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A THESIS FOR THE MASTER DEGREE OF FOREST SCIENCE

**A study on sustainability of green space  
management in Seoul**

**— A water footprint analysis of urban parks—**

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**by**

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# A study on sustainability of green space management in Seoul

—A water footprint analysis of urban parks—

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## ABSTRACT

Urban greening that takes form in projects like urban parks construction, is a pragmatic and artistic way to transform our un-natural modern cities to ecological and sustainable ones. However, the cost of nature resource consumption for such transformations still lacks of deserved attention, which definitely will raise queries on the sustainability of these transformations. This study, based on field research on 8 urban parks in Seoul of South Korea, is trying to offer a new practical method to move us out of the dilemma by shedding light on the new water management paradigm: combining water footprint (WF) analysis with rainwater harvesting practices. This research, using water footprint analysis, estimated the annual fresh water consumption of several Seoul urban parks respectively, and the related rainwater resource that could be potentially utilized by taking the urban park existing landscapes into consideration. This study figured out that in order to maintain urban parks' public services, considerable fresh water resource (varied with park type and size) needs to be consumed (the average WF per m<sup>2</sup> of each park ranged from 340L/m<sup>2</sup> to 444L/m<sup>2</sup>); the recent urban water management neglected bountiful rainwater resource, which could be used for reducing WF consumption of each park locally (replacing around 9% to 38% current blue WF) by utilizing building roofs for rainwater collection.

**Key words:** urban park, water footprint, urban landscape design, rainwater harvesting, Seoul

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## 1. Introduction

More than 50% of the world's population lives in urban areas, and it is expected that half of population of Asia will live in urban regions by 2020 (Heilig, 2012) . According to WHO (2010), by 2030, 6 out of every 10 people will live in a city, and by 2050, this proportion will increase to 7 out of 10 people. Cities are playing a role of engine for boosting world's economic wealth and hubs of creating jobs(Moretti, 2012),innovations(Feldman & Audretsch, 1999) and other social activities(Jacobs, 1984). But, urban metabolism studies reveal that demand of cities for nature's resources and services is worryingly shooting up over time(Browne, O'Regan, & Moles, 2011; Høyer & Holden, 2003; Kennedy, Cuddihy, & Engel-Yan, 2007; Moore, Kissinger, & Rees, 2013; Sahely, Dudding, & Kennedy, 2003). Scholars, like Rees(2012) further argued that city developing pathways was dissipative structures consuming vast quantities of energy and material resources.

More studies have proved that cities massively consume natural resources, such as energy consumption(Dhakal, 2004), food consumption(Collins & Fairchild, 2007; Moore et al., 2013) and so on. Apart from natural resource consumption, myriad studies have focused on the increasing urban waste(Fischer-Kowalski & Hüttler, 1998; Grimm et al., 2008; Moore et al., 2013; Warren-Rhodes & Koenig, 2001). Within such bounty researches on urban resource consumption, the studies on rapidly increasing water resource consumption in urban area grasps scholars' attentions due to the pervasive water scarcity issue.

Water resource is a prime limiting factor in the sustainable development of urban areas throughout human history (Vairavamorthy, Gorantiwar, & Pathirana, 2008)and becomes even more significant with explosive population, in the current era of urbanization and climate change(Clarke, Robin T., 2004).

### **Urbanization and urban water consumption**

Several analysis have been conducted to explore the drivers of expansion of urban water consumption. Increasing urbanization brings significant alterations in urban physical properties of land surface(Kravčik, 2008) and demographic composition , which lead to vulnerability of urban inhabitants, agricultural land and rural life supporting ecological systems(Niemczynowicz, 1999).

On one hand, due to factors such as increasing wealth, degree of technological development, and level of industrialization, urban areas would have an increasing per-capita freshwater requirement (Jenerette, Wu, Goldsmith, Marussich, & John Roach, 2006; Stoker & Rothfeder, 2014). On the other hand, the ongoing concentration of population in urban areas and urban expansion (Loucks, 2000; Vairavamoorthy et al., 2008) pose a strain on limited water resource and raised worrying concern for sustainable water supply of water for urban areas (Heilig, 2012; Tortajada & Castel án, 2003; Varis, Biswas, Tortajada, & Lundqvist, 2006)-between 1950 and 1990, the number of cities with populations of more than 1 million increased from 78 to 290 and it is expected to exceed 600 by 2025 (Serageldin, I., & Mundial, 1995), which has been accompanying with enormous water resources consumed.

Furthermore, besides the impact on natural resources caused by urban expansion of large cities, the rapid development of small cities that have got forward momentum would cast more concerns on water resource exploitation, since the small cities' urban spreading tend to be more susceptible to resources and be less capable to cope with environment degradation due to less specialization for environment maintenance and limited institutional capacities (S. Kim & Rowe, 2012).

### **Climate change and urban water consumption**

Persistent industrialization, population increase, intensive energy usage and rapid land use change have driven a significant anthropogenic changes in the atmospheric (Vairavamoorthy et al., 2008), and this has been accepted by the majority of academic community members as one of the causes of obvious climate change within recent decades (Solomon, Plattner, Knutti, & Friedlingstein, 2009).

As a consequence, many regions are expected to have substantially altered water availability and because of increased variability in climatic conditions reduced water availability associated with short-term draughts will be more likely in all regions (Arnell, 2004; Darrel Jenerette & Larsen, 2006; Royer et al., 2002). This would definitely has tremendous impact on the water supply and consumption to urban areas, especially considering that urban areas usually lack the needed and qualified freshwater resource within local boundaries.

### **Unnoticed urban water consumption from urban greening**

Although the admiration and practices for constructing urban green space to serve the public started to appear around 19<sup>th</sup> century already in western-world (Wallace, David A, 1970), expanding urban green spaces has gained forward momentum within current decades , especially in the metropolitans with highly modernized economy. Because, for metropolitans especially, a cleaner environment with more green spaces is required 1) by residents pursuing a good quality of life , 2) for generating environmental premium<sup>1</sup>(Tajima, 2003) and 3) due to the need to acquire regional competence in global economy leaning on service-based economy more than ever(Daniels, 2008).

Myriad urban greening practices and development plans could be observed : the urban parks project “Big Dig” in Boston of USA is one piece of its extensive urban greening plans (Tajima, 2003); in France, city administration of Paris added thirty-two hectares of green spaces between 2001 and 2008, and Parisian Regreening public projects such as the Parc André Citroën(1992), the Jardin Atlantique(1994),the Parc de Bercy(1997) and the Promenade plantée (2000) have inspired innovations in other metropolitans (Laurian, 2012); between 1988 and 1993, over 19% of brownfield sites in Britain were converted into green spaces(De Sousa, 2003; UK DETR, 1998). Other European cities, such as Freiburg(Dale Medearis and Wulf Daseking, 2012), Copenhagen(Michaela Br üel, 2012), and Helsinki (Maria Jaakkola, 2012), are increasing their urban green spaces by implementing diverse planning policies as well.

Similar practices could be found in Asia’s prosperous megacities that are actively expanding urban green space to satisfy citizens and create appetizing assets as well. Since 2004, Hong Kong has been extending urban green space by active construction of urban park and urban forestation: till 2013, 13.7 million trees have been planted. Between 1990 and 2012, Shanghai has its urban green spaces increased nearly 4.6 times from 186 hectares to 1038<sup>2</sup>(Shanghai Municipal Statistics Bureau, 2013), which represents a sketch of urban green

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<sup>1</sup> As an example, a close proximity to urban open space has positive impacts on property values, while proximity to highways has negative impacts on property prices.

<sup>2</sup> Since 1988, the administrative boundary of the municipality of Shanghai has been fixed by setting one county and around 16 districts in total and has experienced unprecedented urban development over the past 30 years, especially after the initiation of “opening Pudong new area to the world” in 1990, which came with a tremendous transformation in land use from a rural to urban area(Yin et al., 2011).

space growing in metropolitans of China. Even Tokyo , under its steep land price, extended public green space area around 1.55 times from 2001 to 2012(Tokyo statistical Yearbook, 2012).

Admittedly, creating more urban parks is necessary for meeting increasing demand for amenities in modernized cities since urban parks possess multiple benefits to citizens: 1) offering arenas for physical exercises and increasing physical activities(Cohen et al., 2007; Coombes, Jones, & Hillsdon, 2010; Mitchell, 2013);2) enhancing satisfaction of social interaction environments(Bjork et al., 2008; Maas, van Dillen, Verheij, & Groenewegen, 2009);3); reducing stress and mental disorders(Annerstedt et al., 2012; Ward Thompson et al., 2012); 4) improving perception toward life quality and general health(Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Stigsdotter et al., 2010) and so on. By all means, urban greening, especially in terms of urban parks, becomes “*green assets*” for cities.

However, the water resource consumption involved in urban greening activities has not been quantitatively studied thoroughly yet. The fancy word of “green assets” may just tell half the story. One Chinese research typically demonstrated that Shenzhen, a special economic zone in southern China, consumed fresh water from 30 to 40 million m<sup>3</sup> every year for maintaining its public green land which covers approximately 130 km<sup>2</sup>(XIAO Guo- zeng, TAN Yi- fan, SONG Gui- long, ZHENG Xi, 2009), which is a considerable amount and it keeps growing with city development.

But Shenzhen is not an isolated case and we could reasonably argue that the aggregate demand for water resource on urban green land will definitely shot up with global rapid urbanization and increasing civil petitions for more urban green spaces. In other words, the importance of maintaining these urban ecological systems for their multitude of services suggest future sustainable water management will require the dedication of significant quantities of freshwater that might have other application(Darrel Jenerette & Larsen, 2006). Therefore, it is reasonable to ask: are these urban parks, the *green asset* as commonly supposed, becoming “*green burden*” to cities since massive water resource might be consumed for its functioning?

### **Research questions and objectives**

Being suspect that “urban parks are typically overlooked as a salient sector of water consumption in urban area under the era of climate change and urbanization”, this paper

specifically attempt to answer two research questions. 1) How much fresh water resource does the urban park need in order to provide its multiple services to the public? 2) To what extent, the sustainability of water management could be improved by rainwater collection?

Based on representative research sites of 8 urban parks in Seoul in South Korea, this study would outline the framework for water footprint (WF) assessment aimed at urban parks and conduct a comprehensive analysis with attempt of identifying underlying reasons for WF difference in selected parks. Besides, water conservation solution by rainwater collection for urban parks will be demonstrated in this study. Finally, several policy recommendations are offered as well.

## 2. Methods

### 2.1. Study area

#### **Urban parks and water in Seoul**

The city of Seoul, the capital of South Korea, is located in the Midwestern part of the Korean Peninsula, approximately 30 km to the east of the Yellow Sea. Han River transects across Seoul separating the old city Gangbuk and newly built urban area, Gangnam. The climate of Seoul is rather complex with both continental and oceanic features. The average annual temperature varies between 8.6°C to 17°C, with average annual precipitation around 1450.6 mm (“Statistics on Seoul climate,” 2014). The rainfall is distributed uneven throughout the year, which may cause serious droughts in autumn and winter in several years.

As of 2007, Seoul, which has a higher development density accommodated 10.4 million residents within an area of 605.4 km<sup>2</sup>, covering 0.6% of the national total. Its population density reaches a level of 17,127 person/km<sup>2</sup>, making Seoul one of the most densely populated cities in the world(Sung & Oh, 2011).Following the Korean War in the 1950s, South Korea experienced rapid economic growth and urbanization, which brought about the expansion of the city of Seoul. Seoul has 25 administration districts and hosted the Olympic Games in 1998 and World Cup in 2002, which boosted its city appearance much well.



Figure 1 Seoul in map

In order to meet the civil requirement for more relaxing spaces with the natural environment and to enhance the city attractiveness, Seoul has been taking efforts in creating park greenbelts for years (Figure 2). Since the beginning of this century, Seoul has launched several new movement of urban green land expanding on the basis of the the first “urban park and green land expansion project” from 1996 to 2000, which greatly contributed to the urban greening and urban park construction then. Obviously rapid expansion appeared after 2002, when Seoul initiated its project of “expansion one million pyeong<sup>3</sup> living-zone green land ” from 2002 to 2006 and subsequently a batch of urban parks were completed. In the following 5 years after 2006, Seoul propelled its green land expansion ambition by starting project of “further promotion on expansion one million pyeong living-zone green land”.

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<sup>3</sup> Commonly used area unit in Korea, 1 pyeong $\approx$  331 m<sup>2</sup>.

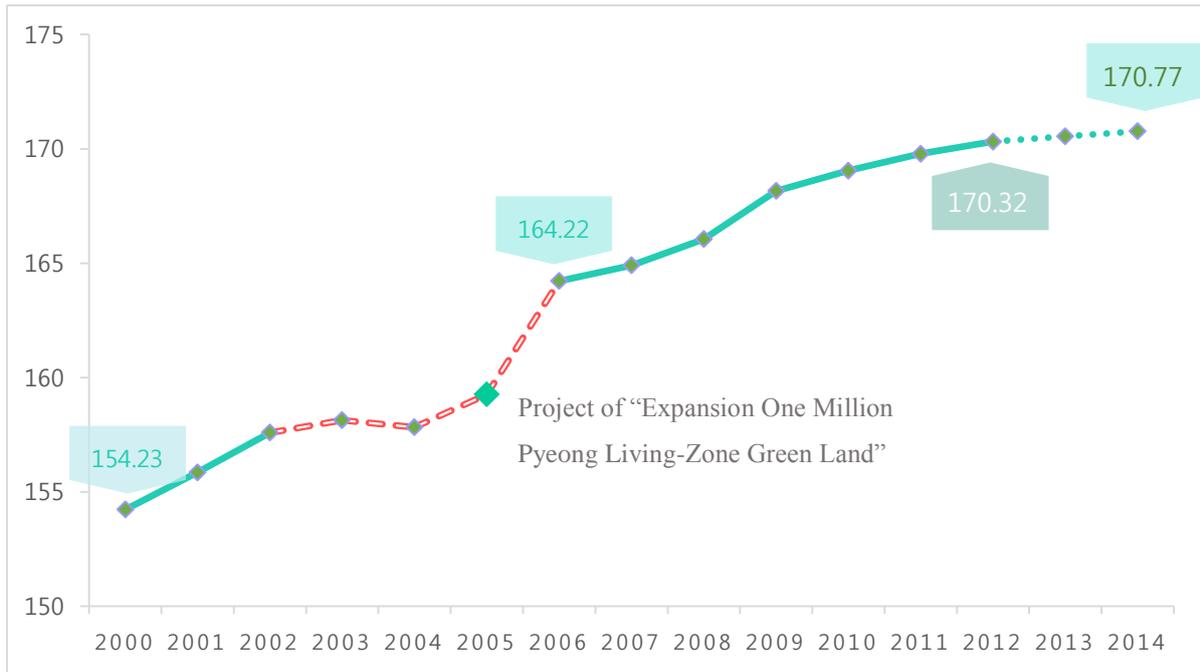


Figure 2 Seoul urban park area (km<sup>2</sup>) increases from 2000 to 2011 (Data source “Western park management office of Seoul, 2013 “)

As a result, in 2012, Seoul has urban parks 1480 in total, including urban nature park (20), neighborhood parks (387), children’s park (1284), small parks (292), sports parks (3), waterside parks (5), ecological parks and so on. Table 1 features each category of urban parks in Seoul.

Table 1 Urban park category and definition (Data source: "ACT ON URBAN PARKS, GREENBELTS, ETC., 2011")

General type	Specific category	Definition	Key feature
Living-zone parks		Any of the parks that are built and managed as parks that take the character of fundamental park in an urban living zone	
	Small parks	Parks built by using a small area of land to foster feelings of restfulness and peace for urban citizens	◆ Less than 1500m <sup>2</sup>
	Children’s park	Parks built to improve the health and peaceful life of children	● More than 1,500 m <sup>2</sup> ● Assessable within 250 m for the nearby ● facility occupation space within 60% of the total
	Neighborhood parks	Parks built to serve to improve the health and to promote recreation and peaceful life of neighborhood residents or residents who live in a	● Assessable within 500 m for the nearby ● Size from 10,000 to 1,000,000 m <sup>2</sup>

		regional living zone that consists of a neighborhood living zone	
Theme parks		Any of the parks that are built for various purposes, other than living-zone parks	
	Historical parks	Parks built for the rest and education of urban citizens in the practical use of any historical place, establishment, relics, any vestiges, etc. of a city	None
	Cultural parks	Parks built for the rest and education of urban citizens in the practical use of cultural features of a city	None
	Waterside parks	Parks built for the leisure and rest of urban citizens in the practical use of the waterside space, including the riverside and lakeside of a city	None
	Cemetery parks	Parks built in combination with a graveyard provided and park facilities in order to provide resting places to graveyard visitors.	None
	Sports parks	Parks built to foster healthy bodies and mind through sports activities, including athletic events, outdoor activities.	None
others	Ecological parks	Specially prescribed by ordinance	None

Several urban greening plans are still under construction and new projects are going to be implemented, too. Seoul started a green land extension project surrounding one segment of a railroad artery in 2009, aimed at having this 6.3 km long railroad encircled by green spaces covering 101,668 m<sup>2</sup> in 2015. Another similar practice has been taken to alter the deserted brown land of old urban rail into plants, in a scale of 281.235 m<sup>2</sup> before 2015. Since 2011, 25 new “customized” urban parks have been under construction and will be completed within 4 years, as responses to civil requirements. According to the working plan of Park Management Office of Seoul(Lee, 2013), living-zone green land will be further enlarged in order to balance between districts , and networking existing urban parks through green belts has been set as a goal in the long term.

However, urban greening in Seoul, in forms of park building, and water consumption have not been thoroughly studied as one object with close relationship. Although enjoyed a relative affluent precipitation, South Korea is actually suffering from fresh water scarcity due to overexploited and climate change. Revenga et al. (2000) made a global projection upon

water supply capacity for per river basin for 2025, they forecasted that the majority territory of South Korea would go through severe water stress even water scarcity in the near future. One research ,combining data source from UN and World Resources Institute (WRI), estimated the freshwater availability globally(Ludwig, Lehmann, & Edelman, 2013) and ranked South Korea as “stress” as to its freshwater availability in 2007. According to an investigation (Smakhtin, Revenga, & Döll, 2004) on water stress indicator(WSI) in global major basins , scholars identified South Korea as a country smothered by serious water stress: overexploited in the southwest part and Seoul (capital area); heavily exploited in the middle and slightly exploited in the west.

In fact, Seoul has been encountered with water management problems for decades as its economy started to booms since 1960s. The changes on quantity and quality of underground water in Seoul could showcase the decades-long underground water overexploitation(Y.-Y. Kim, Lee, & Sung, 2001; J.-Y. Lee, Choi, Kim, & Lee, 2005). Apart from subways construction, leaky sewer systems and various agricultural activities in the suburbs of Seoul, pumping water for public or private use weighs much for the exacerbation of Seoul water condition(Chae et al., 2008).

For the reasons above, Seoul is an appropriate city for an empirical study of water resource consumption of urban parks in metropolis.

### Research sites

This case study selected 8 urban parks, which are scattered in Seoul, as research sites (see Figure 4).

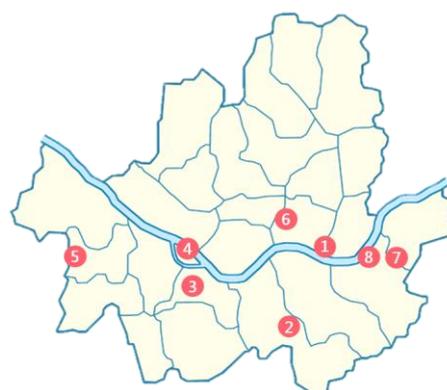
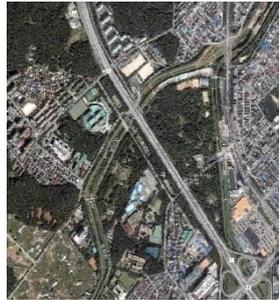


Figure 3 Research sites

Selected research sites covers urban parks with size ranging from around 432,394 m<sup>2</sup> to 26,696 m<sup>2</sup> and diverse in 4 types (Neighborhood Park, Small Park, Waterside Park and Ecological Park) as elaborately illustrated in Table 2.

Table 2 Basic information about selected parks

No.	Park	Size (m <sup>2</sup> )	Category	
1	Seoul Forest	432,394	Neighborhood park	 
2	Boramae Park	424,106	Neighborhood park	 
3	Yangjae Citizens' Forest	258,992	Neighborhood park	 
4	Yeouido Park	229,539	Neighborhood park	 

5	Westlake Park	217,946	Waterside park		
6	Gildong Ecology Park	80,683	Ecological park		
7	Eunbong Park	75,570	Small park		
8	Cheonho Park	26,696	Small park		

Four neighborhood parks were selected since this group of parks is the second most by count (“Children park” is the most one, but they are usually very small in size and nearly without green cover inside). In addition, two small parks, one waterside park and one ecological park are picked into research cases (see Figure 5). This case study covers all the general urban park types and major specific urban park categories described in Table 1, with consideration of park numbers for each category.

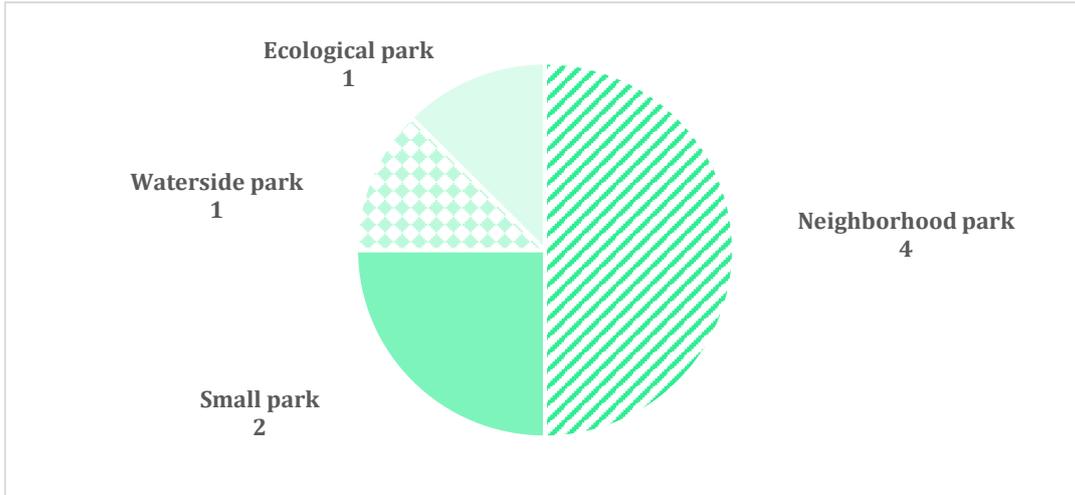


Figure 4 Park types in this study

## 2.2. Research framework

A gradual research process of this study is illustrated below (see Figure 3). A conceptual framework for water footprint (WF) analysis on urban parks is constructed based on previous literatures. This conceptual framework needs further supplementation and modification after the demonstration of a qualitative investigation conducted on selected urban

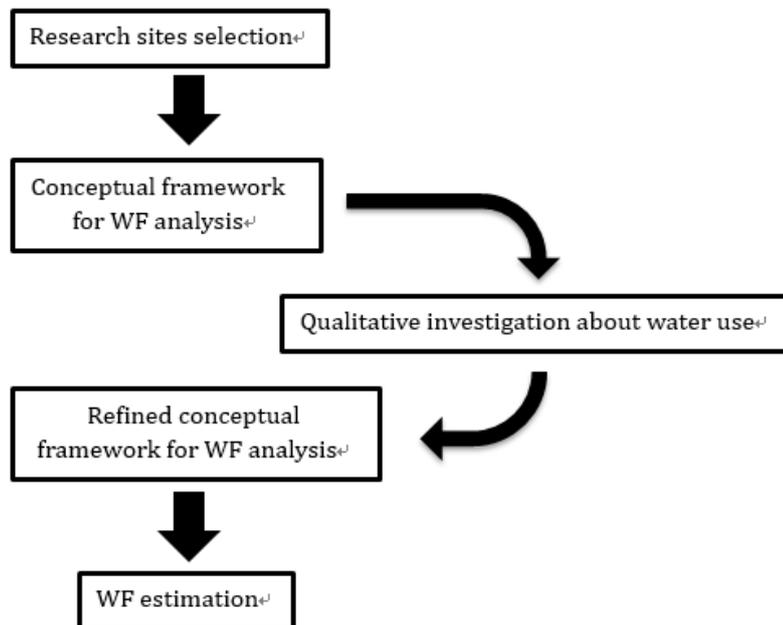


Figure 5 A gradual research process

parks about their water use. Next, estimation of WF of selected urban parks will be calculated according to a refined conceptual framework.

### **Urban park's water footprint (WF) in this study**

New research methodologies on water resource study that have been developed in recent years offered possibilities of investigating water consumption in a more holistic perspective. This study is based on the methodology of water footprint analysis brought up by Hoekstra (A. Y. Hoekstra, 2006; A. Y. Hoekstra, 2003; Hoekstra, A. Y., & Chapagain, 2011) around decade ago.

Inspired by the ecological footprint concept, the water footprint was introduced by Hoekstra and Huang (2002) in search for an indicator that can aggregately map human impact on water resources. The WF denotes the volume of freshwater used to produce goods and services (Hoekstra, A. Y., & Chapagain, 2011). Since WF analysis considers the water use along the whole supply chains, which makes the WF as a comprehensive indicators of fresh water appropriation (Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, 2011).

Many researches have applied WF analysis to investigate the water resource management issues. WF can be calculated for individual, community, nation or business during a certain period. Some scholars have estimated the WF per certain unit for a wide range of food, such as bread<sup>4</sup>, banana, beet, , beef, cheese, cabbage, coffee, cotton, egg, wheat, kinds of fruits and so on (More details in Appendix 1). Some intellectuals put focus on estimating the WF consumed by certain geographic unit. Steen-Olsen etc. calculated the WFs for the member states of the European Union (Steen-Olsen, Weinzettel, Cranston, Ercin, & Hertwich, 2012); Zeng etc. estimated the WF of Heihe of China in river basin level (Zeng, Liu, Koeneman, Zarate, & Hoekstra, 2012). Other researchers paid attention on the total WF within one industry or business. For examples, Yang etc. estimated the WF consumed by a tourism destination (Yang, Hens, Wulf, & Ou, 2011) and Ruini with his colleagues figured out the WF of large food

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<sup>4</sup> To take bread made of wheat as an example, the global average water footprint for one kilogram of bread equals around 1608 liter (M M Mekonnen & Hoekstra, 2011; M. M. Mekonnen & Hoekstra, 2010; WFN, 2011), which means producing a loaf of bread would require more than 1600 liters of fresh water.

company(Ruini, Marino, Pignatelli, Laio, & Ridolfi, 2013). More details about WF analysis will be discussed in section of methods and material.

This research investigated WF of urban park consumed to provide urban park services referring to *The Water Footprint Assessment Manual* on WF of business(Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, 2011). WF usually considers three types of water use in the various steps of the goods/service production/consumption chain: the blue, green and grey water. The first two types refer to the source of water consumption, while the latter pertains to waste dilution.

In this research, I consider all kinds of public services of one urban park as a package or a product provided by urban parks. Then I apply WF analysis to investigate the water consumption of these parks separately. The WF of urban park is defined as the total volume of freshwater that is used directly or indirectly to support its functioning.

The WF of urban park consists of two main sectors: operational (direct) and supply chain (indirect). Figure 6 demonstrates potential sources of types of WF of urban parks. The operational WF, which is the volume of freshwater directly consumed or polluted due to the parks' own operations. The supply chain (or indirect) WF of an urban park is the volume of freshwater consumed or polluted to provide all the services that form the inputs of the park.

Both operational and supply chain sector has its own "overhead WF". As shown in Figure 6, "overhead water footprint" refers to the WF related with the general activities for running an urban park and with the general goods and services consumed by the business, which is necessary for the continued functioning of the park but that does not directly involve within provision of one particular service.

In theory, as to each sector, researchers could distinguish a green, blue and grey WF component. Specifically, blue water represents ground or surface water stored in rivers, lakes, and aquifers that can be directly used for irrigation, industrial, or domestic use. Green water is rain water that is stored in the soil and used by plants to produce biomass. Grey water refers to the volume of water required to dilute pollutants discharged into the natural water system to the extent that the quality of the ambient water remains within the agreed water quality standards.

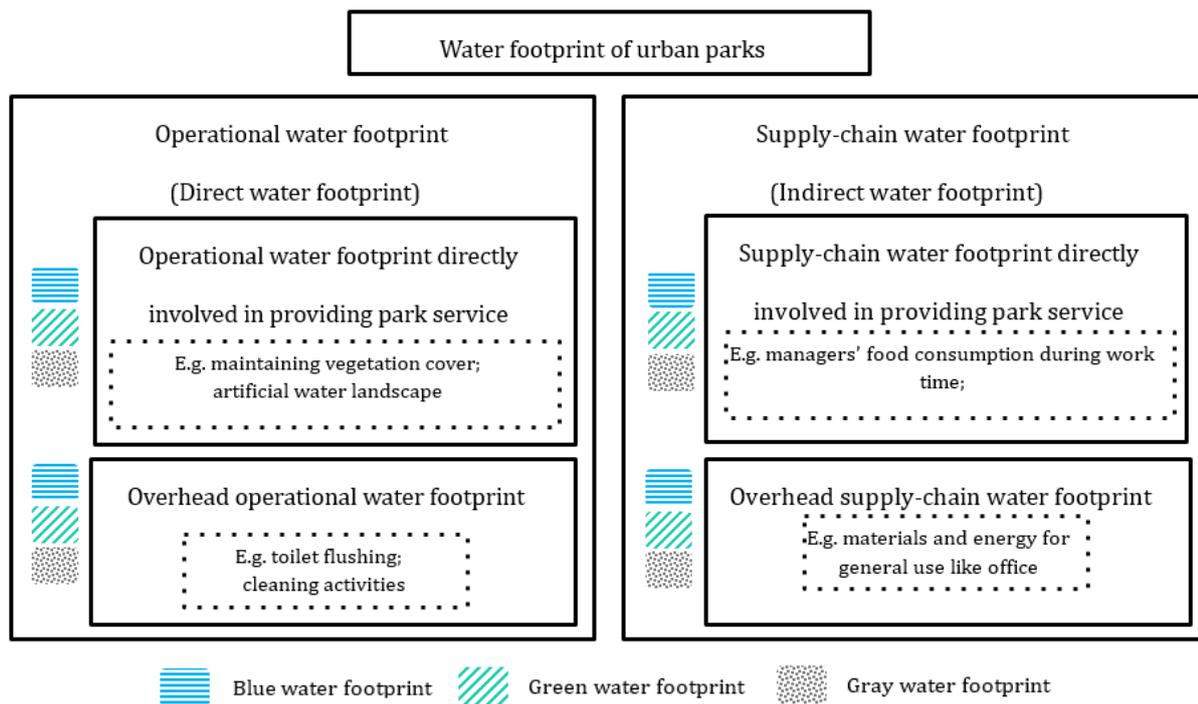


Figure 6 Conceptual framework of water footprint of business based on The Water Footprint Assessment Manual (Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, 2011, p. 64)

The distinction between the blue and green WF is important because the hydrological, environmental and social impacts, as well as the economic opportunity costs of surface and groundwater use for production, differ distinctively from the impacts and costs of rainwater use (Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, 2011).

For this study, operational WF of selected urban parks would result from 1) fresh water consumption of kinds of basic activities that are directly related to providing park services to the public, such as maintaining vegetation cover, artificial springs, man-made lakes or pools and other water landscapes; 2) fresh water consumption in kitchen, toilet flushing, cleaning activities and so on, as overhead WF. Supply chain WF of these parks would be created from 1) WF of items purchased for urban park services, WF from managers' food consumption during work time; 2) WF of infrastructure (e.g. construction materials), materials and energy for general use like office materials, cars and so on, as its overhead WF.

Developing a list of specifics of water usage, as mentioned above, for each research site (what activities done by parks involve water consumption) is fundamental to investigate

the main source of corresponding WF, to distinguish direct and indirect water consumption and to search for potential improvement for water conservation in urban parks. Therefore, a qualitative investigation on selected urban parks' water consumption has been conducted in order to refine our research framework and prepare the basic information for further WF calculation.

### **Qualitative investigation on urban park water consumption**

The qualitative investigation on urban park water consumption took form of interviews with park managers via semi-structure questionnaire (see Table 2) and field observations. Interviews have been conducted with managers of each urban park separately and officials from Western park management office of Seoul since April 2014, via face to face communication and email survey.

With intention of acquiring water consumption data for WF calculating and understanding water management status quo of selected urban parks, this qualitative investigation collected information about data source of water consumption, plantation characteristics, watering activities schedule, park maintenance, park development plan and so on.

Table 3 Sample questions of semi-structure questionnaire for qualitative investigation on urban park water usage

<b>Theme</b>	<b>Key Questions</b>
General	What activities in this park would consume water? Where is the water resource coming from? What activities do you think would cost most water? How many staff working here? How often, when, what is irrigation activities in this park? Is there any extending plan for this park?
Blue WF	What is the amount of water consumption per year within 5 years? What is the source of drinking water for staffs?
Green WF	What are the tree species planted in this park? The grass species? What is the size of green area in total? The trees cover? The grass land?
Gray WF	Did you use pesticide or fertilizer in this park? Do you have separate data of water consumption for toilet flushing?
Rainwater management*	Do you have rainwater collection activities? What is the total size of roof area of buildings within this park?

\* Details will be discussed in later section.

## Refined conceptual framework for WF analysis

By organizing answers to the questionnaire, I could identify the list of main water consumption activities on each park and further optimization of research frame work becomes possible. Figure 7 lists these activities.

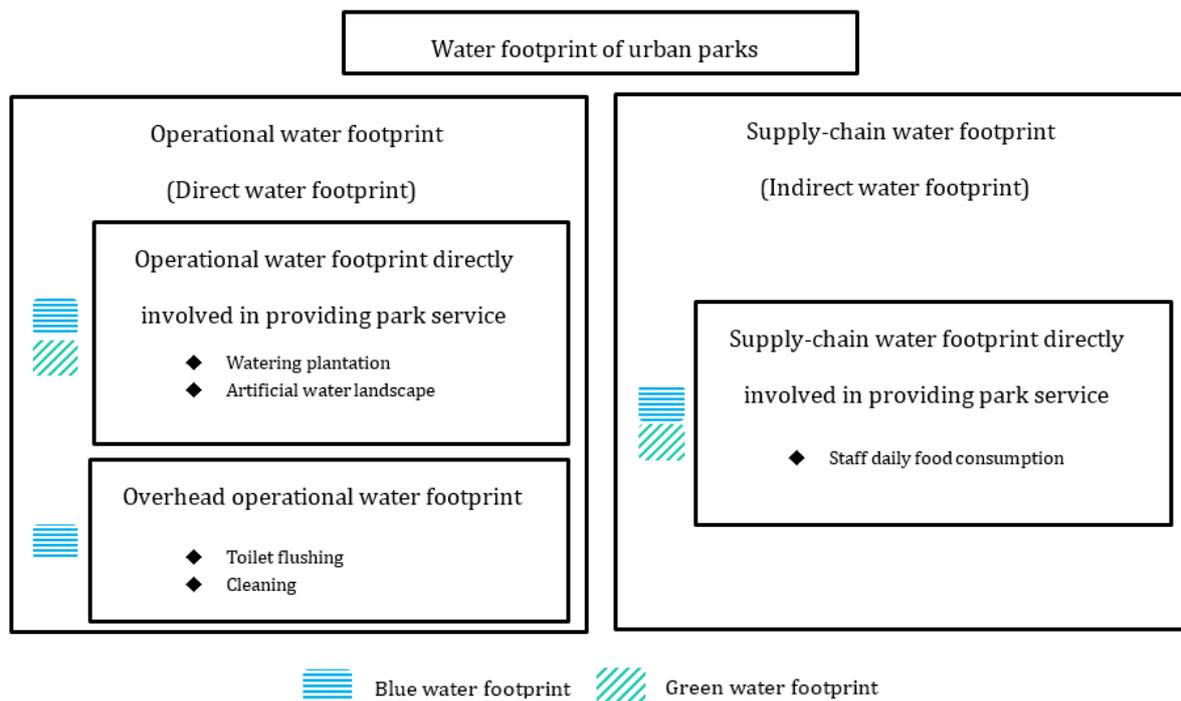


Figure 7 List of main water consumption activities on urban parks (may vary by parks)

This research didn't take grey WF into consideration, only dealing with blue WF and green WF, due to 1) data availability: Calculation of grey WF is a data-intensive work and according to "qualitative investigation on urban park water usage", none of these urban parks regularly monitor or record potential pollutants volume ( e.g. sewage water), which pose difficulties to estimate grey WF; 2) the majority of selected parks (7 parks out of 8 parks in the research sites) never applied fertilizers, pesticides or herbicides within parks, which might become main sources of pollutants discussed in previous literatures(Bulsink, Hoekstra, & Booij, 2010; Liu, Kroeze, Hoekstra, & Gerbens-Leenes, 2012; M M Mekonnen & Hoekstra, 2011; M. M. Mekonnen & Hoekstra, 2010; Yang et al., 2011).These reasons make omitting grey WF estimation in this study acceptable.

### 3. Data collection and analysis

Data needed was collected by multiple methods according to the previously refined conceptual framework. Apart from relevant literature reviews, field surveys, interviews with semi-structure questionnaires and E-mail surveys were used to require water use data and background information of Seoul urban park development from park managers and government officials.

### 3.1. Blue WF from operational water footprint

Blue WF in this research was defined as fresh water (including running water, unprocessed river water, underground water ) directly and indirectly consumed in order to maintain the urban parks' functioning. As shown in previous section, the scope of blue WF calculation in this study will cover 1) operational blue WF directly involved in provision park services, like plantation watering and 2) overhead operational blue WF, such as toilet flushing.

According to surveys, none of selected parks have separate data for various sorts of park management activities, but the total blue water consumption records are accessible regardless of specific use ends. Considering a clear qualitative investigation on urban parks' water usage has been investigated via semi-structure questionnaire illustrated in previous section, certitudes could be guaranteed that absolute majority of blue water consumption of each park was related to maintaining activities demonstrated in Figure 3.

I collected blue water consumption records by multiple methods (see Table). Five consecutive years' records covering blue water consumption from 2009 to 2013 were collected for six out of eight parks, while two years (2012-2013) for Yeouido Park and three years (2011-2013) for Westlake Park. Blue water consumption were recorded after park construction fully completed and park formally opened for public. Average blue water consumption per year was calculated (rounded to the nearest whole number). Slight changes on park landscapes did exist throughout recorded years, but won't pose a considerable impact on calculation of average blue water consumption per year.

Table 4 Blue WF from operational water footprint (direct blue WF) of each park

<b>Park</b>	<b>Data from</b>	<b>Method</b>	<b>Average blue water consumption per year(m<sup>3</sup>)</b>
Seoul Forest	2009-2013	E-mail survey	28,510
Boramae Park	2009-2013	E-mail survey	54,729
Yangjae Citizens' Forest	2009-2013	E-mail survey	17,968
Yeouido Park	2012-2013	Field interview	20,171
Westlake Park	2011-2013	Field interview	18,463
Gildong Ecology Park	2009-2013	E-mail survey	6,156
Eunbong Park	2009-2013	E-mail survey	1,315
Cheonho Park	2009-2013	E-mail survey	3,138

### 3.2. Green WF from operational water footprint

In this study the main plantation creating a green footprint on urban parks are forest and turf. Operational green WF of urban parks are calculated by accumulation of daily evapotranspiration (ET, mm/day) of main plantation over the complete growing period(Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, 2011, p. 41). For permanent plantation, like trees, we need account for the evapotranspiration throughout the year(Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, 2011, p. 42).

Since directly measuring plant evapotranspiration is very costly and unusual, generally, one estimates evapotranspiration indirectly by means of a model that uses data on climate, soil properties and crop characteristics as input. However, as a result of lacking concerned parameters of trees and turf species in existing dataset, the commonly used models for calculating crop green WF doesn't satisfy this study. As a result, this research would use each park's forest area, turf area and evapotranspiration data from related literatures to estimate green WF of plantations in urban parks.

$$GWFp = \frac{Sp \cdot ETp \cdot T}{1000} \quad (1)$$

GWFp: Green Water Footprint of plantation on park (m<sup>3</sup>)

Sp: Plantation area (m<sup>2</sup>)

ETp: Plantation evapotranspiration (mm/d)

T: Growth period per year

### 3.2.1. Area of forest and turf land

Data of green land area of each park is obtained via email survey with each park's manager (Hu, 2014a). None of park management offices has the separate data for forest area and turf. The area of forest and turf was identified via an online forest research tool "i-Tree". i-Tree is a peer-reviewed software suite developed by the USDA Forest Service that provides urban forestry analysis and benefits assessment tools.

With i-Tree Canopy, researchers could review Google Maps aerial photography (taken in November, 2010) at random points to conduct a cover assessment within a defined project area. The accuracy of the analysis depends upon the ability of the user to correctly classify each point into its correct class. Thus the classes that are chosen for analysis must be able to be interpreted from an aerial image. During the process of distinguishing spot' category, I refer to field work photos (in April, 2014), aerial photos from NAVER MAP (taken in March, 2009) and identified around 300 points for each selected parks (Figure 8). As the number of points increase, the precision of the estimate will increase as the standard error of the estimate will decrease. Table 4 shows the result of cover assessment via i-Tree. Area estimation of tree cover and grass cover have been given (rounded to the nearest whole number).

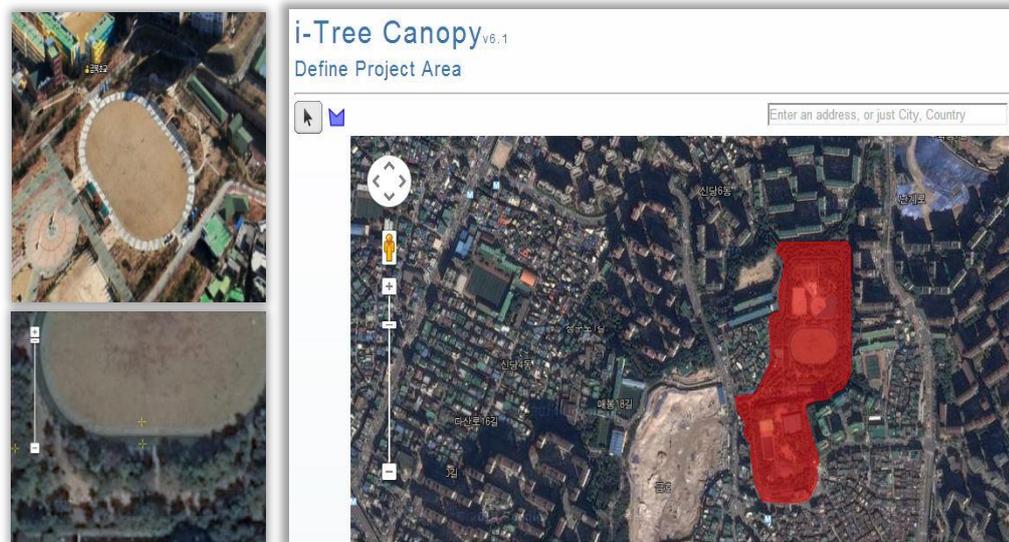


Figure 8 "i-Tree" interface (right), spot distinguishing (bottom left) and NAVER MAP (up left)

Table 5 Area estimation of tree cover and turf cover of each park

Park	Park Area (m <sup>2</sup> )	Tree Cover (%±Se)	Tree Cover Estimation (m <sup>2</sup> )	Grass Cover (%±Se)	Grass Cover Estimation (m <sup>2</sup> )
Seoul Forest	432,394	32.0 ±2.69	138,366	30.0 ±2.65	129,718
Boramae Park	424,106	50.8 ±2.89	216,294	23.7 ±2.46	100,513
Yangjae Citizens' Forest	258,992	71.9 ±2.60	186,215	18.7 ±2.26	48,432
Yeouido Park	229,539	43.6±2.72	100,079	34.1±2.40	78,273
Westlake Park	217,946	59.5 ±2.84	129,024	22.4 ±2.41	48,820
Gildong Ecology Park	80,683	52.5 ±2.89	70,436	25.1 ±2.51	7,019
Eunbong Park	75,570	87.3 ±1.93	39,674	8.70 ±1.63	18,968
Cheonho Park	26,696	76.6 ±2.45	20,449	5.69 ±1.34	1,519

### 3.2.2. Evapotranspiration of trees and its green WF in parks

The evapotranspiration rate of plantation is significantly influenced by local climate condition. Furthermore, selected urban parks have various tree species, and even one tree variety is hardly orderly distributed or clustered (for more details on tree species of selected

urban parks, see appendix). Therefore, a practical way to measure evapotranspiration of kinds of trees in urban parks is to conduct estimation by treating them as natural mix forest nearby with referring to local researches.

This study referred a local study(Physiology lab of department of forest science in SNU, 2014) to make estimation of these trees' evapotranspiration. This local research was conducted in the hills with mix forest surrounding Seoul, which is under a similar climate condition compared with urban forests in Seoul and able to stimulate evapotranspiration context of trees in the parks.

They estimated that the average evapotranspiration rate of natural forests surrounding Seoul is around 320mm per year. According to Equation (1), Table shows the calculation results (rounded to the nearest whole number).

Table 6 Green WF of trees as operational water footprint

Park	Tree Cover Estimation(m <sup>2</sup> )	Green WF Of Trees(m <sup>3</sup> )
Seoul Forest	138,366	44,277
Boramae Park	216,294	69,214
Yangjae Citizens' Forest	186,215	59,589
Yeouido Park	100,079	32,025
Westlake Park	129,024	41,288
Gildong Ecology Park	70,436	22,540
Eunbong Park	39,674	12,696
Cheonho Park	20,449	6,544

### 3.2.3. Evapotranspiration of turf in parks

Out of the same reason, I referred to previous local literatures to estimate turf lands' evapotranspiration volume. The first step is to identify the turf grass species, since turf breed may pose a considerable influence on the evapotranspiration rate(Xin-min Zhang, lin Hu, Xiu-ju Bian, Kun-li Luo, Xin-zhang Sun, 2004). According to the field surveys and expert interviews, selected urban parks mainly plant *Zoysia japonica* (Korean Lawngrass), fractionally mixing with *Zoysia Matrella* (Manila Grass), as turf cover. I will calculate the

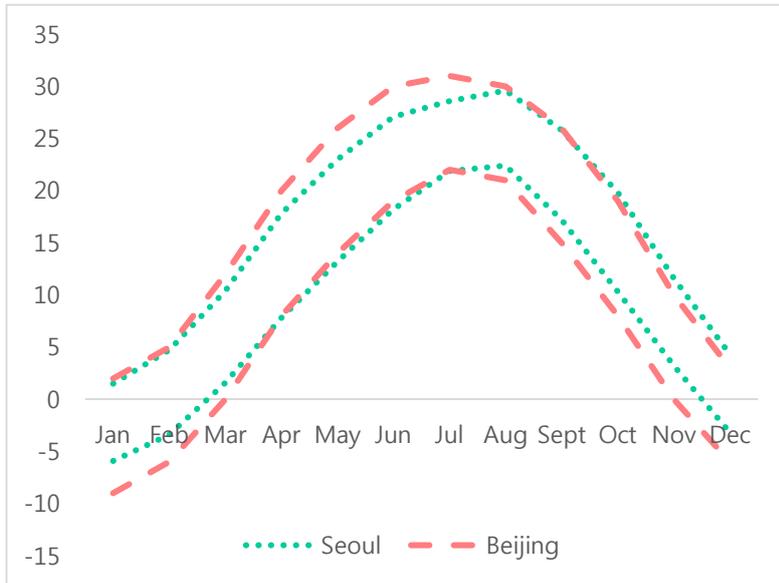
evapotranspiration of urban parks turf grasses based on physiological characteristics of *Zoysia japonica*.

Lacking of local researches studying evapotranspiration rate of such grass species in South Korea yet, I took advantage of a related study in Beijing(Xin-min Zhang, lin Hu, Xiu-ju Bian, Kun-li Luo, Xin-zhang Sun, 2004) to make estimation, since 1) extensive researches on evapotranspiration of *Zoysia japonica* are available and 2) both sites share similarities on key factors affecting grass evatranspiration: temperature, relative humidity and ground wind speed(Shaoyun Lu, 2003). Apart from approximate ground wind speed (average annual value is 2.341 m/s<sup>5</sup> in Seoul and 2.346 m/s<sup>6</sup> in Beijing), obvious similarity in temperature could be observed as well. Relative humidity of Seoul is higher than Beijing throughout the year (see Figure 9 and Figure 10).

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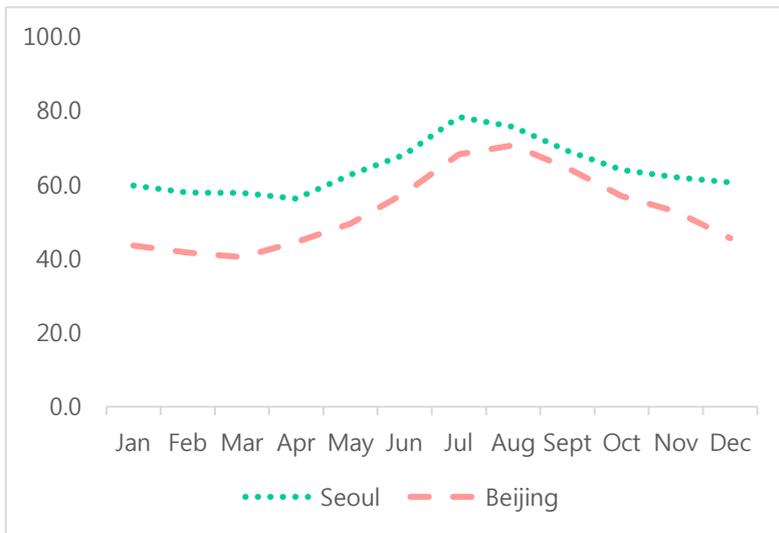
<sup>5</sup> Based on data from 1981 to 2010 of Korea Meterological Administration

<sup>6</sup> Based on data from 1981 to 2010 of *China Statistical Yearbook*



	Seoul °C		Beijing °C	
	max	min	max	min
Jan	1.5	-5.9	2	-9
Feb	4.7	-3.4	5	-6
Mar	10.4	1.6	12	0
Apr	17.8	7.8	20	8
May	23	13.2	26	14
Jun	27.1	18.2	30	19
Jul	28.6	21.9	31	22
Aug	29.6	22.4	30	21
Sept	25.8	17.2	26	15
Oct	19.8	10.3	19	8
Nov	11.6	3.2	10	0
Dec	4.3	-3.2	3	-6

Figure 9 Mean monthly max and min temperature (°C) of Seoul and Beijing. Based on data from 1981 to 2010.



	Seoul (%)	Beijing (%)
Jan	59.8	43.5
Feb	57.9	41.7
Mar	57.8	40.5
Apr	56.2	44.5
May	62.7	49.5
Jun	68.1	57.7
Jul	78.3	68.2
Aug	75.6	70.6
Sept	69.2	64.5
Oct	64	56.9
Nov	62	52.8
Dec	60.6	45.5

Figure 10 Average air humidity (%) of Seoul and Beijing. Based on data from 1981 to 2010

According to their research, under water condition of limited irrigation, evapotranspiration rate of *Zoysua japonica* is around 548mm during growth period (April to November, 224 days in total). As a result, we could estimate the green water consumed by turf grass for each park by Equation. Table 7 shows the calculation results (rounded to the nearest whole number).

Table 7 Green WF of turf lands as operational water footprint

Park	Grass Cover Estimation(m <sup>2</sup> )	Green WF of turf grass (m <sup>3</sup> )
Seoul Forest	129,718	71,086
Boramae Park	100,513	55,081
Yangjae Citizens' Forest	48,432	26,540
Yeouido Park	78,273	42,893
Westlake Park	48,820	26,753
Gildong Ecology Park	7,019	3,847
Eunbong Park	18,968	10,395
Cheonho Park	1,519	832

### 3.3. Blue and green water footprint from Supply-chain

The supply chain (or indirect) WF of an urban park is the volume of freshwater consumed or polluted to provide all the services that form the inputs of the park. Labor input--park managers and other common staffs for daily management and maintenance--is essential to urban parks' normal functioning. Considering data availability, WF consumed by food of working staffs is treated as one of the main sources creating supply-chain WF of urban parks in this research.

#### 3.3.1. Average WF of every lunch

As to estimation the WF of food consumed by staffs, this study only took lunch into consideration since staffs usually take breakfast and dinner out of working place according to local habit. This study referred to a local research on WF of Korean foods using lunch menu data of high schools(N. Kim, Kim, Kim, & Lee, 2013) to calculate for WF of food consumption by staffs for urban park services as indirect WF. The calculation of supply- chain WF will follow equation:

$$WF_{sup} = (IWF_{sup} + DWF_{sup}) \cdot N \cdot T \quad (2)$$

WF<sub>sup</sub>: supply chain WF

IWF<sub>sup</sub>: indirect blue and green WF of each lunch meal per person

DWF<sub>sup</sub>: direct Blue WF of each lunch meal per person

N: the number of working staff      T: work days per year

Local researchers collected lunch menus from three high schools in Gyeonggi province (located in the area surrounding Seoul). Each school possess 20 different circularly used menus that cover the major menus for Korean lunches (for more details, see appendix). Then, researchers summarized ingredients (variety, weight) for each menu according to commonly used recipe books<sup>7</sup> in order to estimate the direct and indirect WF of lunches (only including blue and green WF). They utilize WF dataset of raw materials from both global level (from “Water Footprint Network(WFN, 2011)”) and local WF dataset, such as rice locally produced in South Korea (Chapagain & Hoekstra, 2011).

Researchers replace ingredients to similar ones when needed data is missing due to lacking previous researches. For example, they replace sweet potato with potato, and radish with cabbage. They concluded the WF for each high school students’ common lunch with average WF for 20 menus. All of the procedures they took is aimed at enhancing precision of WF estimation and make it representative to WF of Korean lunches.

The final results from three schools lead to a range of average WF from lowest 558.87 L to highest 1023.89 L per meal (see Table). This diversity could be explained by different “menu status” of three schools: some school tends to add more meat and sea food ingredients

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<sup>7</sup>명품 요리 교과서( 김하진,2010 ); 김진옥 요리가 좋다 (김진옥 2011);한국인이 매일 찾는 매일 레시피. (이보은 2013)

into lunch, which result in big increase in lunch WF compared with some school's menus with more vegetation components.

Table 8 WF of each lunch meal

	Direct WF (m <sup>3</sup> )	Indirect WF (m <sup>3</sup> )	Total WF (m <sup>3</sup> )
A school	0.00035	0.55852	0.55887
B school	0.00032	1.02357	1.02389
C school	0.0003	0.9703	0.97061
Average	0.00032	0.85112	0.8508

\*Only consider blue WF and green WF

### 3.3.2. Working staff number and work days per year

The working staff number of each park was required via email and phone surveys in June, 2004(see Table 9). Basically, there are two categories for staffs working on urban parks: management officials and park workers. Management officials are usually serving at the office in charge of administrative affairs, while park workers are responsible for outdoor activities including cleaning, facilities and plantation maintenance etc. Park works are temporarily hired from May to October every year because less demand for outdoor park maintenance during cold seasons(Hu, 2014b).Management officials work in workdays except national holidays, while park workers would serve throughout the whole working season, generally in two shifts.

Table 9 Working staff number of each park

Park	Management officials	Park workers
Seoul Forest	17	75
Boramae Park	25	50
Yangjae Citizens' Forest	3	14
Yeouido Park	12	22
Westlake Park	5	16
Gildong Ecology Park	4	10
Eunbong Park	3	8
Cheonho Park	2	11

The total work days are counted for two working categories separately according to their work calendars. For management officials, they work for 246 days per year, which has excluded weekends and national holidays; as to a typical park worker, he generally works 92 days per year under the work arrangement of two shifts.

Then we could estimate the annual supply-chain WF (both blue and green) of selected urban parks, according to Equation 2. Table 10 shows the estimation of annual supply-chain WF of selected urban parks (rounded to the nearest whole number):

Table 10 Annual supply-chain (indirect WF) WF of selected urban parks

Park	Supply-chain WF (m <sup>3</sup> )
Seoul Forest	9,429
Boramae Park	9,146
Yangjae Citizens' Forest	1,724
Yeouido Park	4,234
Westlake Park	2,299
Gildong Ecology Park	1,620
Eunbong Park	1,254
Cheonho Park	1,280

### 3.4. Rainwater collection as an approach of WF reduction

As mentioned in the introduction sector, manifestation of WF of selected parks is the first step to the goal of this research. Furthermore, this study would like to reveal the potential of local WF reduction by putting rainwater collection into practice. I suggest utilizing the roof area of buildings within urban parks as tool for rainwater harvesting and use rainwater to

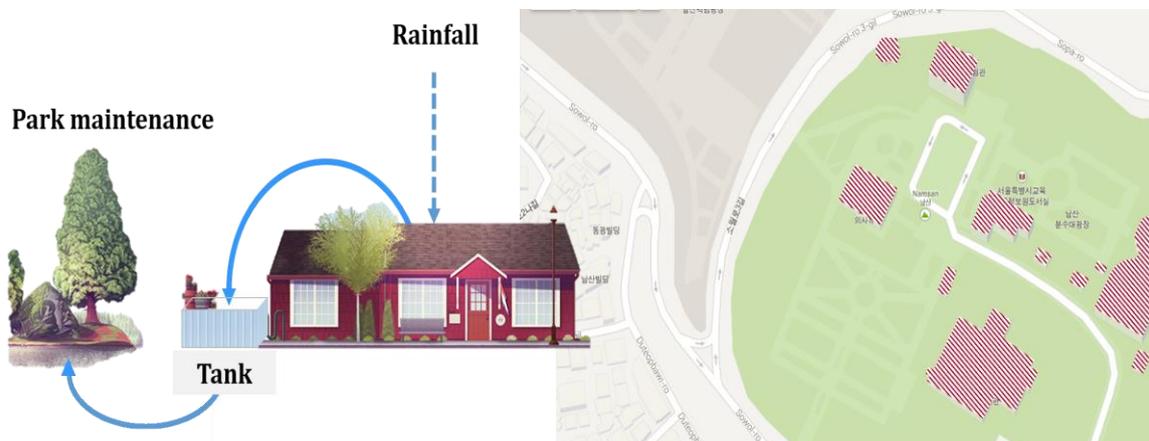


Figure 11 Rainwater collection as an approach of WF reduction

partially replace the operational blue water consumed for park use (see Figure7). In this section, brief background of rainwater harvesting would be discussed and estimation of potential of rainwater harvesting will be given based on parameters of existing rainwater collection systems in Seoul.

Rainwater collection or rainwater harvesting (RWH) is treated as one of the most feasible solutions tackling with water shortages, not only confining in water scarce regions but to areas encountering pressure of stable water supply due to rising water demand, rapid urbanization and climate change(Mun & Han, 2012). Increasing awareness of value of rainwater collection could be observed in a global scale(Hatt, Deletic, & Fletcher, 2006; Pandey, Gupta, & Anderson, 2003; Rygaard, Binning, & Albrechtsen, 2011; Zhang, Chen, Chen, & Ashbolt, 2009). Collecting rainwater is also approved to have benefits of alleviating water-related calamities, such as urban flood, and of restoring water cycle in urban areas(Kravčik, 2008; Mun & Han, 2012).

Discussions on the specific engineering designs and technical parameters is beyond scope of this paper, we make three main assumptions on rainwater harvesting systems that could be leveraged in urban parks:

$H_1$ : the rooftop surface could be a perfect rainwater catchment area without any loss or retention<sup>8</sup>

$H_2$ : water tank design could satisfy the need for rainwater storage

$H_3$ : the size of roof area could be represented by the size of projected area of building

Then, the estimation of annual amount of rainwater that could be used is able to be calculated according to following equation:

$$PV = \frac{S_{\text{roof}} \cdot P}{1000} \quad (3)$$

PV: the annual amount of rainwater that could be potentially utilized (m<sup>3</sup>)

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<sup>8</sup> According to calculation previous literature, there was a small difference of about 0.05%–0.2% in the total volume of real measured and estimated runoff(Y. Kim, Han, Kim, & Mun, 2007)

Sroof: the size of roof as catchment area (m<sup>2</sup>)

P: annual precipitation (mm)

Data of size of total roof area for each park have been collected from park managers or related government officials via email survey. The average annual precipitation in Seoul is 1450.5mm(“Statistics on Seoul climate,” 2014). According to Equation (3), the estimation is shown in Table 11(rounded to the nearest whole number):

Table 11 Potential utilization of rainwater

Park	Roof catchment area (m <sup>2</sup> )	Potential utilization of rainwater (m <sup>3</sup> )
Seoul Forest	5,291	7,675
Boramae Park	14,284	20,719
Yangjae Citizens' Forest	4,652	6,748
Yeouido Park	1,473	2,137
Westlake Park	1,187	1,722
Gildong Ecology Park	687	996
Eunbong Park	300	435
Cheonho Park	486	705

Actually, collected rainwater from roof area could be even potable with simple and cost-effective design(Lancaster, 2008). Therefore, assuming that collected rainwater could thoroughly work as blue water is reasonable.

Furthermore, a comparison between the direct blue WF and the amount of rainwater that could be used for each park may provide us with straightforward insights of the potential of rainwater harvesting activities. “Direct blue WF saving potential” is thus defined as the ratio of potential rainwater collection volume to corresponding direct blue WF, as an indicator to each park’s water saving potential under rainwater collection. Table 12 shows this indicator of each park.

$$BWF_{saving} = \frac{V_{rain}}{BWF_{direct}} \cdot 100\% \quad (4)$$

BWF<sub>saving</sub> : direct blue WF saving potential

V<sub>rain</sub> : potential rainwater collection volume

BWF<sub>direct</sub> : direct blue WF

Table 12 Direct blue WF saving potential

Park	Direct blue WF (m <sup>3</sup> )	Potential rainwater collection volume (m <sup>3</sup> )	Direct blue WF saving potential by rainwater harvesting
Seoul Forest	28,510	7,675	27%
Boramae Park	54,729	20,719	38%
Yangjae Citizens' Forest	17,968	6,748	38%
Yeouido Park	20,171	2,137	11%
Westlake Park	18,463	1,722	9%
Gildong Ecology Park	6,156	996	16%
Eunbong Park	1,315	435	33%
Cheonho Park	3,138	705	22%

#### 4. Result

Integrating the estimation shown above, a comprehensive WF analysis (including direct blue WF, direct green WF, indirect WF, potential rainwater collection volume and direct blue WF saving potential) is demonstrated in Table 13 (results are approximation to bits).

Table 13 WF analysis on urban parks in Seoul

Park	Direct blue WF (m <sup>3</sup> )	Direct green WF (m <sup>3</sup> )	Indirect WF (m <sup>3</sup> )	WF per m <sup>2</sup> (L)	Direct blue WF saving potential by rainwater harvesting
Seoul Forest	28,510	115,363	9,429	355	27%
Boramae Park	54,729	124,295	9,146	444	38%
Yangjae Citizens' Forest	17,968	86,129	1,724	409	38%
Yeouido Park	20,171	74,919	4,234	433	11%
Westlake Park	18,463	68,041	2,299	407	9%
Gildong Ecology Park	6,156	26,386	1,620	423	16%
Eunbong Park	1,315	23,090	1,254	340	33%

Cheonho Park	3,138	7,376	1,280	442	22%
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Figure 12 further visualize the results in order to give straightforward interpretation. At the top of Figure 12, the size of circle represents park area, while tree cover and turf cover are given as percentage separately; direct WF is demonstrated not as a whole due to that direct green WF of plantations (the rainwater consumed by trees and grassland, in this case) is usually disproportionately higher than direct blue WF; direct blue WF saving potential has been shown as percentage above each park. Several results deserve emphasis.

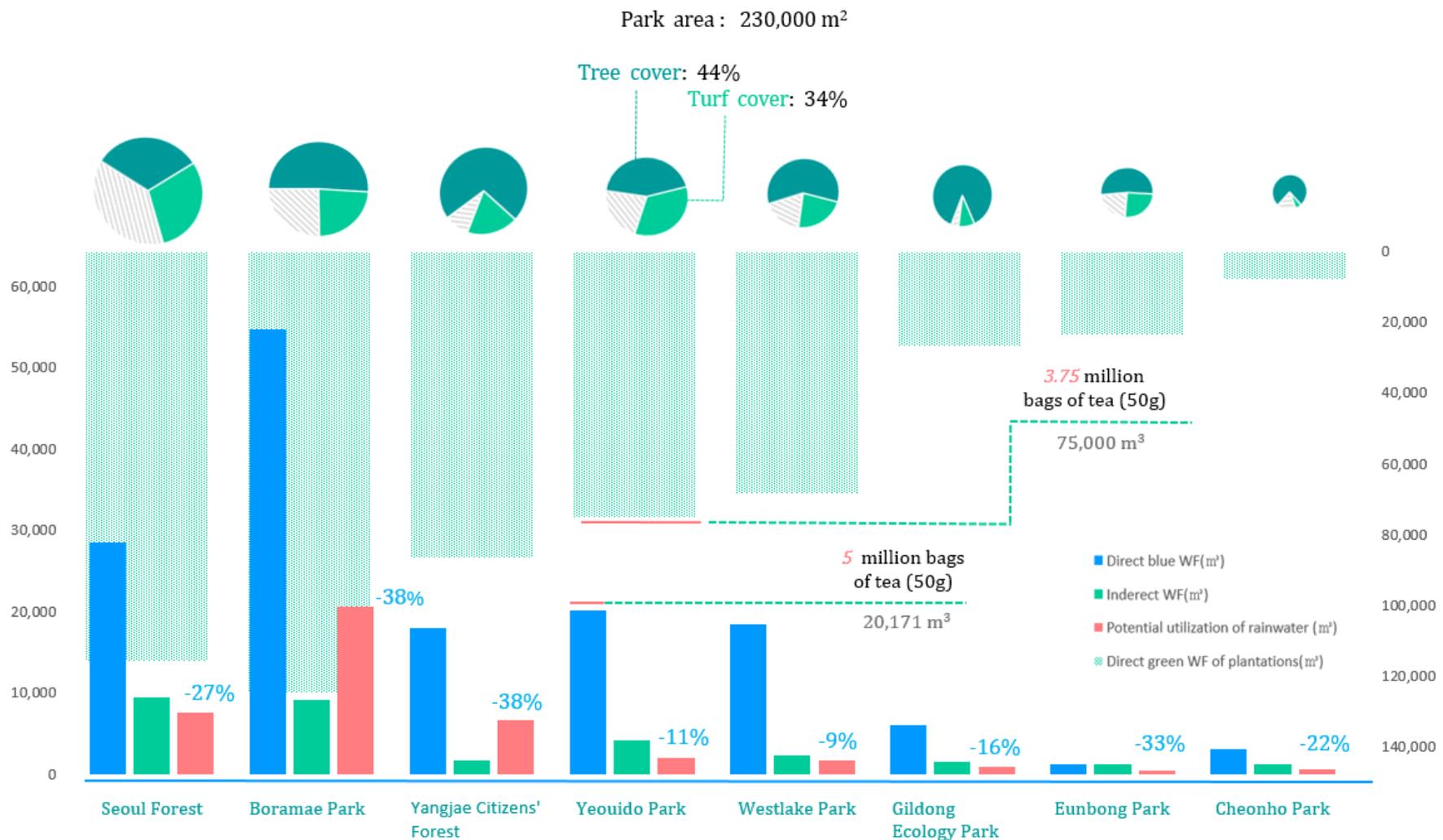


Figure 12 WF of selected urban parks in Seoul

#### *4.1. Considerable water consumption of urban parks*

As summarized in Table 13, from the case study of eight parks in this research, the consumption of direct blue WF per year ranges from 1,315 m<sup>3</sup> to 54,729 m<sup>3</sup>. To be more specific, the Boramae Park occupied the most direct blue WF among eight parks (54,729 m<sup>3</sup> per year), followed by Seoul Forest Park (28,510 m<sup>3</sup>), Yeouido Park (20,171 m<sup>3</sup>), Westlake Park (18,463 m<sup>3</sup>), Yangjae Citizens' Forest (17,968 m<sup>3</sup>), Gildong Ecology Park (6,156 m<sup>3</sup>), Cheonho Park (3,138 m<sup>3</sup>) and Eunbong Park (1,315 m<sup>3</sup>).

As to the consumption of direct green WF per year, the Boramae Park also uses the most annual direct green WF as well (124,295 m<sup>3</sup>), followed by Seoul Forest Park (115,363m<sup>3</sup>), Yangjae Citizens' Forest (86,129 m<sup>3</sup>), Yeouido Park (74,919 m<sup>3</sup>), Westlake Park (68,041m<sup>3</sup>), Gildong Ecology Park (26,386m<sup>3</sup>), Eunbong Park (23,090 m<sup>3</sup>) and ), Cheonho Park (7,376 m<sup>3</sup>).

When it comes to the indirect WF of eight parks, Seoul Forest Park consumes the most annual indirect WF (9,429 m<sup>3</sup>), followed by Yangjae Citizens' Forest (9,146 m<sup>3</sup>), Yeouido Park (4,234 m<sup>3</sup>), Westlake Park (2,299 m<sup>3</sup>), Gildong Ecology Park (1,620 m<sup>3</sup>), Cheonho Park (1,280 m<sup>3</sup>) and Eunbong Park (1,254 m<sup>3</sup>).

In order to provide an intuitive interpretation towards the amount of WF consumed by urban parks, two references on tea product (grown in India and produced in UK)<sup>9</sup> were presented in Figure 12. For example, Yeouido Park will consume green water around 75, 000 m<sup>3</sup> per year. This amount of green water is the green water consumption for producing 3.75 million bags of tea; the direct blue WF consumed by Yeouido Park in one year is about 20,000 m<sup>3</sup>, which could be used as blue WF for producing 5 million bags of tea.

Obviously, an urban park inclines to use significant amount of water resource for providing its services for public in a holistic perspective.

#### *4.2. Significant variation of WF in different parks*

Obviously, variations in WF of each urban parks could be observed. According to the Table 13, from an average point of view, the top three parks that occupy the most WF per unit

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<sup>9</sup> That study (Jefferies et al., 2012) estimated that, in order to produce one bag of tea (50g), it will create around 20L of green WF and 4L of blue WF throughout the whole supply chain.

is Boramae Park (444 L/ m<sup>2</sup>), followed by Cheonho Park(442 L/ m<sup>2</sup>), Yeouido Park(433 L/ m<sup>2</sup>), Gildong Ecology Park(423 L/ m<sup>2</sup>), Yangjae Citizens' Forest(409 L/ m<sup>2</sup>), Westlake Park (407 L/ m<sup>2</sup>), Seoul Forest Park (355 L/ m<sup>2</sup>) and Eunbong Park (340 L/ m<sup>2</sup>).

Although it offered a straightforward sense of WF difference among parks, we should be alert to interpret the WF in such a general way. Because different parks have their own unique combination of characteristics that may pose significant on WF. And this is the fundamental reason why each type of WF, generally speaking, is strong correlated with park size but the variance still exist. For example, although the Boramae Park has the second biggest size among research sites, it consumes far more direct blue WF than the biggest park in this study, Seoul Forest Park.

To be more specific, several factors may cause such a difference, such as the size of the park, working staff number, existence of waterscape and park type.

- *Park size.* Obviously, the bigger the urban park, the more WF it tend to consume. Because the land use for trees and turf will multiple with area increase in park area.
- *Working staff number.* On one hand, working staffs number will have direct impact on indirect WF of each park by daily food consumption. On the other hand, the number of working staffs is a convincing indicator for park area and the scale of park facilities (such as water landscape facility) that may lead WF rising. For example, Seoul Forest, a forest park with many touristic facility like zoos and kinds of exhibition venues, hired considerable staffs for normal functioning.
- *Existence of artificial springs or fountains* in a large scale. In the selected parks of this study, all urban parks more or less possess water landscape facility except Eunbong Park. However, the salient direct blue WF of Boramae Park and Westlake Park could be further explained as a result of large scale fountain facility. For instance, there are “Sound Fountain” with 41 nozzles, “Media Wall Fountain”, artificial streamlets and other water landscape facility built in Westlake Park.
- *Park type.* Park planning, especially the design on park function, determines the building quantity within parks, which poses an influence on volume of potential rainwater collection. Comprehensive urban parks, with multiple park facilities, tend to

require more buildings to be constructed, such as Seoul Forest, Boramae Park, and Yangjae Citizens' Forest. Whereas parks with sole function, like Gildong Ecology Park, Eunbong Park and Cheonho Park, usually have isolated office building.

#### *4.3. Considerable potential from rainwater collection*

In addition, rainwater is free and would be wasted by evaporation unless it could be leveraged in producing food, timber or bioenergy. Therefore, increasing the productivity and efficiency of green water could be effective to reduce the needs for blue water.

By utilizing roofs of existing building facilities on parks as catchment area, the volume of rainwater we could exploit is quite significant. From results of this study, the collected rainwater is able to substitute around 9%-38% direct blue WF of each park, which could substantially contribute to water conservation. Put in the other way, in some urban parks with abundant building facilities, the collected rainwater could even reduce more than one-third of direct blue WF. In practically application, collected rainwater from building roofs could be used to replacing direct blue WF, with simple additional designs, therefore, rainwater collection activities obviously possess considerable potential for reducing blue WF of urban parks and will promote urban sustainable development. Economic concerns about the applicability of rainwater harvesting is going to be discussed in following section.

## 5. Discussion

### 5.1. Data management in this study

Although WF analysis is very meaningful to local policy-makers to manage water resource, but it requires massive data input that bring certain issues related to data accuracy, data availability, data limitation and so on.

#### 5.1.1. Accuracy

All the data used in this study come from authoritative sectors of municipal government and the most concerned literatures. In addition, the data processing tends to utilize the source that produce the most conservative WF estimation. This research attempts to use homogeneous data sources when dealing with certain type of WF, but discrepancies among data sources did exist. For example, the calculation of the indirect WF involves multiple food

WF studies that may cause difficulties to precise estimation of the WF consumed by lunch meals.

#### 5.1.2. Availability

Data gaps can be anticipated. For instance, data on evapotranspiration rates of specific tree species and its precise canopy area at certain park are virtually non-existent. This study therefore used local study on evapotranspiration rate of mixed forests surrounding Seoul to estimate corresponding green WF. Similar methods was taken in calculation green WF of turfs. A general principle used in this study when searching for subsidiary data is to refer the most authoritative sources and the researches that shared the most similarity with this study in term of geological concern .

#### 5.1.3. Limitations

This research leads a minimum estimation of WF of urban parks. For example, I did not take the grey water into consideration due to data availability. For the same reason, green WF consumed other than turfs and tress and indirect WF of infrastructure-building and energy consumption were not involved in this research as well.

### 5.2. Green assets or green burden

As mentioned above, urban parks in Seoul tend to use massive fresh water resource in order to maintain its functioning, and this may pose significant impact to other social sectors and natural system. Fresh water resource utilized in one use end can't be used for other use purposes within certain period of time. It is true for blue water--the water resource consumed for watering turf lands might not be used for producing other industry products—and true for green water as well. Although rainwater is free, it is not limitless. As a matter of fact, rainwater, just like blue water, is a rare resource particularly in certain regions and certain period of a year. If certain quantity of rainwater has been used by human use, there will be less for natural system. Therefore, the more water resource possess by urban greening projects, like urban parks, the less water could be utilized by other sectors.

In addition, if we put the climate change, rapid urbanization, ongoing urban greening process into consideration, we have fair reason to concern the increasing water stress on local environment. For all these reasons, this study argues that urban parks might be “green burden”

instead of purely “green assets” to cities, particularly considering the huge potential for local WF reduction by utilizing rainwater harvesting.

### 5.3. WF reduction of parks for urban sustainable development

Above of all, it needs to be pointed out that this study didn't estimate any “mean” WF for selected research sites for conducting a horizontal comparison between parks due to several concerns. 1) Since different urban park has unique characteristics in park type, size, green cover rate and facilities, a farfetched comparison would not showcase meaningful conclusions. 2) Furthermore, one prime purpose of WF analysis on a business (in the case of this study, the urban parks) is to help business fully realize and fulfill their own social responsibility. If any comparisons needed, it is a self-comparing between the status quo and the future state with a more efficient water management. With the assistance of WF analysis similar to this research, individual institution may have the chance to comprehend the quantity of water resource it utilized and realize the possibilities of potential improvement.

From a perspective of sustainable development, this investigation maintains that the water resource is so enormous that urban parks have to take efforts in order to diminish their WF. First of all, under the background of climate change and rapid urbanization, possible urban water conflicts deserved avoided. Emerging academic interests and civil movements such as “biophilic city”(Beatley, 2011; Kellert, Heerwagen, & Mador, 2011), “green urbanism”(Beatley & Newman, 2008; Beatley, 1999; Lehmann, 2011), “urban agriculture” (Smit & Nasr, 1992; Smit, Ratta, & Nasr, 1996; Viljoen, Bohn, & Howe, 2005) etc., have gained forward momentum these years, with a clear encouragement for urban greening. Although these trends of thought are breezing fresh reflection into urban designing, which is desperately wanted without any doubts, it will court misgivings on their sustainability claim due to that ignorance on water consumption accompanying with urban greening might cause water struggle in urban area.

Secondly, as this study claimed before, it is out of social responsibility for sustainability that corporations need to reduce their total WF as much as possible. When it comes to urban parks, it is particularly true. Just as Chiesura ( 2004) summarized, urban parks is the link between urban life and nature, which becomes symbol of peacefulness, natural beauty and freedom. Urban parks not only provide relaxation to citizens, but also recall the feeling of nature itself and cycle of nature. It becomes ironic now that the urban parks, with

appealing natural appearances, are in fact gobbling up natural resource in massive way. Thus, methods of neutralizing the environmental impact of urban parks should be taken into consideration.

Thirdly, in order to achieve a robust operation of urban parks, we are supposed to limit urban park WF with efforts. A clear comprehension of WF may prepare urban parks in advance with underlying risks of water shortage from operations. Park managers need to consider the potential consequences caused by serious water scarcity under climate change context, since the rainfall pattern tends to be more unpredictable due to climate change (Marvel & Bonfils, 2013; IPCC, 2007). WF analysis like this research will definitely support park managers to outline possible tackling scenarios to deal with unexpected water-related problems.

Furthermore, it will benefit a more sustainable global economy if less WF consumed by, but not limited to, urban parks. Increasing globalization requires natural resource to be allocated efficiently in a global scale, so the improvement on efficiency of water utilization, even in water affluent regions, could relieve water stress of producing certain goods in water scarcity regions. In addition, the water resource saved from urban parks could be utilized for other producing purpose, since blue WF and green WF occupied by one use is not able to be exploited for other purposes. For example, the WF created by water-intensive activities or luxury products like “fountain”, meat production leads to a global implication that less water remains for producing cereal food or other goods fulfilling basic demand.

#### 5.4. Rainwater collection could be an economical approach for WF reduction

Will rainwater collection facilities increase total operational cost of urban parks? Is the monetary benefit of rainwater harvesting worth its investment cost? To conduct a cost-effective analysis of a policy, a meaningful price foundation is required, which could reflect the value of the object in a realistic way. However, the majority of water concerned infrastructures (e.g. dams, canals, pipelines, and waste water processing) are invested and subsidized by governments, and the cost is usually not burdened by water users, which means the water price is so distorted that could not offer appropriate incentive for water conservation. Therefore, cost-effective analysis based on current water price might not reflect the value of rainwater collection activities.

In fact, water price is shooting up, extensively revealing the water scarcity. For instance, according to surveys of Circle of Blue(Walton, 2014), within last 5 years, major cities of US have experienced water price escalation. Cities like Chicago, San Francisco, Charlotte and Austin, water charges expand more than 50 %. Since the beginning of 2014, the average water price across US has increased 6.2%; average share value of American water supply companies has been increased 33%. The same stories are happening in China(“China and water: Drying up,” 2005), Malaysia(Lian, 2014),and Middle East areas(“ISRAEL:Increased water prices to hit most vulnerable,” 2009). Under such a circumstance, rainwater collection is thoroughly an acceptable and feasible way to deal with water shortage.

#### 5.5. Policy recommendation for urban parks WF reduction

Finally, as a response to the attempt of reducing WF of urban parks, this research outlined several policy recommendations below:

- Better designs on flora landscape

Apart from encouraging to cultivate more indigenous vegetation species, since indigenous flora has a more adaptive capacity to local precipitation and the environmental parameters(Walther et al., 2002), vegetation landscape design in urban parks should be mainly based on compound vegetation structure in order to achieve more biomass and eco-services rather than large area of lawns: previous research demonstrated that, under common physical conditions, flora with arbor-shrub-herb structure could gain ecological effect(shading effect, micro-climate modulation, carbon sequestration, ) far more than well managed sole lawn land(Zhu, Li, & Chai, 2002).

- Encouraging to utilize rainwater

Taking fully use of local water resource—rainwater, instead of occupying blue water elsewhere, is not only efficiently utilizing existing park facility (e.g. building roofs) but also a feasible way to tackle with water conservation(see more details in previous section). Besides roof rainwater harvesting, other park designs may facilitate the utilization of rainwater resource. Designs such as slightly silt streets, sunken style

(concave land surface) of gardens and lawns, and water penetrable land bricks, would take advantage of gravity to retain rain and replenish underground water.

- Limiting development of water-intensive park facilities

Efforts need to be made in order to limit the development of large scale of waterscape facilities, especially fountains, springs. Try to use recycled water for waterscape use. Waterscape facilities would be best to be located near natural water body and take advantage of local topography. Moreover, waterscape needs to control surface area to reduce water evaporation.

- Improving irrigation efficiency

Pipes delivering water need regularly checked and updated, since deteriorated pipe lines tend to cause water leakage posing threat to water waste. In addition, the fact that few parks investigated in this study have applied spray irrigation system for plantation watering<sup>10</sup>, leaves more water conservation infrastructures to be desired. Because surface irrigation via water hose, which is the main watering method taken by selected parks, will inevitably cause water waste due to dispensable water evaporation.

- Refining water consumption record

Elaborate water consumption data provides solid foundation for WF analysis. Minute record information, especially including information about water use end is important for prescribing water conservation strategies. Separate water meters are recommended to collect water consumption for different water use.

It is absolutely correct that building more sustainable urban parks is an evolution, not revolution: the transformation from rough exploitation on water resources to smart management could be actualized through myriad small enhancement, like practical policy recommendations given above, rather than great leaps forward.

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<sup>10</sup> Within 8 parks investigated by this study, only Westlake Park has installed small scale of spray irrigation and rainwater collection system as a pilot.

## 6. Conclusion:

In order to enhance living quality in cities and actualize urban sustainable development, constructing urban parks as a prime form of urban greening is gaining forward momentum, especially in metropolises in rich world. However, the fresh water resource consumption, which has a determined impact on urban development, of urban parks has never been thoroughly investigated under the context of climate change and rapid urbanization yet.

One of the objectives of this research is to demonstrate the use of a water footprint (WF) analysis framework to separately estimate annual average water consumption of 8 urban parks located in Seoul. Building on Hoekstra, A. Y. et al. (2011), this study has revealed, from a holistic view, that urban parks are indeed overlooked as a salient sector of water consumption in urban area, which deserves more attention upon under the era of climate change and rapid urbanization.

Underlying reasons for such a huge amount of water consumption have been identified as well. In this research, 1) the plantations (trees and turfs) on urban parks will consume the most water resource in term of both green and blue water; 2) the artificial waterscape facilities (fountains, for instance) would use a large amount of blue water as well; 3) routine maintaining activities, like cleaning activities and toilet flushing, would consume blue water; 4) the working staff, who are important to the normal functioning of urban parks, would take advantages of considerate water resource too. Although not included by this study, other factors are playing roles in consuming water resource in parks from a theoretical water footprint analysis perspective, such as the water resource needed for pollution dilution (grey water) and the water resources consumed within the process of park construction.

After discussion of the necessity of reducing WF of urban parks, several policy recommendations were outlined to improve the water conservation within urban parks for local government planners and policy analysts. Among these possible options for enhancing water use efficiency, rainwater harvesting as a method to reduce blue WF consumption was

quantitatively analyzed in detail, which demonstrated that utilizing rainwater resource could substantially decrease blue water consumption.

By using existing urban landscape, such as building facility, as a tool of water resource “supplier” rather than a “consumer” is an innovative mindset to urban development, which has particular implication to the increasing power of mankind in the environment. After the observation that “Urbanization has increased 13 times in the past century... Similarly large were the increases in several other factors, such as the world economy and energy use... More than half of all accessible fresh water is used by mankind”(Crutzen, 2002), the Nobel Prize-winning atmospheric chemist, Paul Crutzen, called this era of extensive expansion of human footprint and influence on the Earth as “the Anthropocene”, which emphasized that the magnitude of human impact has climbed to a geological level and the central role of mankind in ecology—who may even anticipate that urban green assets like parks could become “green burden”? Nevertheless, this unprecedented human intervention could serve for social sustainable development, given appropriate alteration on thinking pattern.

As far as we are aware, this study is the utmost brand-new trial to investigate the water consumption situation of urban parks with WF analysis to date. Further exploration could be made in incorporating grey WF into consideration with appropriate methods to collect data on water pollution.

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## APPENDIX

Table 14 Main tree species in each park

Park	Main tree species
Seoul Forest	Oak, Pine , Zelkova
Boramae Park	Plane tree, Pine Zelkova
Yangjae Citizens' Forest	Maple, Nut pine, Zelkova
Yeouido Park	Pine, White pine, Zelkova
Westlake Park	Birch, Tassel tree, White pine
Gildong Ecology Park	Oak, Elm, Snowbell tree
Eunbong Park	White Pine, 메타, Zelkova
Cheonho Park	Elm, Pine, Zelkova

Table 15 WF of selected food and product\*

Butter	5553 litre/kg	Mango	1800 litre/kg	Sugar (from sugar cane)	1782 litre/kg
Cabbage	237 litre/kg	Milk	255 litre for a glass of 250 ml	Tea	27 litre for a 250ml cup of tea
Chicken Meat	4325 litre/kg	Olives	3015 litre/kg	Tomato	214 litre/kg
Chocolate	17196 litre/kg	Orange	560 litre/kg	Apple	822 litre/kg
Coffee	132 litre per cup(125 ml)	Peach	910 litre/kg	Beef	15415 litre/kg
Eggs	196 litre for a 60-gram egg	Pork	5988 litre/kg	Beer (from barley)	74 litre for a glass of 250 ml
Leather (bovine)	17093 litre/kg	Potato	287 litre/kg	rose	Litter/Stem (25 Gram)
Maize	1222 litre/kg	Rice	2497 litre/kg	cola	168.4 litre/bottle(500ml)

\*Cited from “Product water footprint”(http://www.waterfootprint.org/?page=files/productgallery). All the data are collected in published journal and summarized by Water footprint Network.

\*\* This is a global average value and the precise water footprint of each product depends on the origin of the component, on where and how it was produced.

Table 16 Examples of lunch menus and corresponding WF from three high schools in Gyeonggi province (N. Kim et al., 2013)

School	Ingredients (weight : g)	Blue and green of WF(litter)
A	<p>Steamed rice; bean sprout soup; grilled squid; cured fish; marinated turnip.                      With other ingredients: adlay, spring onion, carrot, onion, Perilla powder                      울무밥(울무 15, 백미 90), 콩나물국(콩나물 30, 파 5)                      오징어볶음(오징어 150, 당근 10, 양배추 30, 양파 20)                      쥐어채볶음(쥐치 25), 들깨무나물(들깨가루 2, 무 40)</p>	174.08
	<p>Steamed rice; seaweed soup with beef; stir-fried chicken; marinated mushroom and cucumber; cabbage kimchi                      With other ingredients: carrot, onion, sweet potato                      흑미밥(흑미 15, 백미 90) 쇠고기미역국(쇠고기 25, 미역 4)                      닭갈비(닭고기 150, 양파 10, 당근 6) 버섯볶음(버섯 30, 양파 15, 당근 5, 고구마 20) 오이생채(40), 배추김치(30)</p>	1,154.78
B	<p>Shrimp Fried Rice; mini Banquet Noodles; Corn Dog Sandwich; marinated cabbage: fresh tomato                      With other ingredients: spring onion, carrot, onion, Perilla powder, pork; lettuce                      새우볶음밥(새우 30, 양파 20, 당근 10, 파 5) 미니잔치국수(면 40, 파 5, 당근 10, 멸치 2) 핫도그샌드위치(빵 50, 양상추 10, 돼지햄 60)                      배추겉절이(30), 방울토마토 (60)</p>	431.20
	<p>Omelet Rice; sea mustard soup; skewered rice-cake; marinade; cabbage kimchi; Pigs' Feet                      With other ingredients: spring onion; carrot; onion; pork; seaweed; cucumber                      오므라이스(달걀 80, 당근 10, 양파 10, 파 5, 돼지햄 20) 미역국(미역 4, 소고기 25) 방울떡꼬치+양념장(떡 60), 배추김치(30) 족발냉채(돼지 150, 양파 20, 당근 10, 오이 10)</p>	1,692.27
C	<p>Steamed rice; Sausage Stew; marinated cured squid; deep-fried vegetables; Grilled Seaweed; turnip kimchi                      With other ingredients: spring onion; carrot; onion; pork; seaweed; cucumber; starch syrup; adlay                      기장밥(기장 7, 백미 90) 부대찌개(돼지햄 40, 양파 10, 당근 10, 무 5, 파 5) 오징어채볶음(오징어채 30, 간장 5, 물엿 7) 야채튀김(야채 30, 콩기름 5), 김구이(김 4), 깍두기(30) 울무밥(울무 7,)</p>	352.07
	<p>Brown rice; sliced rice cake and dumpling soup; marinated cucumber and squash; grilled rib; cabbage kimchi                      With other ingredients: spring onion; carrot; onion; cucumber; adlay; red pepper                      현미찰쌀밥(현미 6, 찰쌀 10, 백미 90) 떡만둣국(떡 30, 만두 30, 달걀 20, 파 5) 오이지무침(오이 30, 고춧가루 10) 떡갈비스테이크(갈비 150, 떡 30) 호박새우젓볶음(호박 70, 파 5, 새우젓 2), 배추김치(30)</p>	2,841.15