering the differences of the environmental carrying capacity, pollutant emission status; ecological, economic, and social development goals; and the rate of atmospheric pollutants, the taxes on water pollutants should be set by local governments in a range of the national requirements. Different from the environmental levy, the environmental tax revenue will be collected as a whole income and not be earmarked for special spending purposes. The local governments are working on tax rate setting, collection methods, and other implementation issues at the moment. One important task is to rationalize and establish a coherent relationship between environmental tax, compensation for the use of emission rights, and pollution levy policy.

9 Conclusion

This report has briefly reviewed the main economic policies implemented in China with a view to controlling water pollution in the Tai Lake Basin, including pollution levy, green credit, ecological compensation, compensated use of pollution discharge rights and emission trading, environmental pollution liability insurance, and environmental tax. The results of this study indicate that China has made great progress of policy design in the central level. These policies have been further developed in accordance with evolving water pollution control objectives and the environmental status in the Tai Lake Basin. Some of the policies were tested and demonstrated for the first time in this region, such as compensated use of pollution emission right. Moreover, some policies were adapted and innovated in the Tai Lake Basin, like environmental pollution liability insurance. These policies have made relevant contributions to water pollution control in Tai Lake and can also provide valuable experience in policymaking to other areas. At the same time, more progress needs to be made in the future, including improving policy design and enhancing the effective implementation.

Annexes

Annex 1 Related Policies of Green Credit

Title	Time	Department
Notice on Implementation of Credit Policy and Strengthening of Environmental Protection Works	1995	People's Bank of China (PBC)
Notice of the General Office of China Banking Regulatory Commission on Regulating the Performance of Duties by Associations of Rural Credit Cooperatives at Provincial Level to Prevent Risks	2007	General Office of China Banking Regulatory Commission
Notice of China Banking Regulatory Commission on Issuing the Guiding Opinions on the Credit Work for Energy Conservation and Emission Reduction	2007	China Banking Regulatory Commission
Notice of the China Banking Regulatory Commission on Issuing Green Credit Guidelines	2012	China Banking Regulatory Commission
Guidelines for Establishing the Green Financial System	2016	People's Bank of China; Ministry of Finance; National Development and Reform Commission; Ministry of Environmental Protection; China Banking Regulatory Commission; China Securities Regulatory Commission; China Insurance Regulatory Commission
Notice of Jiangsu Province on the Relevant Issues Concerning Enterprise Environmental Protection Information Sharing, Credit Risks Prevention and Financial Services Promotion Relating to Energy Conservation and Environmental Protection	2007	Environmental Protection Department of Jiangsu Province; Bank of China, Nanjing Branch
Notice of Jiangsu Province on the Implementation of Green Credit Policy and Further Improving Information Sharing	2009	Environmental Protection Department of Jiangsu Province; Bank of China, Nanjing Branch
Notice of Jiangsu Province on Jointly Establishing a Mechanism to Share Information of Environmental Trustworthiness in Jiangsu Province	2013	Environmental Protection Department of Jiangsu Province; Jiangsu Economic and Information Technology Commission; China Banking Regulatory Commission

Annex 2 Related Policies of Eco-compensation

Title	Time	Department
Guiding Opinions of the State Environmental Protection Administration of China on the Implementation of the Eco-compensation Pilot Program	2007	(Former) State Environmental Protection Administration of China
Guiding Opinions of the Ministry of Environmental Protection of China on Prevention and Disposal of Trans-boundary Water Pollution Disputes	2008	Ministry of Environmental Protection of China
Ecological Compensation Ordinance (Draft)	2010	National Development and Reform Commission
Opinions of the General Office of the State Council on Improving the Compensation Mechanism for Ecological Protection	2016	General Office of the State Council of China
Accelerating the Establishment of the Horizontal Compensation Mechanism for Ecological Protection of Drainage Basins Upstream and Downstream	2016	Ministry of Finance; Ministry of Environmental Protection; National Development and Reform Commission
Interim Measures of Jiangsu Province for Eco-compensation Transfer Payments	2013	Department of Finance of Jiangsu Province; Environmental Protection Department of Jiangsu Province
Implementation Measures of Jiangsu Province for Water Environment Regional Compensation (for Trial Implementation)	2013	Department of Finance of Jiangsu Province; Environmental Protection Department of Jiangsu Province

Annex 3 Related Policies of Pollution Levy

Title	Time	Department
Notice of the State Development Planning Commission and the Ministry of Finance on the Collection of Sewage Charges	1993	(Former) State Development Planning Commission; Ministry of Finance
Payment Management Rule for Pollutant Discharge Fees	2003	The State Council of China
Measures for the Administration of the Charging Rates for Pollutant Discharge Fees	2003	(Former) State Environmental Protection Administration; (former) State Development Planning Commission; Ministry of Finance; (former) State Economic and Trade Commission
Administrative Measures for the Collection and Use of Pollutant Discharge Fees	2003	(Former) State Environmental Protection Administration; Ministry of Finance

(continued)

Title	Time	Department
Notice on the Relevant Issues Concerning Adjusting the Standards for the Collection of Pollutant Charges	2015	National Development and Reform Commission; Ministry of Finance; Ministry of Environmental
Interim Measures of Jiangsu Province for the Collection of Sewage Charges according to Total Emissions of Water Pollutants	1999	Environmental Protection Department of Jiangsu Province; Jiangsu Provincial Price Bureau; Department of Finance of Jiangsu Province
Interim Measures of Jiangsu Province for the Inspection of the Collection of Pollutant Charges	2005	Environmental Protection Department of Jiangsu Province
Measures of Jiangsu Province for Collecting Sewage Charges on Ammonia Nitrogen and Total Phosphorus Exceeding Environment Standard of Sewage Treatment Units in the Tai Lake Basin	2008	Jiangsu Provincial Price Bureau; Department of Finance of Jiangsu Province; Environmental Protection Department of Jiangsu Province; Jiangsu Provincial Economic and Trade Commission
Notice of Jiangsu Province on Preparations concerning Verification and Collection of Sewage Charges according to Automatic Monitoring Data of State-controlled (Provincial) Key Water Pollution Sources in the Tai Lake Basin	2008	Jiangsu Provincial Bureau of Supervision
Notice of Jiangsu Province on the Relevant Issues Concerning the Adjustment of the Standards for Collection of Sewage Charges	2015	Environmental Protection Department of Jiangsu Province; Jiangsu Provincial Price Bureau; Department of Finance of Jiangsu Province

Annex 4 Related Policies of Compensated Use of Pollution Discharge Rights and Emission Trading

Title	Time	Department
Guiding Opinions of the General Office of the State Council on Further Advancing the Pilot Work for Compensated Use and Trading of Emission Rights	2014	General Office of the State Council of China
Notice of the Ministry of Finance, the National Development and Reform Commission and the Ministry of Environmental Protection of China on Issuing the Interim Measures for the Management of Revenues from the Assignment of Pollutant Discharge Rights	2015	Ministry of Finance; National Development and Reform Commission; Ministry of Environmental Protection
Notice of the General Office of the State Council on Issuing the Implementation Plan for the Permit System for Controlling Pollutants Emission	2016	General Office of the State Council of China

(continued)

Title	Time	Department
Measures of Jiangsu Province for the Administration of Charging for the Use of Main Water Pollutant Emission Index in the Tai Lake Basin (for Trial Implementation)	2008	Jiangsu Provincial Price Bureau; Department of Finance of Jiangsu Province
Detailed Plan of Jiangsu Province for the Pilot Work for the Compensated Use and Trading of Main Water Pollutant Discharge Rights in the Tai Lake Basin	2008	Environmental Protection Department of Jiangsu Province; Department of Finance of Jiangsu Province; Jiangsu Provincial Price Bureau
Measures of Jiangsu Province for the Administration of Water Pollutant Discharge Permits	2011	People's Government of Jiangsu Province
Interim Measures of Jiangsu Province for Administration of Pricing in Compensated Use and Trading of Emission Rights	2016	Jiangsu Provincial Price Bureau; Department of Finance of Jiangsu Province; Environmental Protection Department of Jiangsu Province

Annex 5 Related Policies of Pollution Liability Insurance

Title	Time	Department
Several Opinions of the State Council on the Reform and Development of the Insurance Industry	2006	The State Council of China
Guiding Opinions of the State Environmental Protection Administration of China and China Insurance Regulatory Commission on Environmental Pollution Liability Insurance Work	2007	(Former) State Environmental Protection Administration; China Insurance Regulatory Commission
Guiding Opinions of the Ministry of Environmental Protection of China and China Insurance Regulatory Commission on the Pilot Work for Compulsory Environmental Pollution Liability Insurance	2013	Ministry of Environmental Protection; China Insurance Regulatory Commission
Notice of Jiangsu Province on Issuing the Actively Implementing Liability Insurance for Oil Pollution Damage	2008	Marine Affairs Bureau of Jiangsu Province; Jiangsu Provincial Department of transportation; Administration of Work Safety of Jiangsu Province; Environmental Protection Department of Jiangsu Province; China Insurance Regulatory Commission Jiangsu Bureau

(continued)

Title	Time	Department
Opinions of Jiangsu Province on Advancing the Pilot Work for Environmental Pollution Liability Insurance	2010	Environmental Protection Department of Jiangsu Province; China Insurance Regulatory Commission Jiangsu Bureau; Finance Office of Jiangsu Province
Notice of Jiangsu Province on Issuing the Establishment a Joint Meeting Mechanism for Environmental Pollution Liability Insurance	2010	Environmental Protection Department of Jiangsu Province; China Insurance Regulatory Commission Jiangsu Bureau; Finance Office of Jiangsu Province

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The Eco-Compensation Mechanism in Tai Lake Watershed

Liping Dai and Tianbao Qin

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Tai Lake is the third largest freshwater lake in China. Serious water pollution, especially trans-jurisdictional water pollution, problems are consistent issues in the region. To deal with these problems, four types of the eco-compensation mechanism are applied in this region: eco-compensation between governments, eco-compensation between governments and farmers, eco-compensation between governments and industry and eco-compensation among industries. This chapter analyses these four types of the eco-compensation mechanism from a legal perspective and sheds light on how the mechanism has been applied in China. It aims to provide valuable experiences for domestic water management and elsewhere in the world in protecting the provision of water-related ecosystem services.

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1 Eco-compensation in China

Eco-compensation (*sheng tai bu chang*) in China is mainly a public mechanism to promote environmental protection and restoration, including through the payment for ecological services (Asian Development Bank 2016). It generally creates not only incentives but also disincentives. Incentives refer to a reward or compensation for a right that is foregone in order to maintain a certain ecosystem service. Disincentives refer to charges for the loss of or damage to ecosystems and natural resources (China Council for International Cooperation on Environment and Development (CCICED) 2010; Zhang et al. 2010).

Therefore, eco-compensation in China is defined in both narrow and broad terms. The narrow definition refers to rewards for protecting the environment and natural resources; and the broad definition covers not only rewards but also environmental pollution charges (Li and Liu 2009), for example, the pollution discharge fee. As there are already a series of laws and regulations to deal with pollution charges in China, this chapter focuses on the narrow definition of eco-compensation.

In order to develop internal ecosystem services markets, China's central and local governments have rapidly expanded their environmental protection policies, especially during the past few years, largely under the heading of "eco-compensation". The first official document to stimulate an eco-compensation mechanism was a "Decision regarding Strengthening Environmental Protection" issued by the State Council in 2005, which states that the government "[…] should improve eco-compensation policy, and develop an eco-compensation mechanism as soon as possible […] pilot projects can be launched at both local and national level". Following this, many provinces enacted their own regulations and eco-compensation projects. The "win-win development" principle was later laid down as one of the cornerstones of the eco-compensation mechanism by the Ministry of Environmental Protection (MEP), which recommended carrying out pilot projects in four fields:

- Eco-compensation for nature reserves
- Eco-compensation for eco-function areas
- Eco-compensation for the development of mineral resources
- Eco-compensation for watersheds

As of 2013, three national laws—the Forest Law, the Law on the Prevention and Control of Water Pollution and the Water and Soil Conservation Law—established the principle of eco-compensation (Asian Development Bank 2016), which provide legal basis for the eco-compensation mechanism. In 2016, the State Council approved a paper entitled "Several Opinions on Establishing a Sound Eco-Compensation Mechanism and the Eco-compensation Regulations" (The State Council 2016). The opinions paper calls for the establishment of new mechanisms to promote ecosystem protection, including eco-compensation, and notes that market-based mechanisms should be further studied and introduced (Asian Development Bank 2016).

Most of Chinese experience with eco-compensation is directly or indirectly related to watersheds (Asian Development Bank 2016). The number of eco-compensation projects in watersheds has increased from 8 in 1999 to more than 47 in 2008, with an estimated transacted value of roughly $7.8 billion, covering some 290 million ha (Stanton et al. 2010; Qingfeng Zhang 2010).

Tai Lake watershed in Jiangsu Province is taken as a case study in this chapter since it is one of the selected eco-compensation pilot schemes in China, one of the most developed and polluted regions and one of the watersheds in which few types of eco-compensation are being applied. By analysing the characteristics of the eco-compensation mechanism in the Tai Lake watershed, this study sheds light on how the mechanism has been applied in China and provides valuable domestic experiences for national water management in protecting the provision of water-related ecosystem services.

2 Eco-compensation in the Tai Lake Watershed

Tai Lake is the third largest freshwater lake in China. The watershed occupies an area of some 36,500 square kilometres and extends across multiple jurisdictions: Jiangsu Province (52.6%), Zhejiang Province (32.8%), Shanghai Municipality (14%) and Anhui Province (0.6%) (Monitor Center 2013). As one of the most developed regions in China, with only 0.4% of the land territory but 4.4% of the population, the Tai Lake watershed produced 10.3% of GDP; per capita GDP in this region was 2.4 times more than the national average in 2012 (Bureau of Taihu Lake Basin Ministry of Water Resources 2012). The lake connects seven large cities across East China, including Shanghai and Hangzhou, which have a population of 23.8 million and 8.8 million, respectively.

Serious water pollution has been caused by unprecedented economic growth and rapid urbanization in the Tai Lake watershed region. The entire lake has suffered from eutrophication since 1993, the most serious crisis coming in 2007 when dozens of centimetres-thick algal blooms covered the entire lake and tap water turned yellow and was foul-smelling (Liang and He 2012). Trans-jurisdictional water pollution problems are persistent issues in this watershed as it extends across three provinces and one municipality.

In 2008 alone, China's Central Government allocated more than RMB 111 billion (US $17.9 billion) to improve national lake water quality from Class V to Class IV, with an overall goal to achieve Class III status by 2020 (Liang and He 2012).[1] In 2011, the State Council issued the Regulation on the Administration of the Tai Lake Basin, which requires upstream-downstream eco-compensation on the basis of water quality (Asian Development Bank 2016). The government of Jiangsu Province—which is covered by more than half of Tai's total watershed

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[1] There are five classifications of water quality in China: Class I, water source and national protection areas; Class II, centralized drinking water supply spawn grounds for rare fishes and shrimps, nursery areas for larvae and juvenile and young fishes; Class III, grounds and migration paths for common fishes and shrimps and aquaculture areas and swimming areas; Class IV, general industrial water areas and entertainment areas; and Class V, farmland areas and general landscape.

(52.6%) —has worked to improve its regulatory framework in order to improve water quality in the lake. For example, in 2014, the government issued Implementation Measures on Water Environmental Compensation in Jiangsu Province (Department of Finance of Jiangsu and Department of Environmental Protection of Jiangsu 2014), which aims to establish compensation mechanism within the province. Over the past decade, eco-compensation schemes have been significantly developed across this region.

Four types of eco-compensation have been applied in the Tai Lake watershed: eco-compensation between governments, eco-compensation between governments and farmers, eco-compensation between governments and industry (Luo et al. 2011) and eco-compensation among industries. These are explored in more detail below.

2.1 Eco-compensation Between Governments

Bidirectional intergovernmental eco-compensation between upstream areas and downstream areas within one watershed is a newly developed mode of eco-compensation, aimed primarily at addressing trans-jurisdictional water pollution problems. It can motivate both the upstream and downstream jurisdictions to act jointly in protecting their shared water resources.

Jiangsu Province selected four cities—Nanjing, Changzhou, Wuxi and Zhenjiang—as pilot schemes for applying governmental eco-compensation instruments, beginning in 2007. Seven monitoring areas were selected in the four cities, where water quality standards were set by the provincial government. Using these standards as baselines, the provincial government combines the environmental protection responsibility of city governments with financial incentives. For example, in the Xu River in Changzhou City (one of the sub-watersheds of Tai Lake), a monitoring site was established by the provincial Administrative Department of Environmental Protection. The department records the water quality on a weekly basis and calculates the monthly average. If the result exceeds the baseline, meaning the water quality is below the standard set, the upstream city (Nanjing) has to compensate the loss suffered by the downstream city (Changzhou) in accordance with Jiangsu provincial regulation. The rationale for this approach is that the extra pollution caused by Nanjing City results in extra expenditure on pollution control for Changzhou City. Up to 2008, Nanjing City had compensated Changzhou City by RMB 18, 000 (US $29, 032), and Changzhou City had compensated its downstream city Wuxi City by RMB 180, 000 (US $29, 032) due to the recorded water quality results in the monitoring areas below the standard set.

In order to enhance the motivation for water quality protection, the compensation level is set at twice the pollution control cost. The compensation is incorporated into special environmental protection funds or pollution prevention and control funds for water pollution control and ecosystem restoration (Governmental Office of Jiangsu Province, 2007). In another case, if the recorded results in the monitoring areas between the upstream city and the downstream city are above the designated baselines, the downstream city must compensate the upstream city, which stated by the State Council, "…if the upstream cities achieve the water quality targets in the monitoring areas of administrative boundaries, the downstream regions should compensate the upstream regions" (The State Council 2011). However, the legal nature of such compensation gives rise to further discussion (see Sect. 3).

2.2 *Eco-compensation Between Governments and Farmers*

Diffuse water pollution is a main contributor to water pollution in the Tai Lake watershed. If the total nitrogen (TN) and the total phosphorus (TP)—two main pollutants in diffuse agricultural pollution—had not been included in the evaluation of the water quality, most of the surface water in Tai Lake would have reached Class III. However, when the TN and TP are taken into account, the water quality drops to a level worse than Class V especially in Jiangsu Province.

In 2011, the State Council introduced a special regulation aimed at tackling diffuse water pollution in Tai Lake (The State Council 2011), which required local governments to take measures such as:

- "constructing an ecological protection forest within a 500-metre area around the shoreline of the lake,
- a 1500-metre area around the drinking water source protection zones, and
- within a 200-metre area along both of the river banks of the shore of the lake"
- Local county governments:
- "should provide subsidies and support to farmers who have to change their jobs due to the ban on aquaculture and livestock breeding, and the projects of returning the cultivated land or fishery to the lake"
- "should guarantee basic life for those farmers by skill training or incorporating them into the social security system"
- "should provide subsidies for farmers whose income has decreased or whose expenditure has increased due to the projects to reduce pesticide and fertilizer use"

In fact, Jiangsu Province had already formulated its own regulation in 2007 to address pollution problems caused by algal blooms (Jiangsu Provincial Government 2007). It requires the cities within its jurisdiction "to return the cultivated land to the lake, to plant forests and to remove livestock breeding and traditional planting within 5-kilometres around the first-grade protection zones of Tai Lake". This proved to be a difficult exercise in practice. For example, the East Tai Lake in Suzhou City, an 180,000 Mu (12,000 Ha.) bay on Tai Lake, was occupied by enclosed fish farms with 165,700 Mu (11,048 Ha.) (Han 2010), which accounted for more than 90% of the surface water of the East Tai Lake and more than 80% of the total enclosed fish farm area in the Tai Lake. The intensive enclosed fish farms were one of the main causes of the algal blooms due mainly to the excessive use of fish feed. In order to achieve its water quality target for 2012 (from Class V to Class IV), the government of Suzhou City reorganized its intensive enclosed aquaculture. The City's governmental policy requires the decrease of enclosed aquaculture from 300,000 Mu (20, 000 Ha.) of water areas to 45,000 Mu (3000 Ha.) (Government of Suzhou City 2008), which resulted in significantly improved water quality.

However, problems arose since the rural fish farmers were seriously affected as a consequence of this massive reorganization. For example, in the Wuzhong District of Suzhou City, 426 fish farming families (252 professional and 174 non-professional) were directly affected when 22,521 Mu (1501 Ha.) water areas were reclassified. The government provided RMB 793.3 million (US $ 128 million) in total as compensation subsidies for those farmers who had suffered financial losses, and some of them were compensated by resettling fish farms in other locations. However, the compensation system did not run smoothly, as the actual situation was very complicated, with some unsatisfactory outcomes, discussed in more detail below (see Sect. 3).

2.3 Eco-compensation Between Governments and Industry

According to the Water Environment Comprehensive Management Plan for the Tai Lake Basin, there are some 2.10 million industries in the Comprehensive Treatment Region of the lake. Of this total, around 1.04 million are in Jiangsu Province and 1.06 million in Zhejiang Province; 0.56 million of these industries belong to the six major pollution industries (textile industry, manufacture of paper and paper products, petroleum processing industry, coking and nuclear fuel processing, manufacture of raw chemical materials and chemical products and manufacture of medicines and the manufacture of chemical fibres), which also contribute significantly to the economic development in the Tai Lake region.

To control the water pollution caused by its intensive polluting industries, Jiangsu Provincial Government has implemented an approach that evaluates the receiving capacity of the surface water in water environmental function zones and applies a scheme of pollutant loading cap control and a scheme of the discharge credits paid use (is only limited to chemical oxygen demand (COD) discharge so far). The Price Bureau of Jiangsu Province set different charging standards for emission credits for different industries. Under the pollutant loading cap control system, the amount of the pollution discharge credits is limited, which means that once the government has allocated all of the credits, new applicants cannot purchase any from the government but can only either buy surplus credits from other dischargers via an emission trading platform (Sect. 2.4) or improve their own pollution prevention facilities to save credits themselves. It is a so-called bubble policy, where polluters are free, within an imaginary bubble, to offset excess emissions from one source by a reduction made in another source, as long as the overall quantity is not exceeded (Kraemer et al. 2004).

In the Tai Lake watershed, 1357 dischargers (annual emission greaterthan COD 100 tons) have been selected in the programme of discharge credits paid use until 2010. The purchase amounts of COD achieved 49,700 tons per year during 2009–2010, and the collected payments from discharge permits reached RMB 175 million (US $28.2 million) (Li et al. 2010). The revenue, which is managed as governmental nontax revenue, allocates 10% to a provincial special fund for environmental protection and 90% as local (Price Bureau 2008). This special fund is used exclusively for environmental governance, the establishment of environmental monitoring and the construction and maintenance of the emission credits trading platform in the Tai Lake watershed within Jiangsu jurisdiction.

2.4 Eco-compensation Among Industries

On the basis of scheme of the discharge credits paid use, the emission trading system has been initiated in a few pilot cities in the Tai Lake watershed since 2008 but limited to COD emissions too. The governments of local cities set maximum limits on the total allowable emissions of COD and then allocate these to the governments at county levels, which allocate their credits to selected industrial dischargers for a specified period of time. After receiving a written notice from the local Environmental Protection Bureau, the selected industrial dischargers can buy discharge credits from governments which are embodied in discharge permits. With these permits comes the right to use the environmental capacity resources and to buy or sell their discharge credits.

Emission trading occurs only in one “bubble”—in which the total maximum amount of pollutants is determined, which means that purchasing from out of the region is not allowed for the city or county whose total discharge pollutants have already exceeded the control targets or where the receiving water body has failed to reach the required water quality standards. Trading can be initiated between the dischargers and the Regulatory Authority of Emissions Trading or among the dischargers themselves on a specified trading platform monitored by the Provincial Regulatory Authority. See Fig. 1.

Jiangyin City is one of the pilot cities for emission trading in the Tai Lake watershed. In 2010, 158 dischargers (annual COD emissiongreaterthan100 tons) discharged 6930.7 tons COD and paid RMB 18.7 million (US $ 3 million) for discharge permits. Among these 158 industrial dischargers, 68 received extra discharge credits by emission trading with a total turnover achieved of RMB 6.7 million (US $1.2 million) (Li et al. 2010). As well as the collection from discharge credits paid use, the revenue from the trading is used exclusively for environmental protection measures, the establishment of environmental monitoring facilities and the maintenance of the emission credit trading platform.

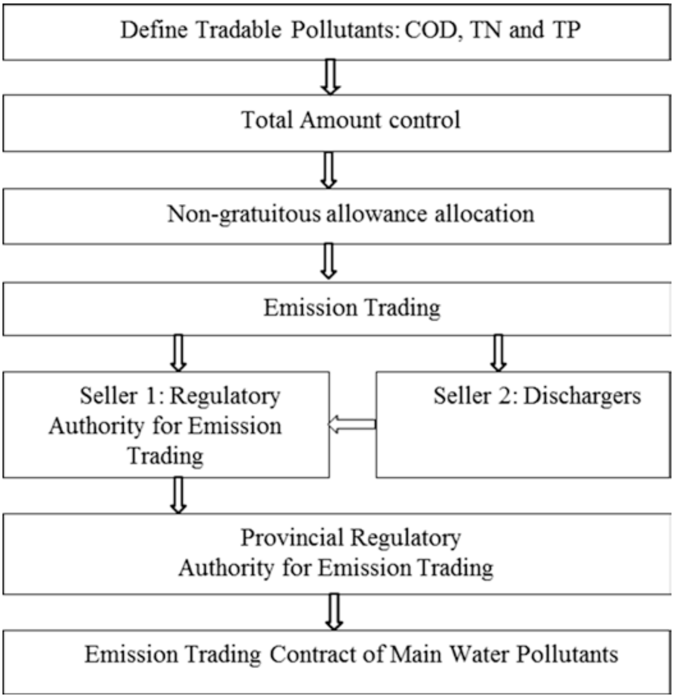

Fig. 1 Water pollution trading scheme. (Source: Dai L 2014. Exploring China's approach to implementing "eco-compensation" schemes: The Lake Tai watershed as case study considered through a legal lens. Water Int 39(5):755–773. Copyright © International Water Resources Association, reprinted by permission of Taylor & Francis Ltd.)

3 Legal Issues Arising from Eco-compensation Schemes in the Tai Lake Case Study

This section considers each of the four typologies of eco-compensation implemented in the Tai Lake case study.

In the first type of scheme (government to government), the upstream jurisdiction is required by law to compensate the losses of the downstream jurisdiction when the monitoring data shows that the water quality is below the legally defined standards in the monitoring areas. This is not a true 'eco-compensation' scheme—in fact, from a legal perspective, this compensation is more akin to payments for pollutant discharge, a legal liability approach, not as compensation per se for ecosystem services.

The national Environmental Protection Law (2014) states that:

> Enterprises and public institutions and other producers and operators that discharging pollutants shall pay a fee for pollutant discharge … The fee for pollutant discharge shall be used exclusively for the prevention and control of environmental pollution…. (Article 43)

Therefore, the “designated discharge standards” are actually compulsory standards regulated by the law; polluters that discharge pollutants exceeding the standards should bear legal liability (Du and Chen 2013). Given this reading, the compensation paid by the upstream city to the downstream city is considered as narrow eco-compensation but only in a broad sense, since it does not provide rewards for protecting the environment and natural resources but only introduces pollution charges.

Under this same line of reasoning, asking the downstream city to compensate the upstream city when the water quality does not exceed the standards also lacks legal support as a true eco-compensation mechanism, because again the standards imposed are compulsory regulations—nobody should be compensated for merely abiding by the law.

One approach to transforming this approach into a true (narrow) eco-compensation scheme would be to establish a “negotiable water quality” (Du and Chen 2013) instead of referring simply to the compulsory regulatory standards. By agreeing on a certain water quality (must be better than the compulsory quality) in monitored areas, the upstream and downstream cities may voluntarily agree to an eco-compensation contract: if the recorded results in the monitoring areas are above the contractual water quality, the party who puts efforts into making this should be compensated by the other one. Through such means, supplementing and building upon the existing regulatory requirements, a more holistic and functional eco-compensatory scheme can be formulated and implemented.

For this type of voluntary eco-compensation to work in practice, however, more scientific and legal research is needed in order to address a broad range of complex issues, such as monetizing the target ecosystem services, governance mechanisms for stakeholder involvement and adequate legal frameworks, as just some of the most pertinent examples.

In the case study examining the farmer compensation schemes, the governments compensate the farmers for changing their water-use practices, which is aimed at improved water quality. The eco-compensation relationship seems to be comparatively clear—the ecosystem service buyers are the Jiangsu Provincial Government, the Suzhou City government and the related district/county governments, and the ecosystem service providers are the fish farmers. The compensation payments include compensation through direct cash payments and fish farm resettlement.

However, these schemes have proved to be problematic in practice, with apparent divergent approaches for professional and non-professional farmers. While the former category is permitted to select their type of compensation—either cash compensation or resettlement—non-local fish farmers and non-professional fish farmers have only one choice, direct cash payments. Thus, this category of farmers is required to give up their primary livelihoods. This unequal treatment led to protests by some non-local farmers, who challenged this discriminatory approach by the governments. Another shortcoming of this scheme is the fact that the city government dominated the entire compensation process, with a marked absence of market party participation, with no third-party evaluations and assessments. This resulted in some poor decision-making—i.e. many of the newly resettled areas were not suitable for aquaculture (Han 2010). This situation meant that farmers had limited options because signing the contract was a precondition for the new farm resettlement, with the new aquaculture zones already planned by government, making the cost of reorganization too high in many respects. Given this reality, the compensation for resettlement made no sense at all for those farmers whose newly allocated farms produced substantially lower yields; it was made even worse in light of the fact that they had given up the option of cash compensation. This has given rise to new social conflicts, although water pollution has been improved to a certain extent.

Another issue relates to the compensation criteria that are used. For example, in the forest rehabilitation project in the Tai Lake region, 68.18% of the farmers interviewed were not satisfied with the government compensation, because the farmland was productive as the irrigation was sufficient and the soil was fertile. Before rehabilitation, farmers could get RMB 13, 890 /hm2 (US $2240/hm2) income per year by growing ordinary vegetables, but after rehabilitation, they could only get RMB 6, 000–9, 000/hm2 (US $968–1452 /hm2) from the government as compensation (Luo et al. 2011). This is not a minor loss for a farmer whose per capita disposable income is RMB 38, 459 (US $6, 203) in 2012 (National Bureau of Statistics 2014). If rational decision-makers are assumed to be participants, they would be unlikely to accept a payment unless it exceeds the sum of the opportunity costs they face (Wunder et al. 2008). In light of all of this, it seems that the "win-win" objective set forth in the regulations has not been achieved.

In the third and fourth typologies, the eco-compensation between the government and industry and among the industries, these have succeeded in making considerable contributions to various environmental protection funds. The scheme of discharge paid use works appears to work quite efficiently. Nonetheless, it must be noted that this system is actually different from the scheme of national pollution discharge fees. Under the scheme of discharge paid use, governments set pollutant loading cap for a "bubble" and allocate discharge credits. Dischargers buy credits guided by the principle of the "user pays"; it reflects the dischargers' right to use natural resources. Under the latter scheme of national pollution discharge fees, dischargers pay fees whether they discharge pollutants into the water in excess of discharge standards or not. The difference from the former scheme is that instead of governments setting pollutant loading cap and allocating discharge credits, dischargers in the latter scheme report to and register with the local governments about the variety, quantity and density of discharged pollutants and wait for the governments' approval. Dischargers pay fees based on the principle of the "polluter pays"; it reflects the dischargers' liability for using the natural resources.

Under the former scheme of discharge paid use, dischargers are more motivated than under the scheme of national pollution discharge fees, as once they save discharge credits, they can keep them for the following year or sell them on the market. Dischargers themselves are the main pollution control bodies; governments only design and control the "bubble". Under the scheme of national pollution discharge fees, dischargers normally do not have enough motivation to reduce emissions if their discharges do not exceed the discharge standards approved by the governments. Governments are the main pollution control bodies. It is less cost-efficient than under the former scheme.

Although dischargers who have legally purchased the emission credits still have to undertake the legal responsibility of pollution control, the two different charges should not be repetitively collected, i.e. who buys the discharge credits should not pay pollution discharge fees. However, in practice, there are no published legal guidelines to address this problem, leaving it unclear how the governments have managed this in practice.

In the scheme of discharge paid use, the governments play the role of ecosystem service providers for the purpose of maintaining a healthy water ecosystem and ensuring that the ecosystem can provide continuous eco-services and they set the pollutant loading cap for a “bubble”, monetize the pollutants and allocate the discharge credits. The selected dischargers are service buyers. In the COD emission trading system, those selected dischargers become service providers, who save discharge credits and provide certain ecosystem services by improving their pollution prevention facilities or inputting some other efforts, and those who buy credits from other dischargers are service buyers.

As new and experimental instruments, both the scheme of discharge paid use and emission trading have some shortcomings. For example, it is uncertain how the provincial governments adjust their pollutant discharge targets and how they allocate or set prices for the emissions in the next 5 years, while the central government adjusts national pollutant targets every 5 years. This lack of transparency leads to considerable uncertainties for the key actors in these schemes; as a result industrial dischargers face considerable risks in making decisions such as whether or not to buy the discharge credits or how many to buy. In addition, the current emission trading in the Tai Lake watershed within Jiangsu Province is limited to COD emissions only; while the prices for TN and TP emission trading were announced in 2011, there is not yet a specific legal regulation covering these. Furthermore, it is also very difficult to evaluate the environmental benefits from the emission trading alone as it is generally applied together with many other policy instruments. According to research, tradable discharge permits are actually among the most challenging regulatory policies in terms of both their design and implementation (Kraemer et al. 2004).

In summary, the case study undertaken here reveals that four types of eco-compensation mechanisms have been deployed across the Tai Lake region (see Table 1). The common feature in each case is the dominant role played by governments (especially in the first three types). The main financial source for compensation is governmental payment. For example, at the time of the algal bloom in 2007, Jiangsu was spending two billion RMB (US$322 million) per year to address Tai Lake’s pollution problems (Liang and He 2012). Since 2008, Jiangsu Provincial Government has contributed 0.2 billion RMB (US$32 million) per year to a special fund to control water pollution in Tai Lake, with local governments asked to contribute 10%–20% (Nan 2013). Governments are the main actors in formulating

Table 1 Types of eco-compensation mechanisms in the Tai Lake region within Jiangsu Province

Types	Water problem	Eco-services	Providers	Buyers	Payment	Laws/regulations
ECM between governments	Pollution disputes	Provision of higher water quality than compulsory standards	Upstream city/ downstream city	Downstream city/upstream city	Cash, others	None
ECM between governments and farmers	Pollution	Improved water quality	Farmers	Governments	Cash, farm resettlement	Opinions of energy conservation and emission reduction in Jiangsu Province, No. 63 [2007] Regulation on the Administration of the Tai Lake Basin, State Council, No. 604 [2011]
ECM between governments and industry	Pollution	Pollution control in certain cap	Governments	Industries	Cash	Implementing measures for main pollutant discharge and emission trading in pilots of the Tai Lake watershed in Jiangsu Province, No. 8 [2008] Administration for charges for credits of main pollutant discharge in the Tai Lake watershed of Jiangsu Province (trial implementation), [2008] Regulation of Jiangsu Province on prevention and control of water pollution in the Tai Lake region, No. 113 [2012]
ECM among industries	Pollution	Improved water quality	Industries	Industries	Cash	Implementing measures for main pollutant discharge and emission trading in pilots of the Tai Lake watershed region in Jiangsu Province, No. 8 [2008] Interim measures for main pollutant emission trading in the Tai Lake watershed of Jiangsu Province, No. 4 [2010]

Source: Dai L (2014) Exploring China's approach to implementing "eco-compensation" schemes: The Lake Tai watershed as case study considered through a legal lens. Water Int 39(5):755–773. Copyright © International Water Resources Association and implementing eco-compensation schemes. Although commercial actors also contribute to the fund (e.g. the revenue of COD trading), this amount is insignificant when compared with the level of governmental payments. The single financial source from the government might weaken the expectations of the eco-compensation projects. An example is the "Three-North" Shelterbelt Project.

4 Conclusions

Well-functioning ecosystems provide human beings with a broad range of important services, many fundamental to sustainable development. Effective eco-compensation schemes can contribute to the preservation of ecosystem services and lead to a more sustainable development both within and outside China.

Through examining the four types of eco-compensation schemes applied across the Tai Lake watershed, a number of observations can be made.

Eco-compensation schemes in Tai Lake watersheds are dominated primarily by governments through primarily governmental-sourced financial transfers. Although market-based eco-compensation, for example, the emission trading of COD, has been experimented with, it is still at a very early stage and needs to be further developed. The single source of governmental financial transfers might lead to a risk of a fund shortage in the future. A shortfall could, in turn, weaken the sustainability of the mechanism itself revealing a critical overall risk.

Constructing effective eco-compensation mechanisms in watersheds is a long-term project requiring multidisciplinary expertise. As has been discussed here, designing a robust legal framework capable of anchoring true eco-compensation schemes (as opposed to pollution liability regimes) requires careful consideration of a range of issues, and focusing only on the mechanism itself is far from sufficient. Attention must also be paid to the preconditions in each case, such as water management system details, the public's willingness to participate and the collaboration between or among provinces and regions and such other conditionalities that might support or impede the mechanism. Even across the legal domain, eco-compensation schemes cross a complex matrix of legal regimes—a multidimensional construct of rules, laws and regulations, including (but not limited to!) administrative, corporate, contractual, public, private, regulatory and trade matters (Wouters 2007).

Despite these challenges, the eco-compensation schemes being implemented in China provide a meaningful platform for addressing the complex issues related to ecosystem services. More legal research is required to address the gaps identified in the current domestic practice.

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Economic Requirements and Instruments for Sustainable Urban Water Management – Comparative Review

Erik Gawel and Norman Bedtke

Abstract Sustainable water management is still one of the major challenges of our times, and economic instruments may significantly contribute to a transition towards sustainability in water management. This chapter provides an overview on the current state of the implementation of sustainable water management in Germany. After introducing environmental policy instruments with a special focus on water pricing, the chapter gives an overview of topical challenges in Germany by looking in particular at the design of key policy instruments and the related need for reforms. The following points will be taken into consideration: contradictory requirements of water pricing, deficiencies of current tariffs against the background of changing demand structures, the role of environmental regulatory charges and the importance of a pending urban water sector transition. It will be shown that Germany's water management is far from being completely "sustainable" – despite all the successes achieved to date.

1 Introduction: Sustainable Water Management from an Economic Perspective

Sustainable water management is one of the major challenges of our times for developing countries but also developed countries. In many developing countries, the fulfilment of the water-related Sustainable Development Goals (access to

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drinking water, access to appropriate sanitary facilities) is still the most pressing problem (UNICEF and WHO 2015). In developed countries improvements over the initial situation in terms of resource efficiency, economic viability and quality are mainly pursued. In particular, this includes a better ecological sustainability and a better ability to meet changing conditions (e.g. climate change). In countries with existing water infrastructures, this is often only achievable by a transition, which means the use of far-reaching technical innovations and substantial institutional and organizational changes in the provision of water services (Bedtke and Gawel 2018). Another general problem is the need for a sustainable use of water resources, as water is an increasingly scarce and depleting resource in many regions of the world (Mekonnen and Hoekstra 2016).

From an economic perspective, numerous economic challenges in the water sectors negatively affect sustainable development. The distribution networks of infrastructure sectors are to be classified as natural monopoly, which implies the need for regulation, to avoid abuse of monopoly power and corresponding inefficiencies. Furthermore, protection of both water resources and aquatic ecosystems reveals characteristics of a public good since its utility for society is "non-excludable" and shows a "nonrivalry" in consumption. Again, this calls for state action. In addition, some water services are so-called merit goods that lie in the national interest (e.g. basic sanitation and wastewater collection). The private consumption of merit goods tends to be below the social optimum, especially because of externalities that are not taken into consideration by private consumers (OECD 2009). All in all, private competitive market schemes will therefore not provide sufficient quantities of water services in an adequate quality (market failures). State regulation may help overcome these deficiencies but, contrary, runs the risk of "state failure" (i.e. missing the societal optimum as well) mainly due to information deficits of a central planner (von Hayek 1968). Therefore, a complex set of "institutions" (= societal rules) is often needed, which is combining market and state approaches to meet sustainability challenges.

Economics as a discipline and derivative economic instruments may significantly contribute to a transition towards sustainability in water management. The aim of water economics is to analyse and design institutional frameworks to provide adequate incentives for decision-makers on both supply and demand side to obtain "efficient" solutions and to minimize the overall societal cost when making use of water resources and services. This can be achieved, in particular by economic instruments, which "are fiscal and other economic incentives and disincentives to incorporate environmental costs and benefits into the budgets of households and enterprise" (OECD 2008, p. 159). By doing so, these instruments encourage environmentally sound and efficient production and consumption through full-cost pricing and associated incentives for all stakeholders.

Given the complexity of the subject, several theoretical concepts address the issue of sustainable water management from an economic perspective. Due to the natural monopoly characteristics of network-based water services, issues relating monopoly regulation and pricing rules are rampant (Finger et al. 2007; Baptista 2014). Another economic key area relates to environmental externalities (e.g.

micro-pollutants, wastewater treatment with positive downstream effects) and public goods (see OECD 2009 for an overview). Finally, another special focus is on transition processes in (urban) water management (Brown and Keath 2008; van der Brugge et al. 2005; Bedtke and Gawel 2018).

This contribution provides an overview on the current state of the implementation of sustainable water management in Germany. After introducing environmental policy instruments with a special focus on water pricing (Sect. 2), the chapter gives an overview of topical challenges in Germany by looking in particular at the design of key policy instruments and the related need for reforms (Sect. 3). Section 4 concludes this article with a summary.

2 Instruments for Sustainable Urban Water Management in Germany and the EU from an Economic Perspective

2.1 Environmental Policy Instruments: Overview

When it comes to the application of instruments of water resources management in Germany and the EU, we may, from an economic perspective, differentiate three general categories: market-based instruments, regulatory law and informational instruments as well as planning. These approaches, in turn, can be distinguished between direct and indirect instruments (see Table 1). First, market-based instruments are defined as "regulations that encourage behavior through market signals rather than through explicit directives" (Stavins 2003, p. 358), which covers a wide range of instruments such as taxes, fees and tradeable permits. If these instruments are well designed and implemented, they encourage economic actors to pursue environmental goals because they are in their own (financial) interests. Quantity-oriented instruments, such as tradeable permits, thereby have a more direct effect in

Table 1 Environmental policy instruments – an overview

Policy tool	Direct instruments	Indirect instruments
Market-based instruments/ economic incentives		Price-oriented:
		Taxes; fees;
		subsidies; liability schemes
		Quantity-oriented:
		Tradable permits
Regulatory law (command and control)	Emissions standards; regulation directives; bans; permits	Technology/product
		Standards
Informational instruments		Awareness/education campaigns; moral suasion;
		Certification schemes
Planning	Infrastructure and water body planning	

Source: Own compilation

comparison with price-oriented instruments, by introducing a quantitative restriction. Second, the conventional approach of regulatory law (also known as command-and-control regulation) typically forces industry and individuals to reach compliance with given environmental standards. They do this in a very direct way by enforceable legal regulations (e.g. wastewater emission standards) or a bit more indirectly by setting universal standards for technologies or products (e.g. technical codes). Finally, informational instruments may positively affect environmental quality by influencing consumer decisions. This is done indirectly by providing information about the environmental consequences of their actions (e.g. saving water awareness campaigns), which allows consumers to make better-informed choices. Planning approaches for infrastructures or water bodies are beyond these categories.

All types of instruments have their advantages and disadvantages with regard to objectives such as environmental effectiveness, efficiency, corresponding transactions costs, distributional impacts or consistency with other policies. However, the main advantage of economic instruments is that they minimize the cost to society. They provide incentives for the highest level of reductions in pollution by those firms with the lowest reduction costs. In contrast, under regulatory law firms are required to achieve the environmental goals regardless of their individual cost structures. It is, however, also conceivable that command-and-control approaches can be the cost-effective way of reducing pollution, though this requires detailed information about the compliance costs each firm faces to set individual standards, which means usually prohibitively high transaction costs (Stavins 2003). Other advantages of market-based instruments are the provision of continual incentives to reduce emissions, thus promoting technological progress (dynamic efficiency).

Today, the use of multiple policy instruments to achieve environmental objectives is common practice in the EU and Germany, although the application of economic approaches is still rather selective and typically embedded by other instruments (policy mix). However, this is a step forward, after economic instruments for environmental purposes were mostly rejected in practice for a long time. In the recent past, the Water Framework Directive (WFD) has introduced in a significant way economic approaches in water policy (polluter pays principle, cost recovery for water services, economic analysis for river basin planning). For instance, the EU legislator calls for the Member States to ensure that “water-pricing policies provide adequate incentives for users to use water resources efficiently and thereby contribute to the environmental objectives of this Directive” (Article 9 WFD). Although there are some early experiences in Germany with regulatory water use charges since 1974 (wastewater charge) and late 1980s (abstraction charges), the full implementation of Article 9 has still to be carried out and faces manifold obstacles (see Sect. 3.3).

2.2 Pricing Water Services

Water pricing is probably the most important economic instrument to promote a sustainable water resource management. Water pricing creates manifold incentives on the supply and demand side. If it is well designed and implemented, it “can help to reconcile sound water resources management with the adequate provision of water services and investment in infrastructure" (OECD 2010, p. 18). The OECD highlights two important functions of water pricing. First, pricing can be an allocation mechanism, which directs water to the most valuable use, by informing users about the value of the resource. Thus, water pricing also provides incentives for the development of water-efficient processes and products.

Second, water pricing is above all a financing instrument, which generates revenues that can be used for maintenance, operation and development of infrastructures (OECD 2009).

Important for sustainable water pricing is the application of two fundamental principles: full-cost pricing and the polluter pays principle. Full-cost pricing is given when all costs incurred in connection with water service provision are taken into consideration. This includes full supply costs (capital costs, operation and maintenance costs), full economic costs (economic externalities, opportunity costs) but also environmental externalities (Rogers et al. 2002; OECD 2010). Full-cost pricing will ensure that economic decisions are made efficient (which means utility exceeds cost) and with reduced environmental impacts. However, prices are almost always below the full-cost level. While in many developing countries, though not only there, even full supply costs are not covered, in developed countries externalities are usually not taken into account (Gawel 2016a).

The basic idea behind the polluter pays principle is that those who produce impact on others ("pollution") should bear the costs of managing it to prevent damage (OECD 1992). In consequence of the application, polluters will be discouraged from emitting as much, and their products will become relatively more expensive, thus reducing the demand for them. Further, the imposition of costs will induce innovation in favour of future avoidance (Bowen 2011).

Sustainable water pricing is a challenge since multiple sustainability objectives have to be addressed by only one single instrument (the price). The OECD identifies in general environmental, economic, financial and social objectives, which can support one another but also can give rise to potential conflicts (see Fig. 1; see OECD 2010 for a detailed discussion). For instance, there is an obvious conflict between ecological and financial sustainability, since an improvement of environmental quality usually means additional costs (e.g. investment and operation costs of a fourth treatment stage). At the same time, the higher costs for environmental improvements cause higher prices or charges, which is in conflict with social concerns of affordability and the right to water (Gawel and Bretschneider 2016; for the efficiency-equity trade-off in general, see Gawel and Kuhlicke 2018). Another prominent example is the conflict between affordability and financial sustainability. Attaching a price to water may be politically unpopular, which is why tariffs are often below the required level of full-cost recovery. However, this may lead to deterioration of infrastructure and services in the long term. The challenging task of designing integrated "sustainable pricing" strategies is further complicated because it is difficult to exactly reconcile the trade-offs (see Gawel and Bretschneider 2014, 2017, specifying affordability challenges of infrastructure services), especially in view of the societal sensitivity of the issue of water services (see Gawel and Bretschneider 2016 on the subject of a right to water from an economic perspective).

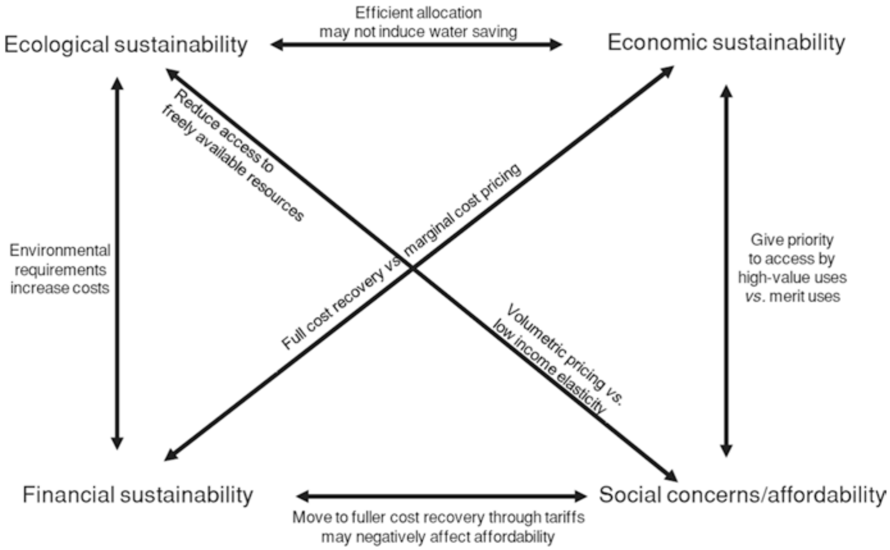

Fig. 1 Policy objectives and trade-offs of water pricing. (Source: OECD 2010, p. 26)

3 Current Debates and Challenges in Germany

3.1 German Water Pricing: At the Same Time "Too High" and "Too Low"

The German water sector is for some time now subject to criticism for a lack of efficiency. A World Bank Report in 1995 confirmed a high quality of the German water and sewerage services but also criticized the insufficient attention to economic efficiency and costs. As evidence of that, it was stated that the prices of water services are much higher and are increasing faster than in all other European and North American countries (Briscoe 1995). In the meantime, counter-assessments have shown that a significant proportion of the additional costs can be explained by the higher quality of water services in Germany (Metropolitan Consulting Group 2006), even though inefficiencies also could be identified (Sauer 2005; Zschille 2015). Nevertheless, the report was the starting point of an ongoing debate about a reform of the regulatory framework in the German water sector, which in turn led to an insufficient strategy of modernization adopted by the Federal Government in 2006 (Gawel and Bedtke 2015). Further, the central thrust of this report is that the water prices in Germany are "too high". Referring to the multiple objectives in water pricing policies, the question has to be, whether the water prices are also "too low". There is some evidence that this is the case. One the one hand, there is the problem of refinancing of services. The preservation of assets is associated with very high costs. German water service providers invest up to 2.7 billion Euros a year in the water supply sector for maintenance and modernization; another

3.4–6.9 billion Euros are spent each year in the wastewater sector (ATT, BDEW, DBVW, DVGW, DWA and VKU 2015). However, there are many strong indications that the high level of expenditures is not sufficient to address the prevalent infrastructure investment gap (OECD 2007). This is even more true if the need for transition of the urban water sector is also considered (see Sect. 3.4), which apparently generate considerable additional costs at the beginning. On the other hand, water prices seem to be low because of the missing full-cost recovery. Financial cost recovery (full financial costs) is not met, because under the German law of local fees, it is not compulsory or even not possible. Furthermore, Article 9 of the EU Water Framework Directive (WFD) requires Member States to take account of the principle of recovery of the costs of water services, including environmental and resource costs. So far, this requirement has been not fulfilled (Gawel 2016a). Cost recovery deficits can be observed not least because of political reasons.

It seems that giving consideration to multiple objectives in water pricing policies, the prices are at the same time “too high” and “too low”. The problem is well known in economic theory and was discussed using the example of a monopolist that provides services with external costs (Buchanan and Stubblebine 1962; Buchanan 1969). However, in practice these are totally fragmented discourses, whereby the aim of increasing efficiency dominates the debates. So far, it is still not at all clear how to integrate these competing requirements both theoretically (“sustainable pricing” – Gawel 2016b) and practically.

3.2 Pricing German Water Services: Deficiencies of Tariffs

A key element of water pricing is the concrete design of water and wastewater tariffs (see Hoque and Wichelns 2013 for an overview). The current tariff setting in Germany is characterized by the guiding principle of financial cost recovery, fiscal burden-sharing and a cost-plus regulation (e.g. by Local Tax Acts). These institutional arrangements have proved their worth over a long period. However, today there is considerable need for reform. Tariffs were initially designed for a continuous increase in water demand resulting from the expected population growth and a higher demand per capita. Predictions assumed up to 220 l of water consumption per inhabitant and per day in 2000 (BDEW 2007). But the reality is far different. The population of Germany is strongly decreasing, and as a result of comprehensive water saving/water efficiency measures, the demand for water is only 123 l/person and day (ATT, BDEW, DBVW, DVGW, DWA and VKU 2015). Additionally, the situation is further aggravated by a declining industrial water demand. As a result, urban water infrastructures are significantly underutilized in many places, which pose serious problems for water service providers. First of all, there are the effects on the network. The decrease in consumption can impair the functioning of the supply network because of resulting low flow rates and long delays in water pipes. As a consequence functional issues can arise (e.g. recontamination of drinking water, deposits in the ducts, premature wear and tear).

The same applies for the sanitation sector, where underutilization leads inter alia to build up of solids and odour problems, which makes frequent flushing or structural adjustments necessary (Hummel and Lux 2007).

Second, apart from technical problems, reduced demand has serious economic consequences. The main problem is the incompatibility of the current revenue structure and cost structures (see also Fig. 2). German drinking water providers usually use a two-part tariff which is divided into a consumption-independent element (basic charge) and a consumption-dependent part. To set up some incentives for water conservation, the variable portion is up to 80%, while the variable costs are comparatively low. However, this is in strong contrast to the cost structure of water infrastructure systems with high fixed costs up to 80%. In consequence, a significant reduction of water demand leads to a substantial drop of revenues and a higher probability of failing cost recovery. The infrastructure systems are far too inflexible to react adequately to changing demand in the short term. Therefore, the loss of revenue needs to be compensated with higher costs of water per person, especially if the number of consumers also decreases. This creates higher financial burdens for households, which will lead them to further reduce their water consumption.

As a result, the problem of underutilization becomes worse, and further price increases are necessary in order to avoid financial shortfalls. To break out of this vicious cycle, new tariff systems are currently being discussed. In the drinking water sector, proposals have been prepared to adjust the ratio of basic charge and the consumption-dependent element in favour of the basic charge (Oelmann et al. 2016). Although this approach of "system prices" may defuse the problem of underfunding, it creates new problems from a sustainable angle. On the one hand, it reduces the perceived pressure caused by problems of underutilization and thus the need for a transition. In the long term, this seems to be the inferior solution from an environmental standpoint, while a customized adaption of the infrastructure sys-

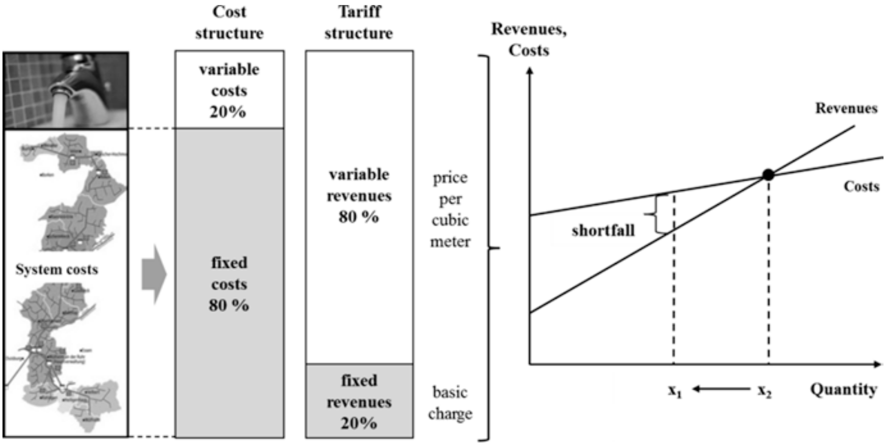

Fig. 2 Link between cost structure and revenue structure. (Source: Oelmann et al. 2017, p. 17, translated)

tems should be preferred. On the other hand, such an adjustment reduces the incentives for water conservation. A similar situation can be observed in the wastewater sector, where the suggested introduction of two-part tariffs (with a basic user fee) reduces the incentives in households to prevent wastewater but stabilizes revenues for local utilities (sustainability conflict).

3.3 Pricing German Water Services: The Role of Environmental Regulatory Charges

Water utilization charges (also called regulatory charges) may complement pricing of water services with respect to external costs. The main objective of regulatory charges is a correction of allocation, i.e. a change in behaviour with regard to the use of water resources by adjusting relative prices which renders use of the resource more expensive (steering function). This influence on behaviour is due not only to direct incentives to substitution (primary change in behaviour) but also to the absorption of purchasing power for the remaining uses (secondary market and price effects and innovation stimuli) (Gawel et al. 2011). In addition, utilization charges are a source for the generation of revenues that will be used to finance environmental protection actions.

In Germany, different types of water utilization charges have been used already for some decades. However, there is still an ongoing debate about the necessity for and design of such utilization charges. The political discussion is usually dominated by the erroneous assumption that a public charge has no steering effect if it fails to achieve a certain pinpoint target (though this is not specified with the charge) or to produce tangible reductions over time. The importance of the revenue accruing from the charge and the burden of payment on other uses is usually not recognized or is regarded as alien to the steering function. In practice, however, environmental charges are typically "demerit charges" – their aim, without any specific pinpoint target, is to set in motion a comprehensive process of ecological structural change. In fact, steering deficits of existing charges tend to arise from the fact that a number of offsetting and reduction clauses have been used to reduce the effective burden of payment for residual pollution and to seek a close connection with regulatory law (Gawel et al. 2011).

The federal wastewater charge in Germany is a good example here. The wastewater charge, introduced in Germany in 1974, levied since 1981, is a "tax" on discharges of wastewater in water bodies. The burden of payment is based on the "harmfulness" of the discharge, which is defined by various parameters (such as chemical oxygen demand, phosphorus, inorganic nitrogen, metals, toxicity, etc.). Although the instrument has made significant contributions to the success of steering measures in the field of wastewater discharges in Germany, today its allocation and innovation effect is thwarted by the reduced effective charging rates (inflation over time, legally offered offsetting opportunities) and its excessively close dovetailing with regulatory requirements of water law. Consequently, there is considerable need for modernisation of the charge with focus on its effectiveness as a steering instrument and the improvement of the target consistency of the entire levy structure (see Gawel et al. 2014).

Another example are water abstraction charges, which are levied on withdrawal of groundwater and surface water. They were introduced in Germany in 1989 and are currently collected in 13 out of 16 German federal states. The amount payable depends on multiple factors, such as amount of water abstraction, the water origin, the intended purpose of water use and the federal state rules, and is currently up to 31 €-Cent/m^3. The revenue is mostly earmarked for water management tasks (e.g. water protection or flood protection measures). Opponents of the extraction charges however argue that there is no shortage of water in Germany which makes this instrument superfluous. Moreover, in their opinion, such a charge has no steering effect because of the low price elasticity of water. However, the arguments fall far short. Even Germany, a country rich in water resources, faces already today situations of water scarcity in terms of time and space. This is clearly shown by the presence of a number of supra-regional water networks. Climate change will further affect water resources, which is why saving water makes definitely sense. Furthermore, a water abstraction charge is not without steering effects in the long term, even if no substitution takes place in the short term: in the industrial sector, secondary market and price effects and innovation incentives ensure a long-term ecological structural shift away from water-intensive production processes. Instead of an abolishment, the level of charging rates has to be adjusted (especially inflation adjustment), and existing differences between and within the *Länder*, which give rise to a number of dubious incentive effects and economic distortions, have to be harmonized (see Gawel et al. 2011).

At the same time, new environmental regulatory charges with respect to water resources were discussed. A main challenge is to address the non-point source pollutions from agricultural lands (mainly pesticides, nutrients). The implementation of command-and-control approaches would raise considerable enforcement problems (e.g. 300,000 farmers, more than half of the area of Germany is farmland) and in addition would be inefficient due to uniform standards regardless of individual cost structures. Again, the benefits of economic instruments are obvious. Setting adequate incentives to avoid the use of pesticides with degrees of freedom along the complete value chain appears to be the most promising approach to achieve efficient solutions and foster innovations. It is therefore no surprise that proposals for a pesticide tax, as already established inter alia in Sweden, France and Denmark, are currently further specified (see Möckel et al. 2015). Similar developments can be observed on the field of a nitrogen tax (see Gawel et al. 2011) and, more recently, a tax on pharmaceuticals with respect to micro-pollutants (see Gawel et al. 2017).

3.4 Urban Water Sector Transition

The above-mentioned debates address specific individual questions of water management and water pricing instruments. In addition, there is also a debate on a transition of the entire urban water sector, which is yet discussed separately, though there are numerous interrelationships. Starting points are several processes that create pressure for change in the existing network-based water infrastructures. The massive decline in population in the east of Germany and altered demand structures lead to an underutilization of established urban water infrastructures. The consequences involve technical and economic issues (see Sect. 3.2). The effects of climate change will alter the availability of water resources and water demand (higher peak load), and they are expected to cause an increase in heavy rain events, which means a risk of urban flash floods and uncontrolled sewage plant overflows (EEA 2012). There are also calls for greater purification capacity (e.g. micro-pollutants) and a strong demand for resource efficiency and economic efficiency of infrastructure operations. It is widely believed that a transition to an integrated and sustainable urban water management by using new flexible technological solutions is required to address this manifold challenges (Larsen and Gujer 1997; Brown et al. 2009; Bedtke and Gawel 2018).

At the moment, is anything but clear, how this transition can be achieved, but the importance of institutional aspects in general and water pricing in particular is obvious. For instance, the enormous costs of operating infrastructure systems are a main reason for the continuation of the current unsustainable path. Many institutional regulations, and the established administrative apparatus that has been built up, are directed at supporting this system through a refinancing model based on the principle of solidarity of as many connected users as possible, thus keeping the unit costs low. At the same time, in Germany, municipal provisions for "compulsory connection and usage" ensure that the usage of centralized systems is high and that the user group that finances the system remains as large as possible. In order to enhance the distribution of decentralized elements, an opening up of the municipal provisions on compulsory connection and usage and tariff-based incentives for novel solutions (e.g. reductions in wastewater charges for rainwater with decentralized seepage) would be required. But the local government agencies have little interest in this, because it would be synonymous with a (further) erosion of the funding base for their central systems, which will, of course, still persist. Consequently, institutional innovations are unlikely here. Bedtke and Gawel (2018) identify an "institutional equilibrium" in the urban water sector, that is, a situation where numerous (relevant) actors do not find it advantageous to expend resources on the formulation of new institutional arrangements (North 1990). Therefore, a starting point for a transition in the urban water sector could be the change of incentives structures via pricing. Taking all (environmental) costs into account, the relative prices of service provision would shift in favour of novel system solutions that have obvious advantages over conventional systems in relation to ecological aspects (resource efficiency/recovery). Water utilization charges play an important role here: they can allocate "environmental and resource costs" and initiate structural change through their incentive effects (see Sect. 3.3). It is also important to remove institutionally induced barriers (e.g. nontransparent water billing) that prevent full price perception at the household level. On the local government level, the application of new solutions (e.g. phosphate recovery, energy recovery) should be better rewarded through tariffs. On the other hand, the more consumption-independent tariff models that are currently being discussed (see Sect. 3.1) are, instead, purely economically motivated and geared towards the current level of system usage; in terms of sustainability, they lead down the wrong path (Bedtke and Gawel 2018).

4 Conclusions

It has been shown that Germany's water sector is far from being completely "sustainable" – despite all the successes achieved to date in improving water quality. It seems very clear that missing institutions of good governance do hinder a necessary sustainability transition worldwide. But in contrary, as can be concluded from the German case, even well-established and "functioning" institutions may restrict a necessary transition towards sustainability. This is due to institutional inertia and technical path dependencies as well as affected societal interests in the status quo. It is therefore not surprising that, in Germany, several debates on tariffs, charge reforms, transition issues and a new efficiency-oriented sector framework currently take place and thus reveal severe sustainability deficits still to be tackled.

Against this background, economic concepts for water resources management may contribute to efficient ("least-cost") service provision, "efficient" demand (benefit exceeds societal cost), environmental protection, comfortable revenues and sustainability-oriented transition pathways. They may do so by designing incentive-oriented institutional frameworks and innovative pricing concepts. However, they are only partly implemented so far in Germany and the EU.

What needs to be done in the future is true full-cost recovery of services, the implementation of incentivising water tariffs and a reform of existing water use charges as well as the introduction of new charges for non-point pollution (nitrogen, pesticides). A consequent internalization of external "environmental and resource costs" across water-using sectors (e.g. agriculture) and a transition management of the entire sector may contribute to a more sustainable development comprising incentives for all kinds of actors, sufficient financing, cost efficiency and affordability of services and improved environmental impacts. Overall, a consideration of (partly) competing sustainability goals and their trade-offs is crucial in this context. Integrated pricing strategies ("sustainable prices") are key in this respect. Hence, further institutionally oriented economic research on innovative governance approaches is necessary taking into account also practical conditions and multiple objectives in real-world water policy.

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Full Cost Accounting of Urban Water-Use

Guo-jun Song and Wen-cheng Gao

Abstract The full cost of urban water use is all the cost paid directly or indirectly by urban society based on market price. According to the life cycle of urban water use, full cost can be divided into five parts: water intake cost, water making cost, water supply cost, water draining cost, and sewage treatment cost. In this study, an accounting method is constructed for calculating full cost of urban water use, and it has been proved reasonable and feasible. The case study of city A shows that city A's full cost of urban water use reaches 6.23 Yuan/ton at least, while local domestic water price is only 2.05 Yuan/ton, which obviously does not cover full cost urban society pay for water use and undoubtedly cannot reflect the real value of urban water resource. It is suggested that water price should be made based on full cost so that the cost of urban water use could be explicit; thus, water price policy can play a more effective role in water resource allocation. Besides, full cost of urban water use accounting can effectively promote popularization and application of private-public partnership (PPP) mode in the field of water service. Lastly, it is necessary to improve information disclosure of full cost of urban water use to realize scientific and democratic management.

1 Introduction

China's urban water consumption increased year by year. China's industrial and domestic water consumption has increased from 171.5 billion cubic meters in 2000 (Ministry of Water Resources of the People's Republic of China 2001) to 212.1 billion cubic meters in 2014 (Ministry of Water Resources of the People's Republic of China 2015), with a compound annual growth rate of 1.53%. According to a study by China Development Research Foundation, the annual water consumption of

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urban areas in China will grow by 2.4% during the 13th five-year plan period, and urban water pressure will continue to increase. Meanwhile, the low efficiency of water resources utilization in cities aggravates the pressure, for current water price is too low to stimulate the water-saving behavior of residents. At present, the water price generally refers to the engineering water price, containing only the cost of water production part, which cannot totally reflect the full cost of water use, making society generally thinks water is cheap and even free public services, and lack deep understanding of the real value of water resources scarcity. In most Chinese cities, water resource cost and sewage treatment cost are also included in the water price. But even the current generalized water price reflects only a part of urban water use cost, and some are not reflected such as the cost of construction of pipe network, cost of environmental damage and land use, etc. Therefore, it is necessary to check the full cost of urban water use and pricing on it to promote water conservation.

Full cost pricing is the basic principle of water price making, and water use cost should include the costs of water resource exploitation, utilization and sewage treatment processing. Water price standard should be based on the full cost of water use (Ma 2014). Rogers et al. indicate that the social cost of water use includes not only the production cost of the entire water system but also the opportunity cost and externality cost (Rogers et al. 2002), which actually means another interpretation of full cost of water use. However, if not based on the full cost pricing, intervention via public policy means such as subsidies will make the real cost of water use be underestimated, leading to market failure (Arpke and Strong 2006). In the United States, all the infrastructure investment costs that make natural water resource available form water price (Mao 1999). For example, in California where shortage of water resources is a big problem, the local state government built large-scale water diversion project to ensure water supply access to everybody, and the project investment and operational costs are both reflected in the final water price. In Europe, it is the key principle of European Water Framework Directive that water price needs to cover all related cost expense about water use (Unnerstall 2007). In order to improve the efficiency of urban water use, the European Union legislation presents clear requirement that water engineering cost and environmental cost must be taken into consideration in the progress of water price formulation (Hansjuergens and Messner 2002). Kanakoudis builds the methodology of the full cost of urban water use system, states that full cost is the basis of urban water price policy, and divided the full cost into direct cost, environmental cost, and resource cost (Kanakoudis et al. 2011). In China, Liang Ruiju et al. think that in addition to the cost of water supply, full cost water price also includes the opportunity cost, the economic externality cost, and the environmental externalities cost (Liang et al. 2003); otherwise it will cause potential water use efficiency loss (Zhang 2002). Some scholars have defined the full cost of water use as resource cost, engineering cost, and environmental cost (Fu et al. 2006) and constructed the basic model of full cost water price (Fan and Ma 2008). At present, the research on China's urban full cost of water use has made some progress, but specific case studies are still limited. Generally full cost water price researches only consider the resource cost, water making cost, wastewater treatment cost, and environmental cost while ignoring the other hidden costs such as the cost on water transporting pipe network and on sewage collection pipe network investment (Chen 2011; Yang et al. 2008); therefore, the full cost water price currently being researched actually did not completely reflect full cost of water use.

In this article, based on the water use process of urban society, full cost of water use is defined firstly. Then the corresponding accounting method is put forward, and typical city case is selected to calculate the full cost of urban water use.

2 Concept Definition and Research Method

2.1 Full Cost Definition of Urban Water Use

From the perspective of users, full cost of urban water use can be defined as the sum of all direct and indirect costs water users pay in terms of market price. Among them, the direct cost is generally expressed as the water bills, and the water resources and sewage treatment fees are always included in the water bills in most cities. Indirect costs include urban water-related infrastructure spending paid by the government finance, the opportunity cost such as land resources cost for the building of waterworks, sewage plants and environmental damage cost, etc.

Based on the concept of full cost of urban water use, all the specific projects of full cost can be further refined. According to urban water use management links, full cost can be divided into five parts: water intake cost, water making cost, water supply cost, water draining cost, and wastewater treatment cost. According to the concrete forms of full cost, it can be divided into land cost, infrastructure cost, operation and maintenance cost, and environmental damage cost. The structure of full cost of urban water use can be seen in Fig. 1.

To keep corresponds with urban water management, management links are selected to do first cost classification; concrete cost forms are chosen to do second

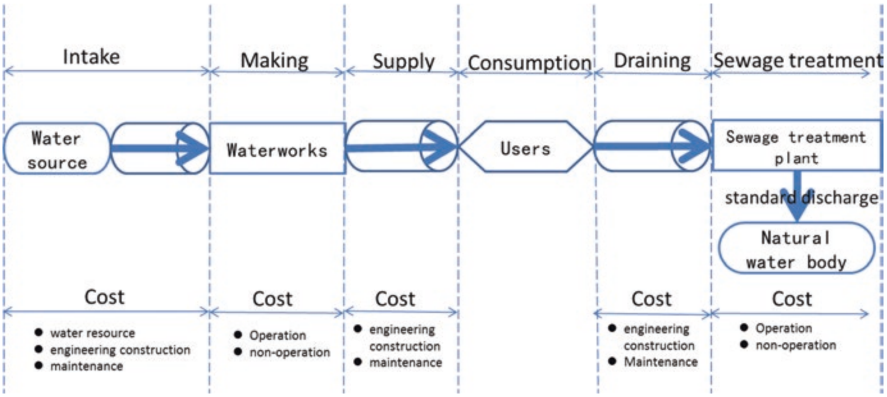

Fig. 1 Structure of full cost of urban water use (Source: compiled by the authors)

Table 1 Instruction on structure and accounting method of full cost of urban water use

Class I	Class II	Class III	Accounting method
Water intake cost	Water resource	–	Water resource fee
	Intake	Engineering construction	Replacement cost method/straight-line depreciation method
		Maintenance	Expert interview method/indirectly calculating method
Water making cost	Operation	Electricity	Market price
		Flocculant	
		Disinfectant	
		Labor	Survey
		Management	
	Nonoperation	Depreciation of fixed assets	Triennial method/straight-line depreciation method
		Amortization of intangible assets	
		Land	Opportunity cost method
Water supply cost	Supply	Engineering construction	Replacement cost method/straight-line depreciation method
		Maintenance	Expert interview method/indirectly calculating method
Water draining cost	Drain	Engineering construction	Replacement cost method/straight-line depreciation method
		Maintenance	Expert interview method/indirectly calculating method
Sewage treatment cost	Operation	Electricity	Market price
		Pharmaceutical	
		Tap water	
		Sewage sludge treatment	
		Labor	Survey
		Management	
	Nonoperation	Depreciation of fixed assets	Triennial method/straight-line depreciation method
		Amortization of intangible assets	
		Land	Opportunity cost method

Source: compiled by the authors

cost classification. Water service belongs to the quasi-public industry; therefore in the process of accounting full cost of urban water use, transportation pipe network cost of water intake, supply, and draining must be considered based on the current market price. At the same time, with the acceleration of urbanization, the scarcity of urban land resources is increasing, and the opportunity cost of land use should be taken into account. The detailed instruction on the structure and accounting method of full cost of urban water use can be seen in Table 1.

3 Full Cost of Urban Water Use in City A

City A is a prefecture-level city located in central China, along the Yangtze River, with per capita GDP of about 1 billion Yuan. Three waterworks from one water company are responsible for the water supply in urban area, and two sewage treatment plants S and W are responsible for the sewage treatment. To ensure the reliability and convenience of water use full cost estimates, the three waterworks are regarded as a whole in the water intake, making, and supply parts research, and an open drainage integration program with PPP model in city A (including sewage treatment plant S and related drainage pipe network facilities) is chosen to study draining and sewage treatment parts. The year of 2015 is taken as the time point.

3.1 Water Intake Cost

Waterworks get water directly from the Yangtze River, so there is no large water intake project and no big water intake expenditure. The water quality of source water reaches II type. According to the local announcement of water quality of the water source in every month, the water quality qualified rate is 100%. The total amount of water got by the three waterworks is 80–90 million tons from the Yangtze River every year. In 2015, 88 million tons of water is got. With the price of 0.08 Yuan per ton for local water resources, the total expenditure of water resources is 7.04 million Yuan. Water intake facilities are all kinds of hydraulic structures used for water diversion, such as entering water gates, pumping stations and collecting water pipes, and so on. According to the similar urban water intake project investment information, the overall water intake engineering construction investment reaches about 250 million Yuan under rough estimate. The average annual depreciation cost is 8.33 million Yuan under concession period of 30 years. As to the water intake facilities maintenance cost, firstly the water making cost is deducted from the total cost of the waterworks, for water intake facilities maintenance cost is included in the waterworks, and then the maintenance cost of both water intake and water supply facilities is estimated to be about 33.99 million Yuan. Secondly, according to the proportion of water intake pipeline length (19 km) in overall water intake and supply pipeline length (1492 km), water intake facilities maintenance costs can be calculated. The result shows that maintenance cost is 0.43 million Yuan per year. Structure of city A’s water intake cost in 2015 is shown in Table 2. It can be found that in the process of water intake, water resources and the construction of water intake facilities constitute the main cost, accounting for 97.3% of the total cost of water intake.

Table 2 Structure of city A's water intake cost in 2015

Cost	Class	Detail	Total cost	Unit cost (Yuan/ton)
Water intake	Water resource	Water resource	704.3	0.08
	Intake	Engineering construction	833.3	0.09
		Maintenance	43.3	0.005
Total	–	–	1580.9	0.18

Source: compiled by the authors

Table 3 Structure of city A's water making/purification cost in 2015

Cost	Class	Detail	Total cost	Unit cost (Yuan/ton)
Water making	Operation	Electricity	1688	0.21
		Flocculant	64	0.01
		Disinfectant	25	0.03
		Labor	3957	0.48
		Management	725	0.09
	Nonoperation	Depreciation of fixed assets	1279	0.16
		Amortization of intangible assets	53	0.01
		Land	2261	0.27
Total	–	–	10,051	1.22

Source: compiled by the authors

3.2 Water Making/Purification Cost

In 2015, the three waterworks totally supplied 82.26 million tons of water, and the water quality qualified rate was 100%. In terms of electricity consumption, the electricity price was calculated at 0.77 Yuan/KWH, the total electricity fee was 21.84 million kilowatt-hours, and the corresponding cost expenditure was 16.88 million Yuan. In terms of flocculant consumption, the total consumption volume of flocculating agent was 705.3 tons, and the corresponding cost expenditure was 0.635 million Yuan, according to the unit price of 900 Yuan/ton. Similar to flocculant, the total cost of disinfectant was 0.246 million Yuan according to the unit price of 2510 Yuan/ton. Labor and management costs in 2015 were 39.57 million Yuan and 7.245 million Yuan, respectively. All the operating costs above add up to 64.58 million Yuan. In terms of the depreciation of fixed assets, the annual depreciation cost is between 1.2 and 1.3 million Yuan, and the average cost of 2013, 2014, and 2015 is about 12.79 million Yuan. Similarly, the average amortization of intangible assets of 2013, 2014, and 2015 is about 0.53 million Yuan. As to land cost, according to local average piece of land used for commercial services (6784 Yuan/square meters), three water plants cover an area of 100,000 square meters, so the land cost is 678.4 million Yuan totally and 22.61 million per year on average under concession period of 30 years. The structure of city A's water making cost in 2015 is shown in Table 3. It can be seen that operating costs accounted for more than

Table 4 Structure of city A's water supply cost in 2015

Cost	Class	Detail	Total cost	Unit cost (Yuan/ton)
Water supply cost	Engineering construction	Pipeline with DN800 and above	184	0.03
		Pipeline with DN500–800	488	0.08
		Pipeline with DN300–500	478	0.08
		Pipeline with DN300 and below	1120	0.18
	Maintenance	Maintenance	3356	0.55
Total	–	–	5626	0.91

Source: compiled by the authors

60%. Actually, waterwork land is free of charge. If the opportunity cost of land is deducted, the unit cost is 0.95 Yuan/ton, and labor costs accounted for nearly half.

3.3 *Water Supply Cost*

The water supply cost includes the construction of water supply facilities and maintenance cost of water supply facilities. The construction of water supply facilities mainly focuses on pipe network, so this paper only calculates pipe network cost, and other facilities such as water pressure pump are not included. The three waterworks serve 750,000 people and sold 61.54 million tons of water in 2015. The total length of the water supply pipe network in the service area is 1473 km, of which the DN300 network is the majority. Based on the market cost of different diameter pipe networks, it can be calculated that the replacement cost of a municipal water supply network construction amounted to 681 million Yuan, and the average annual depreciation cost is 22.7 million Yuan. The maintenance cost of water supply facilities is about 33.56 million Yuan according to the total pipeline transmission network proportion. The structure of city A's water supply costs in 2015 is shown in Table 4. It can be found that the construction and maintenance costs of the water supply pipe network are not small, and the unit cost reaches 0.91 Yuan per ton.

3.4 *Water Draining Cost*

In 2015, city A started to run the urban drainage integration projects through PPP mode. Public information shows that the project value of 788 million Yuan includes a sewage treatment plant named S with a capability of 100,000 tons/day, 206 km sewage pipe network, and other facilities, which means the total nonoperating cost of drainage and sewage treatment is 788 million Yuan. S sewage treatment plant is mainly responsible for local urban sewage treatment, and its fixed assets are worth

Table 5 Structure of city A's water draining cost in 2015

Cost	Class	Total cost	Unit cost (Yuan/ton)
Water draining cost	Engineering construction	2462	0.78
	Maintenance	4120	1.31
Total	–	6582	2.09

Source: compiled by the authors

about 49.37 million Yuan. Except S plant's fixed assets, drainage facilities construction costs are about 24.62 million Yuan per year on average under concession period of 30 years. As to the drainage pipe network operation and maintenance costs, according to relevant experts' opinion, the comprehensive cost of unit length of drainage pipe network operation and maintenance is about 200,000 Yuan/km per year; therefore, 206 km sewage pipe network will take 41.2 million Yuan per year. In addition, the leakage of untreated sewage in urban drainage will generally result in environmental damage, which is in fact part of the full cost of the drainage. If not considering leakage environmental damage, based on 31.55 million sewage flowing into S sewage treatment plant, the structure of city A's water draining cost in 2015 can be calculated and seen in Table 5, in which the unit cost of drainage shows 2.09 Yuan/ton. It can be found that the cost of drainage and water supply is similar, and the operation and maintenance cost of the network facilities is higher than the cost of infrastructure construction. In city A, there are S and W two sewage treatment plants in urban area, and the scale are, respectively, 100,000 tons/day and 50,000 tons/day. According to the size ratio of 2:1, the total cost of urban drainage reaches about 98.72 million Yuan. If considering the leakage environmental damage, the situation is as follows. Due to the cost of environmental damage or damage repair costs are much more than the cost of perfecting the network facilities to avoid leakage, therefore in accordance with city water flow material balance, suppose all the 61.54 million tons of water consumed by users flows into the sewage treatment plant for processing, thus avoiding environmental damage, the corresponding drainage facilities construction, and maintenance costs in proportion to increase. By calculation, the drainage facilities construction and maintenance costs are, respectively, 48.03 million Yuan per year and 80.36 million Yuan per year, and the total cost amount is 128.39 million Yuan per year.

3.5 *Sewage Treatment Cost*

Sewage treatment plant S with a capacity of 100,000 tons/day mainly treats domestic sewage using $A^2/0$ microporous aeration biological treatment process. The treated sewage water meeting the requirement of level 1 B GB18918-2002 standard is discharged into the Yangtze River. In 2015, 31.55 million tons of sewage was treated. The total consumption of electricity was 6437 kilowatt-hours. According to the electricity price of 0.77 Yuan/KWH, the corresponding cost was RMB

49.54 million Yuan. Pharmaceuticals mainly include polyacrylamide, hydrochloric acid, sodium chlorate, etc., and the corresponding cost is 0.316 million Yuan. The total amount of tap water was 7889 tons, and the corresponding cost was 23,000 Yuan, according to the unit price of 2.9 Yuan per ton.

The cost of sludge treatment is divided into two parts. One is the transportation cost. According to investigation, the sewage treatment plant S is only responsible for sludge transport, and the disposal is carried out by a third party. The average transportation cost is about 0.15 million Yuan per year. Another is the cost of sludge disposal. Local sludge is used to make bricks, whose price and environmental standard are both not completely transparent in the current market. It is doubtful whether the sludge can be safely disposed of or not. Therefore, in order to make sure the environmental health, anaerobic digestion technology is taken as the disposal standard, and the disposal cost of sludge is calculated according to the market price of 200 Yuan/ton. As a matter of experience, 31.55 million tons of sewage sludge (water content 80%) produces 22,000 tons of sludge, and the corresponding safe disposal cost is 4.417 million Yuan. The total cost of the two items amounts to 4.567 million Yuan. Labor and management costs in 2015 were 4.575 million Yuan and 14.69 million Yuan, respectively. The operating costs above totaled 14.69 million Yuan. In terms of the nonoperating cost, the depreciation cost of fixed assets and intangible assets of the sewage treatment plant is 5.74 million Yuan per year. According to local data, the average cost of land used for commercial services is at 6784 Yuan/square meters; plant S covers an area of 96,000 square meters, so the land cost is 650 million Yuan totally and 21.71 million per year on average under concession period of 30 years. Similar to drainage link, if the sewage treatment fails to meet the discharge standard, it will also cause environmental damage to the water body, which constitutes a part of the full cost. Therefore it is assumed that all the discharged sewage meets the applicable water body quality standards. The structure of city A's sewage treatment cost in 2015 was shown in Table 6. According to the size ratio of two sewage treatment plants S and W, the actual capacity of disposed sewage was about 47.32 million tons, and the corresponding cost is 63.2 million Yuan. If all 61.54 million tons of water is treated by the sewage treatment plants, the corresponding cost is 82.19 million Yuan. It can be found that the most important cost of sewage treatment is the land, which accounts for more than 50%. If the cost of land is excluded, the unit cost of sewage disposal will be reduced from 1.34 Yuan/ton to 0.65 Yuan/ton.

3.6 Total Cost of Urban Water Use

According to city A's urban water use situation, it can be found that pipe leakage is serious, for the leakage rates of water supply and drainage reach 25% and 23%, respectively. The specific urban water use cycle process is shown in Fig. 2.

The 61.54 million tons of water sold to urban residents plays an important role in city A's social economic activities. To maintain consistency of cost and benefit, the

Table 6 Structure of city A's wastewater treatment cost in 2015

Cost	Class	Detail	Total cost	Unit cost (Yuan/ton)
Sewage treatment cost	Operation	Electricity	495	0.16
		Pharmaceutical	32	0.01
		Tap water	2.3	0.001
		Sewage sludge treatment	457	0.14
		Labor	458	0.15
		Management	25	0.01
	Nonoperation	Depreciation of fixed assets and amortization of intangible assets	574	0.18
		Land	2171	0.69
Total	–	–	4214	1.34

Source: compiled by the authors

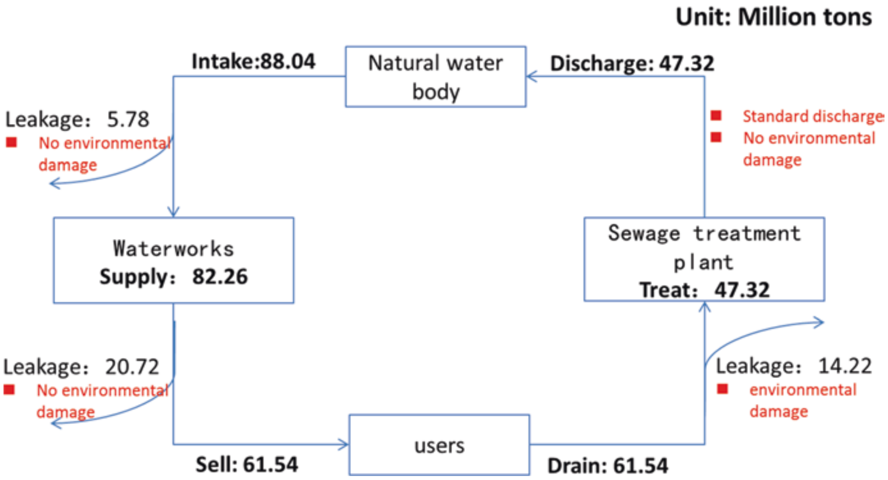

Fig. 2 Urban water recycling process of city A. (Source: compiled by the authors)

61.54 million tons of water sold is regarded as the standard of total full cost accounting in this article. The total full cost actually happened and the full cost meeting the assumption of no sewage leakage which accords with water material balance condition are calculated and shown in Table 7. It can be seen that the actual unit full cost of water use is 5.44 Yuan/ton in which the making and draining costs are important parts. Besides, 14.22 million tons of sewage was not discharged by sewage treatment plants, and these will cause environmental damage that needs to be taken into account in a full cost calculation extending to external cost. If the whole 61.54 million tons of water sold is completely drained and treated by sewage treatment plants, the investment will increase, and the unit full cost of the urban water use in city A will reach 6.23 Yuan/ton.

Table 7 Structure of city A's full cost of urban water use in 2015

Cost	Full cost actually happened			Full cost meeting the assumption of no sewage leakage		
	Total cost (10,000 Yuan)	Unit cost (Yuan/ton)	Percent	Total cost (10,000 Yuan)	Unit cost (Yuan/ton)	Percent
Intake	1581	0.26	4.73%	1581	0.26	4.13%
Making	10,051	1.63	30.05%	10,051	1.63	26.23%
Supply	5626	0.91	16.82%	5626	0.91	14.68%
Draining	9872	1.6	29.51%	12,839	2.09	33.51%
Sewage treatment	6320	1.03	18.89%	8219	1.34	21.45%
Total	33,450	5.44	100.00%	38,315	6.23	100.00%

Source: compiled by the authors

4 Conclusion and Discussion

1. The full cost of urban water in city A is at least 6.23 Yuan/ton. The cost didn't cover land cost for pipeline laying and capital cost; therefore, the actual full cost of water use is higher than 6.23 Yuan/ton. Local water price is 2.05 Yuan/ton (including average water supply price of 1.3 Yuan/ton and average sewage treatment fee of 0.75 Yuan/ton), which is far lower than the full cost. On one side, the price failed to reflect the true full cost of water use, and the price mechanism is disabled which leads to the lack of social water-saving incentive. On the other side, some cost such as pipeline laying cost is not reflected in the water price and paid directly by the local government. These hidden costs are lack of performance evaluation, so the expenditure and benefit are difficult to determine whether it is efficient, which may exacerbate the inefficient allocation of water resources.
2. Generally urban water supply price covers the cost of water intake and making and daily maintenance of the water supply pipe network (excluding water supply engineering construction and land cost). In 2015, the local average water supply price of city A was 1.3 Yuan/ton, and the three waterworks actually sold 61.54 million tons of water; therefore the waterworks got totally 80 million Yuan. According to the calculation, the cost keeping the same caliber of the water price is 118.93 million, indicating that the water price cannot cover the corresponding cost.
3. According to public information of city A's urban drainage PPP project, local government pays service fee of 70 million Yuan every year to enterprise to operate urban draining and sewage treatment system. Full costs of draining and sewage treatment (excluding the cost of sludge disposal and land) are included in the 70 million. According to the calculation, the cost keeping the same caliber of 70 million service fee amounts to 81.83 million Yuan, indicating that actual investment cost of drainage and sewage treatment process is also insufficient. If

assuming all drainage flows into the sewage treatment plant to avoid environmental damage caused by leakage, the actual spending gap becomes bigger.

4. Water price making should be based on full cost principle. All the costs happened in water intake, water making, water supply, water draining, and sewage treatment parts should be incorporated into water price to make full cost of urban water use explicit. Only in this way, it can be possible to completely change our traditional "welfare water" concept and improve users' water-saving incentives. At the same time, it will really make price mechanism comes into play in the allocation of water resources. Through urban water use full cost accounting, the costs of each part become transparent. Firstly, the information between government and enterprise get more symmetrical, which provides important support for both sides to come to PPP cooperation agreement. Secondly, it will do good to reduce malignant price bidding market phenomenon. Thirdly, the full cost of urban water use of different cities can be compared with each other, which will effectively promote urban water use related technology and management level.
5. It is recommended to further improve the scope of public information disclosure. Urban water belongs to public service, so the public has the right to know the full cost information of water use. At present the urban water use cost information in cities of China is still very limited. In order to strengthen the effectiveness of cost management of urban water use and promote the government's credibility and transparency, it is necessary to expand the scope of information disclosure. In addition, more information disclosure will help form water full cost benchmark to enable better enterprise standout and enhance the public understanding of the real cost of water use to avoid unnecessary waste.

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The Economics and Management of Flood Risk in Germany

Volker Meyer and Reimund Schwarze

Abstract Assessing the economic impacts of flooding is a crucial part of identifying appropriate flood risk management options as required by the EU flood management directive. This chapter describes methods for assessing economic flood damage. To begin, some fundamental issues are discussed: Which types of economic flood damage should be taken into account? What kind of information is necessary in general for assessing flood damage in monetary terms, and what is the general procedure for calculating economic flood damage? Having clarified these questions, the methodological challenges posed by economic flood risk management are described. This includes the indirect impacts, i.e. induced loss to customers and suppliers of good and services damaged by floods, and intangible impacts, i.e. the impacts of flooding on mortality and morbidity and the environment. Ways to deal with the persistent uncertainty in damage and risk assessments are discussed in the following chapter. The findings in this chapter will be evaluated in relation to flood risk management practices in Germany, based on examples from Saxony.

Keywords Flood damage · Intangible and indirect effects · Risk assessment · Data requirements · Prioritisation methods

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1 Introduction

Natural disasters can have serious impacts on human welfare, even in regions of the world with limited hazard exposure such as Europe. According to Munich Re's natural catastrophe database (NatCatService), weather- and climate-related extremes in Europe, including storms, river floodings, flash floods and heavy rainfall, have caused economic damages of between 1 and 18 billion US dollars per incident during the last 15 years (2002–2017). Some outstanding events in terms of their economic damage were, for example, the Elbe and Danube floods in Germany and other parts of Eastern Europe in 2002 and 2013, with damages of more than 10 billion US dollars (Munich 2014), and the largely southern European drought of 2003 which caused large-scale loss of life (about 35,000 fatalities) (Munich 2004). Damages and fatalities in China are assumed to exceed these figures substantially, but they are not as well documented. The well-documented numbers of evacuees, however (1.2 million in the Saomai typhoon of 2006 and 1.6 million in the 2012 flooding in Beijing, Zhang et al. 2013), are evidence that the risk of natural hazards is much greater in China than in Europe. According to a recent estimate by Jia et al. (2016), the risk is eight times higher than the global average, meaning a more than tenfold risk compared to what we find in Europe, which globally speaking has a below-average exposure to natural hazards and resulting economic damages. Such figures serve to illustrate the global need for better documentation of the risks of natural hazards and – even more – the need to reduce those risks.

This chapter presents a number of methods for assessing flood risks in economic terms. Economic flood damage assessment is a crucial part of the European Union's new flood risk management approach (EU 2007). It has since become an important part of the decision-making for flood risk managers in Germany and other EU member states. Flood risk assessment provides information about the likely amount and spatial distribution of expected damages and thus provides decision-makers with evidence regarding what efforts are necessary and most effective for reducing these damages. The benefits of risk reduction measures can be determined by calculating their damage-reducing effects, while the most efficient options can be chosen by means of a cost-benefit analysis.

In the following, we explain a number of basic methodological aspects of flood damage assessment (Sect. 2). This includes (1) a categorisation of flood damages and (2) the general procedure for calculating flood damages. We then identify the methodological challenges for research and policymaking in the case of indirect and non-market-related, intangible damage to human well-being and the ecosystem (Sect. 3). Ways of dealing with the persistent uncertainties present in flood risk management are subsequently explained (Sect. 4). Section 5 describes some flood risk management practices in Germany, based on examples taken from Saxony. A few concluding remarks are offered in Sect. 6.

2 Basic Aspects of Economic Flood Damage Assessment

2.1 Types of Economic Flood Damage

Flood damage can be differentiated into tangible and intangible damages (Smith and Ward 1998).

Tangible damages can be easily measured in monetary terms because of an existing market for the repair or replacement of damaged assets or the goods and services derived therefrom. Intangible damage refers to loss of goods and services which are not measurable (or at least not easily measurable) in monetary terms because they are not traded on a market. Hence, they are also referred to as non-market costs (Smith and Ward 1998). Intangible effects include, for instance, environmental impacts, health impacts and impacts on cultural heritage. Tangible economic flood damages can be subdivided again into direct damages, losses due to business interruption and indirect damages (see Fig. 1).

Direct damage is damage to property due to physical contact with floodwater. The most important categories of direct tangible damage are damages to buildings and their inventories. These can be differentiated further into residential properties, i.e. residential buildings and household goods, and non-residential properties, i.e. buildings used for industry, commerce or public affairs and their fixed and movable

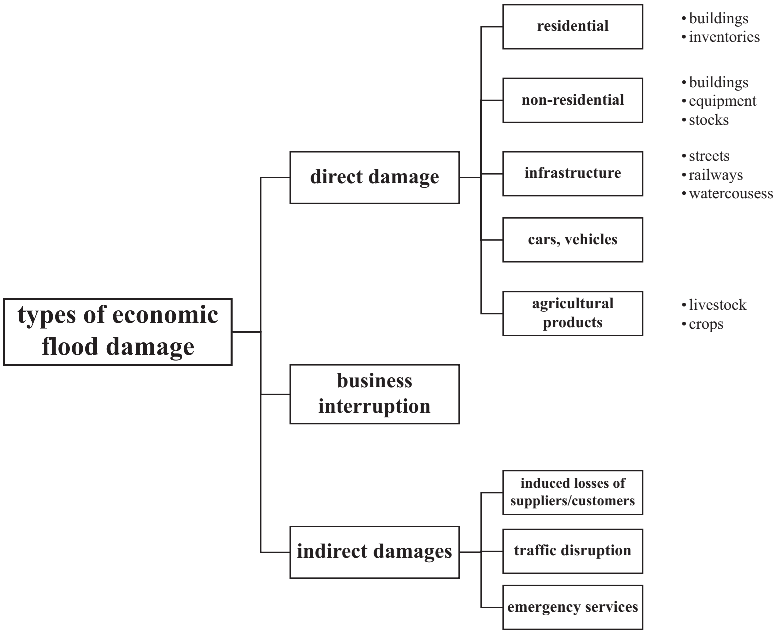

Fig. 1 Categories of tangible economic flood damage. (Source: Adapted from FLOODSITE Consortium (2007), p.10; own compilation)

equipment as well as inventories and stocks. Damage to buildings and inventories often represent the largest proportion of total economic flood damage.[1]

Another category of direct damage is damage to technical infrastructure such as streets and railways but also including flood defence infrastructure and watercourses. Such damage can be considerable, especially in flash flood areas at times of high velocity flows. In contrast, infrastructure damage to streets and railways is usually low in floodplain areas where flow velocities are moderate.

Cars and other vehicles often make up a significant part of the total value of assets at risk. However, given sufficient warning lead time, many of them can be evacuated so that damages to cars and vehicles are generally comparatively low.

Damage to agricultural goods, such as livestock and crops, also generally makes up a rather low share of total damages.[2] Crop damage strongly depends on the agricultural season affected, while livestock damage is highly correlated with the time available for evacuation.

Losses due to business interruption in industry, commerce and agriculture occur in areas directly affected by flooding. When production facilities and offices are flooded, people are unable to carry out their work until the flood is over and their workplace reconstructed. In the literature, such losses are sometimes referred to as direct damages, as they occur due to the immediate impact of floodwater. At the same time, they are often also referred to as primary indirect damages, because these losses do not result from physical damage to property but from the interruption of economic processes. However, the methods used to assess losses due to business interruption are different from those used for direct and indirect damages, respectively. For this reason, and in order to avoid misunderstandings, "losses due to business interruption" will be taken as a separate category.

As a consequence of this categorisation, *indirect damage* refers only to that economic damage which is induced either by direct damage or loss due to business interruption. This includes induced production losses suffered by both suppliers and customers of the companies affected, the costs of traffic disruption or the costs of emergency services. While direct damage is often measured as a loss of stock value, losses due to business interruption as well as indirect damage are frequently assessed as a loss of flow value.[3]

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[1] In the floodings of Saxony, between 36% (2002) and 22.7% (2013) of the total damages were in the residential sector, i.e. damage to buildings and content damage. Cp. WWF (2007); DKKV (2015), p. 34.

[2] In Saxony 2002, only 1.3% of direct, tangible damage affected agriculture and forest sites (IKSE 2004).

[3] The value of a capital good is the present value of the income flow it generates over the rest of its life span (Georgescu-Roegen 1981, p. 220 ff.). Therefore, adding stock and flow values in a flood damage evaluation can lead to double counting (Rose 2004, p. 14, p.19; Bockarjova et al. 2004) and should be avoided.

2.2 *General Procedure for Flood Damage Assessment*

Although the methods for flood damage assessment differ especially with respect to the different damage categories, four main factors or types of information can be identified which are crucial for such an assessment in general (Messner et al. 2007):

(a) The intensity of inundation
(b) The number, type and elevation of properties or business facilities affected
(c) Their value
(d) Their susceptibility to inundation

(a) First, the intensity of a flood scenario, i.e. its *inundation characteristics*, is one crucial factor which determines the degree of flood damage. In this regard, the extent and depth of inundation are the parameters used most often in damage assessment approaches. Although the duration, time of occurrence, velocity and toxicological load of floodwater could have a significant influence on damage, they are not often included in damage models.

(b) Second, the number and type of properties or business facilities exposed to a certain flood event (the *assets at risk*) provides crucial information for damage assessment. Such information can be collected by field surveys or by using existing *land use data* sources, such as topographic maps. The spatial resolution and level of categorisation of such data can vary considerably, ranging from broadly aggregated land use information (e.g. “industrial area”, “residential area”) to detailed information on the type and construction of every single building or property and its contents.

(c) In order to measure damage in monetary terms, information on the *value of assets at risk* needs to be quantified in the third step. This value can be determined either by the stock value of an asset at a given point in time or by the flow value, i.e. the income flow that it generates over the rest of its lifetime. Information on stock values for different economic sectors can be derived on an aggregate level from official statistics which are then related to land use categories. For more detailed approaches, object-oriented assessments of buildings and business facilities and their components are often carried out, based on market values or construction costs.

(d) Finally, information is needed on the degree of susceptibility of specific elements at risk to certain inundation characteristics. Such information is represented by *damage functions*. These functions show either the proportion of damage (relative damage functions) or the absolute monetary amount of damages per property (absolute damage functions) of a certain group of elements at risk as a function of the magnitude of certain inundation characteristics. According to the current state of the art, the main inundation parameter considered in these damage functions is inundation depth (depth-damage functions). Others (such as velocity, duration and time of occurrence) are rarely taken into account. As the susceptibility of elements at risk depends on their type and attributes (e.g. mode of construction), properties of similar types are grouped

> together and expressed by a single approximate damage function. The extent of this aggregation and categorisation varies among the different approaches. Further factors, including the risk perception of the people in flood-prone areas and their preparedness to be flooded, can also influence the susceptibility of elements at risk and, hence, the potential amount of flood damage. Up to now, however, such factors have rarely been included in damage functions.

To calculate the total damage of one flooding scenario, the damage of each affected unit within the floodplain has to be calculated and added up.

$$\text{Damage}_{\text{total}} = \sum_{n}^{i=1}\sum_{m}^{j=1}\left(\text{value}_{i,j} \times \text{susceptibility}_{i,j}\right) \tag{1}$$

with

$$\text{susceptibility}_{i,j} = f(\text{characteristics entity}_{i,j},$$

$$\text{inundation characteristics}_{k},\ \text{socioeconomic characteristics}_{l})\ \ [\%]$$

i = category of tangible elements at risk (n categories possible).
j = entity in an elements-at-risk category (m entities possible).
k = flood type/specific flood scenario.
l = type of socio-economic system.

In order to estimate the expected annual damage (or risk) of a certain area, damage estimates of different flood events with different probabilities have to be taken into account.

In the context of flood risk management, the term “risk” is understood as the probability of negative consequences (FLOODsite Consortium 2005; Schanze 2006). By considering the negative consequences or damages caused by floods for the whole range of probabilities, flood risk can be expressed as the damage expected due to flooding, which is often called annual average damage. For the practical application of a flood risk assessment, this means that flood damage has to be estimated for flood events of varying probabilities in order to construct a damage-probability curve (see Fig. 2). The annual average damage is shown by the area or the integral under the curve. An approximation of this area can be expressed using the following equations (DVWK 1985; Eqs. 1 and 3):

$$\bar{D} = \sum_{k}^{i=1} D[i] * \Delta P_i \tag{2}$$

$$D[i] = \frac{D\left(P_{i-1}\right) + D\left(P_i\right)}{2} \tag{3}$$

where $\bar{D}$ is the annual average damage, $D[i]$ the mean damage of two known points on the curve and $\Delta P_i = |P_i - P_{i-1}|$ the probability of the interval between those points.

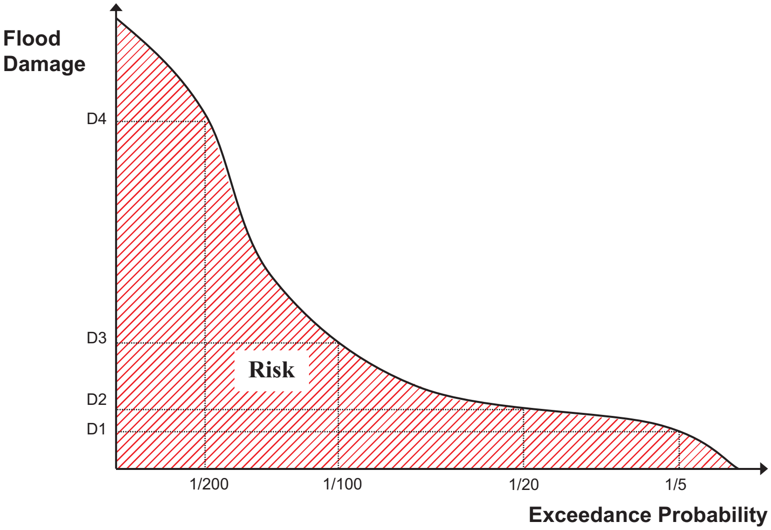

Fig. 2 Damage probability curve. (Source: own compilation)

2.3 Choice of Scale, Accuracy and Information Needs

Apart from this general procedure for calculating flood damage and risk, damage assessment approaches differ considerably in their detail. In terms of their spatial scale and level of accuracy, the existing methods can be broadly differentiated into macro-, meso- and micro-scale approaches (Messner et al. 2007).

- *Macro-scale approaches* often rely on land use information with a low spatial resolution and/or low typological differentiation in order to reduce the effort of analysis. Hence, they are able to consider large river basins as a whole (see IKSR 2001; Sayers et al. 2002).
- *Micro-scale approaches* (e.g. Penning-Rowsell et al. 2003; Apel et al. 2009), by contrast, seek to achieve more accurate results by applying highly detailed land use data as well as value and susceptibility information. However, this requires more effort, which often restricts these approaches to small areas.
- *Mesoscale approaches* (e.g. Klaus and Schmidtke 1990; Kok et al. 2004; Apel et al. 2009) fit in somewhere between macro- and micro-scale approaches, with regard to both accuracy and effort. Hence, they are often applied in small- or medium-sized river basins, coastal stretches or dike ring areas.

The mesoscale approach is used here to explain *information needs* in greater detail (cf. Fig. 3).

First, the total value of assets at risk (e.g., residential assets) and their spatial distribution are estimated on the basis of data from official statistics which is then assigned to corresponding land use categories. To begin with, then, the net value of

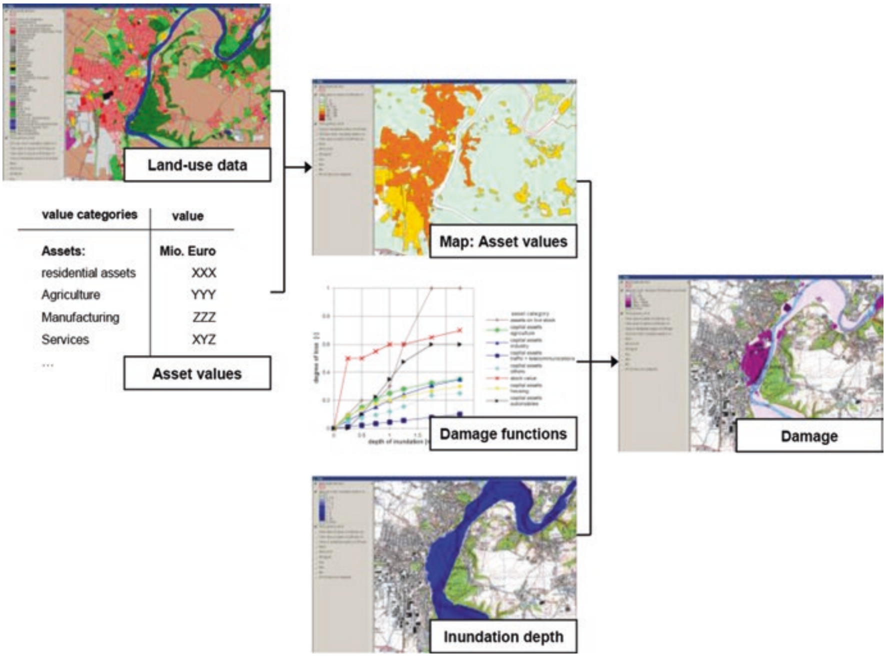

Fig. 3 Basic components and necessary information for mesoscale flood damage assessments. (Source: own compilation)

fixed assets in different economic sectors, including the residential sector, is taken from official statistics, i.e. the system of national accounting. As these values of fixed assets are often published only at a national level or at the level of federal states, they have to be disaggregated to the level of municipalities by using the number of inhabitants (in the case of the residential sector) or employees (in other economic sectors) as an allocation rule. Asset values at the municipality level are then assigned to land use categories, which correspond to the respective sectors. For example, residential asset values are assigned to residential areas and areas of mixed use. By assigning all values to the corresponding areas in a geographic information system (GIS) and dividing the values by the total area, maps of the value of assets per square metre can be produced for each sector (cf. Eq. 2).

Second, relative depth-damage functions are used to calculate the damaged percentage share of these values, depending on inundation depth. In contrast to micro-scale approaches, which apply different damage functions for each building type, mesoscale approaches generally apply only one approximated damage function for each economic sector. By combining these sectoral depth-damage functions with the corresponding asset value map and information on the inundation depth of a certain event, it is possible to estimate the damages caused by this flood event.

Obviously, such mesoscale approaches lead to a much more approximate damage estimate than micro-scale approaches where the susceptibility of each building type is considered. Equally, however, they require less effort and hence are more easy to apply in large-scale studies.

3 Methodological Challenges: Intangible and Indirect Effects

After having clarified basic aspects of economic flood damage assessment in the previous section, we now explain the methodological challenges for research and policy development. In line with the findings of the EU's CONHAZ project[4], the focus is on intangible and indirect economic effects.

3.1 Intangible Effects

Intangible or non-market-related costs of natural hazards need not necessarily be expressed in monetary terms in order to be included in decision support frameworks. In a multi-criteria analysis framework, where they are mostly used in FRM (cf. Sect. 5. detailing the case of Saxony), they can be included as non-monetary decision criteria. Alternatively, in the context of a cost-effectiveness analysis, they can be treated as a non-monetary target measure, e.g. cost per life saved. However, to be included in a cost-benefit analysis framework, intangible costs need to be expressed in monetary terms.

Methods for estimating the monetary value of intangible effects of natural hazards will have to consider both the use and non-use values that individuals derive from environmental or health goods and services. While *use values* relate to direct, indirect or even optional use, *non-use values* relate to the value individuals derive from simply knowing that a certain environmental good exists or that it is being preserved for future generations. Different valuation methods are proposed according to each type of (non-)use value (cf. Table 1). These methods can be categorised into:

1. Revealed preference
2. Stated preference valuation methods

The accuracy and effectiveness of these valuation methods depend on the availability and quality of the data (including the quality of the survey design), the available resources and the decision made in each case on the most appropriate method for estimating intangible effects. Revealed preference methods have the advantage

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[4] The CONHAZ project, which ran from February 2010 to January 2012, identified knowledge gaps and research needs based on a review of existing methods for assessing the costs of various natural hazards in Europe (floods, droughts, coastal hazards and Alpine hazards; for a more detailed discussion, see Meyer et al. 2013).

Table 1 Intangible effects: methods, applications and examples

General method	Specific method	Application and/or examples
Revealed preference methods	Travel cost method	Hartje et al. (2001)
	Hedonic pricing method	Hamilton (2007), Chao et al. (1998) and Cavailhes et al. (2009)
	Cost of illness approach	DEFRA (2007)
	Replacement cost method	Leschine et al. (1997)
	Production function approach	NA
Stated preference methods	Contingent valuation method	Birol et al. (2006), Daun and Clark (2000), DEFRA (2004), Leiter and Pruckner (2007), Pattanayak and Kramer (2001), Zhai and Ikeda (2006), and Zhongmin et al. (2003)
	Choice modelling method	Brouwer and Schaafsma (2009), Daun and Clark (2000), Hensher et al. (2006), and Olschewski et al. (2011)
	Life satisfaction analysis	Carroll et al. (2009)
Benefit or value transfer methods		Martin-Ortega et al. (2012)

Source: own compilation

of estimating the value of a particular good based on actual market behaviour, i.e. ex post. Information obtained from observed behaviour is used to derive an individual's willingness to pay for an environmental improvement or for avoiding environmental deterioration. The main revealed preference methods are the following (cf. Pearce and Turner 1990; Hanley and Spash 1993; Birol et al. 2006):

- *Travel cost method*: recreational or environmental sites are valued by analysing the observed travel time and expenditure of visitors.
- *Hedonic pricing method*: the value of environmental characteristics is estimated on the basis of actual market prices, in particular in the housing market.
- *Cost of illness approach*: costs of health impacts are estimated based on medical costs and wages lost due to illness.
- *Replacement cost method*: the value of an ecosystem good or service is estimated based on the costs of replacing that good or service.
- *Production function approach*: the value of an environmental good which is used to produce a market good is estimated based on the production function.

In contrast to this, stated preference methods create a hypothetical or contingent market in a survey. They use willingness to pay or willingness to accept compensation for not causing environmental deterioration or willingness to forego an environmental improvement. Important stated preference approaches for estimating environmental and health goods or services are the following:

- *Contingent valuation* (CV) method: in order to value non-market goods, people are asked in surveys about their willingness to pay to avoid a given decrement of this particular non-market good or about their willingness to accept its deterioration by receiving a certain amount of compensation.
- *Choice modelling* (CM) method: willingness to pay is elicited by choice experiments in which people can choose between different bundles of goods with varying characteristics. These can be either market or non-market goods.
- *Life satisfaction analysis*: welfare estimates of public goods (health, environment) are made based on life satisfaction surveys.
- In addition, *benefit or value transfer* methods can be used to transfer the results from previously applied valuation methods to a new case study in order to estimate the intangible costs.

Among the stated preference methods, CV has for a long time been the method most commonly used in valuing non-market goods and services. It has also been applied in assessing the intangible costs of natural hazards (see, e.g. Daun and Clark 2000; DEFRA 2004; Leiter and Pruckner 2007; Umweltbundesamt 2007). CM has become more popular in recent years. Both CV and CM can estimate economic values for any environmental resource. Their advantage over other methods is that they can estimate non-use values as well as use values. CM, however, additionally makes it possible to estimate the implicit values of resource's attributes, their implied ranking and the value of changing more than one attribute at a time (Hanley et al. 1998; Bateman et al. 2003).

The increased application of these methods (as depicted in Table 1) has resulted in several recommendations for improvement (Markantonis et al. 2012):

- Improvements in stated preference methods could be achieved if they are applied at regular intervals and similar contexts; this would eliminate the various inherent biases of this method.
- Revealed preferences could be improved by using long-time and verified data series in order to eliminate market price distortions caused by sources other than natural hazards.
- Due to the complexity and uncertainty of the intangible effects, a combination of both methods could help to reveal differences in the valuation approaches and to enhance the accuracy of the results. In other words, stated preference and revealed preference methods should be applied in parallel and complementary to each other. However, such an option would require more resources.

The benefit transfer method can be a low-cost alternative only if the demand for precision is relatively low (as practice examples have demonstrated). Improvements can be achieved if the BT method is applied in assessment studies with very similar characteristics and if adjustments to the needs of the new case study are conducted precisely and transparently (Meyer et al. 2013).

3.2 Indirect Economic Damage

Indirect flood losses are those where damage does not arise due to the *physical* contact of objects with floodwater but where it is induced by direct impacts and transmitted through the supply chain. Thus, for example, a production facility might be lacking an important input (electricity, raw materials, etc.) due to a flood event in its suppliers' area and thus be unable to operate, thereby incurring financial loss. Indirect loss is necessarily attached to some form of interruption of usual business but is fundamentally different from the business interruption caused by the direct physical impacts of floodwater on production facilities. It is a trigger effect caused by the numerous interlinked factors in the economic system.

While recent studies on indirect loss demonstrate the economic importance of this category of damage – Hallegatte (2008), for example, estimates the indirect losses from Hurricane Katrina in Louisiana at 28 billion US dollars – efforts to measure it have not been undertaken to the same extent as for direct loss. In this section, therefore, we identify types of indirect loss and methods for measuring it, particularly existing ex ante modelling methodologies. We also describe ways in which vulnerability score cards can be employed to raise awareness about indirect losses.

In principle, the magnitude of indirect loss is determined by the boundaries in space and time of any damage assessment. From a very broad temporal and spatial perspective, indirect losses from natural disasters are zero. Measured over the entire economy, the negative and positive indirect effects cancel each other out. For any reasonable boundary (city, state, watershed region, etc.), however, there will be net indirect effects from flooding.

In the *short term*, floods produce indirect losses in the following areas:

- Input-output losses to firms who are customers (forward-linked) or suppliers (backward-linked) of the businesses directly affected
- Reductions in consumption due to the income and/or profit losses triggered by business interruption as a ripple effect, i.e. employees or private owners of the firms experiencing reduced production suffer income losses and subsequently cut their own spending

Floods can also have *long-term* indirect impacts such as altered migration flows, relocation of industries, depressed house prices and changes in government expenditure resulting from new patterns of migration and regional development.

Evidence to date suggests that the indirect effects are more important in large-scale disasters than in smaller-scale disasters. With regard to Hurricane Katrina, for example, Hallegatte (2008) demonstrates that significant indirect losses for the state of Louisiana only arise when direct losses exceed 50 billion US dollars. In a separate study, he also demonstrates that indirect impacts are larger if a natural disaster affects the economy during the expansion phase of its business cycle than if it occurs during a recessionary phase (Hallegatte et al. 2007).

Compared to direct effects, indirect losses are much more difficult to measure. Additionally, there are limited available sources of data for measuring indirect losses. Insurance data on business interruptions are of limited value for that purpose, as most indirect effects (e.g. power outage) do not qualify for compensation under business interruption insurance. Moreover, many firms do not possess business interruption insurance. The scarcity of accessible primary data has led to attempts to measure indirect losses using economic models of the type that have long been utilised for economic forecasting such as:

1. Simultaneous equation econometric models (Ellison et al. 1984; Guimares et al. 1993; West and Lenze 1994)
2. Input-output models (e.g. Rose and Benavides 1997; Boisvert 1992; Cochrane 1997)
3. Computable general equilibrium models (Brookshire and McKee 1992; Boisvert, 1995)

Studies evaluating model-based estimates (Kimbell and Bolton 1994; Bolton and Kimbell 1995; West 1996) suggest that the models developed for traditional economic forecasting tend to overstate the indirect effects. Differences of between 70% and 85% exist in relation to observed impacts from post-event economic surveys (West and Lenze 1994).

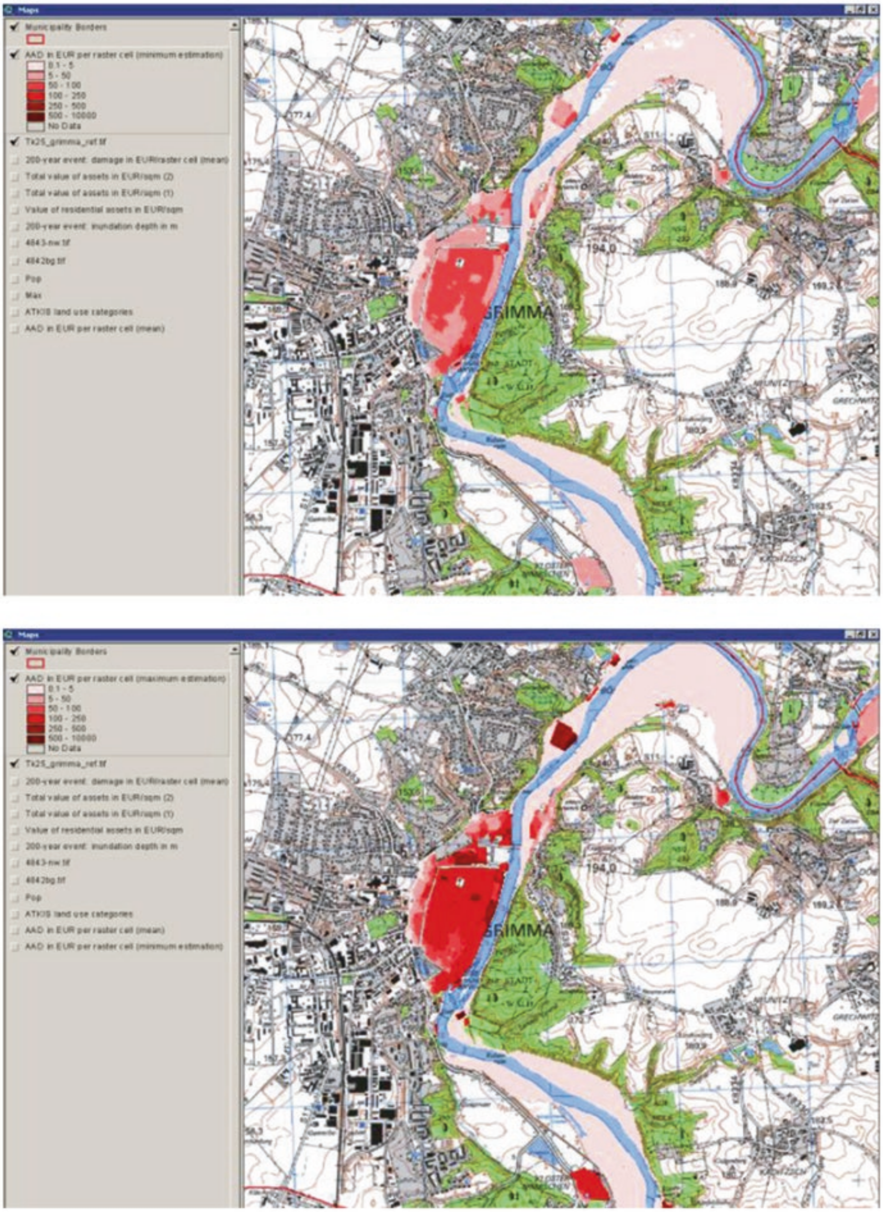
The reason for this overestimation of both indirect regional economic losses from natural disasters and indirect regional economic gains from reconstruction is that statistically based economic models have been designed primarily to forecast the effects of a *lasting* impact (e.g. investment in a new commercial development). The historical interlinked factors embodied in these models are likely to be substantially disrupted and temporarily altered during a flood. Dynamic adjustment features such as recovery, resiliency, interregional substitution, inventory adjustments, changes in labour supply, number of refugees, etc. are not reflected in these models. In short, these models are inappropriate for simulating natural disasters; they must be substantially revised in order to produce reliable estimates of indirect effects. Computational algorithms modelling supply shocks, post-event supply constraints and time-phased reconstruction in disaggregated spatial settings (as, e.g. applied in van der Veen and Logtmeijer 2005 and Yamano et al. 2007) seem promising for overcoming this methodological gap.

4 How to Deal with Uncertainties?

There are high levels of uncertainty in all parts of flood risk assessment, from data and models of flood characteristics through exposure and susceptibility to the costs of a project. More uncertainties are entailed by the need to consider future developments such as climate and socio-economic change.

Scenario-based uncertainty bounds, Monte Carlo simulations and simple probabilistic ranking tools can be applied to support FRM decision-making in such highly uncertain environments.

Figure 4 demonstrates the use of uncertainty bounds in a spatial distribution of minimum and maximum annual average damages (AAD) for flood risk scenarios for the city of Grimma in Saxony.



☑ Municipality Borders
☑ AAD in EUR per raster cell (minimum estimation)
🟥 0.1 - 5
🟥 5 - 50
🟥 50 - 100
🟥 100 - 250
🟥 250 - 500
🟥 500 - 10000
☐ No Data
☑ Tk25_grimma_ref.tif
☐ 200-year event: damage in EUR/raster cell (mean)
☐ Total value of assets in EUR/sqm (2)
☐ Total value of assets in EUR/sqm (1)
☐ Value of residential assets in EUR/sqm
☐ 200-year event: inundation depth in m
☐ 4843-nw.tif
☐ 4842bg.tif
☐ Pop
☐ Max
☐ ATKIS land use categories
☐ AAD in EUR per raster cell (mean)

☑ Municipality Borders
☑ AAD in EUR per raster cell (maximum estimation)
🟥 0.1 - 5
🟥 5 - 50
🟥 50 - 100
🟥 100 - 250
🟥 250 - 500
🟥 500 - 10000
☐ No Data
☑ Tk25_grimma_ref.tif
☐ 200-year event: damage in EUR/raster cell (mean)
☐ Total value of assets in EUR/sqm (2)
☐ Total value of assets in EUR/sqm (1)
☐ Value of residential assets in EUR/sqm
☐ 200-year event: inundation depth in m
☐ 4843-nw.tif
☐ 4842bg.tif
☐ Pop
☐ ATKIS land use categories
☐ AAD in EUR per raster cell (mean)
☐ AAD in EUR per raster cell (minimum estimation)

Fig. 4 Minimum and maximum annual average damages (AAD) for flood risk scenarios in the city of Grimma. (Source: own compilation)

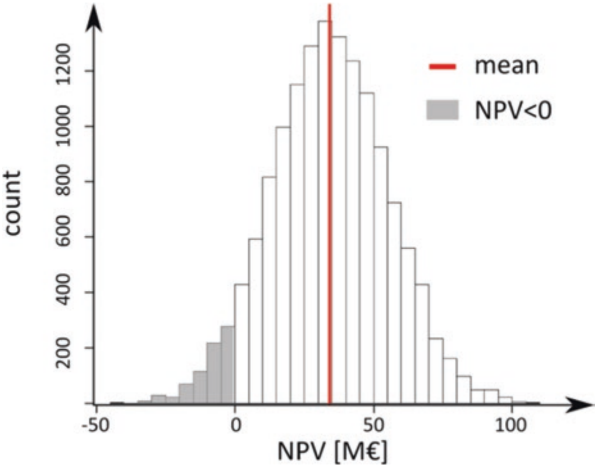


Fig. 5 Empirical distribution of the net present value (NPV) over Ntot = 28,672 simulations and mean value (solid line). (Source: Saint-Geours et al. (2015), Fig. 9)

Saint-Geours et al. (2015) transformed the underlying uncertainties in all input components into a probabilistic cost-benefit analysis. In a large number of *Monte Carlo simulations* of flood characteristics integrating different hydrologic and hydraulic models, land use scenarios and depth-damage functions as well as bounds of investment costs, they establish a probability distribution of the net present value of a project, that is, one which can help to establish probability distributions for efficient flood control measures in the Orb Delta, France (cf. Fig. 5).

The PRIMATE (Probabilistic Multi-Attribute Evaluation) tool developed at UFZ is a simple methodology that is stakeholder driven and thus more adaptable to specific contexts. It extends the PROMETHEE method developed by Brans and Mareschal (2005) and has been successfully applied to flood risk management, water scarcity management, heat stress and climate change adaptation in UFZ projects.[5]

PRIMATE compares stakeholder-selected risk mitigation or adaptation options (individual measures or strategic bundles of measures) with one another in order to evaluate and rank these options probabilistically and thereby support decision-making (cf. Fig. 6).

Decision-makers also choose the weighting of the evaluation criteria. It thus offers a contextual and participatory approach for groups involving multiple decision-makers.

The tool can be used for cost-benefit analysis (with tangible costs being the only criterion) or for multi-criteria analysis under uncertainty. Uncertainty is considered by a range (uncertainty bounds), a triangular distribution or any other probability distribution.

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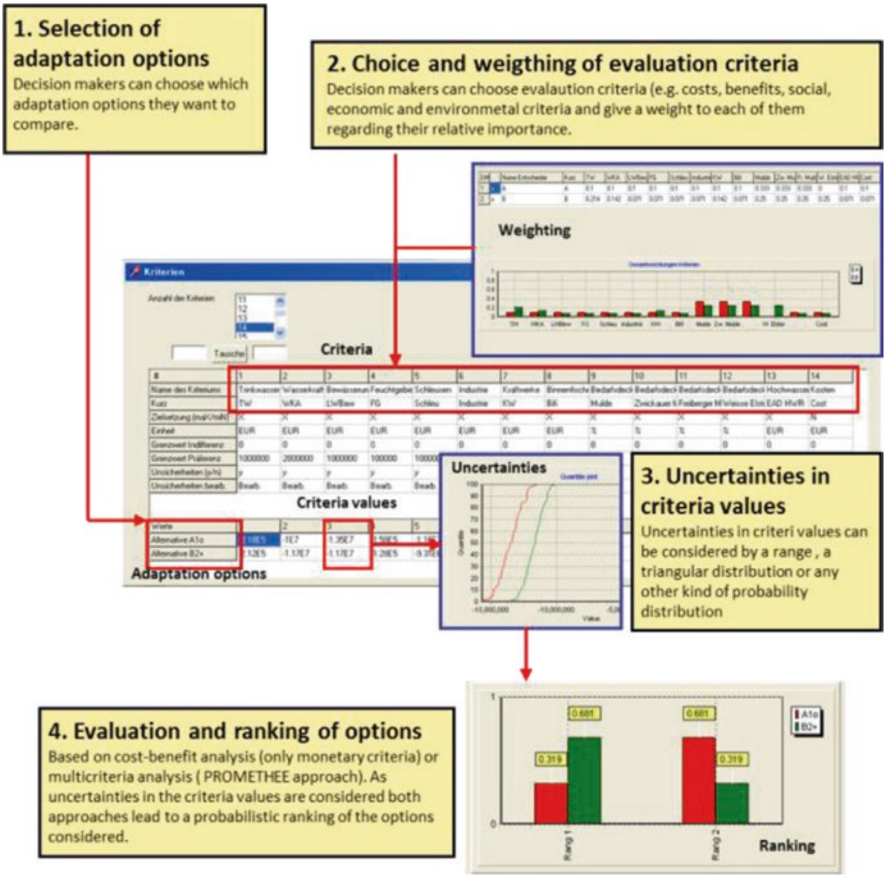
[5] The PRIMATE manual is available as a download on the UFZ website (www.ufz.de). For the free software, please send an email to the author.



1. Selection of adaptation options
Decision makers can choose which adaptation options they want to compare.

2. Choice and weigthing of evaluation criteria
Decision makers can choose evalaution criteria (e.g. costs, benefits, social, economic and environmetal criteria and give a weight to each of them regarding their relative importance.

3. Uncertainties in criteria values
Uncertainties in criteri values can be considered by a range , a triangular distribution or any other kind of probability distribution

4. Evaluation and ranking of options
Based on cost-benefit analysis (only monetary criteria) or multicriteria analysis (PROMETHEE approach). As uncertainties in the criteria values are considered both approaches lead to a probabilistic ranking of the options considered.

Fig. 6 Dealing with uncertainties in decision support. (Source: own compilation)

This selection of methods and tools (and there are more) demonstrates how economics can help to deal with the persistently high uncertainties in flood risk management. Their virtual omnipresence and widespread usage in flood risk management, as well as the continuous development and research devoted to them, show that we are at a crossroads. We need to decide whether breakthrough improvements to the risk-based approach can be made by improved data gathering and validation efforts or, alternatively, whether more qualitative decision support approaches are needed other than cost-benefit and multi-criteria analyses. Choosing the first avenue would imply developing more comprehensive and more consistent damage databases for Germany and Europe, which would make it possible to integrate intangible and indirect impacts. The alternative would be to develop more qualitative decision support tools and participatory procedures such as robust decision-making, adaptation pathways and decision heuristics. Research by Gigerenzer and Brighton (2009), for example, provides ample evidence that decision heuristics, i.e.

decision rules even simpler than the ones presented above, may not only reduce the effort of implementing the decision rule but may also lead to better results in terms of predictive accuracy under conditions of high uncertainty, compared to more complex models. However, for decisions in flood risk management, such heuristics have not yet been put to the test, and we probably need a way to go in terms of more interdisciplinarity in science and policy to arrive at any nonconventional decision support in flood risk management.

5 Flood Risk Management Practices in Saxony

The EU Flood Risk Management Directive (European Union 2007) seeks to establish a coordinated European approach to handling the risk, or generally negative impacts, of flood events. Its implementation requires three basic steps to be implemented in a phased approach (cf. Müller 2013):

1. Preliminary flood risk assessment (phase ending December 2011)
2. Flood hazard and flood risk maps (phase ending December 2013)
3. Flood risk management plans (phase ending December 22, 2015)

Saxony is one of Germany's 16 Länder (administrative regions/states) and is located in the central southeastern part of Germany. It has devised 47 flood protection concepts (for all first-order rivers in the region) including 1600 flood protection measures. These concepts apply uniform sector-differentiated flood protection targets ("flood designs") for settlements (1/100 flood design), single buildings (1/25 flood design) and agricultural areas (1/5 flood design). This section explains how economic decision support tools have been applied in order to prioritise measures (in terms of timing) within dedicated budgets of 0.5 billion euros by 2012, increasing to 1 billion euros by 2020 (cf. Müller 2010).

Table 2 depicts how flood protection measures in Saxony are prioritised according to:

1. *Expected damage* (*Schadpotential*, i.e. flood damage evaluation based on a mesoscale approach as explained in Sect. 2 above; evaluation points up to 25 according to expected damage of € 0–10 million euros and more)
2. *Benefit-cost ratio (Nutzen-Kosten-Verhältnis*, i.e. estimate of annual avoided damages (as described in Sect. 1) relative to cost estimates of the water management authority of Saxony, LfULG; up to 25 evaluation points according to B/C ratio of 0–5 and over)
3. *Effects on water management (Wasserwirtschaftliche Effekte*, including considerations of retention, discharge and river ecology, judgement based on qualitative expert assessment; total of 25 evaluation points).
4. *Special vulnerabilities (Vulnerabilitäten*, including risk to life, indirect loss and special protection needs, e.g. cultural heritage; total of 25 evaluation points; judgement to be made based on expert assessment)

Table 2 Prioritisation scheme in Saxony

Prioritisation criteria	Valuation standard	Prioritisation scores	
		Score	Maximum
Expected damage			
	Near 0 Mio € ((almost) no)	0	
	< 2 Mio € (low)	5	max 25
	2–10 Mio € (medium)	15	
	> 10 Mio € (high)	25	
Benefit-cost ratio			
	Near 1 (extremely low)	0	
	1–2 (low)	5	max 25
	2–5 (medium)	15	
	> 5 (high)	25	
Effects on water management			
Improvement of capability of retention	No or just local improvement	0	
	Improvement with regional impact	5	
	Improvement with transregional impact	10	
Improvement of drain ratio	No or just local improvement	0	max 25
	Improvement with regional	5	
	Improvement with transregional impact	10	
Improvement of water ecology and/or of quality of water structure	No or inessential improvement	0	
	Significant improvement	5	
Special vulnerabilities			
Specific consternation/ vulnerability	No specific consternation	0	
	Moderately heavy specific consternation	5	
	Heavy specific consternation (especially acute danger to life)	10	max 25
Specific dangers following up (hazards starting from objects)	No noteworthy dangers following up	0	
	Moderately heavy dangers following up	5	
	Great, heavy dangers following up	10	
Specific requirement for protection (missing flood defence)	No specific requirement for protection	0	
	Existing specific requirement for protection	5	

(continued)

Table 2 (continued)

Prioritisation criteria	Valuation standard	Prioritisation scores	
		Score	Maximum
		Total	max 100
Rating/prioritisation		0–30 pts	Low
		35–60 pts	Medium
		65–100 pts	High

Source: Adapted from Socher et al. (2006)

Table 3 Prioritisation of flood protection measures in Saxony (2002–2020)

Priority	Measures	Investment costs (bn €)
0–29 points: *low*	548	0.2
30–64 points: *medium*	780	0.6
65–100 points: *high*	268	1.2
	1598	2

Source: Adapted from Müller (2010), p. 252

The prioritisation outcomes for the 47 flood protection concepts including 1598 flood protection measures in the period 2002 to 2020 are depicted in Table 3.

This outcome demonstrates that the high-ranked measures were on average the larger and costlier measures such as dykes and flood protection walls, whereas relatively less investment intensive such as building floodwater retention basins and unsealing land surfaces were all ranked medium or low (they will be funded only up until 2020).

This example also demonstrates that there is an important role to be played by economic flood damage assessment and cost-benefit analysis in the *timing* of measures, though not necessarily in the selection of measures for long-term flood management practices in Germany. The tools applied for this purpose are simple and involve a multi-criteria framework, *including* cost-benefit analysis but also going beyond this.

6 Concluding Remarks

As stated at the start of this chapter, the ex ante assessment of flood damages is an essential part of the flood risk management concept, as it provides a basis for the efficient allocation of scarce funds by means of cost-benefit analysis. However, as shown in this chapter, achieving a comprehensive and exact estimation of future flood damage still poses a great challenge.

Different types of economic flood damages require different approaches for their assessment. Many assessment approaches focus on direct damage to residential properties in particular, while there are few methods available for estimating indirect losses, agricultural and infrastructural damage. However, in order to estimate the full economic impact of flooding, damage assessment should try to achieve a comprehensive picture of the negative impacts. This means that at least the most important damage categories to be expected in the respective case study should be considered in the assessment. This includes social and environmental effects.

It has been shown here too that the accuracy of economic damage assessment is also a matter of scale. Micro-scale approaches deliver quite accurate results but often require huge effort, while mesoscale approaches reduce effort at the expense of greater uncertainty of results. Economic flood damage assessment is consequently always a trade-off between accuracy and effort. The choice of an appropriate approach therefore depends on the objective of the study and the decision situation. To provide sufficient decision support, a damage assessment study should deliver a level of accuracy which is required for choosing between, e.g. different management options.

Even the most accurate and comprehensive approaches involve uncertainties regarding the results of damage assessment. In order to provide good decision support, these uncertainties should not be ignored but documented and – wherever possible – quantified.

The EU Flood Risk Management Directive has led to economics acquiring an expanded role in flood risk management in Europe. The example of Saxony shows that existing frameworks are simple and based on multiple criteria: they *include* cost-benefit analysis but also go beyond it in the assessment of intangible and indirect effects. Pragmatic solutions are needed in this respect.

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Stephan Köster, Moritz Reese, Jian'e Zuo

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The book was inadvertently published with an incorrect author group in chapters 5, 10, and 14. The correct author group is listed below:

Chapter 5 – Fostering Water Treatment in Eutrophic Areas: Innovative Water Quality Monitoring, and Technologies Mitigating Taste & Odor Problems Demonstrated at Tai Hu – Stephan Küppers, Tim aus der Beek, Wenhai Chu, Bingzhi Dong, Anna Dahlhaus, Henner Hollert, Jianliang Hua, Wei Hua, Yunlu Jia, Lei Li, Holger Lutze, Christian Moldaenke, Yanwen Qin, Wido Schmidt, Christian Staaks, Claudia Stange, Daqiang Yin, Ji Zhao, Binghui Zheng, Linyan Zhu, Hua Zou, and Andreas Tiehm

Chapter 10 – Urban Pipe Assessment Method and Its Application in Two Chinese Cities – Jian'e Zuo, Xiangyang Ye, Xiaoqing Hu, and Zhonghan Yu

Chapter 14 – Cross-boundary Evolution of Urban Planning and Urban Drainage Towards the Water Sensitive "Sponge City" – Meiyue Zhou, Stephan Köster, Jian'e Zuo, Wu Che, and Xianping Wang

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