Advance of the Method estimating the Benefit of Storm Water Usage in Urban Area

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Abstract. The storm water causes the flood in urban area, and it could be treated as a special water resource in storm water management which could be divided into three development phases. The urban storm water management systems are analysed in this paper. The methods estimating the benefit of storm water management including benefit identification, index system and estimate method are introduced.

1. Introduction

The urban flood caused by storm water has been widely recognized as one of the main scientific issues that need to be addressed with priority. Since 2010, several impressive urban floods occurred in many cities in China, such as Beijing, Shanghai, Nanjing, Guangzhou and Jinan. These floods brought serious impacts on these cities. However, water shortage becomes a universal problem during the urbanization progress in China. About 50 \% of the China’s 600 cities are experiencing water shortage \cite{1}.

Urban storm water usage is a multi-objects synthesized technology. Both engineering and non-engineering utilities could be employed to manage the storm water, to relief the urban flood, even to improve the river environment. The benefit estimation of urban storm water management is the foundation of the decision making for the developing scheme of cities.

In this paper, we analyze the development phases of urban storm water management, summarize the methods estimating the benefit of storm water management including benefit identification, index system and estimate method are introduced. This work might be useful for city programming, and LID development in urban area.

2. Storm water usage

The storm water which might cause urban flood could be taken as a special water resource by management or engineering projects collecting, storing, exploiting storm water to increase the water resource or improve living environment \cite{2-5}. Recently, many countries conduct the storm water management, and the successful cases could be the valuable experience for storm water usage.

2.1. Development of the storm water usage

The development of storm water usage could be divided into three stages. In the 1960s and 1970s, storage tanks were used to save storm water for irrigating greenland or watering the road surface \cite{6}.
Storm water storage and detention are forced to be implemented in Colorado, Florida, and Pennsylvania[7]. In the 1980s and 1990s, many research and practice were implemented in Japan, Germany, UK and USA[8-12]. Since 1990s, storm water management has considered ecology, water quality, and flood detention.

In 1980s and 1990s, several cities in China built some rain collecting projects to resist the arid events[13]. At the beginning of 21st century, many metropolises in China began to implement the LID conception[14, 15]. Since 2010, the storm water management or sponge city were promoted by the government[16-18].

2.2. Development of the storm water management

The storm water management does not only concern the rainwater drainage, it also involves in the city planning, building and landscape design. Many laws and guidelines have been enacted[19-21], both theory, technology, law and manage system were combined to exploit the resource attribute of the storm water[22]. Some typical management systems are shown in table 1.

Table 1. Some typical storm water management system

| Country/Year | Management system                        | Summary                                                                                                                                 |
|--------------|------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| USA          | Best Management Practices[23]            | Best management practice is a term used to describe a type of water pollution control. Historically the term has referred to auxiliary pollution controls in the fields of industrial wastewater control and municipal sewage control, while in storm water management (both urban and rural) and wetland management. |
| USA          | Low Impact Development[22]               | Low-impact development (LID) is a term used to describe a land planning and engineering design approach to manage storm water runoff as part of green infrastructure. It emphasizes conservation and use of on-site natural features to protect water quality. It implements engineered small-scale hydrologic controls to replicate the pre-development hydrologic regime of watersheds through infiltrating, filtering, storing, evaporating, and detaining runoff close to its source. |
| USA          | Green Infrastructures[24]                | Green Infrastructure is a network providing the “ingredients” for solving urban and climatic challenges by building with nature. The main components of this approach include storm water management, climate adaptation, less heat stress, more biodiversity, food production, better air quality, sustainable energy production, clean water and healthy soils. It also serves to provide an ecological framework for social, economic and environmental health of the surroundings. |
| UK           | Sustainable Urban Drainage System[25]   | A sustainable urban drainage system is intended to reduce the potential impacts which a given development will have on surface water drainage discharges (run-off rates). A surface water drainage strategy is a report which seeks to meet the legal requirement through an investigation of how surface water will affect the site and the areas surrounding it and providing a suitable potential drainage strategy to mitigate the effects of the development. |
| Australia    | Water Sensitive Urban Design[26]         | Water-sensitive urban design is a land planning and engineering design approach which integrates the urban water cycle, including storm water, groundwater and |
wastewater management and water supply, into urban design to minimise environmental degradation and improve aesthetic and recreational appeal.

3. Benefit of the storm water usage

Benefit estimation is conducted to evaluate the urban storm water usage. Benefit estimation involves benefit identification, index selection and quantification, and index system.

3.1. Identifying the benefit of urban storm water usage

Feng and Xu (2009)\cite{27} propose a benefit estimation method considering both the storm water function and the demand of storm water resource. The economic, ecological, and social benefit are estimated by combining the function attributes and resource attributes. Li (2010)\cite{28} also identifies the economic, ecological and social benefit, and analyses the connotation. Zhang (2012)\cite{29} estimates the benefit by combining the function attributes and the human demand. Feng et al (2013)\cite{30} conclude the estimate indexes based on the way of urban storm water usage. Five indexes, substitution for city water, reducing drainage fee, reducing backfill fee for Greenland, water for production, and water environment, are taken as the economic indexes. The water quality, groundwater recharge, relieving land subsidence, and supporting the ecosystem are the ecological indexes. The water efficiency, relieving water shortage, water saving, and promoting eco-friendly society are the social indexes.

3.2. Quantitative and qualitative analysis

Usually, the economic, ecological and social benefit are the common classification for benefit identification. The economic benefit could be divided into direct and indirect benefit. And most of researches give quantitative analysis to the economic benefit. Ecological benefit could be analyzed quantitatively or qualitatively. Usually, the social benefit is analyzed qualitatively.

Zhang et al (2007)\cite{31} give quantitative analysis to the ecological benefit and qualitative analysis to the social benefit. Gu (2007)\cite{32} estimate the economic, ecological and social benefit with input-output analysis. Zuo et al (2009)\cite{33} divide the benefit of urban storm water usage into direct use value, indirect use value, option value, and existence value. They analyze the benefit of city water, groundwater recharge, water saving, contamination reducing, urban drainage, flood controlling, land subsidence controlling. A cost-effectiveness model is constructed and applied on the 267 storm water usage projects in Beijing. Li et al (2010)\cite{34} use the multi-level semi-constructive fuzzy optimization model to estimate the benefit of storm water usage. Multiple objective optimization method with dual water quality supply is used to estimate the benefit of rain water usage\cite{35}. Ma et al (2013)\cite{36} analyze the full life cost and benefit of the LID, including the cost and running expense. Zhu et al (2014)\cite{37} estimate the storm water resource, and allocate them to livelihood, industry, agriculture, and ecosystem. They use water price, using emergy, and allocation coefficient to estimate the storm water benefit of the cities in the plain river network region. Cao and Zhou (2017)\cite{38} employ the benefit transfer method, restoration or replacement cost approach, shadow project approach, and prevention costs to estimate the cost and benefit of the LIDs. They also consider the benefit of contamination controlling, flood prevention and carbon emission reducing.

3.3. Estimating index and method

The benefit estimation could be divided into single benefit and comprehensive benefit. To evaluating these benefit, index system and estimating method are indispensable. Each single benefit might have the unique estimating method, the comprehensive benefit combines the single benefit. There is no uniform index system, and indexes are selected based on the characteristics of the estimated region. Both qualitative and quantitative indexes are involved. Many methods are used to estimate the
comprehensive benefit multi-attribute decision, operation methods, statistical method, system engineering, fuzzy mathematics, heuristic method, et al.

Sun (2007)[39] use analytic hierarchy process to estimate the urban storm water benefit. There are 12 indexes in this research. The economic indexes include water rent, water shortage, water saving, drainage, contamination, social indexes include employment opportunity, flood controlling, water supply self-sufficiency rate, technical benefit, population quality, ecological indexes include land subsidence controlling and water cycle. Xu and Li (2009)[40] analyse the urban storm water resource, evaluate the contribution for national economy. Guo and Lv (2009)[41] use 44 indexes to construct the economic and social benefit system. Kong et al (2009)[42] design an estimating model for environmental benefit, and appraise the environmental benefit with a estimating system consisted of ecological, economic, and social indexes selected by frequency statistic method. Huang et al (2012)[43] add adjusting temperature, reducing dust, increasing negative oxygen ion into ecological indexes, and estimate the storm water usage benefit in Beijing. Hu (2012)[44] analyse the environmental and carbon controlling benefit. Zhang (2012)[29] uses net present value, present value index, and earning yield to estimate benefit of urban storm water usage. Jiang et al (2014)[45] employs the vague set to estimate the landscape benefit of storm water. Yan (2017)[46] calculates the cost, operating benefit and payback period of rain collection.

The storm water usage projects bring the economic, ecological, and social benefit. Most of these researches divide the benefit in to the same types. However, different indexes should be selected for different storm water usage projects. Considering the different background of different cities, the estimating method should be selected carefully.

4. Conclusions
Recently, the storm water usage and management make a great progress. A lot of methods and theories are prompted to evaluate the storm water usage benefit. However, the problem is complex, all the methods cannot be suitable for all the projects and management cases. Further researches are needed in the future.

1) Most researches take the economic, ecological and social benefit as the common classification for benefit identification. The economic benefit consists of direct and indirect benefits. However, the benefit identification is a complex work which elaborate effort should be made in the further study.

2) Constructing the index system is the first step of estimating urban storm water usage benefit. Then the estimating methods are selected. The cost is an important factor for both these indexes and methods, and the indexes and methods should be selected carefully according to the characteristics of the estimated region.

3) Estimating the benefit of the urban storm water usage could be used to predict or evaluate the benefit of storm water usage projects and management schemes, and could be very helpful for management decision making.

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