Chapter 5
Urban Water Management in Beijing and Copenhagen: Sustainability, Climate Resilience, and the Local Water Balance

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Abstract Cities play a critical role for the sustainable management of planetary freshwater. At the same time, cities need to adapt to climate change. This offers cities an opportunity to improve freshwater management. In this chapter, the authors describe the status of urban water management in Beijing and Copenhagen, from the standpoint of sustainable development and climate resilience. In particular, they look into the degree to which the local water balance has been displaced. They review key water challenges and instruments in both cities, as well as related governance aspects. They consider the potential impact of these instruments and the relevance of a green infrastructure (GI) approach, as well as the potential for improving urban sustainability governance. A special focus is on the role of GI for retracking the city towards sustainable urban water management and climate resilience.

Keywords Freshwater management · Sustainable city · Local water balance · Green infrastructure · Urban governance · Beijing · Copenhagen

5.1 Introduction

This chapter compares water management in Beijing and Copenhagen from a governance perspective. The two cities are compared because, firstly, both cities have huge water challenges, have a strong planning tradition, and are proactive with urban water management; secondly, the research was partially funded by Sino-Danish Center for Education and Research (SDC), through which the authors gained good channels for first-hand data in Beijing. We highlight governance approaches that entail a combination of traditional public management (TPM) with new public

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J. Delman et al. (eds.), *Greening China's Urban Governance*, ARI - Springer Asia Series 7, https://doi.org/10.1007/978-981-13-0740-9_5

management (NPM) and network governance (NG) tools to restore the local water balance and enhance urban sustainability and climate resilience.

Globally, freshwater is an essential and scarce resource which is under pressure from overexploitation, contamination, and climate change. If there is to be a transition to the sustainable use of freshwater resources, cities will have to play a significant role in it. Of all the water exploited, one third goes directly to households and industry, which are predominantly located in cities. The remaining two thirds, which go to agriculture, are affected indirectly by citizens' consumption of food and other agricultural products (Shiklomanov 1999).[1] Total water extraction increased from approximately 600 km^3/year in 1900 to about 3700 km^3/year in 2000, with most of the increase occurring after the 1950s. Modern pumps allow for ever deeper aquifers to be exploited, and huge piping systems with average leaching rates of 30% allow water to be transported to consumption sites further and further away (Ibid.). In combination with power dams, this heavy extraction of water causes a quantitative displacement of the local water balance in many places, resulting in severe ecological losses, increasing conflicts over diminishing wells, and abandoned farmland and villages (Pacific Institute 2015).

Cities also account for much of the displacement of the natural balance in terms of water quality. This takes place through stormwater runoff and the discharge of wastewater from households and industry into natural water bodies, with negative consequences resulting for the environment and communities downstream.

If sustainable management of freshwater is to be possible, the use of water will need to be improved in terms of both quantity and quality. While qualitative improvement must be achieved at a local level (every city has to ensure a good quality of discharged water to protect the local environment), it is less obvious how the quantitative aspect (overexploitation) is to be tackled, inasmuch as the pressure from cities is related both to the direct intake of water and to the virtual water. One approach is to focus on the amount of water drawn into the city for water supply from sources outside it. In this respect, a city has better quantitative water management if it takes in less water from outside the urbanized area (be it in the form of surface water or groundwater) and if its water supply originates in a higher proportion from the annually renewable water produced naturally within the local area by precipitation or made available by water reuse therein. In such a case, the wealth and population size of the city will correspond to the amount of water available and to the skills and technologies of the city in the reuse of water. A situation with a zero intake of water from outside the city is illustrated in Fig. 5.1. The situation illustrated is the goal of the fully urbanized island nation of Singapore, which is aiming at zero dependence on the import of water from Malaysia by 2060, and full reliance on wastewater cleansing and all-purpose reuse (PUB 2013). In this chapter, we refer to this environmentally ideal state, with its 'closed' urban water cycle, as a 'City with a Local Water Balance': i.e. the water

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[1] This is so-called virtual water. The virtual-water content of a product (a commodity, good, or service) is the volume of freshwater used to produce the product, measured at the place where the product was actually produced.

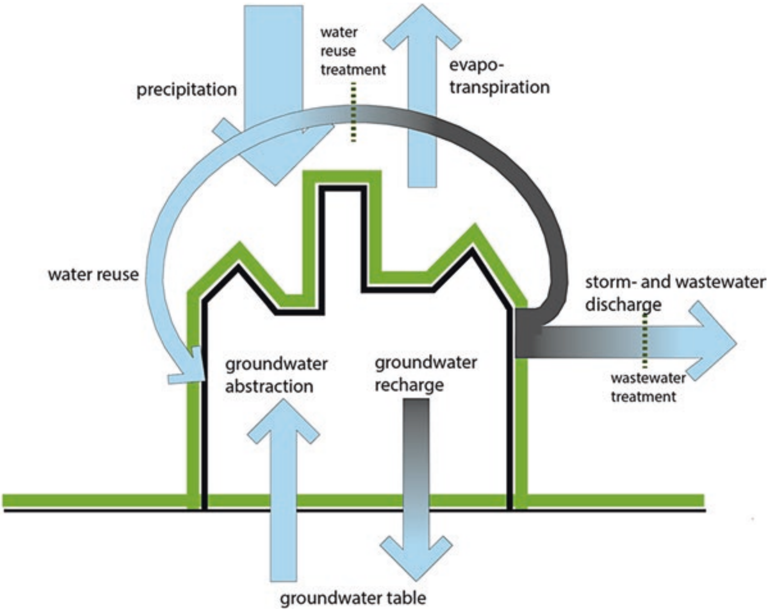

Fig. 5.1 City with a Local Water Balance. This city relies exclusively on precipitation and the reuse of wastewater. Its population size is matched to the extent of local water resources and to the ability of the society to reuse wastewater. The amount of groundwater extracted does not exceed recharging volume. The quality of water released from the city is as high as that of water entering it. The city maintains a significant green infrastructure for urban water management and multi-ecosystem services

supply is taken from renewable natural water resources within the city, in combination with water reuse; the city is resilient to pluvial flooding by means of retention (where stormwater runoff is permanently held back) and detention (where it is temporarily held back) within the urban landscape; the quality of water infiltrated or discharged is comparable to that of incoming natural water; and the city has a strong green infrastructure which is linked to urban water management and which provides multi-ecosystem services. We use this concept here to discuss the direct water supply to the city and the ways in which the water intake can be reduced, but not to calculate the city's local water balance in a strict sense. For the latter purpose, the imported virtual water (see note 1) of the city ought also to be considered, together with the freshwater needed for natural ecosystems outside the urbanized part of the catchment; but these are considerations which fall outside the scope of this chapter.

The degree to which the urban water cycle has been displaced quantitatively varies from place to place. In regions where freshwater resources are plentiful, and where much of the precipitation quickly discharges in any case into the ocean through rivers and groundwater flow, it would be a waste of resources for a city to strive for zero reliance on the import of water from outside the city. In such a case, namely, freshwater can be taken from outside the city without destroying surrounding ecosystems, and a fair local water balance can still be maintained. Another case where the import of physical and virtual water from outside city limits can be seen as sustainable is when the city is located on land with little agricultural or ecological value, such as wasteland or desert.

The need for sustainable urban water management governance approaches is accentuated today by climate change. This is forcing many cities to reconsider their drainage systems, to avoid frequent flooding due to heavier precipitation. If the concurrent investments to achieve climate resilience are linked with efforts to re-establish a local water balance in terms of both quality and quantity, then big steps towards the sustainable management of freshwater can probably be taken. This window of opportunity is the focus of this chapter.

We use the two capital cities—Beijing in China and Copenhagen in Denmark—as our cases., We first describe current practices of water exploitation and contaminant management, in order to assess the degree of local water balance in terms of both quantity and quality. Secondly, we look for discourses relating to the linkage between climate resilience and sustainable freshwater exploitation, with an eye to ascertaining the extent to which the two challenges are approached jointly by decision-makers in the two cities. Our chapter is based on a review of the literature, on an analysis of documents, and on interviews. The two cities have different social-economic contexts and face different challenges. Beijing Municipality, a megacity with strong institutions, is undergoing rapid economic development in a water-scarce region. Copenhagen, a relatively large city on a stable level of development, has strong institutions as well; it enjoys plentiful resources both economically and in terms of freshwater reserves; and it holds high ambitions when it comes to protecting the environment and mitigating and adapting to climate change. Despite the differences, both use a combined TPM-NPM governance model and institutional setup for urban water management, i.e. city administrations are responsible for water administration and planning, and public-owned water companies deliver the water supply and drainage services; being the capital cities, both cities have high ambition on climate resilience entailing growing NG for stormwater management. Therefore, through an investigation of the two cities' practice with some comparative perspectives, we hope to find more nuances in local governance practices on water management and enrich our understanding of governance approaches from different contexts.

We examine water management governance of Beijing and Copenhagen with reference to two other relevant aspects of water governance, i.e. urban climate resilience and urban green infrastructure.

Urban resilience relates to climate change: it is 'the degree to which cities are able to tolerate alteration before reorganizing around a new set of structures and processes' (Alberti et al. 2003). Urban climate resilience can be enhanced by two activities: mitigation and adaptation. Mitigation seeks to reduce greenhouse gas emissions to tackle climate change, while adaptation focuses on vulnerability to the unavoidable hazards and attempts to adjust to them (IPCC 2014; McEvoy et al. 2006). Spatial planning, through the arrangement of land use and development, is a powerful method of governance for both mitigation and adaptation. For at least two decades, an approach high on urban planning agendas globally has been to apply mitigation strategies, such as increasing the use of alternative energy sources and constructing more energy-efficient buildings and transport systems. Urban planning for climate adaptation arrived more recently, but it has become a major discourse of resilience—for instance, in connection with flood risk management (McEvoy et al. 2006; Stead 2014). This chapter focuses on the water-related aspects of urban climate resilience.

In an urban context, green infrastructure (GI) refers to green-blue (vegetated-aquatic) areas and some related open spaces of a city that provide social, biological, or environmental services. But the use of the term varies according to place and circumstance, reflecting the lack of any well-established common understanding. Mark A. Benedict and Edward T. McMahon (2006) refer to GI as 'an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions…and provides a wide array of benefits for people and wildlife'. As suggested in Fig. 5.1, GI may offer unique options for establishing a good balance between a city (meaning both its physical structure and the social-economic activities carried on therein) and its local water reserves. Through the landscaping of urban surfaces, stormwater runoff can be managed in a way that mimics the natural water cycle, allowing for retention processes such as infiltration, groundwater recharge, and evaporation, as well as—in combination with substantial detention volumes—the reduction of flood risk (Austin 2014).

5.2 Management Systems in the Two Cities for Water Supply, Wastewater, and Stormwater

In 2012, Beijing Municipality had an area of 16,410.54 km^2 and a population of 20.7 million (Beijing Statistical Information Net 2013). It has a dry, temperate, and continental monsoon climate. Annual precipitation in the 1999–2009 period was 457 mm. About 3/4 of the precipitation falls in the months of June, July, and August. Potential annual evapotranspiration is 1200 mm (Meng 2014). In this chapter we focus on Beijing Central City, which roughly corresponds to the inner urban districts of Beijing Municipality. This definition, used by urban planners, excludes mountainous areas and some smaller towns from the central urban area.[2] In 2010, according to data from the Beijing Municipal Institute of City Planning and Design, Beijing Central City had an area of 1085 km^2 and a population of about 10 million (Zhang 2014). Copenhagen Municipality, on the other hand, had an area of 86.2 km^2 and a population of 566,906 in 2014 (Statistics Denmark 2016). It has a temperate

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[2] Districts of Dongcheng, Xicheng, Chaoyang, Shijingshan, Fengtai (excluding the area west of the River Yongding), and Haidian (excluding the area north of the mountain with the four towns, i.e. Weiquan Town, Sujiatuo Town, Xibeiwang Town, and Shangzhuang Town), plus the area north of Beiyuan and Huilongguan in Changping District.

coastal climate. Average precipitation during the 1971–2000 period was 523 mm (Danish Meteorological Institute 2002). Precipitation is distributed relatively evenly over the 12 months of the year, with the highest occurring in July and August. Potential annual evapotranspiration is 600 mm. Beijing Central City and Copenhagen Municipality, henceforth referred to as Beijing and Copenhagen, are the focus of this chapter.

5.2.1 Water Systems in Beijing

Beijing is located in a region low in natural water reserves. Together with groundwater, Guanting and Miyun reservoirs have traditionally been important for the municipality's water supply; however, the inflow from the two reservoirs has dropped dramatically. Today they hold less than 10% of their original storage capacity. Guanting reservoir is no longer being used, due to pollution (Probe 2008). Rapid population growth and low water prices without any economic regulator have also given rise to overexploitation of the municipality's groundwater aquifers, especially in suburban areas. The water level has dropped from 3 m below surface in the 1960s to 24 m below surface in 2009—just 11 m above the dry bedrock (Liu et al. 2014; Probe 2008). For Beijing Municipality as a whole, about 6000 mill. m^3 of groundwater had been extracted above the safety limit as of 2008, and the lost groundwater resource capacity may never be replenished. To meet the demand for water, surface water has been transferred into the city and ever deeper groundwater extracted from neighbouring regions for several years, and restrictions have been placed on the use of surface water and groundwater in these regions (Probe 2008). It has been estimated that Beijing Central City can extract 600 mill. m^3 of groundwater annually in a sustainable way (Beijing Institute of Geology Survey 2003); the city's demand for water, however, is almost double that amount. In 2010, of the total 1126 mill. m^3 of tap water supplied to Beijing Central City, 531 mill. m^3 were from groundwater abstraction within the city; 232 mill. m^3 were from Miyun reservoir; 148 mill. m^3 were from emergency groundwater wells located in suburban areas; and 215 mill. m^3 were transferred from other regions. This water was used for households, for public buildings and industry (914 mill. m^3), and for maintaining urban landscapes and the like (49 mill. m^3); the remaining 163 mill. m^3 was lost due to leaching (Beijing Water Authority 2010) (see Fig. 5.2). 380 mill. m^3 of reclaimed water were also used for non-drinking purposes. The water supply network of Beijing Central City consists of nine waterworks, with a daily capacity of 2.95 mill. m^3, as well as a number of self-sustaining wells (*zibeijing* 自备井) (Meng 2014). According to a study done by Beijing Water Authority, the available stormwater-harvesting capacity in Beijing Central City is about 100 mill. m^3 annually (Zhang 2013).

Within Beijing Central City, ten wastewater-treatment plants (with a daily capacity of 2.62 mill. m^3) handle 95% of the wastewater produced within the area. A substantial amount of this wastewater is reclaimed and reused for the city's water supply (Meng 2014). Non-point pollution caused by runoff in the Central City is

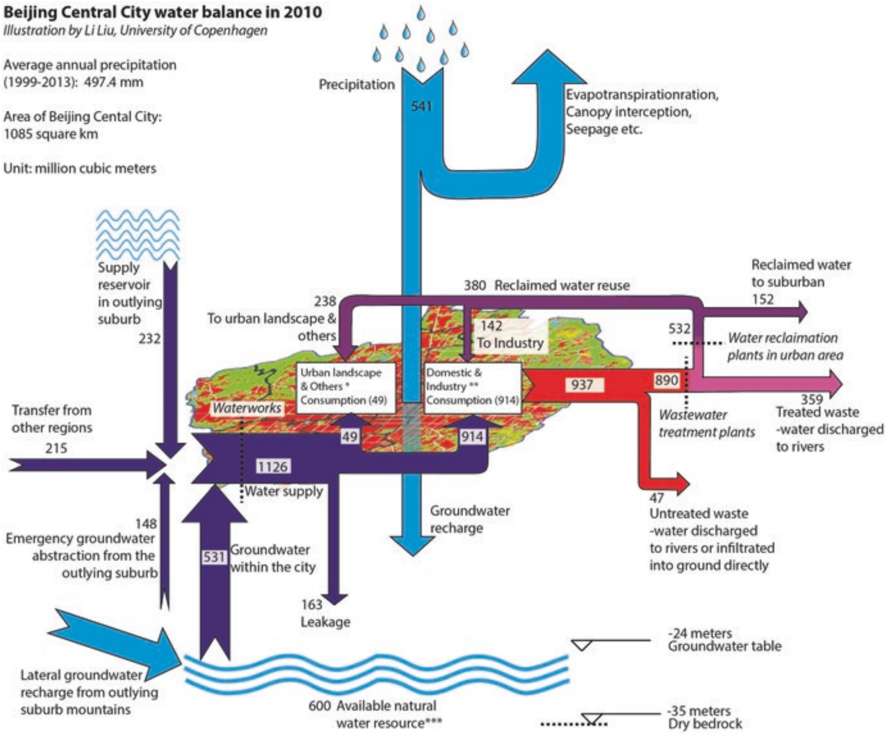

Fig. 5.2 Water balance of Beijing Central City in 2010. Unit: 10^6 m^3 (Beijing Water Authority 2010; Beijing Institute of Geology Survey 2003)

*Urban landscape and other consumption includes supplied water (excluding reclaimed water reuse) used for maintaining urban rivers and lakes, for watering urban green spaces, and for cleaning roads, fighting fires, etc.

**Domestic and industry consumption includes domestic water use (excluding reclaimed water reuse) for households and public buildings, together with industrial water consumption (excluding reclaimed water reuse).

***600 mill. m^3 available natural water resource in Beijing Central City is based on 'Capital Region Groundwater Resources and Environmental Assessment', by Beijing Institute of Geology Survey (2003).

considered more serious than point-source pollution. Of the five main rivers in Beijing Municipality, four fail to meet the national Environmental Quality Standards for Surface Water (GB 3838-2002) (the sole exception being the River Jumahe). The contamination is caused by combined sewer overflows (CSOs), poor sanitation and treatment, and direct discharge of sewage from industries. According to a field investigation carried out in Beijing Central City by Beijing Municipal Institute of City Planning and Design, there have been serious discharge problems in middle-sized rivers within that zone, including the River Qinghe, the River Liangshuihe, and (most polluted of all) the River Xiaotaihou (Zhang 2014).

Within its 2nd ring road, Beijing has a combined sewer system; from the 2nd ring road outward, separated sewer systems often prevail (Zhang 2013). Conventional rainwater systems in Beijing include drainage pipes, pumping stations, and urban rivers and lakes (Zhang 2013). Stormwater pipelines along the main roads are managed by the Beijing Drainage Group. The general service level[3] of the stormwater drainage systems is to manage three-year rain events—a level met by 85% of the system. The service level for future construction will be to manage five-year rain events. Waterlogging or pluvial flooding is increasingly prominent in Beijing, as a consequence of the combination of urbanization and climate change over the last decade (Zhang 2013; Zhao et al. 2014). The extreme flooding on 21 July 2012 involved a total precipitation of 164 mm, lasting 16 hours. Most local floods occurred on roads, under overpass bridges and intersections, and in areas with high pipe densities (Zhao et al. 2014). Frequent flooding and uncontrolled stormwater runoff do not just cause social-economic damage; they also aggravate problems of water pollution, through among other things combined sewer overflows (CSOs).

5.2.2 Water Systems in Copenhagen

Of the 61.5 mill. m^3 of annual precipitation that fell within Copenhagen in 2003, about one third (21.3 mill. m^3) was returned to the atmosphere through evapotranspiration. Another third (23 mill. m^3) was stormwater runoff, which was diverted through sewers to wastewater-treatment plants. Less than a tenth (4.9 mill. m^3) of the annual precipitation infiltrated the surface to charge the groundwater (Binning et al. 2006) (See Fig. 5.3). Almost all of the 32.8 mill. m^3 of drinking water consumed in Copenhagen that year was groundwater abstracted from well-fields distributed over a large part of Zealand, the island on which Copenhagen is located. Because of its relatively high quality, this water goes through a very simple treatment process after abstraction, with only aeration and filtration before being pumped out to consumers. Other water resources play a part as well, for secondary uses, but only on a very limited scale (2% at most): seawater is used for industrial process-cooling and stormwater harvested for laundry and toilet-flushing (Copenhagen Municipality 2012b). The water table in a large part of Zealand has fallen by up to 10 m. This increases the risk that saltwater will enter the aquifers (Binning et al. 2006). Climate change will likely bring changes in the groundwater level, which is expected to rise by 0.5 m along the coastline and to fall by 1 m in the rest of the municipality (Copenhagen Municipality 2011). This may pose a threat to the city's water supply. Moreover, due to contamination by pesticides and chlorinated solvents over recent decades, more than 10% of water supply wells around Copenhagen have been abandoned. Domestic water consumption in Copenhagen has fallen: from about 170 L per person per day in the 1980s to around 110 L per person today. The city achieved

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[3] The service level describes the level of protection that the stormwater drainage system is designed to provide. With a service level of 3 years, the stormwater drainage system can be allowed to overflow every third year on average, but not more frequently than that. In other words, the stormwater drainage system is designed to handle rain up to the level of a 3-year rain event, which is the worst rain that occurs with a return period of 3 years.

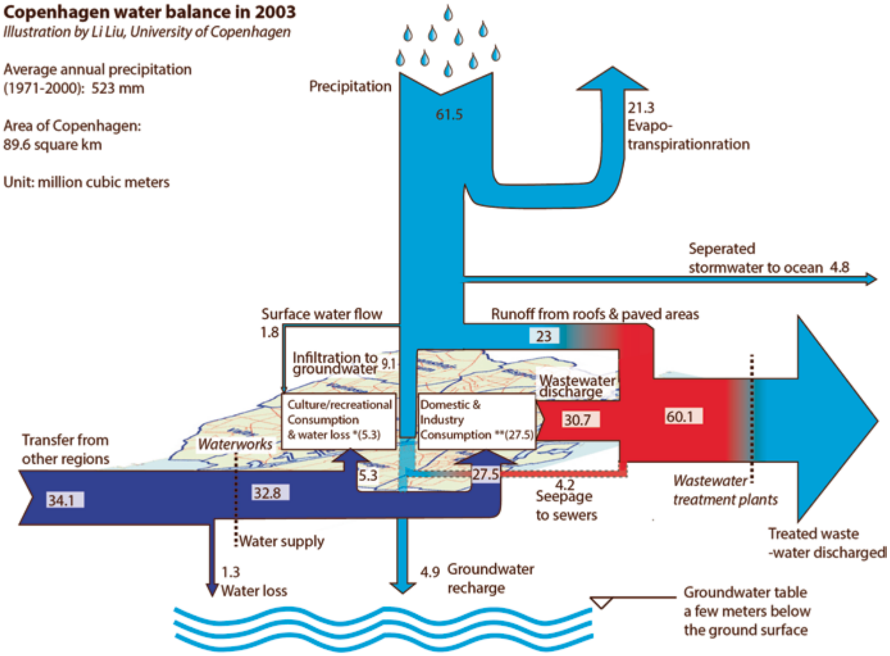

Fig. 5.3 Water balance of Copenhagen in 2003, (89.6 km^2). Unit: 10^6 m^3 (Binning et al. 2006)
*Culture/recreational consumption includes water used in urban ponds and fountains, for recreational and cultural uses, and the like; water loss includes water loss in pipelines, water use for firefighting and cleaning pipelines, etc.
**Domestic and industry consumption includes domestic water use for households and public buildings, together with industrial water consumption.

this by raising water prices, moving major industries out, stopping leakage in water pipes, conducting an intensive propaganda campaign involving school children and the public, and equipping every consumer tap with a water meter linking the bill to the level of consumption (Hansen 1996; Copenhagen Municipality 2012b).

Copenhagen's wastewater is treated in two wastewater-treatment plants, which take in all of the wastewater and most of the stormwater (Copenhagen Municipality and Copenhagen Energy 2008). In general, moreover, citizens in Copenhagen expect water in the harbour to be sufficiently clean for healthy bathing and other bodies of water in the city to be clean enough for recreational purposes. Their demands concerning water quality also seem to be rising. Unfortunately, however, combined sewer overflows bring contaminated water to the rivers and coasts in and around Copenhagen. More frequent and intensive rainfall brings more CSOs, burdening the ecosystem and undermining the well-being of Copenhageners.

Most of the discharge system of Copenhagen is a combined sewer system, with the oldest parts dating some 150 years back. It is sized for 10-year rain events (Copenhagen Municipality 2011; Copenhagen Municipality 2012a). Wastewater and stormwater are transported in the combined sewer to wastewater-treatment plants, from which the effluent is discharged into coastal waters. A minor fraction of stormwater runoff enters the stormwater pipes in a separate system, after which it flows into the ocean without any treatment. The current major challenge in Copenhagen is the increasing frequency and intensity of rainstorms. Meteorologists predict that, by 2100, the city will experience a 25–55% increase in precipitation during winter, up to a 40% reduction in precipitation during summer, and a 30–40% increase in thunderstorms, as compared with the situation at the beginning of the century (Copenhagen Municipality 2011).

5.3 Assessment of the Degree of Water Overexploitation and Contamination in the Two Cities

Major water flows in the two cities are shown in Figs. 5.2 and 5.3. Data are from 2010 for Beijing and from 2003 for Copenhagen. The figures refer to Beijing Central City (1085 km^2) and Copenhagen Municipality (89.6 km^2).

5.3.1 Overexploitation

According to the concept of a City with a Local Water Balance referred to above, a city's sustainable water sources consist of the annually renewable water produced naturally within its local area by precipitation, together with the water made available by reuse. Figure 5.2 shows the following for Beijing: of the 1506 mill. m^3 of water supplied in that city in 2010 (including reclaimed water), about 76% (1143 mill. m^3) came from sustainable water sources, i.e. available natural water resources (763 mill. m^3) in Beijing Central City and reclaimed water (380 mill. m^3), while 24% (363 mill. m^3) came from overexploitation of the city's own groundwater resources (148 mill. m^3) or other administrative regions' water resources (215 mill. m^3). In Copenhagen, as we see in Fig. 5.3, 100% of the 32.8 mill. m^3 of water supplied in 2003 was obtained from other regions' water resources. Beijing relies largely on groundwater abstraction within the city and on reclamation of wastewater. Copenhagen relies exclusively on distant water transfer (up to 50 kilometres), while local groundwater abstraction and reclamation of wastewater is almost non-existent. Stormwater harvesting in both cities is minimal.

Water consumption is correlated with total population. Table 5.1 shows that, in relation to its water consumption, Beijing's population density (9217) in 2010 was more than twice that (4007) which can be theoretically supported by water resources within the bounds of Beijing Central City. Copenhagen's population density (5599) in 2003 fell within the maximum density limit (6860). If per capita water consump-

Table 5.1 Maximum population density that natural water resources can support (Statistics Denmark 2016; Binning et al. 2006; Beijing Water Authority 2010; Beijing Institute of Geology Survey 2003; Zhang 2014)

		Beijing 2010	Copenhagen 2003	Beijing scenario
Population	Persons	10,000,000[a]	501,664	
Available local natural water resources[b]	m^3/year	600,000,000	40,200,000	600,000,000
Water consumption[c] (m^3/person/year)	m^3/person/year	138	65.4	65.4[d]
Theoretical population size supportable from locally available sources	Persons	4,347,826	614,678,899	9,174,312
City area (km^2)		1085	89.6	1085
Supportable population density (persons/ km^2)		4007	6860	8456
Actual population density (persons/km^2)		9217	5599	

[a] Data from 2010 for Beijing Central City, from Beijing Municipal Institute of City Planning & Design (Zhang 2014)

[b] Beijing 2010 data are based on 'Capital Region Groundwater Resources and Environmental Assessment', by Beijing Institute of Geology Survey (2003). Copenhagen 2003 data are based on Binning et al. (2006), as well as on the assumption that available local water resources are formed by precipitation (61.5 mill. m^3) in case area deducting evaporation (21.3 mill. m^3).

[c] Here water consumption is the total consumption per capita, including domestic consumption (household water use), industrial water consumption, and others.

[d] This is based on average annual water consumption per capita in Copenhagen in 2003 (Binning et al. 2006).

tion in Beijing had been reduced to the 2003 level in Copenhagen, Beijing's population density of 9217 in 2010 would nearly have been within the supportable by available local natural water resources (8456).

5.3.2 *Contamination*

In Beijing, of the 937 mill. m^3 of wastewater produced in 2010, more than half (532 mill. m^3) was reclaimed, while about another third (359 mill. m^3) was treated. This means that some 95% of wastewater was subject to quality control. The remaining 5% of wastewater (47 mill. m^3) was discharged directly into rivers or infiltrated into the ground, contributing to an imbalance in the city's local water cycle in terms of water quality. In Copenhagen in 2003, all 30.7 mill. m^3 of wastewater was subject to quality control, in wastewater-treatment plants. However, combined sewer overflows during heavy rain events put ecological pressure on local streams, contributing to an imbalance in the city's local water cycle in terms of water quality. Neither city had treatment procedures specifically designed for stormwater runoff during the years in question.

5.4 Water Management Instruments in the Two Cities

5.4.1 Water Management Instruments in Beijing

To secure Beijing's water supply and relieve pressure on its groundwater, the Chinese government has been carrying out a massive project: the South-to-North Water Diversion Project (SNWDP) with three routes (western, middle, and eastern routes). The middle route brings 1.2 bill. m^3 of water annually from the River Yangtze, in order to supply Beijing Municipality and its surrounding regions. The water is conveyed across 1267 km (Meng 2014). We have found no information on the possible ecological impact of the SNWDP in the River Yangtze catchment area. Besides the SNWDP, moreover, Beijing has a strategy for increasing alternative water sources, by such means as wastewater reclamation and stormwater harvesting. There have been attempts at reusing greywater, but the practice is not common in Beijing due to social concerns. The public, namely, distrusts greywater quality and fears risks to health, especially since the sudden and lethal outbreak of severe acute respiratory syndrome (SARS) in 2002–2003 (although this illness is not water-related) (Liu et al. 2014). The city is building new wastewater reclamation plants, improving water-use efficiency by adjusting its industrial structure, and exploring the desalination of sea water from Bohai Bay as a potential water source (Zhang 2014). In recent years, moreover, the Beijing Water Saving Office (a subdivision of the Beijing Water Authority) has issued guidelines and conducted water-saving campaigns, encouraging and requiring reductions in water consumption, mainly at the institutional level. Public education and propaganda for water-saving by citizens is increasing, but the effects are difficult to estimate (see also Luova, Chap. 4, in this volume). A three-tiered water pricing system was introduced on 1 May 2014, increasing the basic water price by 25% and imposing higher prices for additional use. This is expected to be effective at reducing water consumption (China News Net 2014).

Since 1990, Beijing has been working on improving its system for urban flood control and drainage. The idea is to develop retention and detention volumes in the western part of Beijing Central City and to increase drainage capacity in the eastern part (Meng 2014). The Flood Prevention and Waterlogging Reduction Plan for Beijing City Region being developed by the BWA proposes two deep tunnels in the eastern and western parts of the central city, respectively, in order to convey flood water to the two major rivers outside the 2nd ring road. Another Local Flooding Control Plan for Beijing Central City, under development by the Beijing Municipal Planning Commission, proposes not to dig deep tunnels but to establish a low-impact development (LID) greenbelt around the central city, based on existing and planned green areas, and to use this to manage stormwater by means of infiltration, retention, and detention (Liu and Jensen 2017). The city is also taking engineering measures, like upgrading pipes and pumping stations, in order to strengthen its urban drainage system (Meng 2014; Zhang 2013). In addition, the Beijing Municipal Planning Commission issued a new regulation in 2003, requiring all projects for new construction or reconstruction to apply rain-harvesting techniques (i.e. pervious pavements, sunken green spaces, and retention tanks). The Commission then followed with a detailed guideline in 2012, requiring every 10,000 m^2 of impervious pavement built to be equipped with a 500 m^3 rainwater detention facility (Meng 2014). The assumption in Beijing is that GI is only for managing 3–5-year rain events. Rivers and stormwater pipes are seen as the main methods for handling rain events more intense than the 50-year type, with GI only playing the role of delaying and reducing the peak flow. Beijing's strategy for handling stormwater thus integrates GI and grey infrastructure.

Beijing takes a highly top-down approach to urban water management. The BWA has charge of all water issues (water supply, wastewater management, and flood management) in the urban region. Its approach to governance is to apply traditional public management (TPM). This can be seen from its central control of waterworks, of the SNWDP, of the wastewater-treatment system, and of the city-wide pipe system for distributing reclaimed water. As state-owned companies, the Beijing Water Group and the Beijing Drainage Group administer water supply and wastewater management services, respectively. This institutional setup shows some characteristics of new public management (NPM), such as a strong focus on effectiveness in service delivery. The recent hike in water prices also shows a growing resort to NPM. However, a greater element of network governance (NG) can be expected in Beijing when it comes to managing stormwater and controlling floods by means of urban landscapes. In those areas a more decentralized approach can be expected, with multiple sectors aside from the BWA playing a role in administration. This can be seen in, among other places, the already highly privatized urban construction sector, although it is doubtful the general public will take part in the networks to any substantial extent.

5.4.2 Water Management Instruments in Copenhagen

Copenhagen faces problems of falling groundwater levels and reductions in water quality from aquifer oxidation (Binning et al. 2006). Greater Copenhagen Utility, HOFOR, has looked for ways, in collaboration with researchers, to short-circuit the supply and discharge systems and to use stormwater, greywater, and sewage directly from the wastewater stream for supply purposes. Thought has been given to replacing drinking water in certain places with other water sources for uses that do not require high water quality, in order to limit dependence on the extraction of drinking water in surrounding municipalities (Ibid.). The possibility of using local groundwater as part of the water supply has been investigated; the city's water supply plan, for instance, proposes to increase reliance on alternative water sources from the present 2% of total water supply to 4% by 2020 (Copenhagen Municipality 2012b).

To protect Copenhagen against extreme cloudbursts, two plans were implemented: the Copenhagen Climate Adaptation Plan (CAP) of 2011 and the Cloudburst Management Plan (CMP) of 2012. The objective of the CAP is to keep the 10-year return period service level, notwithstanding 30% heavier precipitation. The aim of the CMP is to avoid flood depths in excess of 10 cm for 100-year return period rain events. The CAP calls for a combination of green and grey infrastructures: diverting rainwater from sewers and managing it locally with green or low-tech solutions wherever feasible, enlarging sewers to reach the service level for 10-year rain events, and diverting floods to areas where they do the least damage (Copenhagen Municipality 2011). The assumption of the CMP is that expanding the ordinary sewer system and increasing retention-detention in green areas are not enough to solve flooding. Underground tunnels will be necessary, to divert flooding waters directly to the ocean. Streets and new cloudburst pipes will convey stormwater from events exceeding a 10-year return period to the tunnels (Copenhagen Municipality 2012b). Three types of stakeholders figure in the CMP: property owners, who are responsible for flood-proofing their properties; the utility company (HOFOR), which has to ensure that drainage systems meet service levels and that adaptive measures are implemented in accordance with the new risk dimensions; and the city administration, which must ensure that adaptive measures are incorporated into municipal master plans and are implemented. A detailed plan was also elaborated later, with more than 300 projects for implementing the CMP.

Copenhagen, with its centralized water infrastructure hardware system, has combined a top-down with a bottom-up approach to urban water management. The city administration is responsible for all water issues (water supply, wastewater management, and flood management), while HOFOR (Greater Copenhagen Utility) implements all water supply and wastewater-treatment services, using a combination of TPM and NPM. Within this general framework, particular attention has been paid to involving and mobilizing the public and the broader society, as reflected in the earlier water-saving campaigns, supplemented by an effort to reduce water consumption by raising water prices. When it comes to the management of floods and stormwater, a growing tendency towards decentralization and bottom-up administration can be observed in recent years. The city has already started to involve various actors from both public and private sectors, as well as property owners and citizens. This indicates a shift to NG for stormwater management.

5.5 Discussion

Water shortage is seen as an issue in Beijing, but not in Copenhagen. Beijing today has a huge system for reclaiming wastewater, which accounts for a significant fraction of the city's water supply. However, while the SNWDP ensures Beijing's water supply, the ecological impact of the project and its associated level of greenhouse gas emissions are unknown. Copenhagen relies very little for its water supply on secondary (alternative) water resources, such as reclaimed water.

Both cities focus strongly on flood control for climate resilience and have developed overall strategies and plans for this purpose. The two plans in Beijing stay at a more strategic level, and they are being developed by two different agencies with less consensus on the main emphasis, thus the conflict between the plans: the one focuses on digging deep tunnels and the other on establishing an LID greenbelt (see also He et al., Chap. 3). The importance of linking stormwater management to water supply, through harvesting or groundwater recharge, is given particular emphasis in the LID plan (although it figures as well in the tunnel plan). By the time of publication of this chapter, the plan for digging deep tunnels in Beijing has been held back in order to explore GI approach further. Copenhagen's plans have gone further, with implementation strategies more fully worked out and with better consensus among sectors and agencies. The goals, however, have changed from the CAP to the CMP, due to a perception of higher flood risk. The focus of the CMP is mainly on water discharge, with little coupling to water supply. In addition to the cloudburst management, the city does however has a plan to disconnect 30% of the city surfaces that today discharge to the sewer. This is to meet the expected 30% increase on annual precipitation without expanding the sewer. Green Infrastructure is among the solutions explored for meeting this goal. Additoinally, Copenhagen is exploring options for improving quality of stormwater runoff by use of filter soil, dual porosity filtration, and other nature-based solutions. Beijing uses top-down regulations and guidelines to implement its strategies, while Copenhagen seeks new ways in governance by involving public and private stakeholders in plan implementation, as well as to integrate the said plans with other urban projects. Both cities have made efforts to achieve clean water goals. Beijing puts the stress on technical solutions for treating water and protecting watersheds. Copenhagen emphasizes water catchment protection and quality control in water source regions. Both cities have a few examples of using green areas for controlling flood control and improving water quality.

To improve its local water balance, Beijing needs to continue reclaiming wastewater while at the same time exploring more innovative ways of using alternative water sources. As our analysis has shown, Beijing has a far higher population density than its natural water resources can sustain. If it retains this population density, it will become urgently necessary to reduce water consumption and to improve water-use efficiency. The effect of the recent hike in water prices remains to be seen, but a further step will likely be needed: the adoption of a full-cost pricing system

(Probe 2008). In the case of Copenhagen, the entire water supply comes from freshwater resources outside the city. While neither a shortage of water nor a danger to the ecosystem has been seen as a serious problem, problems and pressures may arise in the future. The discourse on improving the local water balance in Copenhagen is relatively weak. There is some discussion currently about combining stormwater harvesting with cloudburst management, and there was some discussion earlier about providing stormwater-harvesting tanks to private homeowners and about experimenting with groundwater abstraction wells in parks. In the present climate, however, the discourse in favour of flood control for climate resilience appears to be overwhelming. In neither city is stormwater used for the local water supply to any great extent. When the flood risk is high, priority is often given to securing the city from flooding by discharging flood water out of the city as fast as possible. Despite the risk they pose to cities, stormwater and flood water are part of the freshwater cycle; and they can be used as a local freshwater resource, thereby facilitating a local water balance. Energy can be saved by transporting less freshwater into cities from other regions and by transporting and treating less runoff as wastewater. Linking climate resilience to freshwater exploitation will reduce energy consumption and lessen the impact on the environment, thereby contributing to sustainable development.

Due to its close connection with urban landscapes and geo-biochemical processes, GI has the potential to combine solutions for flood control for climate resilience with solutions for sustainable freshwater exploitation, by such means as stormwater harvesting and infiltration for groundwater recharge. In addition, GI solutions have the potential to provide additional ecosystem services related to social and cultural values as well as biodiversity and crop production. GI solutions should be based on a city's local circumstances; they cannot be universal. A conventional mindset still rules in both Beijing and Copenhagen, with the alternative GI approach only being practiced on a small scale. Beijing puts the emphasis on infiltrating stormwater to its aquifers. It also uses green-blue infrastructure to receive lower-quality water. These practices help to reduce the imbalance of the urban water cycle. Copenhagen stresses the detention and discharge of stormwater and flood water, which is less helpful for reducing the imbalance of the urban water cycle. In Beijing, opportunities lie in solving some major challenges, i.e.. technical challenges posed by the concentrated rainy season, as well as operational challenges arising from distinct sectoral practices in water supply and in stormwater management (or flood control). The potential impact of projects like the SNWDP on climate and the environment may pose another difficulty. In Copenhagen, more awareness is needed of sustainable water supply practices and of the potential contribution of stormwater to this (although water supply pressure is not high yet). Both cities face time pressures in providing grey infrastructure for rain events more intense than the 50-year type, which GI has not proved able to manage. This is a strong barrier against making the necessary link between stormwater management and water supply through GI.

Our study has shown that Beijing mainly uses TPM in water management, together with a degree of NPM. The public has not yet been much involved. Copenhagen applies a combination of TPM, NPM, and NG, whereby the city seeks to involve property owners, citizens, and the private sector. The different choice of governance paradigms reflects differences in political systems, planning traditions, and land ownership patterns in the two national contexts. Water supply and wastewater management are basic and vital services which a city must provide. Neither Beijing nor Copenhagen can neglect to make some use of top-down approaches (TPM and NPM) with centralized hardware systems. However, there is a great potential to inject more in the way of bottom-up practices (NG) into the governance mix, thereby improving water supply and wastewater management in a sustainable way. Copenhagen's success in reducing water consumption over recent decades shows the results that can be achieved when citizens and the broader society are mobilized. (Then, if appropriate water pricing mechanisms are added to the mix besides, the results can be better still.) These successes may serve as to inspire Beijing. In the case of both cities, a greater reliance on NG would seem to be called for, in view of the increasing need for alternative approaches to managing floods and stormwater through urban landscapes and the associated need to engage a wider range of actors from both public and private sectors. The attraction of NG becomes yet more evident when we link issues of stormwater management to questions of water supply and wastewater management, given that decentralized stormwater facilities can provide water supply resources and alleviate pressures on municipal wastewater treatment.

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