

# Potential contributions to Beijing's water supply from reuse of storm- and greywater

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**Abstract:** In order to find new approaches to alleviating the water crisis in Beijing, which is caused by, among others, dwindling precipitation and rapid growth of population, and manifests in a rapidly declining groundwater table, this study explores decentralized stormwater harvesting and greywater reuse at household level as a means to reduce groundwater abstraction and water transfer from other regions. Based on a desktop case study, two concepts for combined harvesting and reusing of storm- and greywater are presented. With rough pre-assumptions, calculations show that a saving of 67.8% of tap water consumption can be achieved with the upgrading concept, compared with 5.9% with the simple downgrading concept. The saving with the upgrading concept equals  $0.545 \times 10^9 \text{ m}^3$  annual water volume, if 20 million Beijing people apply this approach. Despite numerous prerequisites, such as water treatment technology, space demand, energy and cost, and public acceptance, this paper advocates combining stormwater harvesting and greywater reuse in households with other measures for Beijing's sustainable water management.

**Key words:** urban water cycle; water supply; water reuse

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In per capita terms, China's water resources are not rich, accounting for about 75% of the average of Asia and 35% of the average of the world<sup>[1]</sup>. The water resources are unevenly distributed geographically and seasonally. 80.4% of China's precipitation falls in the area south of the Yangtze River, but it is available for only 53% of China's population, 35.2% of the arable land and 55.5% of GDP. Water availability per capita in south of the Yangtze is almost four times that of the north regions, and per hectare of arable land about eight times greater<sup>[1]</sup>.

China's economic development is mainly associated with urban areas, but the distribution of the Chinese cities is uncoordinated with water resources. Because of this, cities face great water challenges. This is especially the case for China's capital city, Beijing. It has developed

into the country's political, cultural and economic center, while at the same time facing severe environmental and resource challenges, among which is the lack of freshwater resources.

Beijing is located in a dry climate with limited freshwater resources. Rapid growth in both population and the economy in the recent two decades has deteriorated the situation. Currently, Beijing's water resource per capita is less than  $300 \text{ m}^3$ , about 1/8 of the country average and 1/30 of the world average<sup>[2]</sup>. While the annual precipitation is decreasing, the city's water consumption keeps growing. Based on data from 2009, to meet the annual demand of  $3.55 \times 10^9 \text{ m}^3$ , Beijing's natural groundwater resources are grossly overexploited<sup>[3]</sup>.

To provide more water, the city takes two major strategies: reclaiming water from wastewater treatment plants, and diversion of water from the Yangtze River in the south, 1 267 km away and 119 m lift up through the South-North Water Transfer Project (SNWT). Today, approximately 68% of all treated wastewater from urban water treatment plants is reclaimed, providing approximately 1/5 of the total demand. When the SNWT project is completed in 2014, it is expected to relieve the pressure of demand on groundwater. It is, however, insufficient for reestablishing the groundwater table. Water saving, pricing systems and some stormwater harvesting actions are applied in Beijing, but these count less compared with the two major strategies. New concepts are needed to save and use available water resources more efficiently.

Fig. 1 shows Beijing's water supply, discharge, and consumption in 2009. Precipitation is based on the average annual precipitation of 457 mm between 1999 and 2009. Of the annual precipitation of  $7.45 \times 10^9 \text{ m}^3$  in Beijing City ( $16\,410 \text{ km}^2$ ) only  $2.03 \times 10^9 \text{ m}^3$  is available for the city as a water resource. Most of the precipitation ( $5.42 \times 10^9 \text{ m}^3$ ) goes directly back to the natural water cycle by evaporation, canopy interception, infiltration, etc. The city has to depend on groundwater and imported water from other regions for water supply. Groundwater abstraction ( $2.17 \times 10^9 \text{ m}^3$ ) compared with groundwater replenishment ( $1.36 \times 10^9 \text{ m}^3$ ) reveals 160% overexploitation of groundwater in the year 2009. Overexploitation has resulted in a drop in groundwater

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level from approximately 3 m below the surface in the 1960s to 24 m below the surface in 2009, leaving only 11 m before the dry bedrock is reached. The drop rate has gradually increased and reached 1.2 m on average in the 2000—2009 period. A positive aspect is that a substantial

amount of wastewater is reclaimed and reused for the city's water supply. When the SNWT project is in function in 2014, the amount of imported water in the left of the figure will be much bigger, and groundwater abstraction is expected to decline.

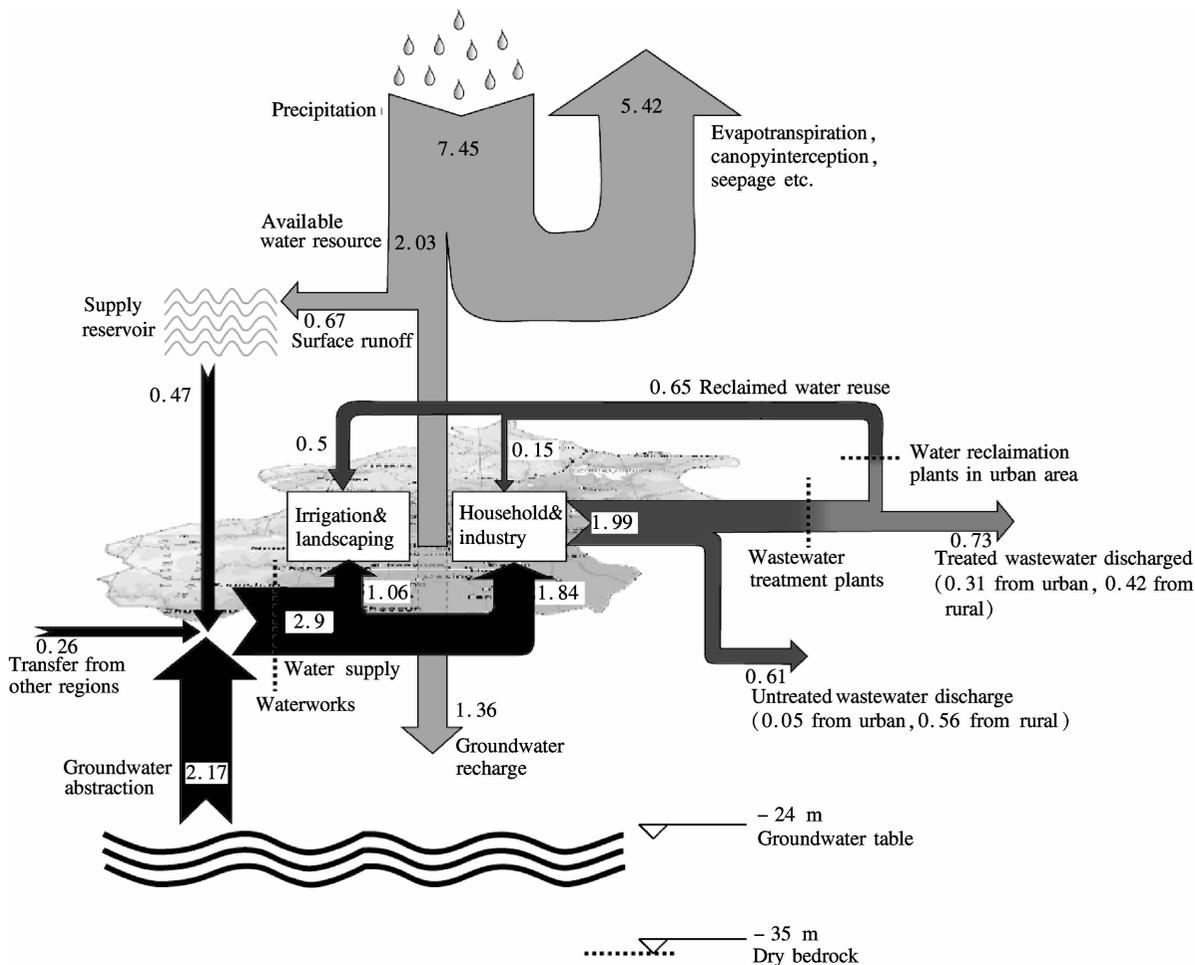


Fig. 1 Beijing's water balance in 2009 (unit:  $10^9 \text{ m}^3$ )

Having set the scene with this overview of the critical situation of Beijing's water resources, the aim of this paper is to discuss options for closing the urban water cycle by means of decentralized stormwater harvesting and greywater reuse. We assess two concepts for combined harvesting and reuse of storm- and greywater in urban households, followed by a discussion of advantages and drawbacks of these concepts.

## 1 Background of Concepts

### 1.1 Impact of urbanization on urban water cycle

Urbanization has a significant impact on the local natural water cycle. When a natural or rural setting is urbanized, the most visible consequence is the increase of ground imperviousness that limits stormwater infiltration and thus reduces the recharge of groundwater aquifers. On the water supply aspect, the increase in urban population and improved sanitation result in increased water con-

sumption. For economic reasons, the supply water is typically withdrawn from the closest source like rivers or local aquifers. This often results in lowering surface water flows and the groundwater table, which may bring further problems such as drying out of rivers and land subsidence<sup>[4]</sup>. As one of the urbanization practices, construction of networks for runoff conveyance and discharge increases the catchment runoff volumes and shortens the response time. Canalization of urban streams and rivers further breaks down the natural water networks' self-adjustment mechanism and increases the risk for flooding, when the flow exceeds the defined capacity.

Water enters urban areas as relatively clean groundwater, rainwater and surface water. Water leaves urban areas mainly in the form of urban wastewater effluents (UWWE), including stormwater runoff, municipal wastewaters, and combined sewer overflows (CSO). UWWE is discharged into receiving surface waters ranging from streams, rivers, lakes, reservoirs to estuaries

and oceans. Although UWWE is often treated before discharge, untreated wastewater and left-over pollutants result in an increase of pollutants concentration in receiving waters. Pollutants also get into groundwater aquifers through natural leaching or intentional infiltration of stormwater runoff. When the pollutants in the receiving surface water bodies and groundwater aquifers exceed certain levels, this will cause the loss of beneficial water uses, for example, drinking water safety, ecological functions, and urban water for recreation and amenity<sup>[4]</sup>.

A common approach to urban water management is the fragmentation of the urban water cycle into sectors, where water supply, stormwater and wastewater are managed in separate and non-circular systems without taking advantage of the numerous links between them. For example, lack of integration leads to missing the opportunity of using rainwater and recycled wastewater as a water source for non-potable uses. In other cases, over-abstraction of river water without thinking of the reduced ability to support downstream regions may bring unexpected impacts<sup>[5]</sup>. Thus urbanization and conventional approaches to urban water management result in an unbalanced urban water cycle from both quantity and quality points of view. In order to close the urban water cycle and regain the balance, an integrated urban water management approach is needed at the strategy and planning levels as well as on technical levels, allowing for water supply systems to be linked to systems for storm- and wastewater discharge systems.

## 1.2 Aspects on urban water reuse—stormwater and greywater

Reuse of water for urban water supply is a key issue for achieving a closed water cycle, especially in resource poor cities. Water for reuse in urban areas can be sourced from stormwater, greywater, industrial wastewater and effluent from municipal wastewater treatment plants. Water reuse can reduce both demands for fresh water resources and pollution loads to surface water.

### 1.2.1 Stormwater

Stormwater is defined as the runoff from pervious and impervious surfaces in predominantly urban environments. Impervious surfaces include roofs, drive ways, pavement, footpaths, and roads<sup>[6]</sup>. It flows directly into surface waterways or is channeled into sewers, which eventually discharge to surface waters. Urban stormwater includes pollutants, such as sediments, nutrients, organic macro-pollutants like plant debris, heavy metals, oil and grease, hydrocarbons, organic micro-pollutants like pesticides and PAH's, road deicing agents like NaCl, and pathogens<sup>[7]</sup>. The stormwater harvesting system depends on the rainfall characteristics, area of runoff catchment, water demand for specified usage(s), water quality and storage area required due to seasonal variation<sup>[6]</sup>. Exam-

ples of significant stormwater harvesting do exist, for instance in Sharland Oasis, Australia, where 40% of the total water supply is based on rain water<sup>[8]</sup>.

### 1.2.2 Greywater

Greywater is all wastewater except for blackwater (toilet water) produced in households. It includes water from showers, bathtubs, sinks, dishwashers, washing machines and water used for cleaning. The fraction of greywater in household wastewater is up to 75%<sup>[9]</sup>. Sometimes, wastewater from the kitchen is also excluded as greywater for reuse, because it is more heavily contaminated than greywater from other sources<sup>[10]</sup>. According to Australian experience, reuse of greywater for toilet flushing and lawn gardening could achieve water savings from 30% to 50% of total household water usage<sup>[8]</sup>. Greywater is of lower quality than harvested stormwater, as it contains dissolved contaminants from detergent or soap products, household chemicals, nutrients, pathogens, etc. However, greywater is produced more regularly, allowing for a smaller storage volume compared with stormwater<sup>[11]</sup>. Examples of greywater treatment technologies include constructed wetlands, rotating biological contactors (RBC), sequencing batch reactors (SBR), and membrane bioreactors (MBR)<sup>[12]</sup>. Greywater systems have disadvantages compared with stormwater harvesting from roof tops because of the greater technical challenges for treatment<sup>[6]</sup>.

### 1.2.3 Reuse of storm- and greywater

During the past decade, reuse of water in cities has been intensively investigated especially in Australia, the European Union, Israel, Japan, Jordan and the USA<sup>[13]</sup>. For some countries like Germany, experience of reuse of stormwater and greywater has been collected over two decades. Treatment concept for greywater reuse, following a process of sedimentation, biological treatment, a clearing stage and eventually UV disinfection, has proved to be effective and suitable for household toilet flushing<sup>[10]</sup>. In Australia, the quality of treated stormwater from the existing practices is proved within the limits prescribed by the Australian Drinking Water Guidelines. The greywater treatment system, if following EPA Victoria Accreditation, can achieve a water quality suitable for garden watering, toilet flushing and use in washing machines<sup>[8]</sup>.

Among many others, stormwater and greywater reuse demonstration cases can be found in Nordhavns gaarden, at Østerbro, in Copenhagen, Block 6 in Berlin and two residential buildings of Beijing Water Infrastructure Corps. In Nordhavns gaarden, greywater is collected from the showers of 130 apartments, treated in the basement by means of RBC and redistributed to 85 apartments for toilet flushing<sup>[14]</sup>. Block 6, Berlin uses a storm- and greywater recycling system. The high load greywater from kitchens and washing machines, in addition to greywater from bathtubs and showers from 71 dwelling units (250 per-

sons), are collected and treated in SBR to produce water for toilet flushing and garden irrigation<sup>[15]</sup>. In the case of Beijing roof runoff from the two buildings is treated in an IRM High-Flow Inline filter and greywater from bathtubs and showers from one of the buildings is treated in RBC. The treated storm- and greywater are reused for toilet flushing respectively in each of the two buildings with 60 apartments each (120 persons)<sup>[16]</sup>.

**1.3 Objective**

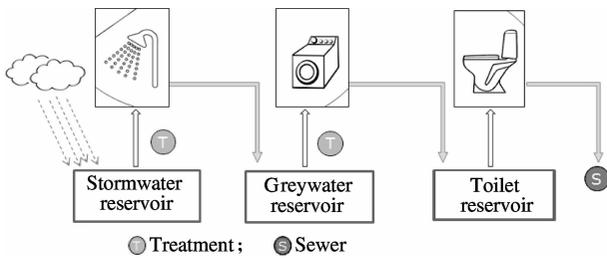
The objective of this study is to assess the water saving potential in households in Beijing upon stormwater harvesting and greywater reuse, following either a simple downgrading concept, or a multiple reuse upgrading concept. Furthermore, the major challenges of citywide greywater implementation are discussed.

**2 Methods and Materials**

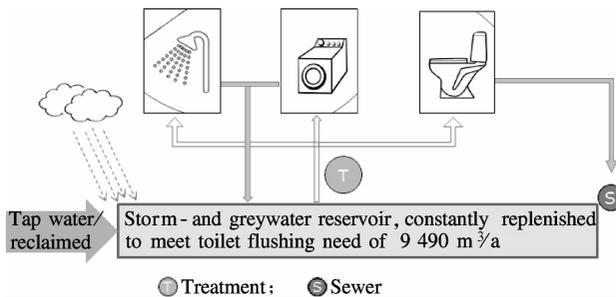
The results presented reflect education-based research within the Sino-Danish Water and Environment Master Program (www.sdc.dk).

**2.1 Two concepts for stormwater harvesting and greywater reuse**

The down- and upgrading concepts are presented in Fig. 2 and Fig. 3, respectively.



**Fig. 2** Concept 1: downgrading



**Fig. 3** Concept 2: upgrading

**Concept 1 (downgrading)** The harvested stormwater is treated and used for the most sensitive purpose (personal hygiene, dish washing). The resulting greywater is treated and used for less sensitive purposes (laundry, cleaning), and then for the least sensitive purpose (toilet flushing), in a cascading manner, where the quality requirements become less in each step. The harvested stormwater is reused three times. Three separate tanks, at

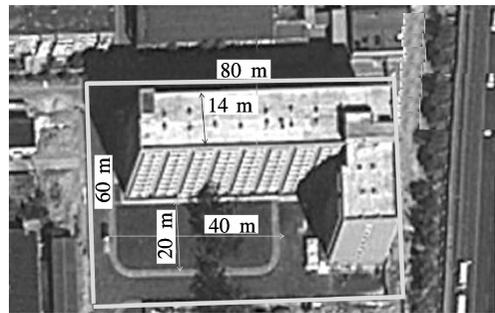
least two treatment technologies, and the conventional tap water backup system are required.

**Concept 2 (upgrading)** Storm- and greywater are mixed in the same tank. Treatment ensures adequate water quality for personal hygiene, dish washing and thus all inferior uses. In dry periods, the tank is replenished with tap or reclaimed water to the minimum level. The harvested stormwater is used multiple times, and water is only leaving the storage tank through the toilet. A single treatment technology for stormwater and greywater treatment to top quality is needed. The conventional in-house tap water system is needed for kitchen uses only.

**2.2 Case description and data input**

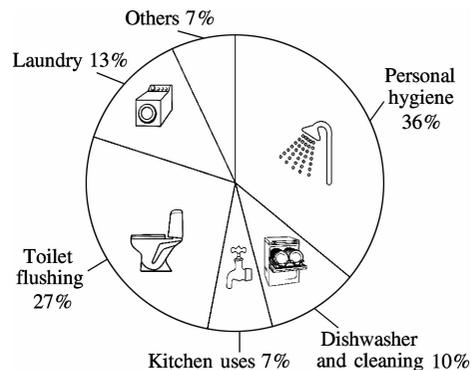
The concepts are applied to a nine-story block building serving as a student dormitory at Chinese Academy of Science in Beijing, located on No. 3, Datun Road, Chaoyang District, Beijing. The neighboring stormwater catchment area is approximately 4 800 m<sup>2</sup>, including the roof area and the surrounding pavements. The annual precipitation of Beijing is 457 mm (see Fig. 1). It is assumed that 80% of the annual precipitation can be harvested and stored.

The dormitory contains 432 three-person-shared rooms, corresponding to approximately 1 300 residents in total (see Fig. 4).



**Fig. 4** The block building site (based on Google earth, 2013)

Household water consumption is estimated to 200 L/ (person · d) based on Beijing Water Resource Bulletin 2009<sup>[3,17]</sup>. Water use distribution in households (see Fig. 5) is based on data from Denmark<sup>[18]</sup>, as data for Beijing are not available.



**Fig. 5** Water distribution in households<sup>[18]</sup> (DANVA)

For both concepts it is assumed that storm- and greywater can be treated to a quality allowing for replacement of all tapwater except water for kitchen uses. It is further assumed that no water is lost during water use activities.

### 3 Results

#### 3.1 Water saving potential

With a runoff coefficient of 0.8 and an annual precipitation of 457 mm the stormwater harvesting potential from the 4 800 m<sup>2</sup> dormitory catchment area amounts to

$$\begin{aligned} \text{Stormwater harvest} &= \\ &0.8 \times 4\,800 \text{ m}^2 \times 0.457 \text{ m}^3/\text{m}^2 = 1\,755 \text{ m}^3 \end{aligned}$$

**Tab. 1** Annual water demand in dormitory with 200 L/(person · d) for different uses, corresponding water quality requirement and category after use

Water use	Annual dormitory demand/m <sup>3</sup>	Quality requirement	Category after use
Kitchen (7%) (drinking, cooking)	6 643	Highest (clear, no risk of pathogens, no harmful chemicals)	Non-reusable greywater
Personal hygiene (36%) (showering, etc.)	34 164	High (clear and no risk of pathogens)	Greywater
Dish washer & cleaning (10%)	9 490	High (clear and no risk of pathogens)	Greywater
Laundry (13%)	12 337	Medium (clear, only few bacteria)	Greywater
Other (7%)	6 643	Medium (clear, only few bacteria)	
Toilet flushing (27%)	25 623	Low (some turbidity is OK, only few bacteria)	Black water
Total (100%)	94 900		

The water saving potential in the downgrading concept is estimated by multiplying the stormwater storage with a factor of 3 as the stormwater is reused three times before discharged to the sewer. The amount of tap water needed in this concept amounts to

$$\begin{aligned} \text{Downgrading tapwater demand} &= \text{total water} \\ &\text{demand} - \text{three times reuse of stormwater} = \\ &94\,900 \text{ m}^3 - 3 \times 1\,755 \text{ m}^3 = 89\,275 \text{ m}^3 \end{aligned}$$

The downgrading concept results in water saving of

$$\begin{aligned} \text{Water saving downgrading} &= \\ &\frac{94\,900 \text{ m}^3 - 89\,275 \text{ m}^3}{94\,900 \text{ m}^3} \times 100\% = 5.9\% \end{aligned}$$

In the upgrading concept the water level in the storage tank drops only when toilets are being flushed. All other uses of water in the tank will not result in a reduction in volume as the water is returned to the tank after use. Thus the volume in the tank can be used for all other pur-

With a 200 L/(person · d) water consumption by the 1 300 residents, the total annual water demand amounts to

$$\begin{aligned} \text{Total water demand} &= 0.2 \text{ m}^3/(\text{person} \cdot \text{d}) \times \\ &365 \text{ d/a} \times 1\,300 \text{ persons} = 94\,900 \text{ m}^3 \end{aligned}$$

Using the ratios for water distribution in Danish households (see Fig. 5), the total water demand in the dormitory distributes as shown in Tab. 1, which also categorizes the water demand after quality requirements and category after use.

poses multiple times, before the water is flushed through the toilets to the sewer. In this way the demand for tap water equals the kitchen and toilet flushing demand, subtracted the harvested stormwater:

$$\begin{aligned} \text{Upgrading tapwater demand} &= \text{kitchen water} + \\ &\text{toilet flushing water} - \text{harvested stormwater} = \\ &6\,643 \text{ m}^3 + 25\,623 \text{ m}^3 - 1\,755 \text{ m}^3 = 30\,511 \text{ m}^3 \end{aligned}$$

The upgrading concept results in water saving of

$$\begin{aligned} \text{Water saving upgrading} &= \\ &\frac{94\,900 \text{ m}^3 - 30\,511 \text{ m}^3}{94\,900 \text{ m}^3} \times 100\% = 67.8\% \end{aligned}$$

#### 3.2 Comparison of the two concepts

Tab. 2 compares the two concepts for combined harvesting and reuse of storm- and greywater in urban households as introduced above.

**Tab. 2** Comparison of the two concepts for stormwater harvesting and greywater reuse in households

Item	Downgrading	Upgrading
Water saving	5.9%	67.8%
Number of tanks	3	1
Number of treatment systems	2 (3 if clear water for toilet flushing is required)	1
Water quality	Three different qualities	All water meets requirement for personal hygiene
Public acceptance	Easier to accept showering in stormwater runoff	More difficult to accept showering in greywater

### 3.3 Upscaling to Beijing city

If 20 million Beijing people cut their daily use of tap-water by harvesting stormwater and reusing greywater as in concept 2 (67.8% reduction) it will correspond to an annual water volume of

$$\text{Upscaled saving} = 2 \times 10^7 \text{ persons} \times 0.2 \text{ m}^3 / (\text{person} \cdot \text{d}) \times 365 \text{ d} \times 67.8\% = 0.99 \times 10^9 \text{ m}^3$$

## 4 Discussion

The annual water saving, if the upgrading concept is applied citywide, of almost  $1 \times 10^9 \text{ m}^3$  represents a significant fraction compared with the annual water supply of  $3.55 \times 10^9 \text{ m}^3$  (see Fig. 1). The number is so high that it is likely to overrule the many rough and to some extent unrealistic assumptions, for instance the neglect of evaporation loss, this estimate is based on.

A study in Ireland estimates that optimized integration of the storm- and greywater reuse system will save 94% of public water supply in Ireland<sup>[11]</sup>, also based on stormwater harvesting and greywater reuse but in two separate systems. This high value reflects a significant stormwater contribution. But for cities with poor rainfall like Beijing the stormwater resource will be minor and reuse systems will have to rely more on multiple greywater recycling, as suggested in the upgrading concept (see Fig. 3). No documentation is found for applications like concept 2. However, initiatives by the authors in cooperation with local public baths have been started in Copenhagen to test the upgrading concept.

Worldwide, most common practices for storm- and greywater reuse provide water for toilet flushing, irrigation, car washing and similar low-quality water uses. In Germany there are standards for greywater reuse for toilet flushing, but not for other purposes<sup>[10]</sup>. With advanced and thus more costly treatment processes greywater can be reused for laundry and personal hygiene<sup>[11]</sup>.

According to Nolde<sup>[10]</sup> water from recycling systems should fulfill four criteria: hygienic safety, technical and economic feasibility, aesthetics and environmental tolerance. Water recycling for households is still a new approach in Beijing. The two proposed concepts for household water reuse can be considered long-term scenarios based on theoretical potentials rather than well-proved models that are ready for application. Various challenges can be expected, considering current socio-cultural and technical realities in Beijing.

### 4.1 Challenges on space, energy and cost

The uneven seasonal distribution of precipitation in Beijing with almost all rain in only three months requires large storage capacity, which may be in conflict with the limited space in urban Beijing. Innovative ways to pro-

vide space for local water storages would be to construct buildings with space in the basement, on the top floor, or at the façades.

Solutions for saving the freshwater resource should not be at the expense of higher greenhouse gas emissions. A German study shows that in large multistage Rotating Biological Contactor (RBC) greywater systems, the energy demand for greywater treatment, UV disinfection and treated water distribution is less than  $1.5 \text{ kW} \cdot \text{h}/\text{m}^3$ <sup>[10]</sup>. Likewise, storm- and greywater reuse systems should not cause chemical contamination and should use no or less chemicals compared to conventional waterworks.

In a study of economic feasibility of on-site greywater reuse in multi-storey buildings, assuming only the individual consumers pay for the system, it is estimated that the RBC-based system needs less than 0.5% investment costs for buildings of more than 20 flats, while MVR-based systems need 1.7% of flat price for the same building size. If implemented at city scale the added benefits of reduced overall water consumption and reduced sewage flows increase the cost-effectiveness of on-site storm- and greywater reuse systems<sup>[19]</sup>.

### 4.2 Challenges on public acceptance: water quality, health issue and psychological acceptance

It was more than a decade ago that a strategy of storm- and greywater reuse for toilet flushing was introduced and the first generation of demonstration projects was established in Beijing. However, the plan of spreading this strategy was put aside after a few years. The main reason was the fear of health risk, especially after the outbreak of severe acute respiratory syndromes (SARS) during 2002 to 2003. For the implementation of the two concepts mentioned here, more challenges for public acceptance are expected, since more personal hygiene issues are involved when storm- and greywater are used for showering, dishwashing and laundry.

A study in Australia shows that public acceptance to greywater reuse was high for uses such as toilet flushing and watering gardens. Willingness decreased when it came to body contact with greywater<sup>[8]</sup>. Earlier studies in European cities point to health risk, costs, operation regime and environmental awareness as factors of importance to public acceptance of storm- and greywater reuse<sup>[20]</sup>. According to Nolde<sup>[10]</sup> common chemicals from bath (including occasional medicinal baths) and house cleaning, and even pathogens from faeces and other sources expose no health risk, if greywater systems are properly functioning with efficient carrier materials for biofilm fixation and UV disinfection. It should be noted that lack of negative examples may be due to the fact that high level human contact with recycled water is not a common practice<sup>[20]</sup>.

To reach a higher satisfaction level for the recycling

system, both technological improvements and better communication with the stakeholders, especially the users, are important. German experiences recommend that every greywater system be tested once before operation, under several different contamination conditions, and the recycled water pipe system being in special color (purple is used in Australia) to avoid cross connections with the drinking water network<sup>[10]</sup>. Users need to be motivated and effectively involved in the process. Since the user's behavior influences the composition of greywater and therefore the complexity of the treatment procedure, greywater reuse programs need to be combined with public education for proper household water use behaviors. Public education on environmental awareness and the awareness of water challenges in Beijing may motivate a large amount of citizens and greatly improve the public acceptance to recycled storm- and greywater for household uses, where toilet flushing may be a good starting point.

#### 4.3 Prospect of storm- and greywater reuse in Beijing

As seen from Fig. 1 Beijing's water demands and resources are extremely unbalanced. The local water resources can by no means support the population and functions of the city. Beijing as a capital city and political, economic and cultural center for China may not be adequately located, or it has simply grown oversized. The water issue is closely linked with urban development as a whole, because most economic activities in a city are dependent on a reliable supply of water and a healthy living environment<sup>[5]</sup>. To this point, an optimum city planning may have an influence on releasing urban water stress by, for example, relocating some urban functions to other regions.

While Beijing's action of using reclaimed water from wastewater plants is encouraging and inspiring for other cities, we keep a skeptical view to the SNWT project. It is likely based on enormous energy costs and engineering expenses, as well as environmental and social problems in the water source regions. We believe that much can be done to optimize the usage of local water resources, both in terms of water saving programs, and by promoting water reuse technologies, as the upgrading concept suggested here.

#### 5 Conclusion

A review of Beijing's water balance shows that groundwater is overexploited to meet the demands of the densely populated city. Drawbacks of the present water supply approach can be seen by the serious decline of the groundwater table and the tremendous water footprint of the city on regions far away. Beijing's water stress represents a common urban challenge—unbalanced urban water cycle brought by urbanization. Urban water reuse, hereby stormwater harvesting and greywater reuse, is a valuable

approach to alleviate this. Based on a case of a dormitory building in Beijing, it is showed that the two concepts for storm- and greywater reuse, downgrading and upgrading, can reduce tap water demand. The upgrading concept indicates a water saving potential of 67.8% if applied city-wide. Although the concepts are based on theoretical assumptions, successful implementations of similar approaches are widespread, however mostly aiming at low-quality reuse like toilet flushing and irrigation. In addition to development of treatment technologies for high-quality reuse like personal hygiene, related factors like space requirements, energy consumption, and lack of public acceptance need further investigation. While storm- and greywater reuse for households cannot alone solve Beijing's water shortage problem, it may, if the upgrading concept is implemented, make a significant contribution. When combined with other measures such as water saving and more integrated urban planning, it has a potential of leading Beijing to a sustainable future.

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## 雨水和中水回用对北京供水的潜在贡献

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**摘要:**为寻找新途径以缓解北京市因日趋减少的年降水量和人口快速增长等因素引起的水危机,及地下水位迅速下降的状况,探讨了基于住户的分散式雨水收集和中水回用,作为减少地下水抽取和从其他地区调水的手段.通过案头案例研究,提出了雨水和中水结合式收集再利用的2个理念.基于粗略假设,计算表明采用升级理念可节约生活自来水消费的67.8%,而采用降级理念则节约5.9%.如果2000万北京市民采用升级理念,将节约相当于 $0.545 \times 10^9 \text{ m}^3$ 的年供水量.尽管先决条件诸多,如水处理技术、空间需求、能源和成本,以及公众接受能力,主张采用住户雨水收集和中水回用与其他措施相结合,以实现北京可持续的水管理.

**关键词:**城市水循环;供水;水的再利用

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