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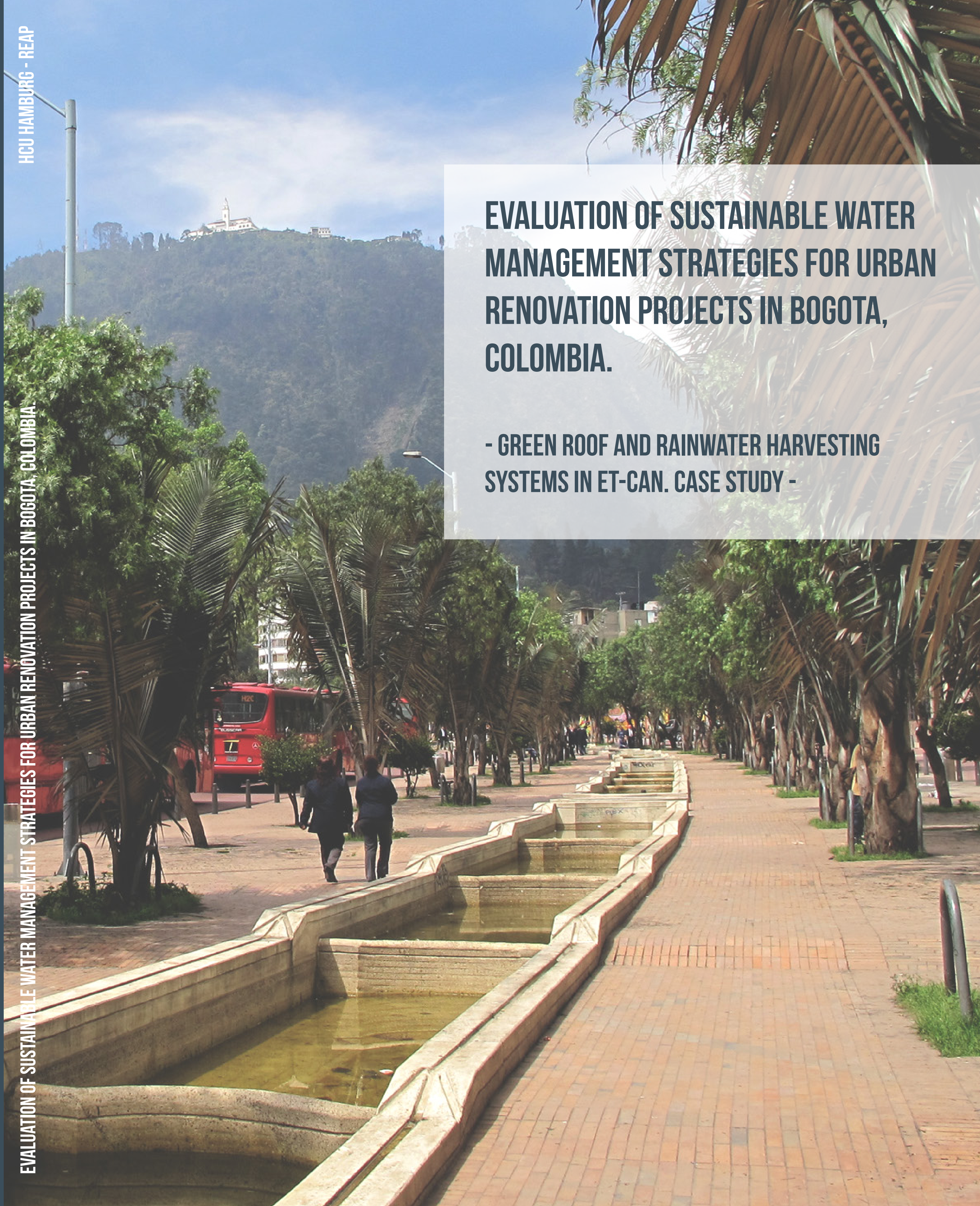
Master Thesis

July 2016

HCU HAMBURG - REAP

EVALUATION OF SUSTAINABLE WATER MANAGEMENT STRATEGIES FOR URBAN RENOVATION PROJECTS IN BOGOTA, COLOMBIA



EVALUATION OF SUSTAINABLE WATER MANAGEMENT STRATEGIES FOR URBAN RENOVATION PROJECTS IN BOGOTA, COLOMBIA.

- GREEN ROOF AND RAINWATER HARVESTING SYSTEMS IN ET-CAN. CASE STUDY -

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Under Supervision of: Prof. Dr.-Ing. Wolfgang Dickhaut
Second advisor: Dr.-Ing. Anke Jurleit

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ABSTRACT

Resembling several cities in developing countries, intense rural-urban migration starting in the 1950's led to an extremely rapid urban development in Bogota, the capital city of Colombia. Together with a poor urban water management, this has resulted in the worsening of water quality; channelization and interring of rivers; destruction of wetlands; and the growth of low-income neighborhoods on river floodplains.

Water Sensitive Urban Design (WSUD) is defined as a design approach which integrates local natural hydrological cycles into urban planning and development projects. Private surfaces constitute a large share of Bogota's land, making it necessary to include WSUD practices in private developments.

This thesis, using the ET-CAN development project as case study, realizes a quantitative and qualitative assessment of the performance of two WSUD strategies: Green Roof and Rainwater Harvesting and Use Systems, for the specific characteristics of Bogota. The assessment has been based on water management criteria, together with additional environmental and financial aspects. Results evidence that the use of both strategies would be successful and complementary. A holistic analysis on the effects related to the implementation of both strategies results into optimized designs which, supported by sensible policy incentives, could reduce the impacts of decades of poor urban water management in Bogota.

Keywords: stormwater management, green roofs, rainwater harvesting, water sensitive urban design.

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1. INTRODUCTION

WATER IN COLOMBIA & BOGOTA
CHALLENGES
RESEARCH OBJECTIVE

Caño Cristales or River of the 7 Colours
Obtained from: httpwww.canocristales.co

1.1. WATER IN COLOMBIA

Considering the current worldwide situation in terms of available fresh water resources, Colombian citizens could considered themselves extremely fortunate. Data from (The World Bank, 2013), ranks Colombia as the country with the 6th largest renewable internal freshwater resources volume. Colombia's total resources volume is only surpassed by those of Brazil, Russia, Canada, the United States and China, all countries with a total land surface at least 8 times larger than Colombia's (The World Bank, 2013). Colombia sums an estimated 48.000 m3 of renewable freshwater availability per capita per year. A considerable higher value than the world's 1.240 m3 per capita yearly average (Hoekstra & Chapagain, 2007).

The northernmost country in South America enjoys an enviable offer of freshwater resources, and this is precisely due to its privileged geographical location, which together with a rugged topography, result in large precipitation volumes. A national average of 3.240 mm of rain per year triples the global annual estimated precipitation rate (FAO, 2016).

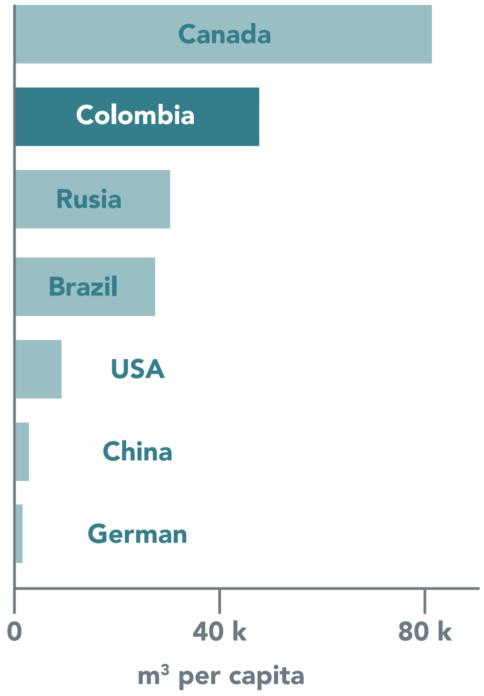


Figure 01
Total renewable internal water resources by country. Own compilation. Data extracted from (World Bank,2013)

Geographically, total precipitation varies greatly across the country during normal conditions. With 10.749 mm of rainfall a year, places like Quibdó raise the national precipitation average (Richter, 2014). Quibdó is the capital city of the Chocó region, and is considered the rainiest city in the world. On the other hand, regions like the Cundinamarca – Boyacá high plateau receive on average less than 600 mm of yearly rainfall (Dominguez, Rivera, Sarmiento, & Moreno, 2008).

Contrastingly, the latter region is one of the most important national centers for socio-economical activities, whereas the Chocó is an isolated area with a very low weight on the country's economic productivity. Bogotá, capital city of Colombia, is also the capital of the Cundinamarca region.

1.1.2. Water and Energy

Such abundant water resources have without doubt a special effect on the country's total economy. One particular sector which has almost completely been built upon water availability is the Colombia's electrical power generation system. By the year 2013, hydropower represented in Colombia 64% of the total installed power generation capacity, exceeded only by Brazil (71%) within the regional context. The share of hydro power in the global installed power generation capacity is as low as 2.1% (XM, 2013). Currently, Colombia counts with a total dam storage capacity of 11.4 km3 (FAO, 2016) and will be considerably increased in the following years.

Although debatable, hydropower is considered a sustainable source for power generation. In deed hydropower required infrastructure works cause serious local environmental damage and social affectations, however, concerning global warming potential, it is a clean source of energy. Thanks to its hydropower capacity, the global warming footprint of Colombia's total power generation system is 136 grCO2/kWh, less than a third of that from Germany's (447 grCO2/kWh) and only a fourth of the global average (504 grCO2/kWh) (IEA, 2011).

Despite the evident global environmental benefits of the hydro-based energy sector, high dependence on one single source for energy generation poses a tread to the entire system's reliability. Especially, when that particular source is dependent on non-manageable factors such as climate.

Figure 02
Share of Hydropower in Colombia and Worldwide. (XM, 2013)

Given its geographical location, Colombia is particularly sensitive to the El Niño climatologic phenomena. El Niño results from the increasing water temperature in the Pacific Ocean. It has a normal return period of 7 to 8 years and it affects various countries worldwide (NOAA, 2016).

For Colombia, this phenomena implies lower precipitation on most of the national territory. Although it's a recurrent event, the strength and length of it fluctuates greatly, leading to extreme low levels of water availability in certain cases. Particularly for the energy sector, this means lower volumes of dam-retained water volumes, lowering the total system's generation capacity. In 1992, an extreme El Niño event brought the country near to a power shutdown, leading the government to implement harsh emergency measures for energy and water use reductions.

As a result from the 1992 experience, the laws 142 and 143 of 1994 known as "Ley Eléctrica Colombiana" deregulated the energy market. To overcome the vulnerability inherent to non-diversified market and stimulate the investment on alternative generation sources, the government introduced a reliability charge to be paid to additional generation plants so that, despite not being constantly generating power, they would be available to operate during events of extreme drought. This policy increased the share of thermal power generation, particularly gas based, from 20% in 1992 to 35% in 2012 (XM, 2013). Nevertheless, the 2015 – 2016 El Niño event was again strong enough to bring the country back to fear a possible electrical shut down

1.2. WATER IN BOGOTA

Bogota is the capital and largest city in Colombia. Following to the last national census performed, the city counted with a population of 7.3 million inhabitants, number which is increased to 8.5 million when including to total metropolitan area (DANE, 2005). These numbers make Bogota the 25th most populated city in the world. It is located on a plateau at approximately 2650 meters above sea level on the eastern branch of the Colombian Andes (Andrade, Remolina, & Wiesner, 2013). Not surprisingly, it is the most important financial and industrial hub in the country, averaging a GDP per capita of US$8.400 (World Bank, 2012).

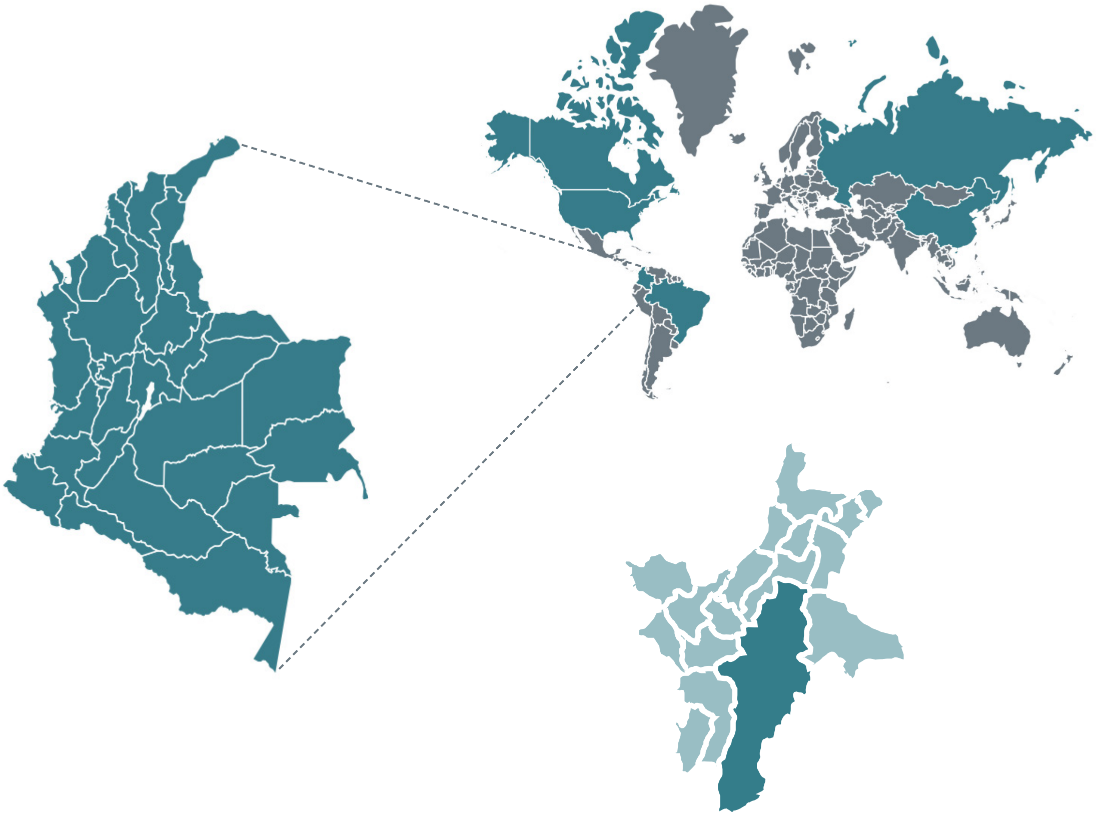


Figure 03
Top 6 countries with the largest total renewable internal water resources. Adaptation using data from
(The World Bank, 2013)

Colombia and geographical location of Bogota.

Bogota's greater Metropolitan Area. Adapted from
(Wessels, 2012)

1.2.1. Local Hydrology

Given it´s tropical latitude, Bogota does not experience yearly temperature variations which derive into meteorological seasons. Temperatures remain stable throughout the year, averaging 18°C daily maximums and 7°C daily minimums (WMO, 2016). Yearly precipitation in Bogota accounts for an average of 799 mm height, a value lower than the world's yearly precipitation average of 1033 mm (WMO, 2016). Unlike temperature, precipitation volumes do vary throughout the year following a well-established bi-modal pattern. As it is visible on Figure 04, there are two high precipitation peaks and two low precipitation valleys throughout the year, being April and October the rainiest months of the year, whereas January and July are the driest.

As previously stated, the city sits on a high plateau which receives the same name: Bogota Savanah. The city spreads along a mountain chain that serve as natural barriers and limits the city on the east. On the west, the city is limited by the main river in the Bogota Savannah basin. Not strangely, it also receives the same name. The Bogota River serves as the west border that separates the capital city from other municipalities on the savannah.

Both river and mountains not only constitute the borders of the city, but are also the origin and end bodies of the city's natural drainage system. Several creeks and small rivers runoff down the mountain chain, draining the area from east to west, discharging their water into the Bogota River. Smaller rivers would not directly discharge their water flow into the Bogota River, but rather to a series of wetlands on the western area of the city which are then connected to the main river. These wetlands are a vestige of the vast lake which used to cover most of the Savannah area (Moreno, Garcia, & Villalba, 2000).

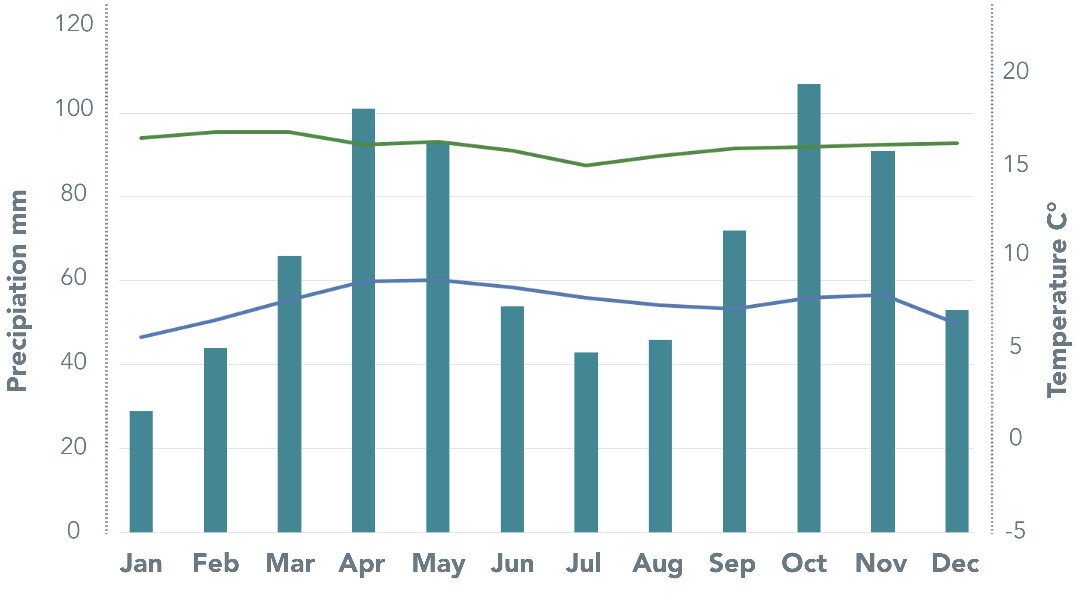


Figure 04
Monthly Climatological Average Data for the city of Bogota. Self-Compilation using data from
(WMO, 2016)

1.2.2. Hydrological Structure Components

PARAMOS:

The paramos are unique mountain ecosystems which fulfil the important task of regulating water resources. These ecosystems are normally found at heights between 3,100m and 4,000m amsl. 99% of the world paramo areas are located between the Andes and Costa Rica and 49% of these ecosystems are located on Colombian soil. Although paramo areas occupy only 1.7% of the national territory, they are the water source for over 70% of the total country population (Greenpeace, 2013). The Sumapaz paramo, with a total surface of 266,250 ha is the largest paramo ecosystem in the world and it is officially part of Bogota's districts territory and it is the main source for the city's freshwater supply.

Sumapaz Paramo National Park - Entrance

AQUIFERS:

Additionally to the surface water bodies, the Bogota savannah counts with an extensive network of underground water bodies. This network is principally conformed by the Bogota, Cacho, Guadalupe, Guaduas, Sabana, Tilat, Tunjuelo Usme, Villeta and Regadera formations (Lobo-Guerrero, Geología e Hidrogeología de Santafé de Bogotá y su Sabana , 1992). Altogether, the network currently mainly serves as the water supply body for various municipalities located on the Bogota Savannah as well as for the intensive agricultural activities taking place west of the Bogota River.

Sumapaz Paramo National Park - Lagoon

RIVERS:

As previously mentioned, the city is located on the Bogota River basin. The watershed of the river covers 6,000 km2 and includes 46 municipalities, together with the Bogotá Capital District (IDEAM, 2001). The Bogotá River drains the agricultural rural and suburban areas of the Bogotá Savanna along a course of about 150 kilometers, before entering the city from the north. Then river flows along the west border of Bogotá, receiving 100% of the wastewater discharge from the city's sewage infrastructure. This wastewater reaches the Bogota River via three main tributaries: the Salitre, Fucha, and Tunjuelo rivers, which have historically been the main natural drainages of the city (Uribe, 2005). After bordering the city limit, the Bogota River is biologically dead. It counts with zero dissolved oxygen and high levels of pathogens. Before entering the city the average river flow is 12 m3/s, then the city of Bogotá discharges an additional of 19 m3/s of wastewater, from which only 20% has been treated (World Bank, 2009).

WETLANDS:

The Bogotá River, once entered what now is the Capital District's territory, used to meander through the wide riparian areas, extensive flood plains, and thriving ecosystems such as the La Conejera, Juan Amarillo, and Jaboque wetlands (IDEAM, 2001). By the end of the 19th century, between the eastern peaks and the Bogota river laid more than 50,000 hectares of wetlands from which now only 670 ha remain (Calvachi, 2003). Currently, there are 13 different wetland bodies identified within the city limits (Ospina, 2008) which, though greatly diminished, still fulfil their water retention function, acting as buffer during strong storm events.

1.3. WATER RELATED CHALLENGES

Insufficient water offer is a problem affecting Colombia at a far greater extent than exclusively the energy sector and it is a challenge not only faced during specific events. According to (UN-Consejo Economico y Social, 1997), a condition of scarcity is reached when the projected volume water to be extracted from renewable resources in order to meet demand for human, agricultural and industrial consumption is larger than that which the natural system is able to provide. A demand – offer raio higher than 20% is already considered as a limited availability of water resources for a specific area of analysis. In Colombia, despite the overall abundant water resources, scarcity levels were reached by the year 2000 in various locations throughout the national territory (see Figure 05).

Areas with high or very high scarcity index levels do not necessarily match those with low precipitation or lower water availability. However, Figure 05 does evidence that all mayor urban agglomerations in the country do have high scarcity levels, despite the fact that most of them are located within basins with high water availability volumes. According to (IDEAM, 2004), whilst only 3% of the total numbers of municipalities in Colombia accounted for high scarcity levels during normal weather conditions, 32% of the more densely populated areas were catalogued

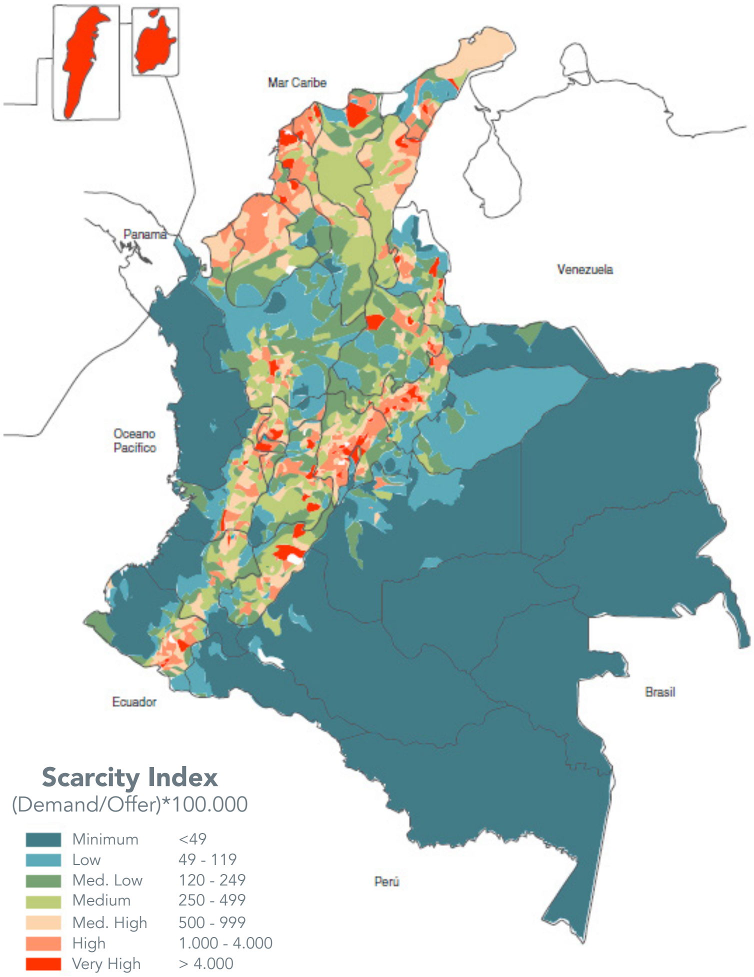


Figure 05
Hydrological pressure index as a relation demand/offer. Average hydrological conditions for municipal systems. (IDEAM, 2004)

under this condition. Urban agglomerations in Colombia, the 6th freshwater richest in the planet, are facing serious water availability challenges.

Although possibly with lower economic consequences, Colombia is also heavily affected when experiencing the opposite scenario. Larger and stronger rain seasons result in numerous negative outcomes over the national territory. La Niña, is the climate phenomena resulting from the contrary circumstances in the Pacific Ocean. Lower than average water temperatures produce larger precipitation volumes over most of Colombia's surface. The normal output during La Niña months is vast flooded areas that affect agriculture and transportation. In the case of extreme events however, devastating social consequences. Throughout most of 2010, La Niña brought intense rains that lead to extended flooding that accounted for more than 1.600.000 ha of the territory (IDEAM, 2011). Additionally to great crop and cattle loses, thousands of people lost their homes, in both urban and rural areas. Cundinamarca, the most urbanized region in the country and where the city of Bogota is located, had 7.1% of its urban area under water (IDEAM, 2011), displacing thousands of families.

1.4. PROBLEM STATEMENT

The urbanization process inherently comes with impacts on the area where it takes place. As a settlement grows, so does its demand for natural resources to build it and the demand of goods to supply the increasing population.

The needed resources and goods would be ideally extracted or produced in the immediate site or its surroundings. Additionally, given the nature of the urban fabric, virgin landscape is greatly altered. Particularly, enlarged urbanization results on important alterations on a site's hydrological cycle. These are due mainly to two factors: Increased water demand for numerous different uses; and the use of impervious materials to cover ever larger surfaces. An increased demand and a decreased permeability lead consequently to adverse scenarios such as water scarcity and flood events. Worsened by climate change, these scenarios, although somewhat opposite, can occur at the same location.

During the 90's decade, water used for agricultural irrigation accounted for approximately two thirds of the volume extracted from water bodies (Shiklomanov, 1996). Nevertheless, increased urban water use is not only increasing its share on total water consumption, but also focalizing the demand at much more specific points which often need the reallocation of water resources between basins. According to (Arnell, 1999), by 2025 approximately 5 out of 8 people will live in areas facing water scarcity conditions.

On the other hand, imperviousness of urban surfaces has a direct relationship with runoff water volumes a quality. During rain events, less water is being infiltrated resulting in lower underground water recharge rates and larger runoff volumes containing a high level of pollutants. For heavy rain events, increased runoff volumes can result in extreme flooding, leading to social, economic and health problems.

Urban conglomerations have to change the traditional and typical way in which urban water has been managed during the previous centuries. A new approach commonly known as Water Sensitive Urban Design (WSUD) has been followed in various locations during the past decades. WSUD aims to return as close as possible to the natural water cycle of a specific area (Hoyer, Dickhaut, Kronawitter, & Weber, 2011).

This requires the involvement of the scientific community to better understand the hydrological process and to design implementable technical strategies to achieve specific goal (Brown & Farrelly, 2009). Additionally and more importantly, WSUD requires a great effort from local governments in order to find paths that can lead to an appropriate implementation of the designed strategies. There are numerous examples of policy making that follow WSUD worldwide, however, there are many barriers to overcome in order to reach a successful implementation. According to (Brown & Farrelly, 2009), most of the identified barriers deal more with institutional and social issues rather than technical issues.

Bogota, the capital city of Colombia, as an example of a large and rapidly urbanized metropolis in a developing country. As such, it suffers from all of the consequences of poor urban water management. Colombia's national social crisis during the last half century worsened the migration of population from rural to urban areas, being Bogota the receiver of the largest share. Unfortunately, local policy has so far failed to control extreme rapid urbanization, and even less so, to adapt to the new WSUD approach to mitigate the effects of traditional urban water management.

1.5. RESEARCH OBJECTIVE

Nevertheless, environmental and social consciousness towards water issues has started to be raised amongst citizens and private developers, which has lead the local and national government to react. A representative example of local raised awareness towards WSUD is the Ciudad CAN (National Administration Center) project, a considerably large scale urban redevelopment plan in a fairly central location in the city of Bogota. As it name states it, in over 109ha, the development will host the headquarters of several national government entities (OMA & G+C, 2013).

Given the importance of the project, the national government intends for it to be a symbol of the country's commitment towards sustainable development. For this reason, the development of the master plan was carried out by worldwide renowned consultants and calls for very high sustainability standards, especially in the field of water management.

The ET-CAN is the first building to be developed within the Ciudad CAN urban renovation project (Empresa Virgilio Barco, 2015). The building's design proposal intends to incorporate the standard required in terms of Sustainable Water Management, reason for which they have opted for the implementation of two WSUD strategies: Green Roof and Rainwater Harvesting Systems (Daniel Bermudez Arquitectos, 2014).

Nevertheless, the local government has hardly started the adaptation of planning guidelines and regulations towards WSUD methodologies. Furthermore, local construction, architectural and engineering companies have little experience regarding the implementation of WSUD strategies and technologies which, in some cases, are possibly not easily available locally. The aforementioned constraints could make it particularly challenging for the local market to meet the standards set by the master plan.

Through a quantitative and qualitative assessment, the objective of the present study is, for the specific hydrological conditions of the city of Bogota, to evaluate the performance of the two chosen WSUD strategies to be implemented in the ET-CAN project in terms of Sustainable Water Management. Specifically in terms of fresh water use reduction and runoff discharge reduction.

1.6. RESEARCH QUESTION

Taking the ET-CAN project as Case Study, the present study intents to evaluate:

How much impact do Green Roof and Rainwater Harvesting systems have in terms of freshwater use reduction and stormwater runoff generation reduction?

In order to assess performance of both technologies, a quantitative assessment is to be performed using ET-CAN building design proposal detailed information. This has been provided by the ERU (Empresa de Renovacion Urbana Virgilio Barco), the national entity in charge of structuring the complete Ciudad CAN project. Thorough hydrological data for the specific geographical location of the ETCAN project was obtained from the local Secretary of Environment. With this information, a water flow balance is performed following a methodology thoroughly explained further into this document.

In addition, the study also intends to obtain significant conclusions regarding the following aspects:

- Is the implementation of Green Roof systems counterproductive when aiming to reduce freshwater consumption through rainwater harvesting and use?

- In addition to total water demand and offer volumes, do internal water consumption and local precipitation daily profiles affect the performance of the Rainwater Harvesting System?

- Would a variation of the daily consumption profile have an impact on the Rainwater Harvesting system retention capacity during strong storm events?

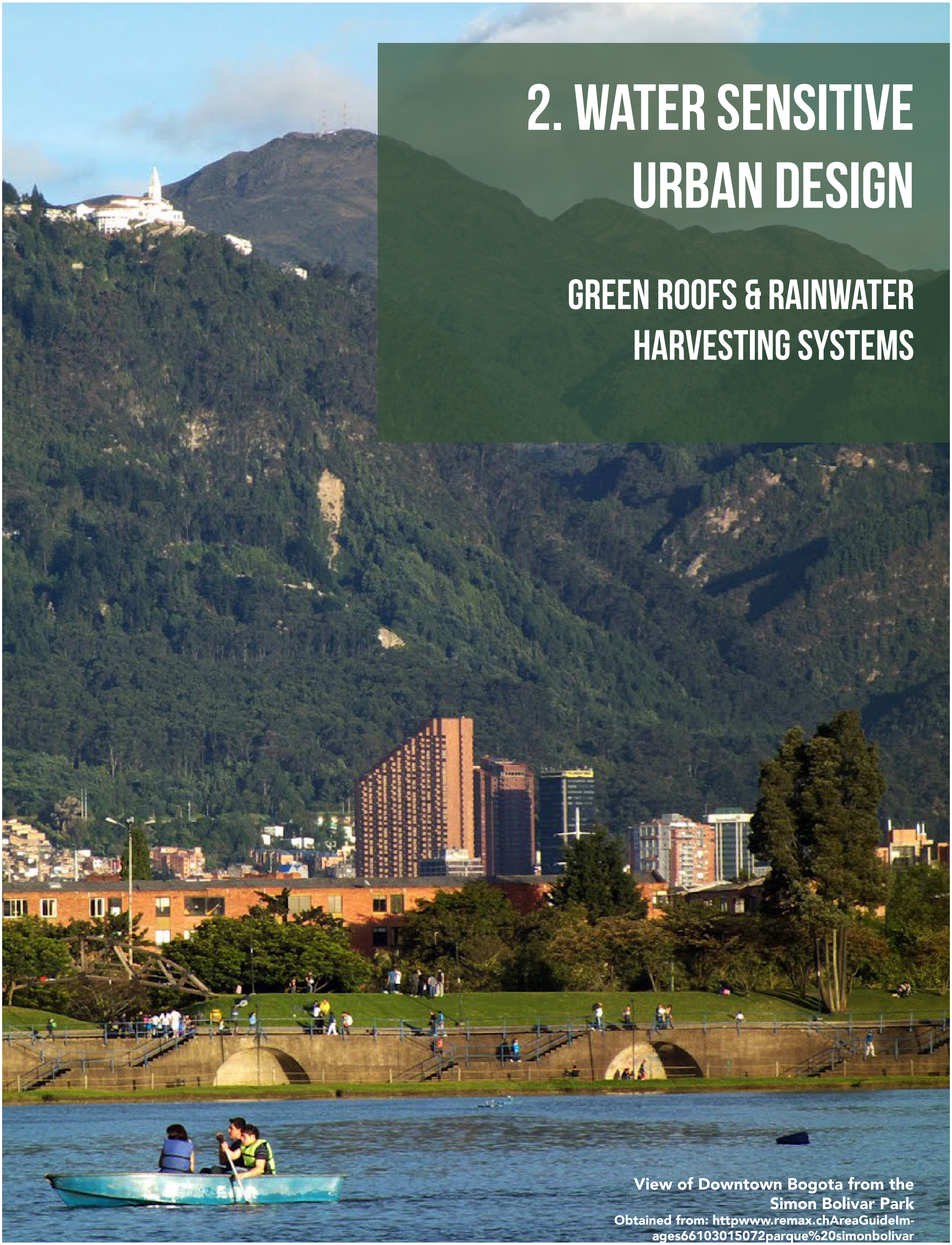
- Additional to Sustainable Stormwater Management objectives, what other environmental and social benefits could the chosen WSUD strategies provide in the local context?

1.7. RESEARCH LIMITATIONS

The validity of any quantitative analysis is completely dependent on the accuracy of the used data. For the purpose of the present study, detailed daily preciWpitation data was needed. Daily precipitation data has been gathered by several entities who count with numerous meteorological stations throughout Bogota. However, hourly precipitation data has not been started to be gathered until fairly recently. For this reason, hourly data required for the present analysis is only available since January 2012. Ideally, a much longer period should be used to obtain more significant and reliable results.

2. WATER SENSITIVE URBAN DESIGN

GREEN ROOFS & RAINWATER HARVESTING SYSTEMS



View of Downtown Bogota from the Simon Bolivar Park

Obtained from: httpwww.remax.chAreaGuideImages66103015072parque%20simonbolivar

2.1. WHAT IS WSUD?

In their a report prepared for the Australian industry and authorities (Lloyd, Wong, & Chesterfield, 2002) define Water Sensitive Urban Design (WSUD) as a design and planning approach which targets to reduce as much as possible the impacts that urban development have on the hydrology of the environment where it takes place.

This approach takes into account all processes which compose the hydrological cycle and requires the cooperation of various urban related fields as are water management, urban design and landscape planning (Hoyer, Dickhaut, Kronawitter, & Weber, 2011). The UK's Construction Industry Research and Information Association (CIRIA) defines WSUD as "the process of integrating water cycle management with the built environment through planning and urban design" (Morgan, 2013). This process should result in beneficial effects in a wide range of urban related topics (See Figure 06).

As a key component of WSUD, sustainable stormwater management as a practice should have as objective to protect human health and assets whilst preserving the natural ecosystems (Roy, y otros, 2008). To do so, urban areas should reduce stormwater runoff by managing and treating rainwater as close as possible to where it is precipitated. This approach contrasts with that of conventional stormwater management in which the objective is to collect and discharge stormwater as fast as possible into the sewage infrastructure (Hoyer, Dickhaut, Kronawitter, & Weber, 2011).

In their article, (Roy, et al., 2008) provide three premises which they consider are fundamental for an urban agglomeration government to acknowledge when aiming to achieve a sustainable stormwater management: Stormwater management should conserve the natural ecological structure and purpose of receiving water bodies; there are existing technologies which can simulate the natural water cycle; and urban stormwater management should be planned and implemented at a complete watershed scale.

2.2. WSUD PRACTICES

Practices to be implemented to attain a sustainable urban water management can be categorized in two groups: Planning Practices and Management Practices (Lloyd, Wong, & Chesterfield, 2002). Planning practices comprise the whole evaluation and analysis process which should be undertaken during the first steps. It is necessary to achieve a thorough comprehension of the site in order to come up with specific objectives which would shape an overall Land Use Plan.

Management practices can themselves be also split in two groups: Non-structural and structural practices. Non-structural refers to as set of non-physical strategies which would allow to: create and inforce policy; incentivize the implementation of the structural-practices; and raise awareness and encourage behavior changes regarding water resources. As a synthesis, these are the legal, economic and educational instruments which would serve as base for the implementation of a sustainable urban water management and will be discussed further in this document.

Structural practices are the physical systems and technologies which, as previously mentioned, can mimic the natural hydrological cycle by replacing the elements that compose a natural environment (Roy, et al., 2008). These elements would seek to regain the processes which are being lost due to traditional urbanization. Some of these processes are: Infiltration, evapotranspiration, retention, detention, storage and treatment (Hoyer, Dickhaut, Kronawitter, & Weber,

Figure 06
WSUD Process according to CIRIA, UK.
(Morgan, 2013)

2011). Most of these strategies are related to the permeability of the urban surfaces, as according to (Lee & Heanay, 2003), imperviousness is the urbanization factor which has had the most critical effects on the natural water cycle. It's worth mentioning that these strategies or technologies could be implemented on both public space (squares, parks, roads, sidewalks, etc.) and private allotments (buildings or yards). Depending on where it is to be implemented, the type of strategies varies, as it does the scale and the instruments needed to promote them. There are several structural practices that have been widely implemented around the world. Some of the common practices are (Hoyer, Dickhaut, Kronawitter, & Weber, 2011):

- **Rainwater Harvesting and Use**
- Bio-retention Systems
- Biotopes
- Gravel or Sand Filtering Systems
- Retention Systems
- **Green Roofs**
- Permeable Paving
- Detention Systems

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2.3. GREEN ROOF SYSTEMS

2.3.1. History

The concept of vegetated roof surfaces has existed for over 3000 years. In cold Nordic climates, former architectural practices included the use of turf (grasses and plant roots) as roof materials. This practice is even still used today in countries like Norway or Iceland. Vegetated roofs where also implemented in warmer climates, for example in the famous historical Hanging Garden of Babylon (Rufai, 2016). However, Green Roofs as technically designed systems were not created until the 1960´s in Germany and Switzerland thanks to several scientific researches. In 1975, the technical FLL guideline, "Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau" for the implementation of Green Roof was stablished and it continues to be the document which rules the technical design and installation of Green Roof systems in Germany and other countries which have decided to adopt it (Volder & Dvorak, 2014). By the 1980´s, the green roof market in Germany exploded due to specific incentives provided by the national government. The market for Green Roofs has expanded worldwide; however, Germany remains as the country which contributes more m2 of these systems every year.

2.3.2. Technology

Green Roofs have been developed as a layered system which simulates the processes occurring in natural vegetated surfaces and the soil layers underneath them. According to (ZinCo, 2016), one of the world´s largest Green Roof systems manufacturers, most of these technologies count with 6 basic layers:

1. Root Barrier: Protects the building roof structure from penetration of roots contained in the Green Roof system.

2. Protection Layer: It consists of a thin water proof membrane which prevents rainwater from filtering through the building roof structure.

3. Drainage Layer: Fulfills the tasks of retaining infiltrated rainwater, evacuating volume surplus and allowing ventilation of the root area.

4. Filtration Layer: Prevents soil particles to be lost and wash away with rainwater whilst maintaining the drainage layer clean and unblocked.

5. Soil Substrate: It is the natural or artificially designed growing medium which provides nutrients to the planted species. It most cases, it also accounts for most of the water retention capacity of the system.

6. Vegetation Layer: Selected plants which vary greatly in size and water consumption. Ideally, native or adapted species are selected.

As most actors involved in the Green Roof systems market, the International Green Roof Association IGRA categorizes these technology into three basic groups (IGRA, 2014). See Table 01. This categorization is mostly made based on the depth of the Soil Layer, as it is this variable which has the most important affectation on the system´s performance, weight, cost and type of species which it can support.

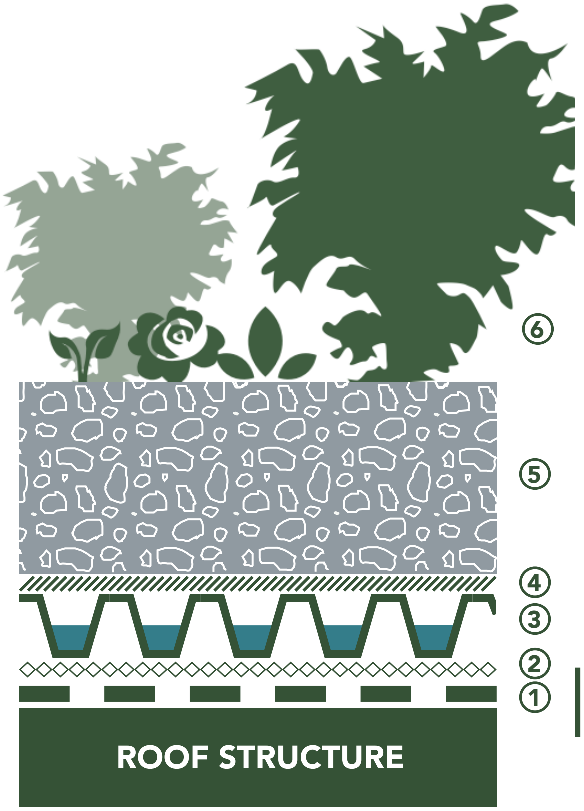


Figure 07
Green Roof Layered Structure. Adaptation from (IGRA, 2014)

	Extensice GR	Semi - Intensive GR	Intensive GF
Maintenance	Low	Periodically	High
Plant Types	Moss-Sedum-Herbs Grasses	Grass-Herbs Shrubs	Lawn / Shrubs Trees
Height Weigh	60 - 200 mm 60 - 150 kg/m^2	120 - 250 mm 120 - 200 kg/m^2	150 - 1000 mm 180 - 500 kg/m^2
Cost	Low	Medium	High

Table 01
Main Green Roof Categories. Adaptation from (IGRA, 2014)

2.3.3. Sustainable Water Management

Green Roofs make part of the set of SUWD practices because of their ability to retain rainwater during storm events. As it does in natural vegetated areas, rainwater slowly runs through the system´s layers, thus reducing both runoff volume and attenuating peak runoff flow. There are several factors which affect Green Roof retention capabilities. Some are inherent to the type of rain event and some are inherent to the system itself. The characteristics of the soil used as growing medium are commonly the most crucial factors determining the amount of water which is effectively retained within the system. The most important characteristics are moisture content, percentage of voids and thickness (Berndtsson, 2010). Nevertheless, new drainage layer technologies have started to be developed in order to enhance retention capacity without the need of incrementing the depth of the soil layer.

Although several studies agree that Green Roof systems do increase rainwater retention on buildings surfaces, their results on actual retention performance vary greatly. For example, (DeNardo, Jarrett, Manbeck, Beattie, & Berghage, 2005) concluded that Green Roofs systems analyzed under their study could retain 45% of the rainfall volume, whereas (Carter & Rasmussen, 2006) found a total retention share of 78% under their conditions. This variation is evidently due to the numerous variables affecting retention performance, which result in an extremely low likelihood of having two different experiments with identical conditions. For this reason, (Berndtsson, 2010) also points out the need of further research for specific urban environments.

2.3.4. Additional Benefits

Additionally to stormwater management, researchers have found that Green Roof systems implementation has a positive effect on various environmental and social aspects. Ranging from noise control to decreased heat island effect, the impact of Green Roof systems is both at a small and regional scale. Some of the better studied impacts of this technology are the following:

AIR QUALITY IMPROVEMENT:

All plants absorb CO2 from the air in order to realize their photosynthesis process. The amount of absorbed CO2 depends on their biomass or size. Green Roofs, being vegetated surfaces, would also evidently contribute to the absorption of CO2 present in the urban air. The institute for Agro & City-ecology Projects of the Humboldt University in Berlin has concluded, after a thorough study using various Green Roof systems, that on average, extensive systems can absorb up to 1.2 kg CO2 per m2, whereas intensive system can absorb up to 2.9kg CO2 per m2 (IASP, 2012). These values, when transferred to a larger scale, represent a major potential to improve local urban air quality.

BIODIVERSITY:

Depending on their design quality and specifications, Green Roof systems can provide a habitat for species which are affected by land use and surface changes inherent to the urbanization process. If succeeding to create a system which can maintain plant species during dry seasons, green roofs can serve as additional colonization and support space for birds and insects within the urban landscape (Brenneisen, 2006).

HEAT ISLAND EFFECT REDUCTION:

Low-reflectance impervious materials which are commonly used on building roof surfaces generate an excess of urban heat, increasing average temperatures of the urban area, compared to the surrounding suburban or rural areas. A study performed by Columbia University shows that under the same climate conditions, the use of extensive Green Roof systems would reduce the peak surface temperature by 33 °C when compared to a dark common surface (Gaffin, Rosenzweig, & Eichenbaum-Pikser, 2010). Additionally, the process of evapotranspiration performed by all vegetative species helps cool-down the air temperature. Both effects together help reduce the ambient temperature in urban areas (Oberlander & Matsuzaki, 2002).

THERMAL INSULATION:

In addition to the reflective properties, the layered Green Roof systems provide extra thermal insulation to the roof surface. This specific factor can result in lower energy consumption related to both internal -space heating and cooling (Gaffin, Rosenzweig, & Eichenbaum-Pikser, 2010). The larger the roof surface to total built surface ratio, the larger the insulation benefits.

2.3.5. Financial Cost

Although Green Roof systems are currently a worldwide accepted technology and the market for them has seen a steady growth, cost remains as a discouraging factor for developers (Clark, Adriaens, & Talbot, 2007). Particularly for Intensive systems, both initial and maintenance costs are much higher than common building practices in most countries. Despite scientific evidence for all of the aforementioned positive impacts, and several others which have not been described in this document, it is still complex to monetize these benefits in order to have a stronger financial support argument when deciding to opt for the implementation of Green Roofs (Banting, Doshi, Li, & Missios, 2005). Furthermore, some of the environmental and financial benefits derived from Green Roof implementation do not directly benefit the building owner or developer. For example, Heat island effect reduction or reduced stormwater runoff volumes carry great benefits to the local government and their public utilities; however, it is hard to transfer them to the project investors (Carter & Fowler, 2008).

Nevertheless, when a thorough study is performed and a monetary value for all potential beneficial effects is assigned, Green Roof systems have been found to be economically favorable. In cases like the city of Toronto, Canada, thorough studies have allowed the local government to assess the benefits of Green Roof technology and have been used as support for the creation of policy which creates financial incentives for their implementation (Banting, Doshi, Li, & Missios, 2005).

2.4. RAINWATER HARVESTING SYSTEMS

2.4.1. History

Rainwater harvesting as water supply has been used since pre-historic times. Civilizations and tribes inhabiting areas around the world where water availability is not constant throughout the year started to build systems to collect, store and use rainwater. These ranged from small single units for one family use, to large and complex structures for the use of an entire community. Arguably, the most developed examples were found in India, where several old written works contain references to canals, tanks and wells. One of the most known examples is Dholavira, a site where the Indus Valley civilization dwelled already since three millennia B.C. In this area, where the average yearly rainfall sums a mere 260 mm, the inhabitants built a network of reservoirs which could catch and store water from monsoon season and could then be used during dry periods (Agarwal & Narain, 1999).

The decline of rainwater harvesting as common practice worldwide started during the 19th century when larger local or reginal governments or even states started to become the main providers of water supply which led to a centralized infrastructure, replacing single house or community schemes (Agarwal & Narain, 1999). Nevertheless, during the 1980´s, national governments of several developed countries started to recognize the disadvantages, inefficiency and risks of a fully centralized water supply infrastructure; and alternatives such as small scale rainwater harvesting were reconsidered. Thus, more technical systems have been developed and marketed. According to (Nolde, 2007), in the early 2000´s, Germany was installing approximately 50.000 individual rainwater retention and treatment plans every year.

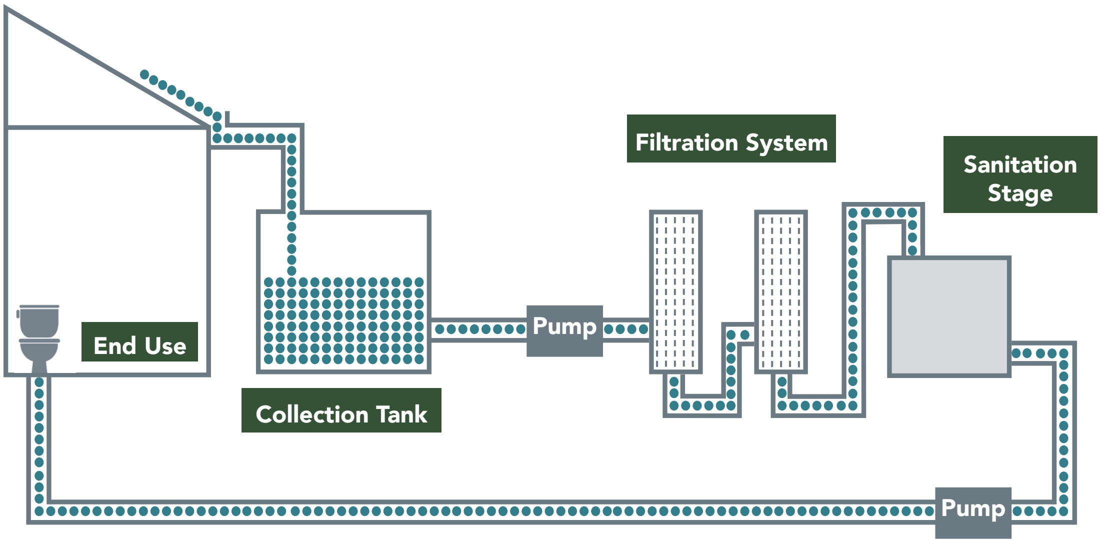


Figure 08
Traditional rainwater harvesting and treatment system.
Adaptation from (Cleanwater, 2016)

2.4.2. Technology

Traditional rainwater harvesting as a system comprises four basic steps: Collection; Filtration; Further Treatment; and Use (Nolde, 2007). The treatment process and level is entirely dependent on the final use that is intended to be given to the harvested water. Most common uses for harvested rainwater include:

- Toilet and Urinal flushing
- Landscape Irrigation
- Car and Exterior Surfaces Cleaning
- Clothes Washing
- Dish Washing

Rainwater can also be considered for uses which have a direct contact with the users body, in these cases however, the required level of treatment would be much higher as for those uses, there are in most cases, clear water quality standards. On the contrary, it is still not common to find regulation and set water quality standards for normal rainwater uses (Domenech & Sauri, 2011). Commonly, water is harvested from roof surfaces or ground level areas with little car traffic, given the higher pollution level of runoff generated on streets and parking areas. Nevertheless, that runoff type can also be collected and provided a higher level treatment for its later use (Nolde, 2007). Average pollution levels of low or no-traffic surfaces generated runoff pre- and post-treatment in Germany can be seen on Table 02. Moreover, traditional treatments performed in rainwater harvesting systems are not energy intensive. With an average 0.88 kWh/m3 demand for cleaning and distribution, additional energy consumption is not considered an impediment for the implementation of this technology (Nolde, 2007).

2.4.3. Sustainable Water Management & Additional Benefits

The main environmental argument which was initially used when promoting the implementation of rainwater harvesting systems was the reduction of freshwater extraction from rivers, lakes and underground reservoirs. The term Water Saving Efficiency or WSE has been used to refer to the percentage of water demand that, instead of being supplied by drinking water, is supplied by collected rainwater (Fewkes, 1999).

Indicator	Rainwater Runoff		Post-Treatment	
	Avg.	Max	Avg.	Max
COD	14 mg/L	36 mg/L	6.8 mg/L	15.8 mg/L
BOD	6.4 mg/L	45 mg/L	0.9 mg/L	3 mg/L
E. Coli	1060/100 mL	43,000/100 mL	<4/100 mL	43/100 mL

Table 02
Runoff water quality indicators pre- and post-treatment.
(Nolde, 2007)

Numerous research projects have been carried out estimating WSE potential for several locations around the world. In their study in Sant Cugat del Valles, a province close to Barcelona, Spain, (Domenech & Sauri, 2011) estimated that rooftop harvested rainwater could supply approximately 16% of the town´s total water demand. Studies in Brazil performed by (Ghisi, Lapolli, & Martini, 2007) concluded that an average of 41% of potable water savings could be achieved. Results ranged from 12% up to 79% depending on the specific analyzed location.

Moreover, recycling and treating rain water results also beneficial for the water quality of water bodies receiving sewage discharge from urban settlements, as this practice can reduce the non-point pollutant loads (Nolde, 2007). Furthermore, the total retention capacity resulting from adding all individual rainwater harvesting systems has been proven beneficial to reduce the risk of floods in urban settlements. Considering the urban scale benefits of small scale stormwater recycling, local governments should encourage the implementation of such practices on their planning schemes (Nolde, 2007).

Apart from all the water-related potential benefits of rainwater harvesting, communities could also be positively affected by decentralization. Communities and individual implementing their own small supply infrastructure are more likely to increase their environmental awareness, as well as their sense of ownership (Agarwal & Narain, 1999). In their study (Domenech & Sauri, 2011) also concluded that rainwater harvesting systems would provide greater environmental, economic and self-sufficiency benefits when installed at a community scale rather than separately installed by individuals.

2.4.4. Disadvantages

Financial feasibility of rainwater harvesting systems depends on many variables. Technology, although not too complex, is however not easily available at certain locations, thus increasing installation costs. As for investment return, the period would depend on both the actual WSE of the system and the price of regular water supply at every specific location. (Domenech & Sauri, 2011) points out that the actual end-use which can be given to harvested rainwater determines at great extent implementation feasibility. The higher the demand share covered by rainwater, the larger the savings during operation. Additionally, the scale of the system plays an important role. Whilst (Rahman, Dbais, & Imteaz, 2010) obtained an average 38 year payback time for rainwater harvesting system implementation in multi-storey buildings in Melbourne, Australia, (Zhang, Chen, Chen, & Ashbolt, 2009) obtained payback period ranging from 11,6 to 13,7 years for high-rise developments in Melbourne and other Australian cities. In any case, small and large installations would reduce the stress on local sewage infrastructure (Nolde, 2007). For this reason, local governments should provide incentives so that a common implementation of rainwater harvesting is attained.

In addition to financial aspects, an important concern and challenge is water quality control decentralized systems. (Domenech & Sauri, 2011) stress how more complex it would be for local authorities to guarantee water quality levels and control the final-use given to rainwater, than it is with the current centralized infrastructure. Nevertheless, in their study, they also found that health risk is not an issue that people perceive as an impediment for the installation of rainwater harvesting systems.

2.5. IMPLEMENTATION IMPEDIMENTS

Being WSUD such a multifaceted notion, it is only normal to understand that its implementation carries various challenges. In their study, (Brown & Farrelly, 2009) have concluded that most of the barriers for a successful transition towards WSUD are more social and institutional rather than technical. Following the same notion, (Roy, et al., 2008) have summarized the most important impediments which are faced when aiming to implement a sustainable stormwater management and their possible respective solutions.

2.6. WSUD LEGAL AND ECONOMIC INSTRUMENTS

It has been previously stated that WSUD is a concept that could be taken into account when developing regional and local policy, but these policies have to be based on a national framework which already addresses the issue of sustainable water and environmental management. This national framework can, and should, empower and encourage local and regional governments to create and implement

Impediment	Solution
- Uncertainties in performance and cost	- Conduct research on costs and watershed-scale performance
- Insufficient engineering standards and guidelines	- Create a model ordinance and promote guidance documents
- Fragmented responsibilities	- Integrate management across levels of government and the water cycle
- Lack of institutional capacity	- Develop targeted workshops to educate professionals
- Lack of legislative mandate	- Use grassroots efforts to garner support for ordinances and regulations
- Lack of funding and effective market incentives	- Address hurdles in market approaches to provide funding mechanisms
- Resistance to change	- Educate and engage the community through demonstrations

Table 03
Major impediments and solutions to sustainable stormwater management (Roy, et al., 2008)

development master plans which consider the hydrological cycle and ecosystems, basically, to implement good planning practices.

2.6.1. Types of Policy

When a local government decides to follow a sustainable water management oriented planning, they could include WSUD strategies as mandatory practices in public and ecologic infrastructure manuals.. However, these practices should not be relegated exclusively to publicly owned land. According to (UN-Habitat, 2013), only an average of 45% of the total city surface (30% streets – 15% public space and parks) of large cities throughout all continents is actually public land. This value varies greatly and reaches an average low of only 15% on sub-urban areas. This means that on average, more than half of a city's land is the sum of private allotments. Implementing WSUD structural practices on private areas is then equally or more important as it is to do so on public areas.

Unfortunately, a well widespread high social awareness towards water and the environment is not enough to achieve an extensive implementation the implementation of WSUD structural practices on private areas. It is for this reason that local governments need tools or instruments to achieve this. For years, environmental policy or instruments that have been use around the world have been categorized under two approaches: Command-and-Control and Market-Based (Karp & Gaulding, 1995). (Carter & Fowler, 2008). The Command-and–Control category denotes those policies which induce compliance of determined factors based on legal ordinances and the application of sanctions On the other hand, Market-Based policies rely on economic benefits as incentive, or as (Karp & Gaulding, 1995) state it, they rely on the greed and self-interest. More specifically for the WSUD-related policies, and particularly analyzing Green Roof systems, (Carter & Fowler, 2008) sub-categorizes policies under four groups.

Technology Standard policies are those which through building codes require and mandate the implementation of a certain system (Carter & Fowler, 2008). Policies could order a total or partial use of a certain technology. In the case of Green Roofs or example, order the use of the system on either the total roof surface or a minimum percentage of it.

Performance Standard policies on the other hand, do not directly encourage the implementation of a specific solution. Instead, they set specific water management goals or benchmarks, and it is up to the developer to select the way to achieve them (Carter & Fowler, 2008). Performance can be directly measured through different indicators adopted in the policy. As a variant, performance can also be indirectly controlled through existing performance certification systems as it is, for example, the Leadership in Energy and Environmental Design (LEED) rating system created by the U.S. Green Building Council.

Both Technology and Performance Standard policies. Directly or indirectly mandate the implementation of certain measures to achieve a sustainable water management. These strategies are normally easily applicable for public infrastructure and buildings as, as it's been explained throughout this document, they represent major environmental and even economic benefits for a municipality. However, these benefits are not always seen directly on the place where measures are implemented. In the case of private land, the benefits of WSUD systems are not internalized by the developer or the owner (Carter & Fowler, 2008). Furthermore, whilst there exists scientific evidence that the implementation of WSUD strategies at a municipal scale result economically beneficial than traditional water infrastructure, at individual smaller scales, this is not always the case (Roy, y otros, 2008). Thus, to encourage the implementation of WSUD practices on private land and developments, it is necessary to appeal to market-based policies.

Direct Economic Incentives would be the policies which directly subsidize or finance the implementation of WSUD practices with public funds, either totally or partially. These policies are of course subject to municipalities budgets constraints. Indirect Economic Incentives are those policies which allow the owners of a certain land or building to offset the costs of utilities fees. The most straightforward and probably the most common approach adopted in environmental policy is the "polluter-pays principle" which can be applied to both water use and water runoff discharge: The more one "pollutes", or consumes, or discharges; the more one pays (Partzsch, 2009). With this approach, any measure taken by the user to reduce the amount of water consumed or discharged, regardless if it is a change in the behavior or the installation of a physical system, would result in a lower utility fee. Economic incentives are arguably the most commonly used strategies to encourage private developers, particularly in countries where WSUD systems are still very expensive (Carter & Fowler, 2008). Some examples of the aforementioned policies, specifically for stormwater management, will be described next.

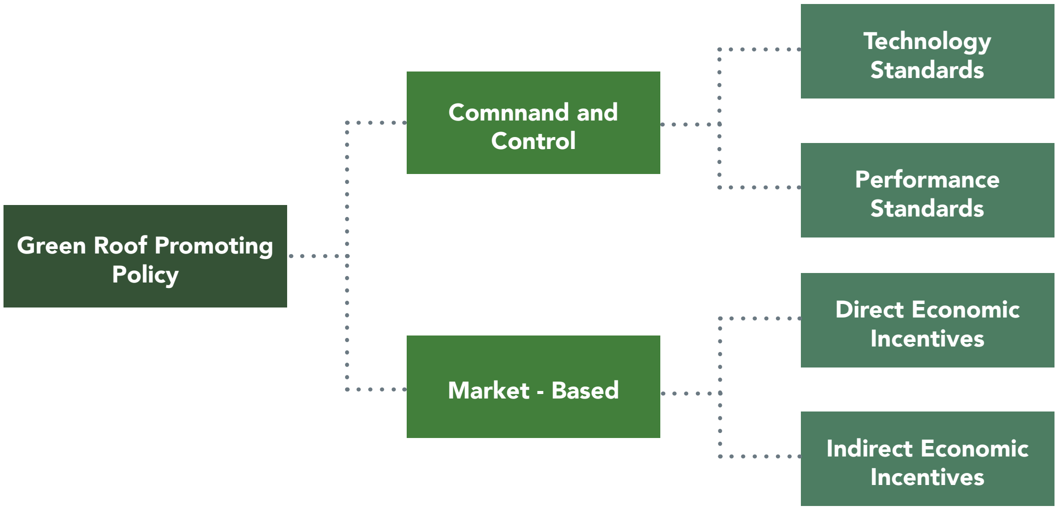


Figure 09
Policy types to promote Green Roof systems implementation. Own compilation using info from (Carter & Fowler, 2008)

2.6.2. International Policy Examples

The concept of WSUD is not new and since several decades it has started to be included in the drainage infrastructure manuals of several cities worldwide. Since the 1980's, the city of Tokyo has included WSUD practices in the new suburbs development manuals attaining an estimate 50% stormwater run-off volume reduction when compared to the drainage infrastructure they traditionally implemented (Mikkelsen, Jacobsen, & Fujita, 1996).

Australian cities are also pioneers in terms of WSUD public infrastructure policy, as they have financed scientific studies and transferred their results into a more permeable public infrastructure design manuals since the 1990's (Mikkelsen, Jacobsen, & Fujita, 1996). The Green Urban Alleys proposal is a practice which aims to transform unused narrow and dark alleys, which would normally be unpleasant areas, into more natural and green spaces functioning as infiltration spot. This proposal has started to be followed by several North American and European cities (Newell, y otros, 2013).

WSUD has also already reached national policy, being Switzerland the first country to mandate the infiltration of urban storm water run-off as early as 1993 (Mikkelsen, Jacobsen, & Fujita, 1996).Concerning private areas and projects, there are several examples of the four types of policy previously mentioned, most of them addressing Green-Roofs and Rainwater Harvesting systems as they are the most suitable for private buildings.

TECHNOLOGY STANDARDS:

This type of policy been adopted into the requirements for new developments in several North-American cities building manuals in which they include various options of best management practices (BMP) from which developers can choose from (Carter & Fowler, 2008). Following a study positive study on environmental benefits and costs of Green Roof systems commissioned in 2005 by the local government (Banting, Doshi, Li, & Missios, 2005), Toronto became the first North-American city to mandate the implementation of these systems on commercial, institutional and residential developments (City of Toronto, 2016).

Although basing it mostly on their insulation properties, since March 2015, France is the first country to require the use of green roofs on all new commercial development to implement Green Roof systems at a national level (Agence-France-Presse, 2015). In India, where rainwater harvesting is an important element of their vernacular architecture, the government of various cities took measures to reintroduce it into the urban context. Amongst many other cities, Chennai introduced rainwater harvesting practice into their development plans and has mandated it for new as well as for existing buildings. Punitions deriving from not following these policy include the denial for connections to public water supply and sewage infrastructure (Gurjar, 2012). Malta, a country in which sealing materials account for 13% of the total national territory, has also decided to mandate rainwater harvesting cisterns and wells into new developments (European Commission, 2012).

PERFORMANCE STANDARDS:

Berlin, Germany and Malmo, Sweden have opted for Performance Standards to increase the green areas on the cities. Both have adopted a performance indicator called Biotope Area Factor (BAF) which is defined as he relation between "ecologically effective surface" and the total land surface of a development. BAF values vary depending on many factors such as the implemented strategies, whether is a new construction or a refurbishment, the type of land where the project is located, amongst other. A final BAF is obtained through a combination of these factors and minimum benchmarks are required (Carter & Fowler, 2008).

As it has been already mentioned, an alternative within the Performance Standard type is the inclusion of existing rating systems into the policy. Several cities in the United States mandate a minimum level of certification within the LEEED rating system for specific development projects (Carter & Fowler, 2008). A downside to this alternative is that, given the broad scope of the LEED rating system, projects can get certified without obtained any credit points related to water management. However, minimum requirements for each topic, sustainable water management included, do have to be met.

DIRECT ECONOMIC INCENTIVES:

For the particular case of Green Roofs, this alternative has been specially used in Germany since the 1980's at regional and municipal levels and has been adopted by approximately half of the German cities (Ngan, 2004). An estimated 86 million m2 of Green Roofs gad been installed in Germany by 2012, approximately 14% of the total national roofs surface (European Commission, 2012). From 1983 to 1997 the city of Berlin provided a subsidy accounting for approximately 50% of the total acquisition and installation costs, resulting in an estimated 63,500 m2 additional Green-Roof systems surfaces (Carter & Fowler, 2008).

The city of Hamburg currently promotes an initiative called "Hamburger Gründachförderung" which provides subsidies for up to 50,000 € depending on the building size, location and the selected systems (IFB HAMBURG, 2016). Hamburg also promotes the implementation of rainwater harvesting subsidizing up to 50% of the cost of such systems (Partzsch, 2009). In Toronto, through the Eco-Roof Incentive Program, Green Roof installation projects can receive funding for CAD 75 per m2 and up to CAD 100,000 (City of Toronto, s.f.).

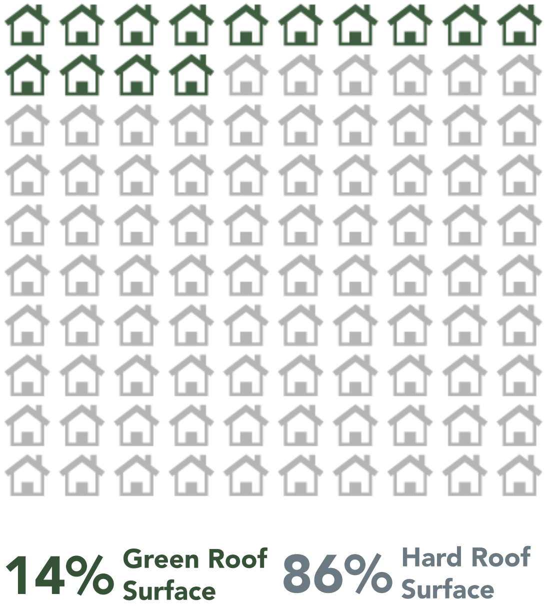


Figure 10
% of Green Roof Systems on total roof area in Germany (European Commission, 2012)

INDIRECT ECONOMIC INCENTIVES:

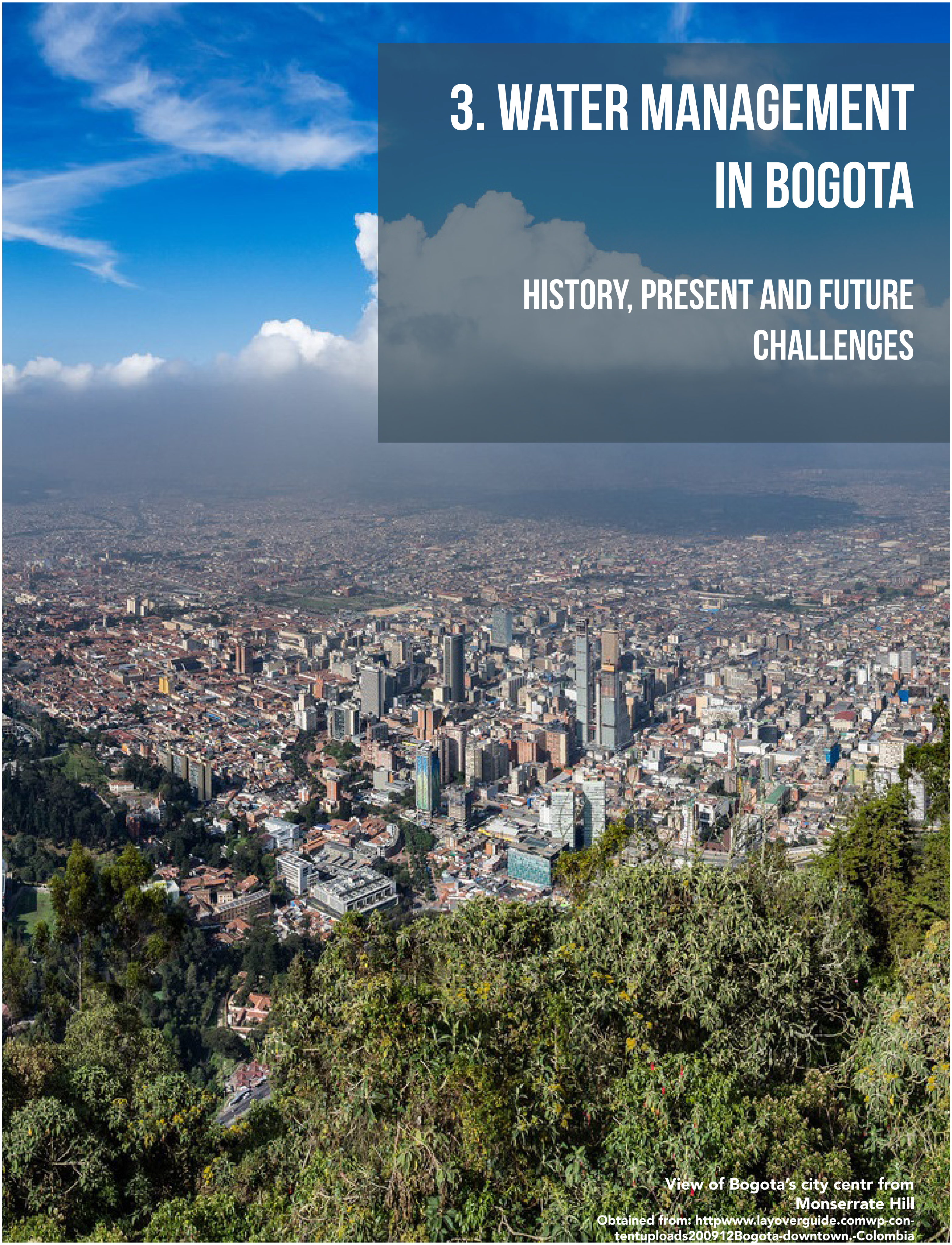
As previously stated, these strategies are mostly applied through utility fees. Addressing fresh water extraction, users in German municipalities pay an extraction fee which can vary from 0.0025 euros/m3 for fish farms in Bremen to 0.31 euros/m3 in Berlin. These amounts however never exceed 17% of the total extraction tariff (Partzsch, 2009). In order to use this type of incentives to address rainwater runoff reduction, rain drainage fee must be separated from the sewage fee, which is very often not the case. An effective way to take in rainwater discharge into the fee is to include the percentage of sealed surfaces into the equation (European Commission, 2012).

In Germany, 9 out of 10 households are under regulations which separate rainwater from sewage fees. When separated rainwater discharge fees were introduced in Essen, Germany, various large plots where businesses such as logistic centers were located, reduced their sealed surfaces by up to 50% (Partzsch, 2009). In the United States, cities various cities are now following the same approach. Portland grants up to 35% discount on the stormwater utility fee depending on how effective the stormwater management within the plot is. Minneapolis grants reductions which can be up to a 100% of the fee (Carter & Fowler, 2008).

All of the previous examples are however not always successful as they are only attractive to private users and developers when the total utility fees are high enough to encourage them, which is not always the case. A more innovative alternative which has been being adopted by cities in the United States is granting density bonuses to new developments. In certain designated areas of the city, Portland, Oregon, allows in additional construction ft2 when Green Roof systems are installed. Bonuses go from 1 additional ft2 per ft2 of Green Roof for coverages up to 30% of the total roof, and increase to 2 bonus ft2 for coverages up to 60% and 3 bonus ft2 for higher coverages (Liptan, 2003). The city of Chicago has also implemented a density bonus policy, only following a different formula (Carter & Fowler, 2008).

3. WATER MANAGEMENT IN BOGOTA

HISTORY, PRESENT AND FUTURE CHALLENGES



View of Bogota’s city centr from Monserrate Hill
Obtained from: httpwww.layoverguide.comwp-contentuploads200912Bogota-downtown,-Colombia

3.1. PLANNING HISTORY

Bogota's approach towards water bodies has not been historically a responsible one. The city was founded at the beginning of the 16th century between the smaller rivers of San Francisco and San Agustín, which make part of the Fucha sub-basin. Naturally, these two rivers received the storm and waste water generated within the city. At the beginning of the 20th century, with a population of approximately 100.000 inhabitants, the water bodies in the city had already lost their ability to naturally manage the large waste volumes (Mejía, 2000). Seeking to drain the city in the fastest and most economical way, whilst trying to remove the bad smell already emanating from the rivers, the government started paving over water bodies, turning them completely into sewers.

Population in Bogota had been experiencing steady linear growth rated until it reached an inflection point during the 1940's. Prior to this population burst, the landscape surrounding the city was very different to the actual one. Former individual municipalities like Usaquén, Engativá, Usme or Fontibón, which now make part of the capital district, were at hours horse-travel distance from Bogota. The territory between the capital and these other municipalities consisted in great part of large wetlands and meadows (Cuellar & Mejía, 2007). However, considering the approach that the local government traditionally had towards water management, the landscape was drastically and rapidly changed.

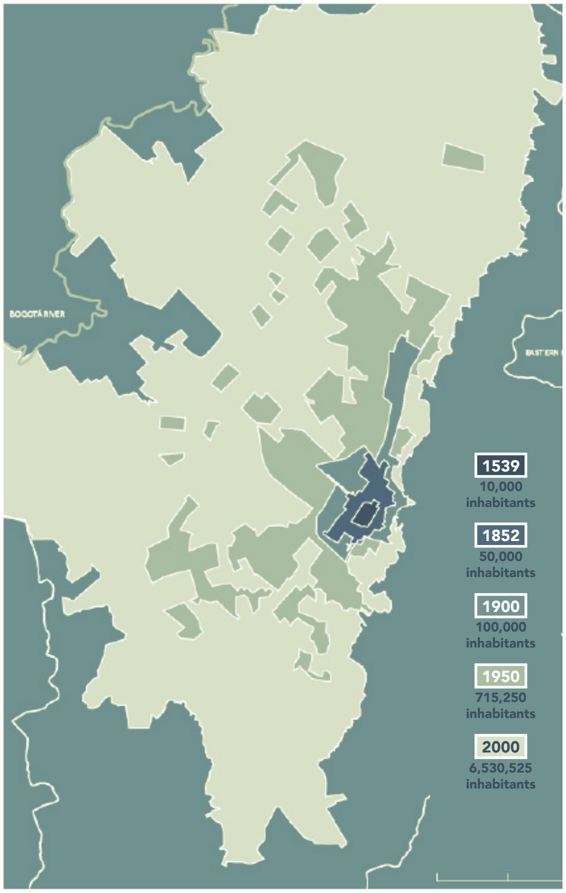


Figure 11
Urban expansion of Bogota. Adaptation from (Wessels, 2012)

Foreseeing the influx of people into the city, during the 1930's, the local government commissioned the first development plan for the city to the Austrian architect Karl Brunner (Cuellar & Mejía, 2007). This plan was already greatly influenced by the arrival of motorized vehicles to the city. Brunner projected new avenues stretching from the city center towards neighboring towns. These avenues were projected to go along the rivers without causing mayor alterations. Brunner paid particular attention to the region hydrology and natural elements, using water bodies to connect important new planned developments. Sadly, only few of his designs were actually followed. The National University campus, today one of the largest green areas in the city, is one of them (Pinilla, 2008). After Brunner's plan, came several others developed by local architects. All greatly influenced by the new motorized traffic introducing then larger avenues to connect the city and the region whilst determining where the city would grow. The city however, instead of building roads along water bodies, decided they were to be built above the rivers and across wetlands, resulting today in a tremendous impact on the hydrology of the savannah.

With the construction of the new avenues, the land started to lose its agricultural value and was given a real state developing value instead. Rural and pervious surfaces gave way to impervious surfaces such as paved roads, buildings and parking spaces. Large volumes of rainwater were no longer infiltrating and recharging the aquifers, but running off to the channelized rivers instead. This situation worsened with the decades as regulations starting in the 1960's allowed larger percentages of plots to be built on (Pinilla, 2008). According to (Rodriguez, y otros, 2008), the average coefficient of imperviousness over the urban area of Bogota is an estimated 50%. During significant rain events, this value results in an extremely large additional volume rapidly flowing west towards the Bogota River. Rainwater is evacuated at a non-natural speed through impervious canals which now replace the sub-catchment rivers and streams. The actual amount of vegetated and pervious surfaces in the city is dangerously low. According to (Observatorio Ambiental de Bogota, 2014), the city averaged 4.1 m2 of vegetated areas per inhabitant by 2012. A value which improved from 3.4 m2 in 2002, but remains far below the international standard of 10 m2 per inhabitant recommended by the World Health Organization. Furthermore, the city accounts with only 1 tree per every 6 inhabitants. This number is extremely low when compared to the suggested standard of 7 – 8 trees per inhabitant (OMA, G+C, 2013).

Figure 12
Number of trees per inhabitant in Bogota and international recommmended ratio. Own compilation using info from (OMA, G+C, 2013).

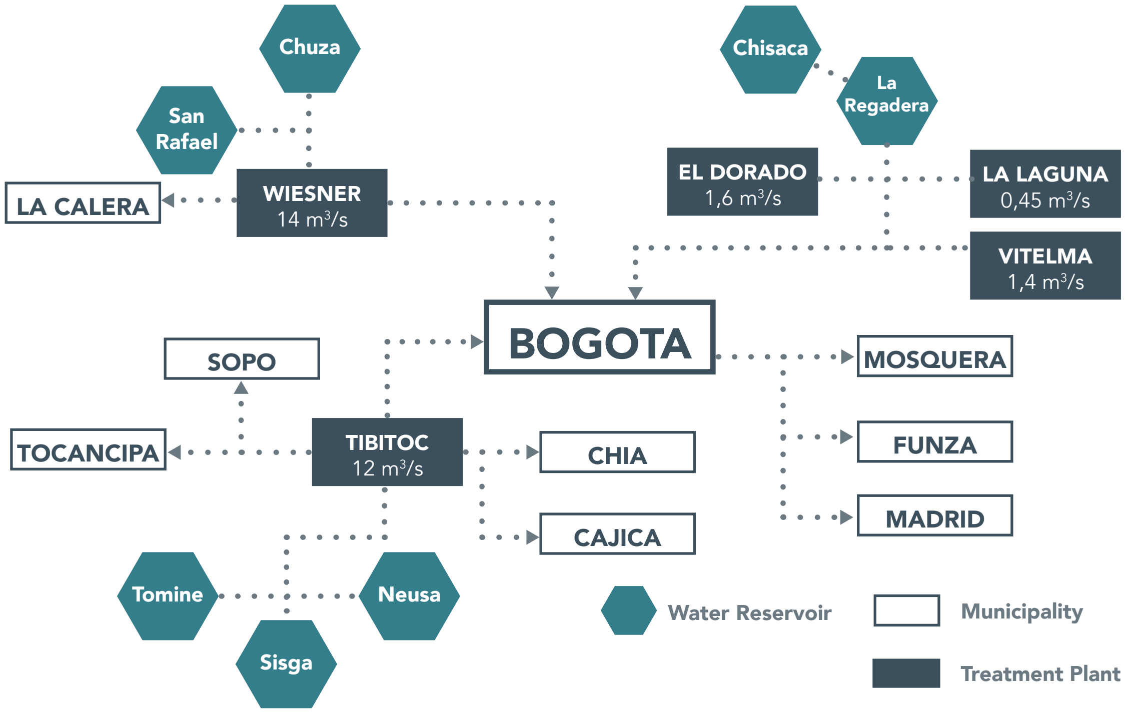


Figure 13
Bogota's freshwater supply system. Own compilation using info from. (EAAB, 2006)

3.2. WATER INFRASTRUCTURE

3.2.1. Water Supply

Bogota's fresh water supply is based on two main sources: the basins of the Bogota and the Sumapaz rivers. The Bogota River collects surface water from the Bogota Savannah and pours it into the Magdalena, Colombia's most important river, which then flows across a large surface of the national territory and ending at the Caribbean Sea. On the contrary, the Sumapaz does not belong to the same larger basin. Their waters would naturally flow east to the Andes wing on which Bogota is located and would drain into the Orinoco larger basin. The Orinoco is one of the rivers with the largest water flow worldwide, and after bordering Colombian territory, it flows north through Venezuela and pours its water into the Atlantic Ocean (Alfonso & Pardo, 2014).

The system that supplies fresh water to meet the city's demand is comprised by 5 main treatment plants (See Figure 13). Altogether they add up a total treatment capacity of approximately 30 m3/s. They do not only supply fresh water for Bogota but also to surrounding municipalities. Wiesner is the largest plant from the system and counts with a total treatment capacity of 14 m3/s. The plant treats the water pumped from two large reservoirs, San Rafael and Chuza, which are both located east from Bogota and fed with the waters of the Sumapaz river basin. North from Bogota there is a second plant, Tibitoc, with almost the same treatment capacity and which treats water from three large reservoirs which store water from the Bogota river basin. Additionally, there are three much smaller treatment plant which help meet the total demand. After continuous efforts during the some administrations on the 90's and early 2000's, Bogota managed to bridge the gap and reached a total coverage close to 100% for fresh water supply within the city limits, a very good situation when compared to cities with similar average income values (Siemens AG, 2010).

In addition, there is another source of water external to the system displayed which also supplies a great share of the regional demand. As previously stated, underground water bodies have traditionally been used as a source for the agricultural and industrial activities taking place in the municipalities located in the Bogota savannah. Numerous industries have located their facilities west of the Bogota River, as the price of land decreases once being outside the capital district.

3.2.2. Wastewater and Stormwater Management

In terms of wastewater management and sanitation, the actual situation in Bogota is unfortunately not very positive. The city produces approximately 235 million m3 of waste water per year (Alfonso & Pardo, 2014). This water is drained from the city using an infrastructure that is composed by three sub-catchment areas which match the basins of the three mayor tributary rivers that flow across the city and into the Bogota River. The infrastructure built before 1965, roughly 74 km2, was built as a combined waste-water and rain-water sewage system. Infrastructure built after that date consists of a separated system (Rodriguez, y otros, 2008). Wastewater treatment only began in Bogota as late as the year 2000 when the Salitre treatment plan started operations. The plant was given this name as it only treats the water discharge from the Salitre River sub-basin infrastructure. It counts with a treatment capacity of 4 m3/s which barely accounts for 20% of the total discharge flow of the city (World Bank, 2012).

The rainwater system consists mainly in channelized natural streams or additional built open channels. The infrastructure accounts with more than 2000 km of pipes for the rainwater drainage and 5400 km for waste water collection. Following computer simulations, the current infrastructure has the capacity of properly managing only up to 5 years return period events, which evidently leads to constant sewer overflows (Rodriguez, y otros, 2008).

3.3. INSTITUTIONAL FRAMEWORK

Water management in the Bogota metropolitan area functions at a local and also a regional scale. Being such a large metropolitan region, institutional framework tends to be very complicated as it there are many stakeholders involved. Table 04 gives a brief overview of the most important institutions involved with the city's water management.

The institution with the greater power and most responsibilities regarding water management is the "Empresa de Acueducto

Institution	Level	Solution
"Empresa Acueducto y Alcantarillado de Bogota" - EAAB	District	Designing, building, operating and maintaining most of the city's water related infrastructure
Secretary of Environment	District	Setting technical standards, creating and promoting policies for environmental protection, improvement of water quality and restoration of natural habitats
"Instituto Distrital de Gestión de Riesgos y Cambio Climático" - IDIGER	District	Designing and implementing strategies to reduce risks related to natural events and for the city to adapt to climate change
"Instituto de Desarrollo Urbano" – IDU	District	Setting technical standards, creating manuals and building public infrastructure such as roads and public space
"Corporación Autónoma Regional" - CAR	Regional	Environmental agency in charge of the management of regional water basins, natural resources and protected areas
Ministry of Housing, City and Territory	National	Responsible for the water and sanitation policy. Responsible for land use policy in urban areas.

Table 04
Institutions Involved in Bogota's Water Management. Self-compilation using info from (World Bank, 2012) and websites of local and national institutions.

y Alcantarillado de Bogota" - EAAB. It is a 100% publicly owned utility created in 1955 with the main purpose of providing water supply, sewage and sanitation services for the city. However, during the first five decades of existence, it focused almost exclusively on increasing coverage and quality of water supply, relegating drainage and sanitation to a second plain (World Bank, 2012).

3.4. CHALLENGES

As it has been previously mentioned, Bogota has experienced an extremely rapid urbanization process. As most countries throughout Latin America and most of the developing world, during the 20th century, Colombia saw a large urban population increase. Additionally to the rural-urban migration seen around the world, Colombia's urbanization process was worsened by an internal social crisis that has lasted over half a century and has resulted in amplified internal migration as rural population sought to escape violence. Over the course of 60 years, total population in the district area of Bogota increased by a factor of 8.5, moving from around 880,000 inhabitants in 1952 to 7.47 million in 2011 (Alfonso & Pardo, 2014).

This rapid demographic growth inherently meant a physical uncontrolled expansion of the city, process which resulted in great consequences on the region surfaces water bodies and exerted a significant pressure on the city's water supply and drainage infrastructure. Because of this situation, together with the already existing effects of climate change, Bogota is currently facing two mayor challenges related to water management: Fresh water undersupply and extended flooding on residential and productive areas.

3.4.1. Fresh water shortage

As early as the 1970's, the EAAB comprehended that the fresh water available within the Bogota River basin was insufficient to meet the rapidly increasing demand. For this reason, in 1972 started the project to transfer water from the Sumapaz to the Bogota basin (World Bank, 2012). The project which was only completed by 1997 temporarily secured Bogota's internal water supply ignoring however the environmental impacts of an inter-basin water transfer.

Within the regional context, average water consumption volumes in Bogota are relatively low. With a daily average of 114 liter per person, Bogota's consumption is less than 50% of the regional urban average for large urban agglomerations which is estimated to be 264 liters per person (Siemens AG, 2010). However, this number is not necessarily encouraging as the city average consumption has actually slightly increased during the last decade after numerous years of improvement. By 2006, when daily consumption was even lower than 100 liters per person, the EAAB estimated it to decrease down to 90 liters per person (EAAB, 2006). These estimations had their foundations on a clearly decreasing trend (See Figure 14). The decrease achieved during the last half of the 90's decade were due to a higher public awareness and introduced changes in the tariff system (Alfonso & Pardo, 2014), both partially as a result of the El Niño event in 1992 which was previously introduced in this document.

According to official reports, residential consumption accounts for an estimated 80% of the total city's demand, whereas water use for industrial purposes accounts for 17% (Alfonso & Pardo, 2014). This numbers however could be deceiving as a great part of the local industry is not located within the capital district itself. As previously mentioned, many businesses located on the external perimeter of the city supply their demand using wells through which they directly extract water from the underground formations, unfortunately, they do so at non-sustainable rates. The analysis performed by (Lobo-Guerrero, Descenso de los Niveles de Agua Subterránea en la Sabana de Bogotá, 1995) indicates that by the 1970's and 1980's, the water table level of various formations in the Bogota Savannah was decreasing at rates

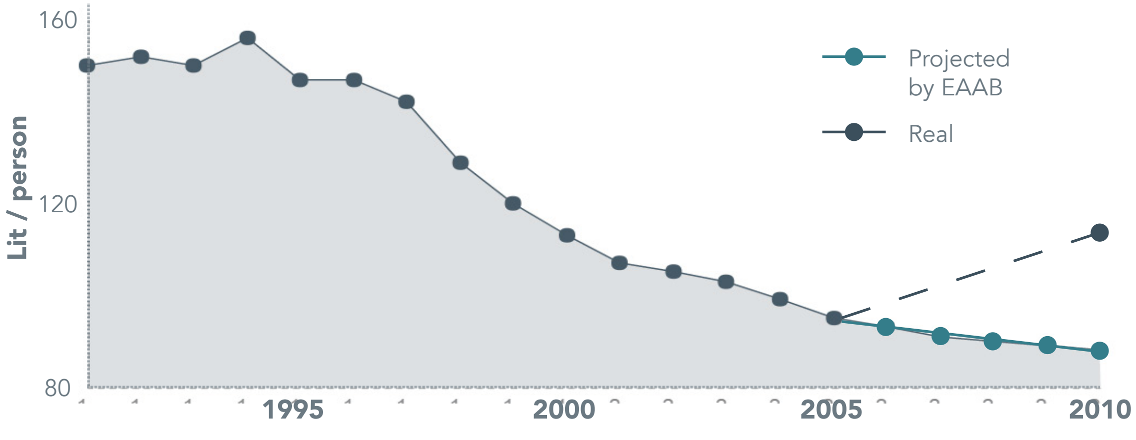


Figure 14
Residential water demand 1990-2010 in liters per person per day.
Adaptation using data from (EAAB, 2006) & (Siemens AG, 2010)

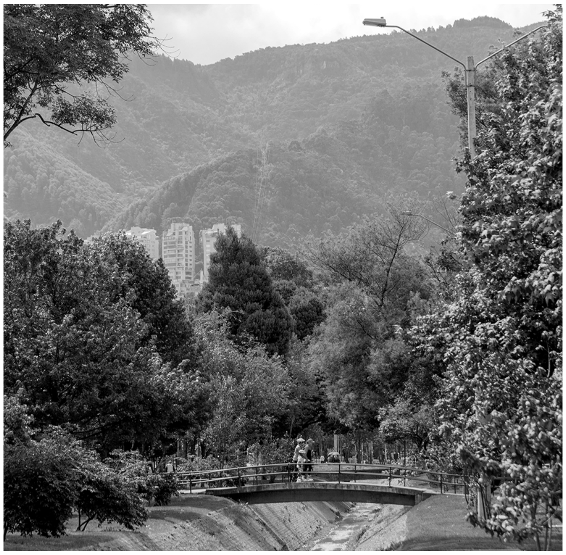
ranging between 3 and 5 meters per year. This strong descent has not raised awareness on the main extractors, it had just made it more complicated to reach the water level. However, industrial facilities and agricultural companies have just kept digging deeper wells, a solution that is no longer possible for local individual farmers.

Both superficial and underground water sources for the city are being exploited at non-renewable rates posing a great treat for the entire city's population and economy.

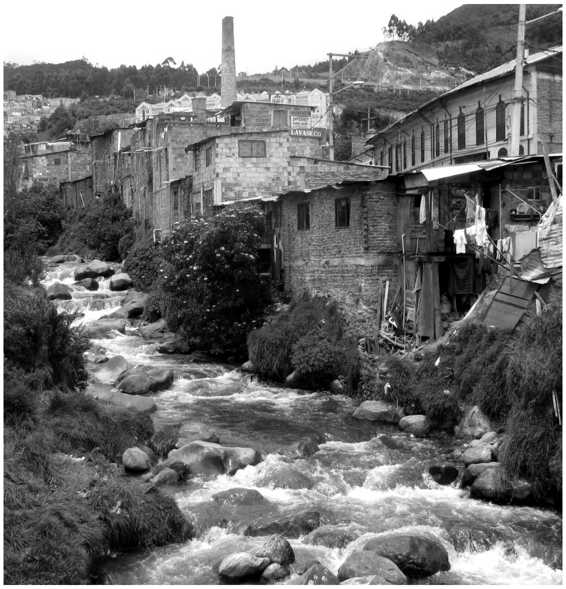
3.4.2. Treads related to strong rain events

A quick view of the banks of the larger rivers immediately reflects the lack of control and policies that the city has had to protect them, especially the lower basin section of the Tunjuelo River, in the area where it meets the Bogota River. Seriously dense urban areas grew just meters away from the constant flow of the rivers, a situation which now presents permanent treat for a very large population. The Tunjuelo river is the second longest of the capital district and flows through various localities. Amongst them are: Usme, Ciudad Bolivar, Tunjuelito and Bosa. These localities, together with the neighboring municipality of Soacha, count between them with a population larger than 2 million inhabitants and, according to (Acebedo, 2002), host the largest economically disadvantage population, not only in Bogota, but in Colombia.

During the already discussed La Niña event of 2010 – 2011, the capital district had to emergency alerts over 12 localities due to flooding and landslide risks. By April 2011, 58 emergencies had been reported due to the Bogota and Tunjuelo rivers overflow. By the end of the rain season an estimated 12,400 families received economical, food and health aid, a number which was certainly below the total affected population (Bueno & Bello, 2014). This is however just one example which illustrates a permanent situation affecting the most vulnerable population of the city.



View of the Negro River running through a high income neighborhood



View of the Fucha River running through a very low income neighborhood

3.5. LEGAL FRAMEWORK

3.5.1. National and Local Policy

It has been stated that historically urban water management in Bogota was not directly addressed and it was in most cases just a result of the spatial development plans, or lack of them. Today however, there is an existent legal framework which addresses water management, both at national and local levels. These policies are however in most cases very vague and broad, introducing concepts and responsibilities, but failing to define specific and detailed goals related to the problems and challenges described beforehand. In fact, the actual water supply and drainage system in Bogota is a direct response to these policies: ambitious in terms of coverage and water quality, however not taking into account the complete hydrological cycle.

With the implementation of the Law 388 from 1997, the Colombian cities where given the instruments to create and inforce Land-Use plans (Lampis, 2013). Bogota has implemented since then several plans and policies that address public space, environmental conservation, as well as the protection of vegetation and existing habitats within the city area. These efforts would have an indirect effect on the challenges regarding water management.

Document	Level	
Law 388 / 1997	National	Municipal territories planning and development. Urbanism as means of improving quality of life. Delimitation of green public areas
Decree 619 / 2000	District	Formulation of Bogota's first Territory Development Plan
Decree 215 / 2005	District	Public Space Master Plan. Balance between population densities and environmental conditions
Decree 319 / 2066	District	Sets out mechanisms to compensate the city for the alteration of pervious surfaces.
Agreement 323 / 2008	District	Formulates a standard for sustainable building in Bogota
Agreement 418 / 2009	District	Promotes the use of sustainable architectonic solutions
Decree 109 / 2009	National	Creates the Eco-Urbanism and Environmental Management Division. Responsible for sustainable urban development.

Table 05
Summary of recent legal framework indirectly addressing water management.
(Secretaria Distrital de Ambiente, 2016)
(MinAmbiente, 2016)

3.5.2. Economic Instruments

Since the first legal approach concerning the water resources in Colombia, two economic instruments were instated. The aforementioned Decree 2811 from 1974 sets the application of fees related to water extraction from natural sources, together with fees related to the use of water bodies for the discharge of pollutant flows (MinAmbiente, 2014).

When introducing this instruments, the evident goal was to achieve a more efficient use of the water resources and to reduce the volume of pollutants delivered into the rivers and ecosystems. Therefore, the national entity in charge of regulation for the water supply and sanitation services (CRA) defines tariffs to be applicable in proportion to the extracted volume, as well as to the pollutant delivered volume (CRA, 2004). In the case of Bogota, the EAAB does apply the concept for the water supply, but does not apply it for the sanitation service. Tariffs for drainage water in the capital district are applied proportionally to the total water volume consumed by the user (EAAB, 2016).

The established basic fees should incentivize the users to make a more efficient and responsible use of the water resource. They should have a value that would make it more economically beneficial for the users to make efforts to reduce their consumption, as well as to make efforts to reduce the pollutants discharge. The collection of basic use and discharge fees has the additional purpose to generate resources to finance the Regional Environmental Authorities – CAR (CRA, 2004), entities which are the maximal environmental authority for each regional jurisdiction. The fees regime set by the (CRA, 2004) determines a fixed minimum fee per volume unit applicable nationwide. In addition there is a regional factor that increases the fee depending on regional and local aspects which include the natural water availability. Finally the total tariff charged by each local utility to their users includes the operation and maintenance costs. As additional incentive to reduce fresh the non-necessary use of fresh water, a tariff is set for monthly consumptions up to 20 m3 per user and it is increased for volumes exceeding the set benchmark (EAAB, 2016).

Colombia has created a very singular tariff system for the public services. In order to comply with principles of solidarity and wealth distribution, lower income individuals see their tariffs subsidized whit resources that for the most part come from tariff surcharges made to higher income individuals. The differentiation between lower and higher income is based on the geographical location of the user's connection.

For every registered residential plot, a ranking denominated as socio-economic stratum is given. Ranging from 1 to 6, where 1 indicates the most vulnerable situation. Tariffs are subsidized by 70%, 40% and 15% for stratums 1, 2 and 3 respectively (Cadavid, 2008), stratum 4 is charged the tariff which corresponds to the average cost to provide the services, whereas stratums 5 and 6 are surcharged up to a 264% due to the solidarity fees (World Bank, 2010).

Stratum / Use	Quantity		m^{e} per capita / year	m^{e} per capita / month	lit per capita / day
	Million m^{e} / year	%			
E1	13.88	7.28	0.43	1.70	56.76
E2	62.72	32.88	21.77	1.81	60.47
E3	66.49	34.86	25.80	2.09	69.68
E4	26.83	14.06	38.91	3.24	108.08
E5	10.46	5.49	53.10	4.43	147.50
E6	10.34	5.43	80.73	6.73	224.24
Total Residential	190.72	80.00	26.39	2.20	73.32
Industrial	40.51	17.00	151.90*	12.66*	416.16*
Service and Commerce	7.15	3.00	4.08*	0.34*	11.18*

** For industries and services by number of personel employed*

Table 06
Water consumption by socioeconomic stratum and productive sector in Bogota by 2010.
(Alfonso & Pardo, 2014).

These solidarity scheme, although has created a social sense of equity, it does not have a major impact on water consumption levels. Table 06 shows that water consumption volume per person from the highest socio-economical stratum is four times larger than that of the lowest stratum.

Furthermore, when looking at the resulting tariffs for the water supply and sanitation services in Bogota, the basic water use and discharge fees represent a mere 0.13% and 1.85% respectively of the total tariffs charged to the users (Rudas, 2008). The basic fees established by the CRA are so low that they scarcely reach to finance an average 1.8% of the CAR's budgets (Rudas, 2008).

This does not mean however, that the tariffs for water supply and sanitation in Bogota are low. In fact, the EAAB charges the highest tariff rates to its users compared to the other public utilities from mayor cities in the country. This high tariffs are a result of the significant investments necessary for the construction and operation of the water management infrastructure previously discussed in this document. The infrastructure's construction, operation and maintenance costs are transferred to the users. The efficiency of Bogota's system is unfortunately not very high. According to the EAAB itself, due to mostly leakages and false connections, approximately 35% (7.1 m3 monthly per user) of the total fresh water volume extracted from the reservoirs does not reach the registered users (EAAB, 2015). The extra costs inherent to this inefficiency are of course paid by the inhabitants of the capital city.

Moreover, the EAAB has also established a tariff for those users extracting water from underground sources instead of the city's supply system. According to (Gómez, 2012), when extracting water directly from underground sources, industrial facilities and large and intensive agricultural producers located on the district area pay a tariff per m3 of 60 times lower than that of regular industrial use. This situation encourages the overexploitation of the savannah acquirers.

3.6. ACTUAL ADVANCES SUSTAINABLE WATER MANAGEMENT

Despite the lack of consideration for hydrological and environmental structures in the reviewed development history of Bogota, a few important milestones have been set during the past years. A first advance was made in the year 2000 when, for the purpose of creating the first Territorial Master Development Plan, the district collected and processed data to elaborate a comprehensive map of its ecological structure. Another major tangible achievement came in 2011 and was the final establishment of the Thomas Van der Hammen Natural Reserve, a protected corridor on the northern border of the district which resulted on a forest reserve of approximately 6,750 ha (Lampis, 2013).

In terms of WSUD practices, the Agreement 418 of 2009 mandated the implementation of Green Roofs systems on public buildings, although the arguments for it were other than water management (Alcaldia de Bogota, 2009).

Additionally, there has been several rulings and policies which, though at a lower scale, addressed sustainable water management. A couple examples are the Decree 624 of 2007

Green Roof and Vertical Garden systems installed on the Bogota Secretary of Environment following initial WSUD policy which states the district's policy towards the management and recovery of wetlands; and the Agreement 1998 of 2014 which stablishes a methodology to increase the ratio of green surfaces.

Furthermore, educational guidelines have been published to promote responsible behaviors towards water and also to promote the implementation of certain technologies. One example is the "Green Roofs and Vertical Gardens Practical Guidelines" document which was published in 2014 (Secretaria Distrital de Ambiente, 2014).

3.6.1 Decree 043 of 2010

The first time that one of the WSUD derived concepts was mentioned in local policy was in the Decree 043 of 2010, where the Districts Secretary of Planning includes Sustainable Urban Drainage Systems as practices to be used in a specific development area on the northern territory of the city. The document which determines the technical criteria for the development of that area is called "Plan de Ordenamiento Zonal del Norte" or POZN.

Following this Decree, the 6523 Agreement of 2012 regulates, designs and mandates the WSUD practices to be implemented on a 2,014 ha development area (Secretaria Distrital de Ambiente, 2011). This document not only includes many of the WSUD structural practices on the public space design manuals, but also mandates strategies to be adopted on private areas. It requires 50% Green Roof coverage of the total roof area and the use of pervious materials on 50% of the open areas (Secretaria Distrital de Ambiente, 2011). Unfortunately, as it is common in the Colombian context, the POZN development has been delayed for political reasons and it is very likely to be changed under the actual government, meaning that the efficiency of the local WSUD policy can't yet be tested.

Figure 15
Cover of the Green Roofs and Walls guidelines. Published by (Secretaria Distrital de Ambiente, 2014).

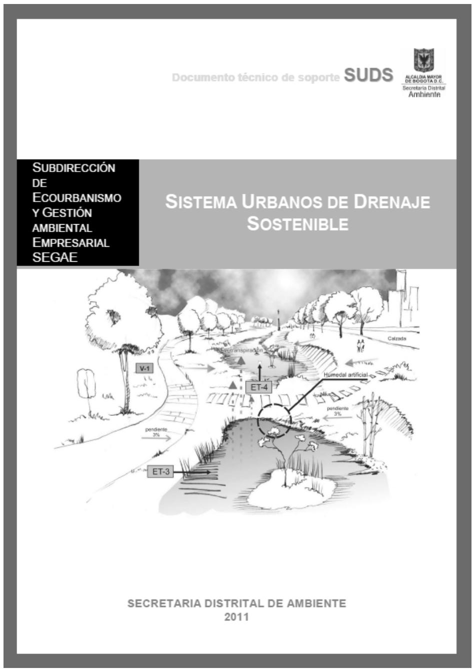


Figure 16
Cover of the POZN SUWD manual or Decreee 043 of 2010 published by (Secretaria Distrital de Ambiente, 2011).

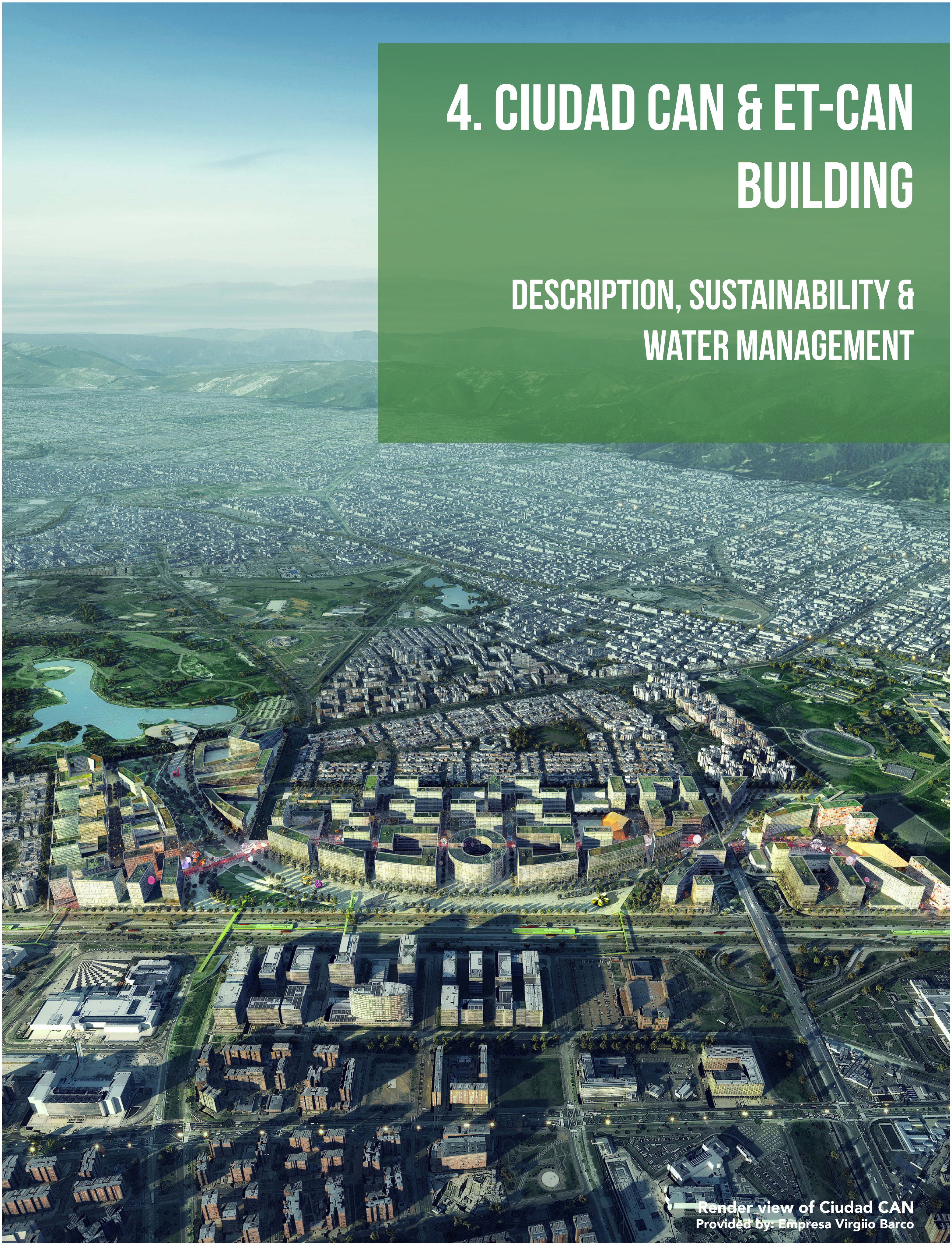
3.6.2 Decree 528 of 2014

Although an advance, the implementation of the POZN WSUD oriented policy would apply to less than 5% of the total urban surface of Bogota. A newer law, the Decree 528 of 2014 is perhaps the most comprehensive and general document which could trigger the implementation of WSUD practices on the entire district (Alcaldia de Bogota, 2014). This document establishes the city's aim towards a Sustainable Stormwater Management. It defines clear responsibilities and tasks to be carried by several district entities in order to transform the city's drainage infrastructure. Specific technical documents are expected to be developed after the ruling of this Decree and which will apply to the city's public infrastructure and public areas. However, this Decree still does not mention policy to be created in order to promote WSUD practices on private properties.

Private actors have at a small extent already implemented SWUD practices in the city. Green Roofs systems for example, have gained popularity during the last decade. However, for residential developments, this has been mostly done for commercial and "green image" reasons. As for industrial and large commercial developments, they have been installed driven by the LEED certification system which big developers pursue mostly, again, for commercial and "green image" reasons. The few WSUD practices installed by privates that had indeed water management purposes, have been mostly done by universities and academic institutions.

4. CIUDAD CAN & ET-CAN BUILDING

DESCRIPTION, SUSTAINABILITY & WATER MANAGEMENT



Render view of Ciudad CAN
Provided by: Empresa Virgiio Barco

4.1. OVERALL DESCRIPTION

In the year 2011, the Colombian national government saw the need to restructure the management of all real state and buildings property of the National State. With the Law-Decree 4184 of November 2011, the National Presidency created the "Empresa Nacional de Renovación y Desarrollo Urbano –Virgilio Barco Vargas" -EVB, a public entity whose objective is to identify, promote, manage and execute urban renovation, conservation and development projects throughout the National territory (Empresa Virgilio Barco, 2016). Particularly, one of the responsibilities of the EVB is to manage and update all of the real state property of the National State. This of course includes all of the properties where national entities operate. The biggest assembly of this type of properties is the "Centro Administrativo Nacional" – CAN, which is located at a central location of the capital city, Bogota D.C.

Currently, on a total land surface of 57.1 Ha, the CAN project hosts 18 national entities, including 4 ministries: the Ministry of Defense, Ministry of Education, Ministry of Transport and Ministry of Energy and Mines. These 18 entities operate on a total of 66 buildings which altogether add 424,000 m2 of built area and are the workplace of more than 21,000 employees (Empresa Virgilio Barco, 2016). This buildings conglomerate, together with the adjacent space is for evident reasons considered as one of the monumental public space ensembles in Bogota, given its high emblematic, symbolic and civic content (Gamboa, 2010).

In 2013 the EVB launched an international contest for the creation of the Master Plan for the renovation and development project Ciudad CAN. The winner proposal of this contest was the one presented by the temporary consortium OMA & G+C: A union of the worldwide leading architectural and urban planning firm OMA directed by the internationally renowned Dutch architect Rem Koolhaas; and two national firms led by Colombian urbanist Julio Gómez and architect Lorenzo Castro. Their renovation proposal called "CAN 2050" aims to conform a National Administrative Center which stands as a symbol of modernity and articulation, a space that serves as a model for which Colombia can be regarded as a regional and international development leader (OMA, G+C, 2013).

Ciudad CAN Rendering
View from Av. Calle 26

Two years later, the EVB announced the winner (Empresa Virgilio Barco, 2015) for the architectural contest of what will be the first building developed under the Ciudad CAN Master Plan: the ET-CAN building. Its name is an acronym for the Spanish of "Transition Building", given that it will be an institutional building which will temporarily host the offices of several national governmental entities during the development of the entire Ciudad CAN project.

Given the Sustainable Water Management standards set under Cuidad CAN Master Plan and the fairly detailed stage of the designs, the ET-CAN building provides a great opportunity for the analysis intended under the scope of the present document.

4.1.1. History

The actual CAN development is a result of actions and lack of action of national governments throughout the past 6 decades. The idea started in 1954 when General Gustavo Rojas Pinilla, Colombia's president at that time, decided to relocate several national entities into an entirely undeveloped plot in the capital city. This relocation proposal included: the Government Palace; the Presidential Guard; 11 National Ministries; the National Radio and Television Institute; and the Official National Press (Empresa Virgilio Barco, 2015). His main goal was to centralize and organize the national public administration so that it would be more coherent and unified (Gamboa, 2010).

This project, originally called "Centro Administrativo Oficial - CAO", required a development master plan which was assigned to American architects Skidmore, Owings & Merril. The master plan looked for symmetry, efficiency and gave great relevance to public space, projecting large square, gardens and fountains between buildings. It created a very large block with no internal motorized traffic, locating it completely on the perimeter fence (Gamboa, 2010).

The main road infrastructure considered in the master plan was initially developed between 1956 and 1962 (Empresa Virgilio Barco, 2015). One of these bordering roads, the southern limit of the project, is the avenue now called "Calle 26" which connects Bogota's international airport and the city center. The designed and approved master plan was never followed. Throughout several decades, the occupation of the plot was carried out in a fragmented and disorganized fashion, disrespecting the urban norms set by the American architects. The 66 buildings that now are located within the complex were built with very different standards and during various administrational periods (Empresa Virgilio Barco, 2015). The complex and its internal lack of connection illustrates that of the national administrations.

According to a study performed by the National University of Colombia in 2007, this uncontrolled and disorganized process resulted in: Buildings with inadequate standards and very high degree of vulnerability to fire and earthquake hazards; limited offer of parking places leading to the occupation of streets and public space; insufficient public space and public transport; almost nonexistent activity during off-work time; and lack of complementary services for the floating population of the complex (Empresa Virgilio Barco, 2015). This study, together with some others, presented solutions for a partial renovation and densification of the area. However, these attempts failed and led the current national and regional governments to structure the present "Ciudad CAN" project.

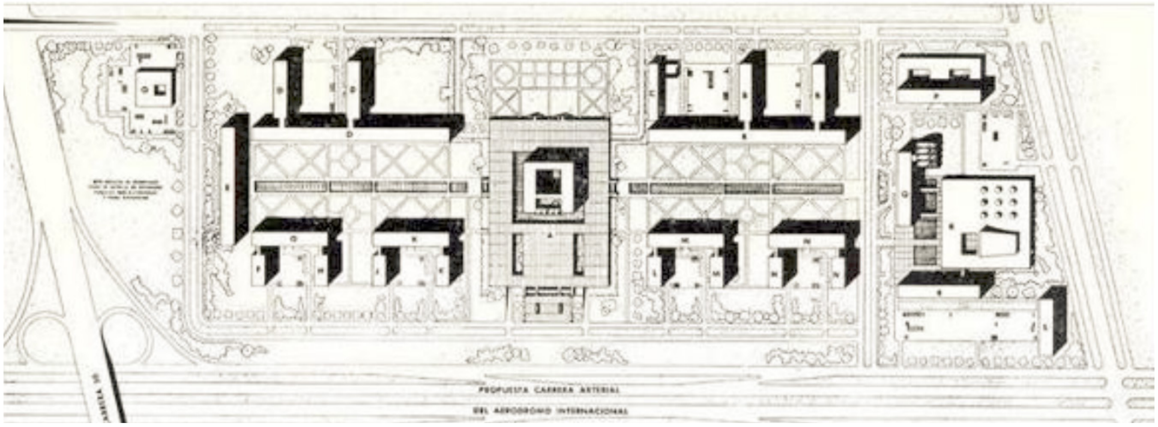


Figure 17
Skidmore, Owings & Merril Master Plan for the CAO (Gamboa, 2010)

Figure 18
CAN Buildings by the year 2006 (Gamboa, 2010)

4.1.2. Location

The CAN complex is located in what could be called the actual geographical center of Bogota. It is a point of critical importance for the city's every day operation as, additionally to the CAN, the area contains several urban facilities and amenities such as: the National University of Colombia; the Simon Bolivar Metropolitan Park: the Virgilio Barco public library; and numerous public sport and cultural facilities.

The complex is surrounded by the Salitre-Greco residential neighborhood to the west; La Esmeralda residential neighborhood and the Simon Bolivar Metropolitan park to the north; the National University to the east; and the aforementioned avenue "Calle 26" to the south. It is located almost at the middle point of this long axis which entirely traverses the city from east to west, connecting the financial and traditional center with the "El Dorado" airport. In front of the complex, across the Calle 26, is located the Salitre area which is currently a development and innovation pole for the city, attracting investments which are reflected in several large commercial, office and residential projects. One of the main urban objectives of the CAN project is to positively articulate the important elements surrounding it.

4.1.3. Details and Figures

The Ciudad CAN project considers not only a renovation of the current CAN, but an expansion of it. The development is divided into 3 larger polygons. As it had been previously stated, former president Rojas Pinilla's CAO original project summed 57.1 which are currently split in two plots (polygons 1A and 1B) separated by the Batallon Caldas Avenue. Polygon 1B included plots owned by the National University which have been comprised into the project development.

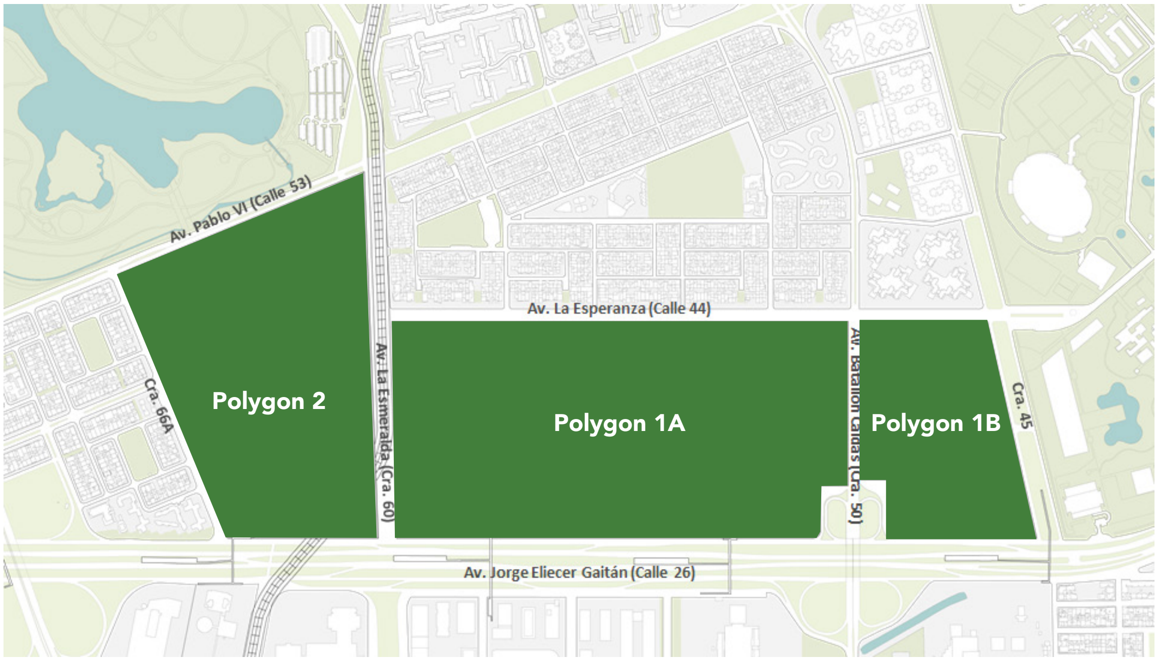
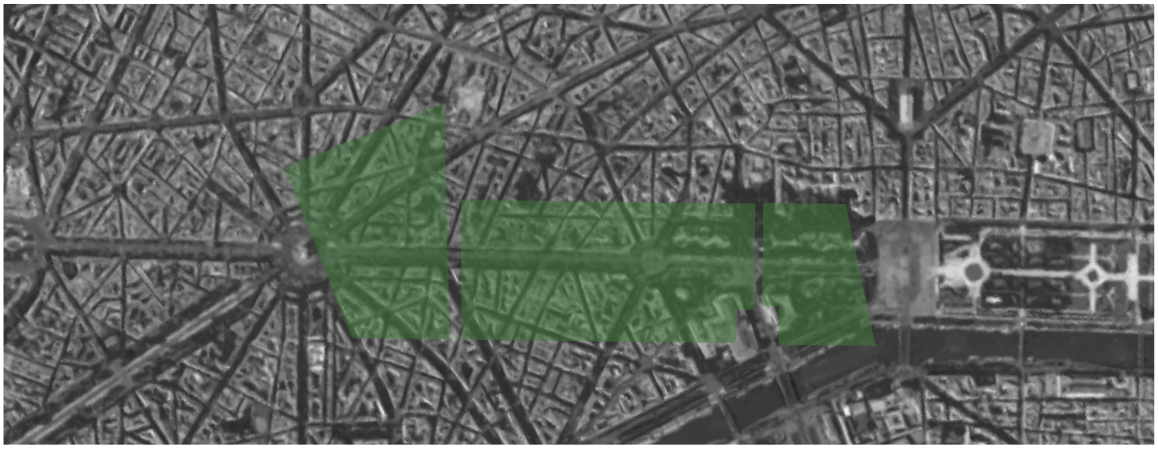


Figure 19
CAN Total Developable Surfaces. Adapted from (OMA, G+C, 2013)



Champs Élyseés
Paris

HafenCity
Hamburg

Figure 20
Surface comparison of Ciudad CAN with known international areas

Additionally, a large undeveloped plot property of the Cundinamarca Regional Government which is located west of the current CAN (polygon 2) has been included into the development project, adding 29.5 Ha. Finally, existing avenues, roads and public space between the polygons add an additional 21.9 Ha to the project, resulting in a total of 108.7 Ha surface to be developed (OMA, G+C, 2013). When compared to developments in other cities in the world, it is possible to appreciate the scale of the Ciudad CAN Project (See Figure 20)

The total surface of the project will be redistributed, assigning approximately 20% of the total area for open public space. From this land, a minimum of 8 Ha will be assigned to parks, 2.5 Ha to public amenities and 9.15 Ha for roads, sidewalks and bike lanes. The remaining area will be split into so named developable "super-blocks" which would have a maximum surface of 1 Ha each. Every single "super-block" varies in terms of shape and volumetric development, however, due to the proximity to "El Dorado" international airport, the maximum building height was set up to 70 m for all of them. The total projected buildable surface is 2,750,000 m2, out of which 920,000 m2 will be assigned for the governmental entities which give the name to the project. Together with the open public space, these areas result in a fairly balanced public-private use of land.

4.2. SUSTAINABILITY REQUIREMENTS

The National Government aims for Ciudad CAN to be an example of good governance and administration. It is currently impossible to deliver those ideas without embracing the concept of sustainability and that is why the Government explicitly requested for the project to be a national and international model of sustainable development. The "Technical Support Document" included in the winning Master Plan presented by OMA & G+C when translated from Spanish states: *"…sustainability involves various elements: the promotion of alternative and massive means of transport which improve air quality; environmental continuity; energy efficiency; water consumption reduction; and the use of technical mechanisms for sustainable drainage, green roofs and permeable materials which ensure the conservation of the hydrological cycle"* (OMA, G+C, 2013).

Following the government request, the CAN Master Plan has set up the following main objectives related to sustainability:

ENVIRONMENTAL OBJECTIVE:
Contribute to the conformation of Bogota's ecological structure, connecting the two large immediate ecological bodies around it: The Simon Bolivar Metropolitan Park and the National University Campus. Thus, making part of a larger ecological connection between the protected mountains to the east and the Bogota River to the west. Additionally, promote the culture of environmental sustainability through public educational spaces within the project.

URBAN DEVELOPMENT OBJECTIVE:
Promote a dense urban center, which adequately balances private developments with public spaces, amenities and services. The total development is to follow a varied and integral program design to promote a proper mix of uses and which demands high quality architectural and spatial standards.

LIVABILITY AND SOCIAL OBJECTIVE:
Promote the offer of high quality social housing within the project which must be well distributed and connected to the other components of the development, thus avoiding segregation. This is to be done through high quality urban public space immediately connected to commercial and social services on ground floor areas, promoting an urban life and sense of community.

In order the achieve the conceptual objectives previously described, the Ciudad CAN Master Plan has provided a set of more specific objectives on several topics related to sustainability. It has also provided a list of individual requirements to be met for each of them.

4.2.1. Mixed Uses

The mix of uses is a mechanism to insure permanent activity and occupation. It also reduces the need for long distance commuting which normally translates into a more intensive use of private vehicles. The project proposes a development program which include a wide range of uses, both private and public, arranging them in a compact and well distributed manner, which aims for a synergy between them, thus contributing to a 24 hours per day active city.

- Uses with more diurnal activity such as private and governmental offices would mostly be placed on the main façade of Ciudad CAN, that facing the linear park which traverses the project.

- Residential uses will be mostly located towards the north and west, connecting them to existing residential neighborhoods.

- Ground level of most blocks will be set for commercial use, regardless of their location within the project.

Figures 21 and 22 display the distribution of assigned buildable space for each type of use. The mix of uses is not only granted within the large urban project but within individual blocks as well.

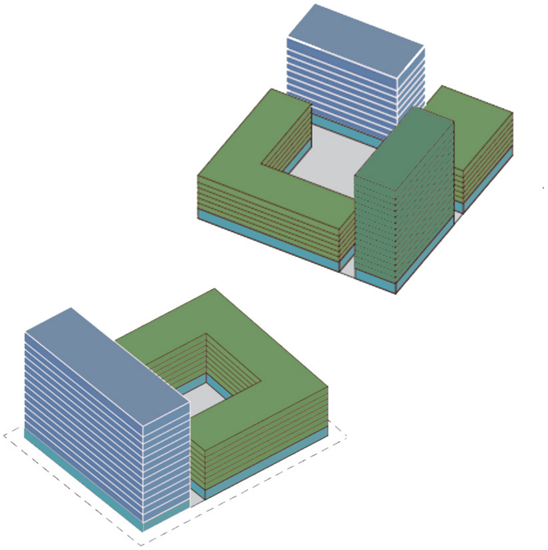


Figure 21
Examples of uses distribution within blocks. Adaptation from (OMA, G+C, 2013)

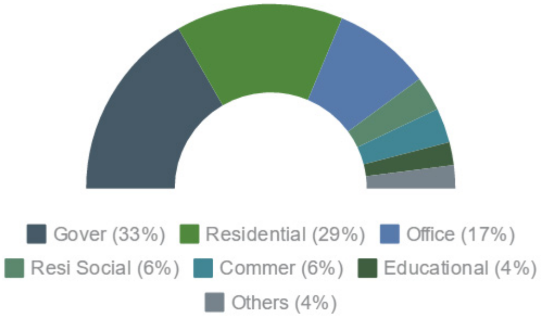


Figure 22
Distribution of buildable space per use. Adaptation from (OMA, G+C, 2013)

4.2.2. Energy and Transport

In order to reduce the CO2 emissions inherent to private vehicle use, the Master Plan includes a pedestrian and bicycle friendly grid within the project. Ciudad CAN will be connected to the other areas of the city through sufficient massive public transport infrastructure, initially using the existing BRT system connection on the Calle 26 Avenue, which currently counts with 4 stations along the section that serves as borer for the project. Further ahead, a larger multimodal interchanger station is planned to be built, connecting the BRT line to a potential light rail line subject to the city's transport development plans. Additionally, the plan states specific requirements for individual buildings. Some examples are:

- Provide parking spaces for maximum 20% of users and visitors of non-residential buildings.

- Provide bicycle users facilities such as parking areas and showers. Figures vary depending on the building main use.

- Designate a minimum 10% of the parking spaces for low emitting vehicles.

Ciudad CAN also aims to reduce CO2 emissions related to the buildings construction process and their operation. For this purpose, the Master Plan includes some minimum requirements for sustainable building:

- Buildings within the Ciudad CAN project are obliged to meet the energy efficiency building standards set by the American ASHRAE 90.1 building codes or similar.

- Buildings must count with energy metering and control systems which allow to monitor a disaggregated internal energy consumption.

- At least 75% of the hot water demand should be met using thermal collector systems

- The use of on-site renewable energy generation systems will be mandatory when local market conditions allow for a return of investment period shorter than 6 years.

4.2.3. Environmental Continuity

As it has been previously mentioned, one of the main environmental objectives of Ciudad CAN is to connect two of the largest green and ecological surfaces in the city which are the Simón Bolivar Park and the National University campus. This connection it's planned to be made through an ecological axis which traverses the entire project from southeast to northwest, constituting altogether a larger green public space for the citizens of Bogota and its visitors.

The proposed ecological axis stablishes a corridor which eliminates the fragmentation between the two existing habitats, articulating their fauna and flora which are now separated by heavy and paved urban surfaces. In order to achieve the expected outcome, it is planned to increase the vegetated areas within the project surface and only the use of native plant species will be allowed. The ecological connectivity will also be supported in the buildable blocks thanks to the mandatory green central patios and the use of green building roofs. Given the objective of the present document, this last particular topic will be discussed in much further detail.

Figure 23
Planned ecological integration. Adaptation from (OMA, G+C, 2013)

Expected additional benefits of the increase of vegetated areas are:

- Reduction of the heat island effect experienced in Bogota due to high reflective surfaces coverage.

- Increase the ratio of 1 tree for every 6 inhabitants which, as previously mentioned, it's extremely below recommended values and international standards.

- Increased aesthetic value of public spaces.

- Increased interaction of the citizens with nature.

- A more natural and responsible urban water management, which is the focus of this document and will be discussed next.

4.3. WATER MANAGEMENT

Included within the environmental objectives in the Master Plan of the project, there is a strong focus towards Sustainable Stormwater Management. The ecological connectivity comprehends at a great extend the connectivity of water bodies which naturally drain the area from the eastern mountains to the Bogota River. Recovering the natural hydrological cycle of the site is one of the environmental issues that is most strongly addressed by the project.

Additionally to the environmental benefits related to a more natural local hydrological cycle, there is a great economic advantage. Lower water consumption and drainage volumes would need a smaller infrastructure to supply those services. As it has been previously mentioned in this document, those economic benefits are mostly seen by the cities and the utility companies, in Bogota's case, the EAAB. Users and developers however, do not profit from the benefit of needing a smaller infrastructure. This is why in order to incentivize lower water consumption and drainage volumes, the ciudad Master Plan has stablished certain specific requirements for both public spaces and private developable areas.

4.3.1. Current Situation

The Ciudad CAN project is located within the San Fransisco sub-basin which it's part of the larger Fucha River drainage basin. The Fucha River extends for over 26 km draining and area of approximately 15,000 Ha (Empresa Virgilio Barco, 2015). As it is an already developed area, there is an existent water supply, drainage and sewage infrastructure on site. However, its capacity has yet to be studied as the redevelopment project signifies a much greater density, exerting additional pressure on both water supply and sewage infrastructure.

In terms of the site surfaces, the disorganized development of the site has led to a very varied materiality. In the already developed Polygons 1A and 1B, large low rise buildings and the sealed space between them used mostly for parking, contrast with the entirely green and undeveloped Polygon 2 and the large green areas along the streets that delimit the project.

Current state. Large paved parking areas and few green surfaces on internal streets.

Current state. Large green areas on permeter avenues and Polygon 2.

4.3.2. Reduction of Freshwater Consumption

In terms of fresh water consumption, being the entire area exclusively devoted to official offices use, the CAN would currently average a consumption of 11.18 liters per employee per day (Alfonso & Pardo, 2014). When comparing this value to average consumption for residential use (73.32 liters per person per day) and taking into account the much higher density expected with Ciudad CAN project, it is evident that the total water demand volume will increase.

The Ciudad CAN project states two key paths to reduce freshwater consumption within the project when compared to the standard consumption volumes in the city. The first one is to directly reduce consumption volumes through higher efficiency and increased awareness. The second path is to use an alternative water source in order to reduce freshwater extraction from paramos and aquifers, thus reducing their current level of degradation.

Comprised on the first path, the Master plan makes use of three main strategies:

- It requires the installation of low consumption devices in all buildings to be developed, regardless of their use.
See Table 07.

- It mandates the use of native or adapted species for landscaping purposes. Landscape designs must nor require additional artificial irrigation.

- The green corridor connecting both ends of the project will serve an additional purpose as educational space. The so called "Water Thematic Park" will comprise educational programs in order to increase public awareness towards responsible water use care of water bodies.

As for the alternative sources of water the Master Plan makes use of a single instrument:

- Runnoff water generated within the project area must be retained and reused on-site. This requirement specifically asks for the implementation of Rainwater Harvesting Systems which will be further studied in the present document.

Device	Max. Allowed Consumption	Units
Toilet	1.28	Gal per Flush
Urinal	0.125	Gal per Flush
Faucets	0.50 0.25	Gal per min Gal per Cycle
Showers	1.7	Gal per min
Dish-washers	1.7	Gal per min

Table 07
Maximum allowed water consumption for internal devices
(OMA, G+C, 2013)

Rendering of proposed
Water Thematic Park.
(OMA & G+C, 2013)

4.3.3. Sustainable Stormwater Management

In order to reduce the total runoff volume discharged into the drainage infrastructure during rain events, the Ciudad CAN Master Plan aims for the reduction of the imperviousness of the total project surface. For that purpose, not only larger green areas are proposed, but the use of several systems and strategies is requested for both public and private areas.

PUBLIC AREAS:
For the linear park, the main ecological and public space connector element, materiality of its surface has been determined so that it maintains a high degree of permeability throughout its entire length. Moving from completely pervious surfaces on both its ends and gradually decreasing towards the area that limits with the Calle 26 Avenue, as this are will also serve as a public square (see figure 24).

Several other WSUD strategies are to be implemented on all public surfaces of the project. These strategies will follow the requirement established in the "Sistemas Urbanos de Drenajes Sostenibles" issued by the Secretaria Distrital de Ambiente which has already been introduced this document. Next is a summary list of the required strategies:

- Pervious materials: Additionally to the perviousness of green and natural surfaces,

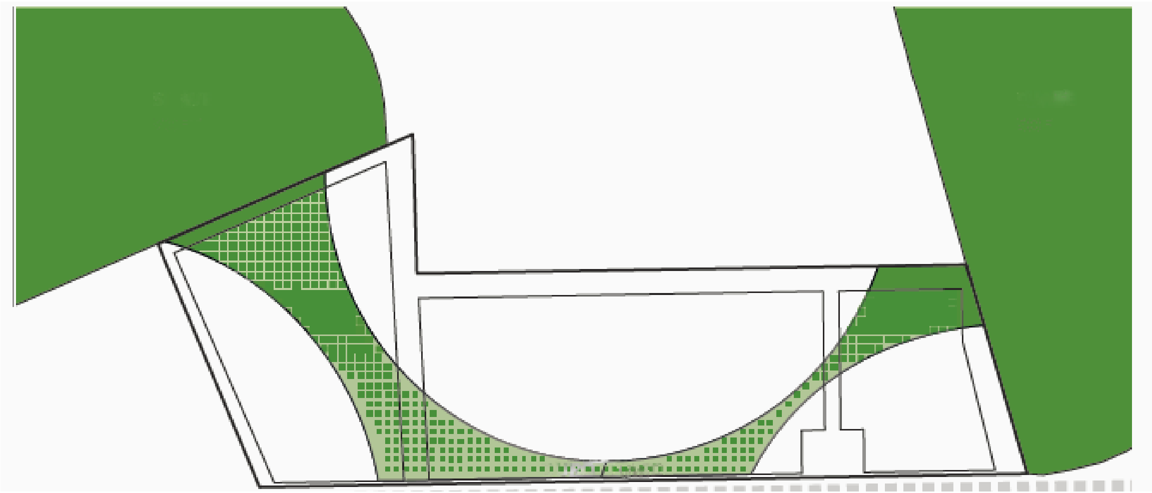


Figure 24
Surface materiality on the connecting linear park. Adapted from (OMA & G+C, 2013)

constructed surfaces such as roads and sidewalks shall also be built using materials such as pervious concrete, pervious asphalt and grass-concrete blocks.

- Bio-swales and tree-pits: These type systems are to be implement along both pedestrian and vehicular roads.

- Rain-gardens and bio-retention ponds: These strategies are to be implemented along the linear park which has a larger surface availability. They must be dimensioned to manage excess runoff water from the park and the adjacent hard surfaces.

- Modular Retention-Infiltration Boxes: These systems will be installed underneath vehicular roads. They will retain and infiltrate water which will enter from permeable pavements directly above them or directed from paved sidewalks and bike lanes.

PRIVATE AREAS:
Most of the aforementioned strategies can also be applied on developable plots as they can be implemented either at smaller or larger scales. However, the Ciudad CAN Master Plan only require the implementation of two specific strategies on these surfaces: **Green Roofs and Rain Water Harvesting Systems.**

4.3.4. Green Roof Systems

The designers of the winning proposal for the new CAN project are quite aware of the many environmental benefits inherent to the implementation of Green Roof systems which were introduced in Chapter 02 of the present document. These benefits are have even larger effects when the implementation of these systems is done at larger scales.

The Technical Support document of the Master Plan (OMA, G+C, 2013) includes the following list of goals and benefits which are expected to be attained through the implementation of Green Roof systems within the CAN project:

- Rainwater volume retention which help reduce discharge peak volumes during strong rain events. According to this document, Green Roof systems would potentially be able to retain 130,000 m3 of stormwater per year.

- The potential absorption of 80 tons of CO2 per year, exclusively by Green Roof surfaces every year.
- Aesthetics and landscape improvement.
- Urban Heat Island effects reduction
- Filtering of suspended particles
- Creation of additional spaces for leisure
- Improved energy efficiency of buildings
- Longer life of use of building rooftops.
- Biodiversity connectivity

In order to achieve these goals and effectively receive the aforementioned benefits the same document has stated very clear requirements and benchmarks for the implementation of this technology:

- Green Roof Coverage: 80% of all building free roof area have to be covered by Green Roof systems (excludes areas required for the installation of technical equipment necessary for the building operation).

- Intensive Green Roof Systems: 60% of the total Green Roofs area (48% of the total free roof area) will have to implement systems of a substrate depth of minimum 15 cm which allow the plantation mixed native species which guarantees the continuity of the biotic system.

- Extensive Green Roof Systems: The remaining 40% of Green Roofs area (32% of the total free roof area) can be covered with extensive systems with substrate depths lower than 15 cm.

Figure 25
Minimum Green Roof requirements in CAN Master Plan. Own compilation using info from (OMA & G+C, 2013)

4.3.5. Rainwater Harvesting Systems

The Master Plan of the project does not mention these type of systems or their benefits at the same extend it does with Green Roofs. However, without being at all specific regarding the treatment process or type of collection and retention infrastructure, the document does set a very ambitious benchmark for stormwater collection and use:

- 80% of the total stormwater runoff volume generated within a development project must be harvested and used on-site. Only 20% of the generated volume would be allowed to be discharged into the city's rain drainage infrastructure (OMA, G+C, 2013).

The aforementioned retention and use levels must be met for a 24 hours duration event with 2 years of return period. This specific event was chosen based on the requirement stablished by the LEED certification guidelines developed by the U.S. Green Building Council (OMA, G+C, 2013).

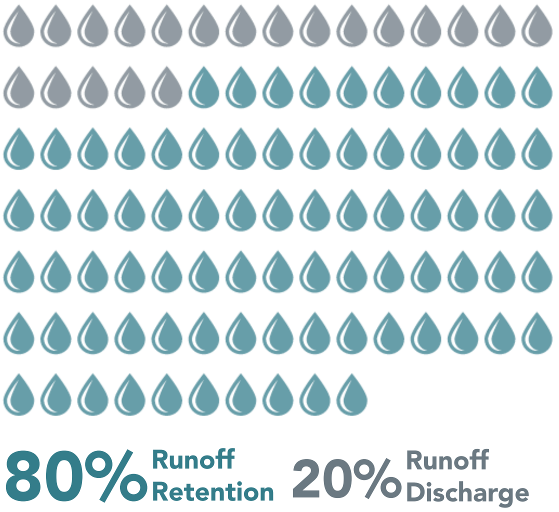


Figure 26
Minimum benchmark for Rainwater Harvesting and Discharge. Own compilation using info from (OMA & G+C, 2013)

4.4. ALTERNATIVE SUSTAINABILITY REQUIREMENTS

Despite having stablished very specific and direct technology and performance standards, the Ciudad Master Plan also provides an alternative way for individual building projects to meet the sustainability their sustainability requirements. Section 4,4 of the Master Plan's Technical Support Document (OMA, G+C, 2013) when translated from Spanish states: "In order to facilitate and simplify the implementation of the sustainability strategies during the development and construction of the Ciudad CAN project buildings, the execution of all sustainability strategies which are proposed next in this document can be avoiding if international certification standards LEED® (Silver or higher) or BREEAM® (Very Good or higher) are obtained."

This alternative way of complying with the sustainability standards of the project applies to all topic except for Sustainable Transport, meaning that Sustainable Water Management is comprised under this indirect instrument.
International certification systems designed to assess sustainability in building can have very different requirements and standards. Furthermore, and particularly for the topic of Sustainable Water Management, the standards of the two proposed systems vary significantly from those directly required by the Master Plan. As an example, Table 08 lists the credits and prerequisites of the LEED rating system which are directly related to Water Management and those directly related to Green Roof and Rainwater Harvesting Systems.

The LEED Rating System created by the U.S. Green Building Council is a points-based system which grants certain levels of certification once specific point thresholds are met. The LEED 2009 for New Construction and Major Renovations Rating System is based on sustainability criteria divided under 5 main topics. For each topic or chapter, the system states a list of prerequisites which are of mandatory compliance and a list of optional credits which have been granted weight through points (USGBC, 2016) . The Silver certification level stated as an alternative path by the Ciudad CAN Master Plan requires individual projects to achieve a minimum of 50 credit points of the total 110 possible.

Sustainable Sites Chapter	
Credit	**Requirements**
SS. 5,1 Site Development - Protect or Restore Habitat	Restore or protect a minimum of 50% of the site (excluding the Building footprint) or 20% of the total site area (including building footprint), whichever is greater, with native or adapted vegetation.
SS. 5,2 Site Development - Maximize Open Space	Provide a vegetated open space area adjacent to the building that is equal in area to the building footprint.
SS 6.1: Stormwater Design - Quantity Control	Case 1. Sites with Existing Imperviousness 50% or Less: Implement a stormwater management plan that prevents the post-development peak discharge rate and quantity from exceeding the pre-development peak discharge rate and quantity for the 1- and 2-year 24-hour design storms. Case 2. Sites with Existing Imperviousness Greater Than 50%: Implement a stormwater management plan that results in a 25% decrease in the volume of stormwater runoff from the 2-year 24-hour design storm.
SS 6.2: Stormwater Design—Quality Control	Implement a stormwater management plan that reduces impervious cover, promotes infiltration and captures and treats the stormwater runoff from 90% of the average annual rainfall using acceptable best management practices.
SS 7.1: Heat Island Effect—Roof	Option 2: Install a vegetated roof that covers at least 50% of the roof area.
Water Efficiency Chapter	
WE Prerequisite 1: Water Use Reduction	Employ strategies that in aggregate use 20% less water than the water use baseline calculated for the building (not including irrigation).
WE 1: Water Efficient Landscaping	Option 1. Reduce by 50% (2 points) Reduce potable water consumption for irrigation by 50% from a calculated midsummer baseline case. Option 2. No Potable Water Use or Irrigation1 (4 points)
WE 2: Innovative Wastewater Technologies	Option 1: Reduce potable water use for building sewage conveyance by 50% through the use of water-conserving fixtures (e.g., water closets, urinals) or non-potable water (e.g., captured rainwater, recycled graywater, on-site or municipally treated wastewater). Option 2: Treat 50% of wastewater on-site to tertiary standards. Treated water must be infiltrated or used on-site.
WE 3: Water Use Reduction	Employ strategies that in aggregate use less water than the water use baseline calculated for the building (not including irrigation). The minimum water savings percentage for each point threshold is as follows: 30% - 2 points / 35% - 3 points / 40% - 4 points

Table 08
LEED Credits related to Water Management, Green Roof and Rainwater Harvesting Systems. Info from (USGBC, 2008)

4.5. ET – CAN BUILDING

Ciudad CAN urban renovation project will officially start with the construction of the ET-CAN Building. Since several buildings which currentlz host national entities will be demolished during the redevelopment process, there is an immediate need for office space where these entities can transitionally operate. In 2015, the EVB announced the winner of the architectural design contest for the ET project. This was awarded to the Colombian architectural firm Daniel Bonilla Arquitectos. The contest was framed under the Ciudad CAN Master Plan proposed by OMA & G+C and had very specific objectives and 6 main evaluation criteria: Flexibility; Sustainability; Accessibility and mobility; Image and identity; Financial Viability; and Health and productivity (Empresa Virgilio Barco, 2015). Some details of these criteria relevant for the present study are:

FLEXIBILITY: Given the very specific circumstances of the project, the ET Building must be design under the notions of low-cost flexibility and adaptability. These notions must be applied more notably to platform areas where costumer service will be provided.

FINANCIAL VIABILITY: The proposed design must be very cost sensible and promote the use of technologies and products easily found in the national market.

SUSTAINABILTY: The building will make the most of natural lighting and ventilation on all facades. Open public space must be maximized and designed using water efficient landscaping. Green roof systems will have to cover a minimum of 50% of the total roof area.

4.5.1. Project Details

The ET-Building project must follow the ET-CAN Management Plan designed by the EVB. The building will be developed on Block 12 of the Master Plan. A plot located within the 1B polygon and which is bordered by the Calle 26 Avenue which means it will be part of the main façade of the Ciudad CAN project. Currently, the plot belongs to the Ministry of Mines and Energy and contains several buildings where some branches of this entity operate (Empresa Virgilio Barco, 2015).

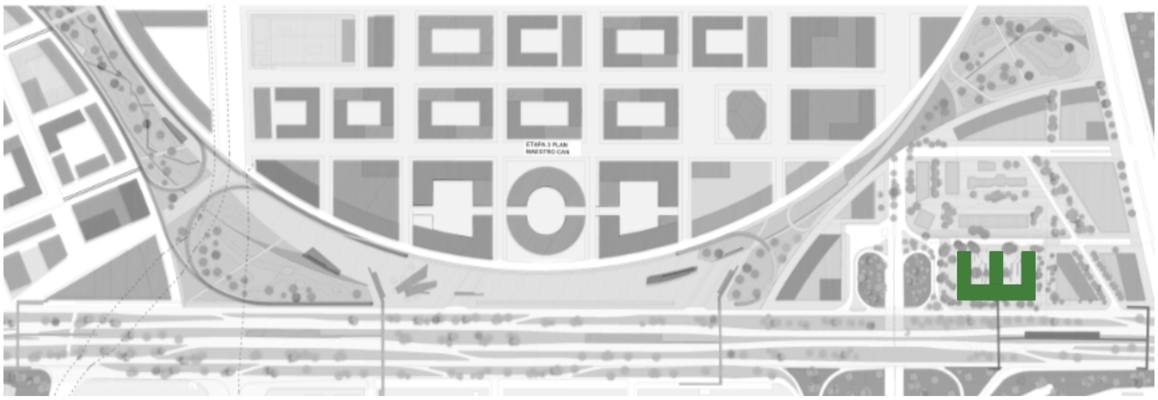


Figure 27
Location of ET Building within Ciudad CAN. Adaptation from (Daniel Bermudez Arquitectos, 2014)

The site's management plan applies to two plots which together account for a total surface of 50,543.6 m2. The plan allows an occupation index of 0.3, a building index of 1.78 and a maximum building height of 70 m. The ET building will be located on the smaller plot which has a surface of 24,546 m2, however, only 14,900 m2 will be intervened under the architectural proposal from Daniel Bermudez Arquitectos (Daniel Bermudez Arquitectos, 2014).

The proposed design consists of 3 identical towers of 66 m height and a total of 16 stories. The towers will be connected by a 4 story platform on the south-east façade of the project which is limited by the Calle 26 Avenue, forming the main building façade. Additionally to the main building, two smaller 2-story structures will be located in the space generated between the towers, one of which will be given a commercial use and the other will be the center for bicycle use. As it has been stated, the main use of the building will be public entities office space, however, given the mix-use approach of the Ciudad CAN Master Plan, certain areas will also be devoted for commercial use.

Rendering of proposed ET-CAN Building. (Daniel Bermudez Arquitectos, 2014)

4.5.2. Water Management

The building designer has decided to opt for the international certification systems alternative in order to meet the sustainability standards required in the Ciudad Master Plan. In the architectural proposal it has been clearly stated that the project will aim for a level Gold LEED certification (Daniel Bermudez Arquitectos, 2014), exceeding the requirements of the Master Plan. In order to do so, the designer has gone over every individual prerequisites and credits of the applicable LEED rating system and has provided a short description of the means to be used to achieve the set goal.

Regarding water management, the design proposal has decided to implement 4 main strategies in order to meet the LEED water use and stormwater runoff reduction criteria:

WATER EFFICIENT LADNSCAPING:

There are three types of gardens proposed to for the ground level landscaping. These three types have been designated as Rain Gardens, Fauna Niches and Permeable Stripes. All species selected for the project landscaping are either native or adapted.

WATER EFFICIENT APPLIANCES:

In order to reduce the freshwater consumption during the building operation, the following water-efficient appliances have been selected:

- Toilets – 1 gal/flush
- Dry Urinals
- Sensor Faucets – 0.5 gal/min
- Kitchen Faucet – 1.7 gal/min

RAINWATER HARVESTING:

The runoff water generated by the surface within the excavated perimeter (10,073 m2) will be harvested and reused within the building. This area includes building roofs and a part of the ground floor open surfaces. For retention and storage purposes, 3 rainwater tanks will be built under the 3rd underground level, one under each tower.

The total retention volume will account for 100 m3.

GREEN ROOF SYSTEMS:

The project design includes the installation of both intensive and extensive Green Roof systems. Intensive systems will be used on large roof areas of the towers and the platform. Intensive systems will be installed specifically on the roofs of the towers cores (17th level) and the additional smaller 2 story buildings (Café and Bicycle Center). Additionally, a share of the permeable stripes previously mentioned will be located on the ground floor open space directly above underground parking area.

The total Green Roof surfaces considered in the design are as follows:

- **Intensive Green Roofs: 1740.7 m2**
- **Extensive Green Roofs: 820.8 m2**
- **Permeable Stripes on Open Ground-floor: 348.55 m2**

The ET-CAN building is going to be first step and a symbol of what will be Colombia's largest urban renovation project. Given the specific Water Management proposed strategies and the fairly advanced design stage, it presented itself as on optimal opportunity to make an assessment of the performance of both Green Roof and Rainwater Harvesting systems in the local context of Bogota. The level of detail of the aforementioned strategies and figures are the base of the assessment proposed by this document.

ET-CAN Info Summary	
Total Project Surface	14,901 m^2
Building Footprint	5,808 m^2
Building Gross Area	71,351 m^2
Typical Tower Floor Area	1,450 m^2
Excavation Footprint	10,073 m^2
Total Underground Area	30,258 m^2

Table 09
ET-CAN Building Surface Information Summary (Daniel Bermudez Arquitectos, 2014)

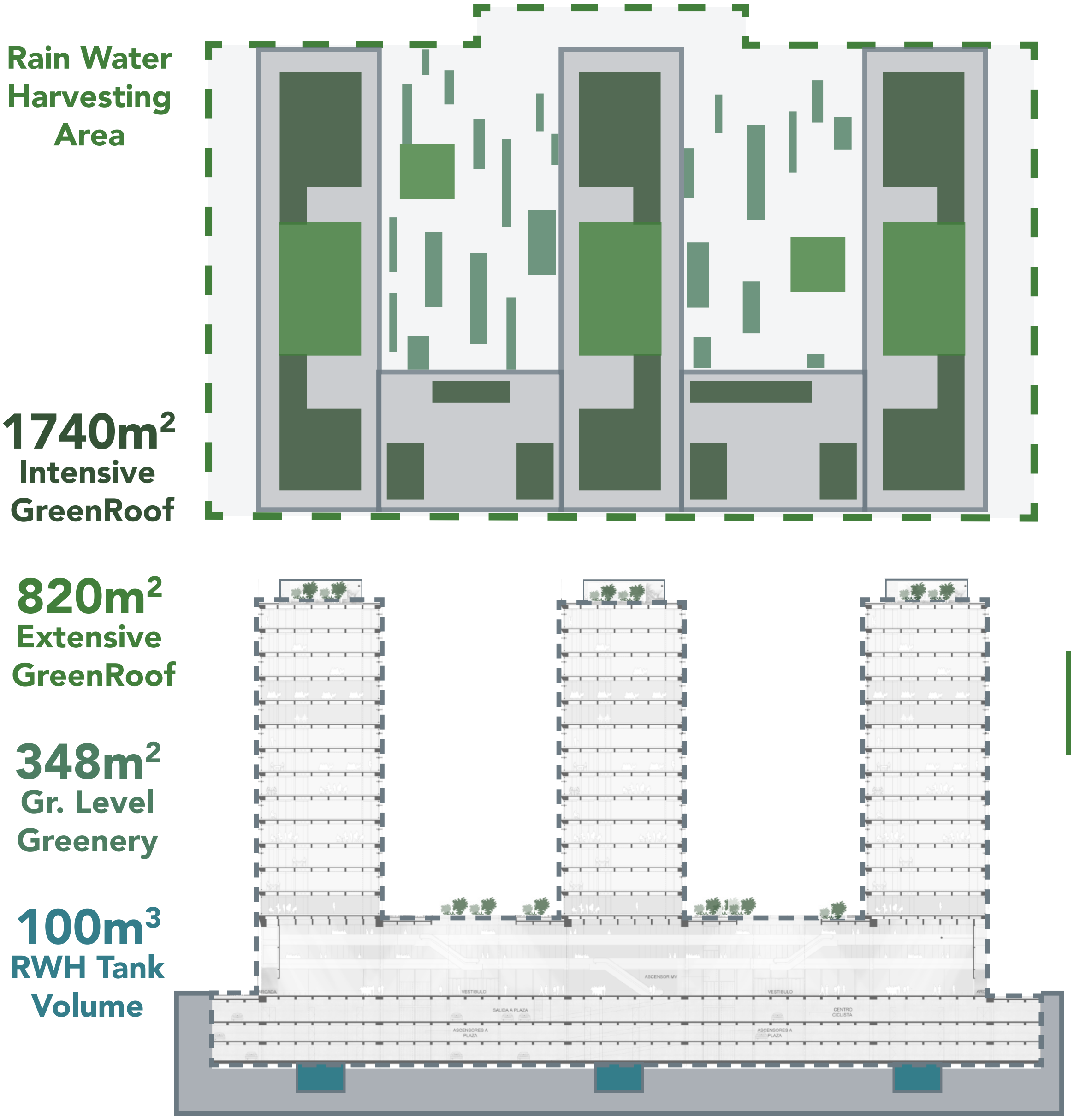
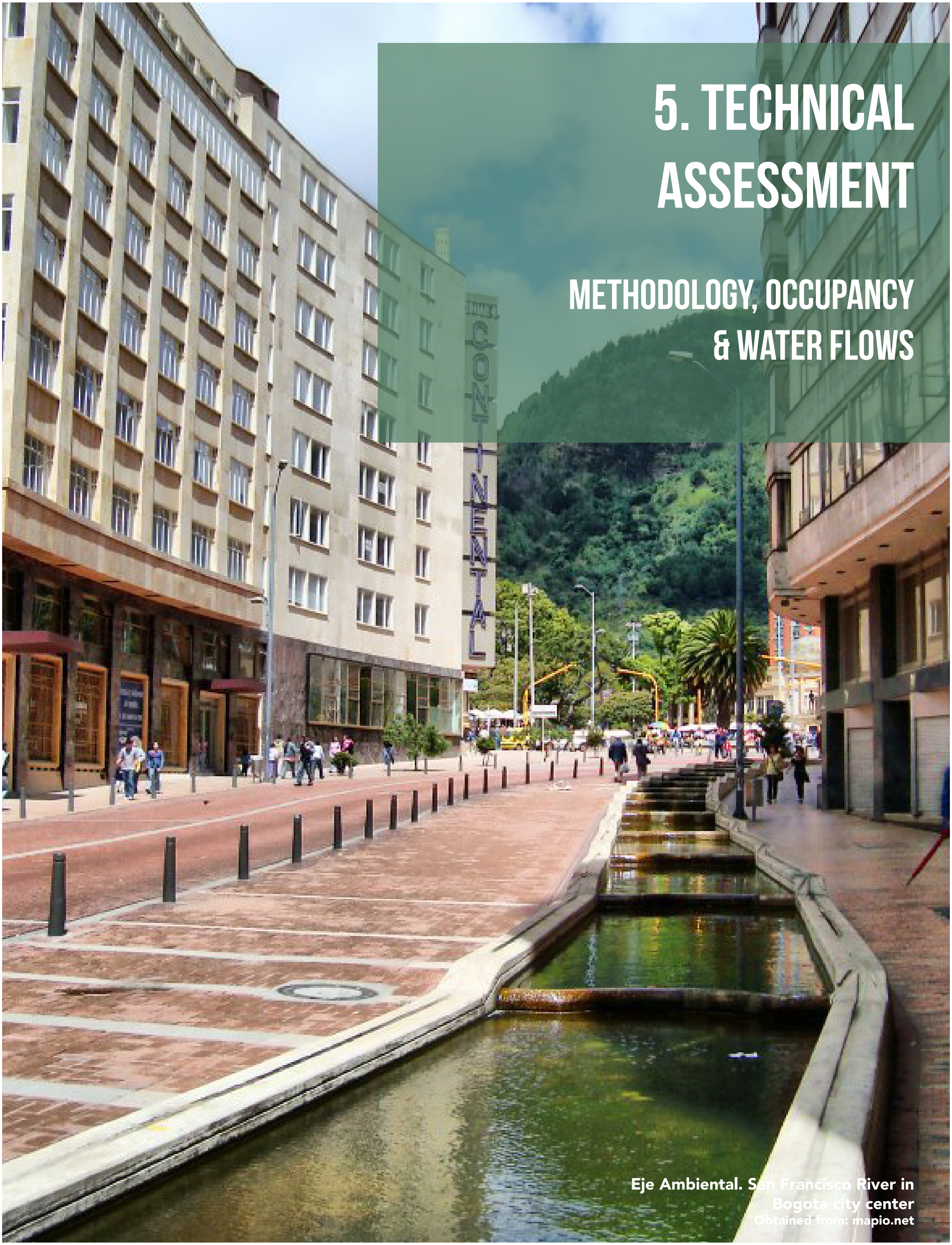


Figure 28
ET CAN Sustainable Water Management Strategies. Adaptated from (Daniel Bermudez Arquitectos, 2014)

5. TECHNICAL ASSESSMENT

METHODOLOGY, OCCUPANCY & WATER FLOWS



Eje Ambiental. San Francisco River in Bogota city center

Obtained from: mapio.net

5.1. ASSESSMENT METHODOLOGY

As it has been stated, the intent of the present document is to analyze the performance of Sustainable Water Management strategies to be implemented by the ET-CAN Building in Bogota. The present assessment is based on two of the main goals which the WSUD approach aims to achieve:

- **Reduction of Stormwater Runoff Discharge**
- **Reduction of Freshwater Extraction**

Moreover, the study aims to analyze the individual performance of two of the strategies which will be used in the project:

- **Green Roof Systems**
- **Rainwater Harvesting Systems**

The water management process within a building could be rather complex. Several elements and processes interact with each other at different stages. Any variation of element properties or to the interaction between elements would result in altered water flows. The number of elements and variables that take part in the water management process within a building can be very large. However, for the purpose of the current study, the total process has been simplified down to only two factors: Water Flows and Interaction Spaces.

5.1.1 Water Flows

Water is constantly flowing into and out of a building project and, in most cases, this process occurs as follows. Water naturally flows into a site or project through precipitation or surface runoff. The total natural inflow leaves the site either by a mix of evaporation, evapotranspiration, infiltration and surface runoff. Additionally, water also flows into a building via water supply infrastructure. This water flow meets various types of internal demands and then, almost 100% of it is evacuated via sewage infrastructure.

For the present analysis, the number of water flows has been simplified to:

- Precipitation
- Evaporation – Evapotranspiration
- Runoff generated on site
- Internal water demand
- Final water discharge

5.1.2. Interaction Spaces

This term has been chosen to name the physical space where a certain water flow is split into others. Normally, natural and artificial flows do not interact; however, the introduction of a Rainwater Harvesting System changes that traditional process. Additionally, Green Roof systems represent an alternation to the surfaces materiality which has a great effect the internal water flows. Looking to assess the performance of two selected systems, the interaction spaces used in the analysis are the following two:

- Building Surfaces
- RWH System Retention Tank

5.1.3. Performance Indicators

The analysis process is a basic water volume balance performed at both interaction spaces during any chosen time range. The relation between in and out flows at these spaces provides the necessary information to assess the performance of both strategies in terms of water use reduction and total runoff discharge.

5.1.4. Data Collection and Calculations

From the five water flows used in the analysis, only Precipitation and Internal Water Demand are completely unaffected by the implementation of Green Roofs or Rainwater Harvesting systems. Sufficient external information and data for these two wateflows would allow the analysis to reach more precise and relevant results. The remaining three types of flows directly depend from both the design characteristics of the project and the two aforementoined flows. Next, it will be explained how each of the five types of flows was estimated and balanced.

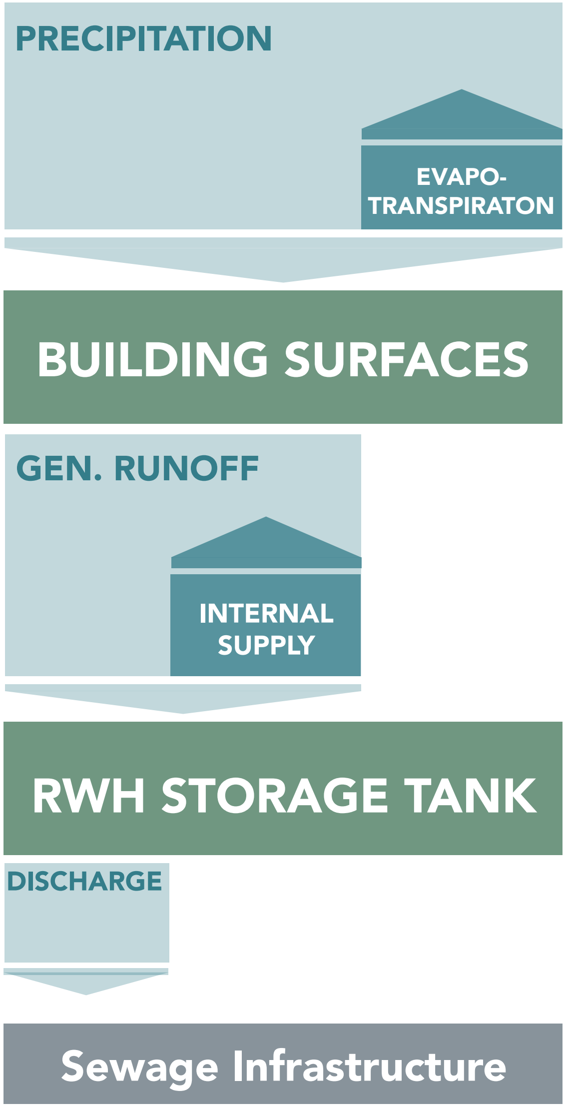


Figure 29
Water Flows and Spaces interaction

Figure 30
Location of Meteorological Station used for precipitation data collection

5.2. PRECIPITATION

Precipitation volumes and patterns are very specific to each geographical location. Even within Bogota limits, precipitation trends differ greatly. According to (Ruiz & Escobar, 2012), average yearly precipitation depths between the city districts can have differences of up to 1500 mm. The yearly precipitation pattern can also vary; however, the same study has found that approximately 80% of the meteorological stations analyzed show a bimodal yearly pattern as it has been shown in Chapter 01 of the present document.

The variation of precipitation heights within the city area makes it very important to select data from a meteorological station located as close as possible to the ET – CAN building. Fortunately, the Municipal Secretary of Environment counts with a fairly extensive network of stations which are managed by Bogota's Environmental Observatory (Obervatorio Ambiental de Bogota, 2016).

From the available stations constituting the OAB's network, the one located at the "Centro Distrital de Alto Rendimiento" was found to be the closest one to the ET-CAN project.

The selected station has been recording information of various meteorological variables since the year 2012. For the purpose of this study, hourly precipitation depth data was gathered over a four year period January 1st 2012 – December 31st 2015. Unfortunately it is the only period for which detailed information is available.

5.2.1. Yearly profiles

Figure 31 evidences that annual precipitation depths in Bogota can vary greatly from one year to another, even within a 4 year analyzed period. Total precipitation in 2015 was more than 40% lower than the precipitation fallen in 2014. These values show the local effects of the El Niño phenomena which recently took place. However, the average yearly precipitation depth of the analyzed period is 869 mm, a value not too different from the historical average of 799 mm.

When looking at the yearly profile, it is again evident the bimodal precipitation trend. There is a clear dry season and two wet seasons throughout the year. Together, the months of March, April, October and November account for approximately 50% of the total yearly precipitation, whereas the months from June to September account for less 15%.

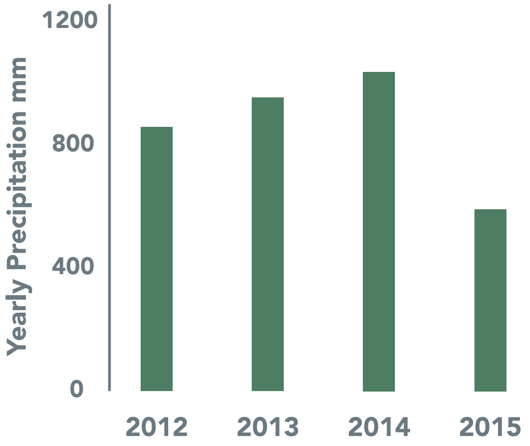


Figure 31
Reported Yearly Precipitation Depths

For a deeper precipitation analysis, it has been decided to group the months depending on the yearly precipitation volumes they receive:

- High: > 10% year precipitation
- Medium: between 5% and 10%
- Low: < 5 %

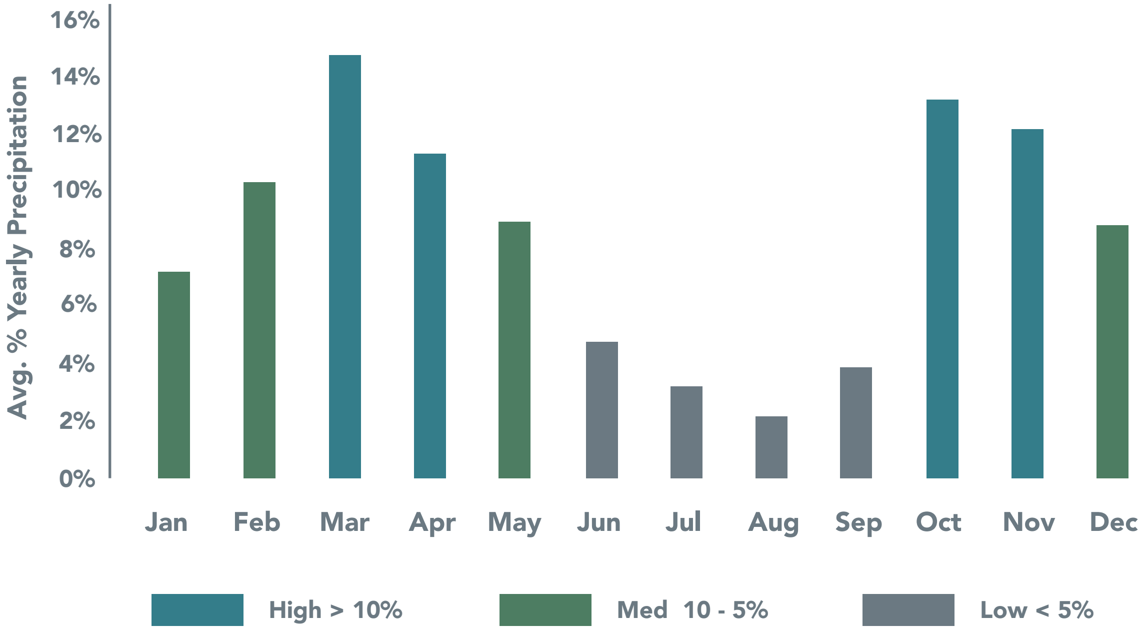


Figure 32
Average Yearly Precipitation Profile by Month

5.2.2. Daily profiles

In order to perform a thorough analysis of the performance of the systems proposed for the ET-CAN project, more detailed information about the precipitation pattern on the site was needed. For this reason, hourly precipitation data was gathered over the 4 year available period. The hourly information was gathered into 3-hour gap periods in order to simplify the analysis and results display.

Figure 34 shows the average daily precipitation pattern for our specific location. Scarcely 10% of the total precipitation falls before midday and more than half of the total precipitation falls between 12:00 and 18:00. According to (IDEAM, 2004), this particular pattern is due to mountains which border the city on the east. Whilst the morning sun heats up the water rich land on the east, the moisture ascends resulting in large cloud formations that are later blown over the mountain peaks and where they find lower temperatures, thus precipitating the water on the city during the afternoon hours.

Furthermore, despite the clear total depth difference between the categorized high, medium and low precipitation months, the daily pattern does remain rather stable throughout the year as it can be seen on Figure 33.

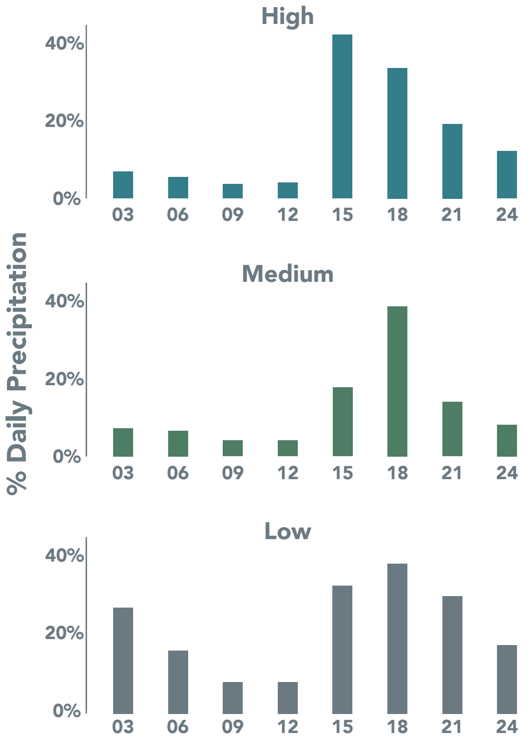


Figure 33
Daily Precipitation Profiles by Type of Months

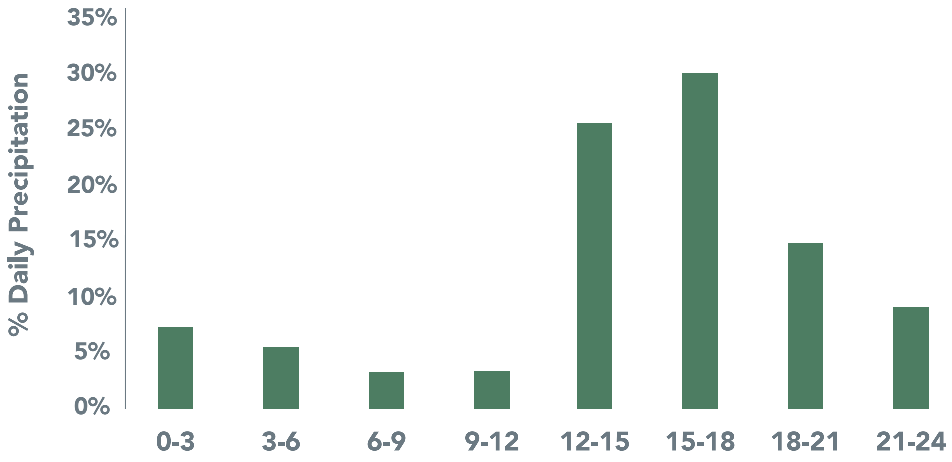


Figure 34
Average Daily Precipitation Profile. 3hour Time Gaps

5.3. ON SITE RUN-OFF

After precipitated water interacts with the project surfaces, the followed assessment process divides it into two flows. A percentage of the water is retained on the surfaces due to different factors, whereas the remaining water volume runs off the project surfaces and is directed to the storage tank of the RWH system.

The percentage of water that runs off from each surface of the project depends mainly on the surface's materiality. There are several methods to estimate this percentage, some more complex than others. However, for the purposes of this study, it has been chosen to follow the Rational Method developed by Kuichling in 1889. According to (Thompson, 2006), this method states a very simple equation to estimate the total runoff volume generated during a rain event:

$$Q=Cu*i*A*C$$

Q = Runoff Flow (Lenght3/Time),
Cu = Units Conversion Coefficient ,
i = Intensity of rain event (L/T),
A = Drainage Area (L2) and
C = Runoff Coefficient (dimensionless)

The Runoff Coefficient represents the fraction of rainfall that is converted to runoff by each surface. It is a dimensionless variable that can take values between 0-1. This coefficient is a property of each surface material and depends on a great number of variables such as perviousness, steep gradient, layer depth, rain intensity, roughness, amongst many others.

To simplify the runoff volumes estimations, different coefficients have been assigned to the most common materials present on construction projects or urban or rural landscapes. Table 10 is a summary of the

Type of Surface	Material	Runoff Coefficient C_u
Sloped Roof	Metal, Glass, Fiber Cement Brick, Paperboard	0.9 - 1.0 0.8 - 0.9
Flat Roof (Slopes 3 -5%)	Metal, Glass, Fiber Cement Paperboard Gravel	0.9 - 1.0 0.9 0.7
Green Roofs (Slopes 15 - 25%)	Thickness < 10 cm Thickness > 10 cm	0.5 0.3
Streets/ Paths/Sqaures (flat)	Asphalt, Concrete	0.9
Gardens and Grass	Flat Steel	0.05 - 0.1 0.1 - 0.3

Table 10
Runoff coefficients for various constructon materials
(DWA, 2009)

standard runoff coefficients for the design of drainage infrastructure in Germany (DWA, 2009).

The ET-CAN design is still not at a very advanced stage, reason for which there is no available information of the materials intended to be used for the projects surfaces. However, the set of documents included in the architectural design proposal elaborated by (Daniel Bermudez Arquitectos, 2014) provided information on the types of exterior areas and their total surfaces.
(See Figure 35)

According to the design proposal, 100% of the runoff water generated within the excavation perimeter will be harvested and directed to the storage tanks located under the lower underground parking level. Thus, only the surfaces within that perimeter have been taken into account for the analysis.

5.3.1. Surface Materials

HARD SURFACES:

The ET-CAN project will be a traditional reinforced concrete building with flat roofs. Thus, it is expected that the material used on the hard roof will be concrete covered with waterproofing sealers. Additionally, a large area of the roof will be used for mechanical equipment.

According to the renders and the common local building standards, concrete- or stone-slabs would be expected to be use for the exterior hard surfaces on the ground level of the project.

The runoff coefficient C recommended for this type of surfaces is 0.9 and could be assumed as constant according to the reviewed German standards (DWA, 2009).

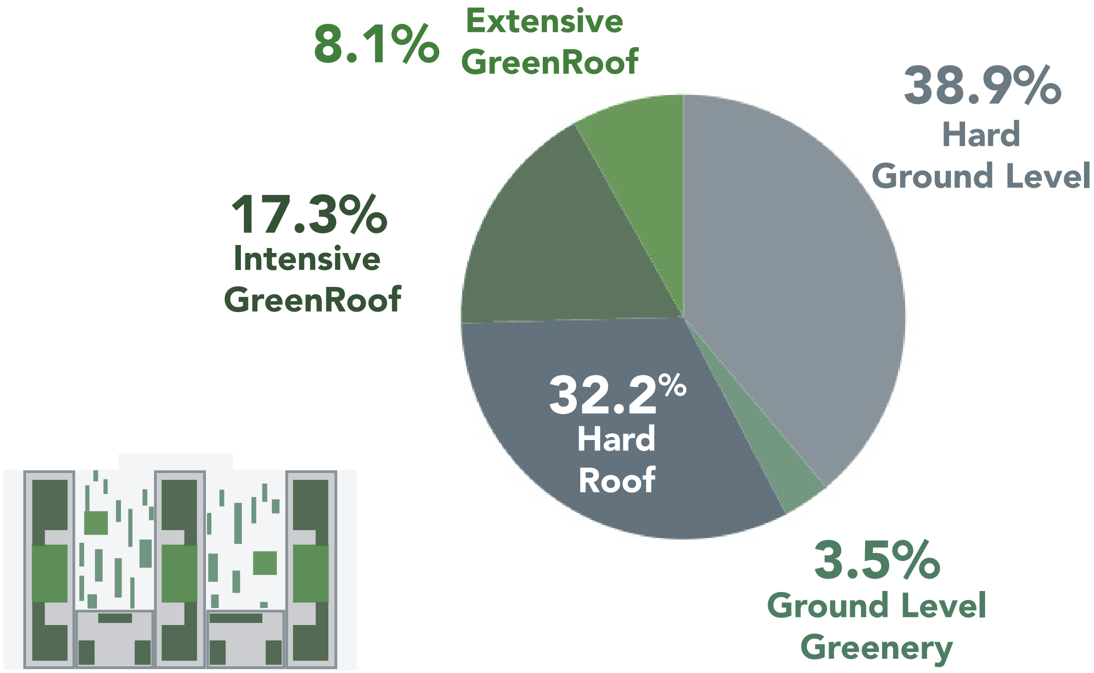


Figure 35
Project Surface Distribution

GREEN ROOFS:

Unlike hard materials, the estimation of the runoff generated by Green Roof Systems can be much more complex. In order to achieve more realistic results, it cannot be assumed that they operate with constant runoff coefficients. As it has previously been mentioned in this document, retention performance of Green Roof systems depends on various factors both inherent to the system itself and the environmental conditions of the site where they are installed. However, the variables that mostly affect their retention properties are the thickness of the substrate layer and it´s porosity or void ratio (Berndtsson, 2010).

Unfortunately, the Green Roof market in Colombia remains very small and manufacturers still do not provide detailed technical information of their systems. For this reason, it has been decided to use the information of two conventional systems manufactured by the German company OptiGrün International AG. Being a worldwide market leader, they provide detailed information for each one of their solutions. Also, given the low local market status for Green Roofs, the most basic solutions from this company were selected for both intensive and extensive systems.

Although the manufacturer provides a Runoff coefficient that has been calculated following the suggested methodology by the FLL (Forschungsgesellschaft, Ladschaftsentwiklung Landschaftsbau), the German Research Society for Landscape Development, these guidelines request the coefficients to be estimated for a very specific rain event. Given the nature of the calculation process of this study, which is done with real data and determined time gaps, these coefficients could not be applied.

Instead, it has been decided to variate the runoff coefficient of the systems taking into account to the amount of water precipitated during current and the previous 3hour gap. Three different values have been assigned as follows:

	Intensive	Extensive
System	OptiGrün Garden Roof	OptiGrün Nature Roof
Total Height	260 mm	100 mm
Subsrate Layer Height	200 mm	50 mm
Weight	320 kg/m^2	100 kg/m^2
Runoff Coefficient	Aprox. 0.2	Aprox. 0.56
Water Storage Capacity	0.3	0.35
Price	50 euro/m^2	22 euro/m^2

Table 11
Info Summary of selected Green Roof Systems (Optigrun International AG, 2016)

- Precipitation depth < 10% substrate height (C = 0.0): A share of the water fallen on vegetated surfaces is evapotranspirated by the plants. This amount depends on the plant species and environmental conditions. However, to simplify the calculations, it has been assumed that any precipitation depth within this range is completely evapotranspirated over the 3hour period which signifies a 0% runoff flow for both systems.

- Precipitation depth > Saturation depth (C = 0.9): When the substrate layer of each system reaches saturation, it can no longer retain water and behaves as a completely impervious surface. Saturation depths of both systems were calculated according to the Water Storage Capacity of their substrates following the information provided by (Optigrün International AG, 2016).

- Saturation Depth Intensive GR
  200mm * 0.3 = 60 mm

-Saturation Depth Extensive GR
  50mm * 0.35 = 17.5 mm

- For precipitation depths not applying to the previous two cases, the estimated Runoff Coefficient provided by the manufacturer (Optigrün International AG, 2016) was used for each system.

GROUND LEVEL GARDENS:

Given that all of the collection surfaces are located above an underground parking structure, vegetated areas on the ground level cannot be assumed to act as natural landscaping. Granted that the soil located underneath these areas has a defined depth, the generated runoff has been calculated following the same parameters used for Intensive Green Roof surfaces.

5.3.2. Total Volume Estimation

A total Runoff Generated volume value for each 3hour time gap has been then calculated as a weighted sum of all volumes generated by each of the 5 selected surface types.

$$\text{Tot RunOff Vol}_i = \text{Precip. Depth}_i * (A_1 * C_1 + \ldots + A_1 * C_1)$$

5.4. EVAPORATION/ EVAPOTRANSPIRATON

For the present analysis, it has been assumed that the total precipitated volume that is not harvested during a time period has then been retained on the project surfaces via either evaporation or evapotranspiration:

$$\text{Tot. Surface Retained Vol}_i = \text{Tot. Precipitation Vol}_i - \text{Tot Runoff Vol}_i$$

5.5. INTERNAL RAINWATER DEMAND

In Chapter 02 it has been explained the most common uses which are suitable to be supplied using harvested rainwater. According to the design proposal, the RWH system would follow a treatment process so that the water quality is suitable for two uses: Landscape Irrigation and Sanitary Flushing Devices.

5.5.1. Irrigation

Although irrigation has been mentioned as a possible use for harvested rainwater, it has been discarded from the present analysis for two main reasons: Precipitation yearly patterns in Bogota; and landscaping water efficiency requirements in the Ciudad CAN Master Plan.

Using the data obtained from the selected meteorological station, the average numbers of rain days were calculated for every month. Figure 36 shows that, even during low precipitation months, the daily chances of rain remain higher than 40%. Throughout the year, the average daily chance of rain events is approximately 53%. From this information it's possible to assume that, for the project location, rain events occurrence remains reasonably constant despite the great variations in terms of volume.

Moreover, the Ciudad CAN Master Plan requires the use of native or adapted species for the landscaping design, which theoretically should not require artificial irrigation. The selection of species included in the design proposal does follow this requirement, reason for which it can be assumed that artificial irrigation for landscaping areas will not be required.

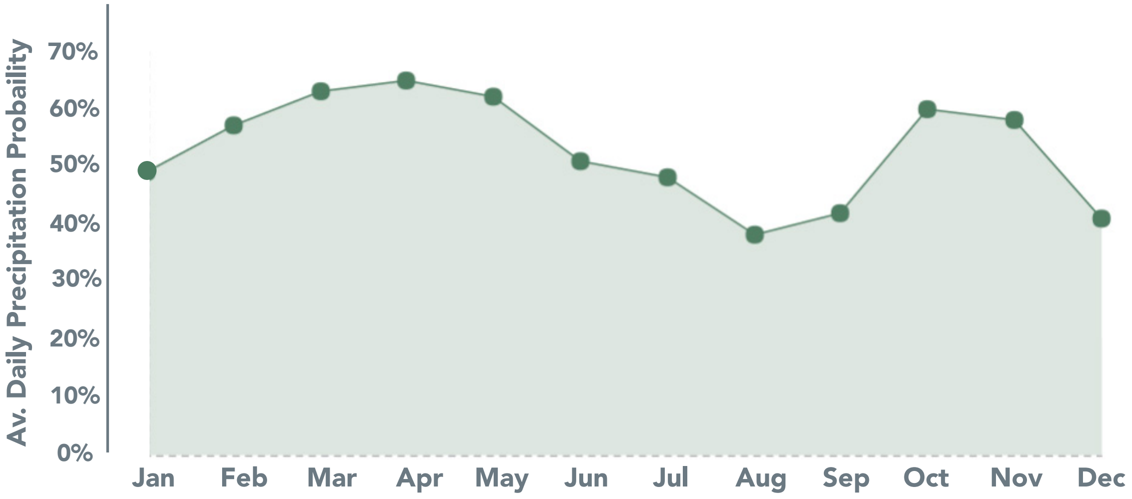


Figure 36
% Raindays by Month / Chances of Daily Precipitation

5.5.2. Building Occupancy

As it has been mentioned before, the ET-CAN project will pursue the LEED certification. The certification process requires the project to base their performance estimations on certain specific American standards applicable to each topic. Given the lack of precise information within the design proposal documents regarding the expected occupancy of the building, expected occupancy figures have been estimated following the standards required by the LEED certification process.

The applicable standard used for LEED when estimating a building's occupancy is the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) 90.1 from 2004 (USGBC, 2008). This standard assigns average occupation rates to different space uses. The calculation method suggested by the ASHRAE standard was followed as it is explained next:

1. Disaggregate the total ET-CAN building areas depending on its final use.

2. Apply the relevant occupancy ratio from ASHRAE 90.1 for each surface type for both employees and visitors

According to the standards required by LEED, the ET-CAN would have an estimated occupation of 2774 employees and would receive 913 additional visitors daily.

Use	Underground	Platfrom	Towers	TOTAL
Parking	27,843.5 m^2			27,843.5 m^2
Technical	1,642.0 m^2			1,895.7 m^2
Commercial	315.8 m^2	1,256.7 m^2		1,572.5 m^2
Service		9,386.0 m^2		9,386.0 m^2
Office	456.4 m^2		58,784.1 m^2	59,240.5 m^2

Table 12
Total Project Surfaces by Use
(Daniel Bermudez Arquitectos, 2014)

Use	Surface	m^2/Employee	m^2/Visitor	# Employees	# Visitors
Parking	27,843.5 m^2	0	0	0	0
Technical	1,895.7 m^2	0	0	0	0
Commercial	1,572.5 m^2	51	12	31	131
Service	9,386.0 m^2	56	12	168	782
Office	59,240.5 m^2	23	0	2,576	0
Total	**99,939.2 m^2**			**2,774**	**913**

Table 13
Total Project Occupancy following ASHRAE 90.1 2004. Ellaboated using info from (USGBC, 2008)

5.5.3. Daily Consumption Volume

Previously in this document, information about daily water consumption provided by the EAAB was shown. This data would be very applicable to the present analysis as it is determined on actual consumption readings for different uses in the city. However, this data provides information on the average total water consumption per building use only. Yet, for the purpose of this analysis, information on water consumption specifically for flushing devices is needed.

Fortunately, the ET-CAN design proposal included specific information on water consumption of the hydro-sanitary devices to be installed in the building. This information is enough to estimate the water demand suitable to be supplied by RWH if also following the process required by LEED for this purpose.

1. Water consumption information for flushing devices provided by the design proposal. Given that ET-CAN is an office building, rainwater suitable consumption such as clothe-washers is non-existent.

- Toilets – 1 Gall/flush
- Dry Urinals

2. The relevant LEED certification guidelines (USGBC, 2008) provide standard information on total daily uses per user. The default standards used by LEED are based upon the U.S. requirements from the Energy Policy Act (EPAct) of 1992, issued by the Environmental Protection Agency (EPA´s) Office of Water. The number of uses varies depending on the user´s gender and type.

Device	Employees	Visitors	Retail Costumers	Students	Residents
Toilet (male user)	1	0.1	0.1	1	5
Toilet (female user)	3	0.5	0.2	3	5
Urinal	2	0.4	0.1	2	0

Table 14
Default daily uses of sanitarz devices per type of user. (USGBC, 2008)

Flush Devices					Daily Consumption (m^3)		
	Consumption		Uses				
Item	Gal/ flush	m^3/flush	Employ.	Visitors	Employees	Visitors	Total
Toilet (male user)	1.0	0.0038	1.0	0.1	5.25	0.17	5.42
Toilet (female user)	1.0	0.0038	3.0	0.5	15.75	0.86	16.62
Urinal	0.0	0.0	2.0	0.4	0.00	0.00	0.00
Total					**21.00 m^3**	**1.04 m^3**	**22.04m^3**

Table 15
Estimation of daily water consumption for Flushing Devices

3. Using the estimated occupation, together with the previous information; and assuming a gender split of 50% male / 50% female for both employees and visitors, a total daily demand for flush sanitary devices was estimated.

The total estimated daily water consumption for flush devices in the ET-CAN project would be 22.04 m3.

5.5.4. Daily Consumption Profile

Detailed information containing daily consumption profiles is important for all water supply utility providers in order to optimize their operation. However, as it has previously stated, disaggregated information on daily profiles for different purposes for the same user is not easily found. This is because most utility providers meter the consumption volumes at individual user connections to the main water supply infrastructure. Unfortunately, the way how water is consumed within the user property is normally not metered. Considering this, no real information could be found on how much of the total daily water consumption in Bogota is used for purposes which are suitable for harvested rainwater.

Not having this information available for Bogota, it was necessary to use data from studies performed elsewhere. In 2011, the California Public utilities Commission hired a study to assess the embedded energy in water use. For this purpose, a large study on end-use water demand profiles was made (Aquacraft, 2011). This study collected data to elaborate end-use disaggregated daily consumption profiles for various types of buildings or users such as residential, commercial, agricultural and industrial. Specifically for office use, meters were installed on several office buildings from the cities of Santa Rosa and San Diego which were found to be the most significant. Figure 38 displays the resulting daily disaggregated consumption profile.

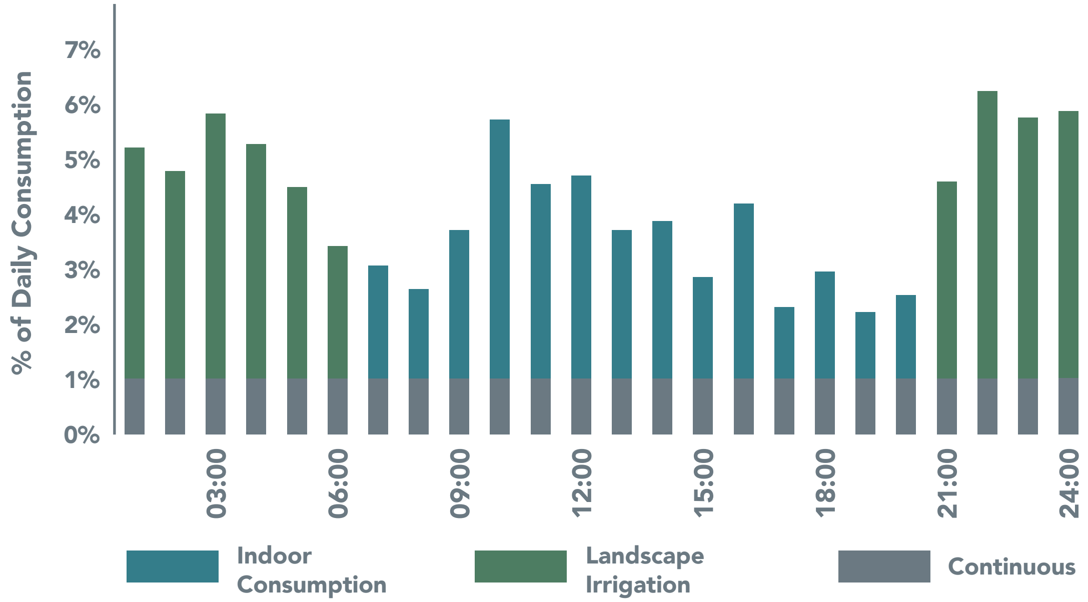


Figure 38
Average Daily Internal Demand Profile by End Use. Adapted from (Aquacraft, 2011)

For the purpose of this study, the resulting consumption profiles data from (Aquacraft, 2011) was taken and applied to the local case study by using the following assumptions or alterations:

- Irrigation demand was ruled out, as in the ET-CAN project is non-existent
- Hourly data was grouped to 3 hour time gaps
- The consumption profile for total indoor process was applied to flushing devices exclusively

Figure 38 shows the resulting adapted daily consumption profile.

5.6. WATER DISCHARGE

By the definition given in the methodology described earlier in this chapter, the total water discharge volume is the residual water flow generated when together the tanks stored volume and the total rainwater harvested volume for any given 3hour time gap exceeds to maximum capacity of the RWH system retention tank. The previous tank volume would already take into account internal demand flow related to the analyzed time gap.

$$\textit{Tot. Discharge Vol}_i = \textit{Runoff Vol}_i + (\textit{Tank Level}_{i-1} - \textit{Int. Demand}_i) - \textit{Tank Max. Cap.}$$

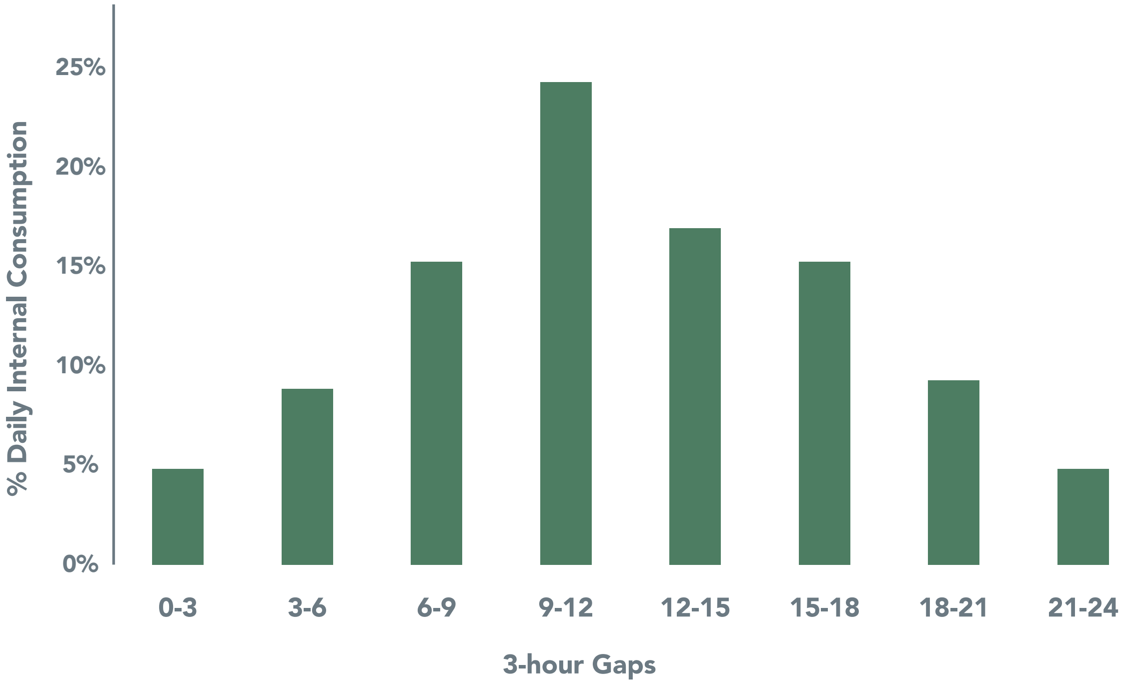
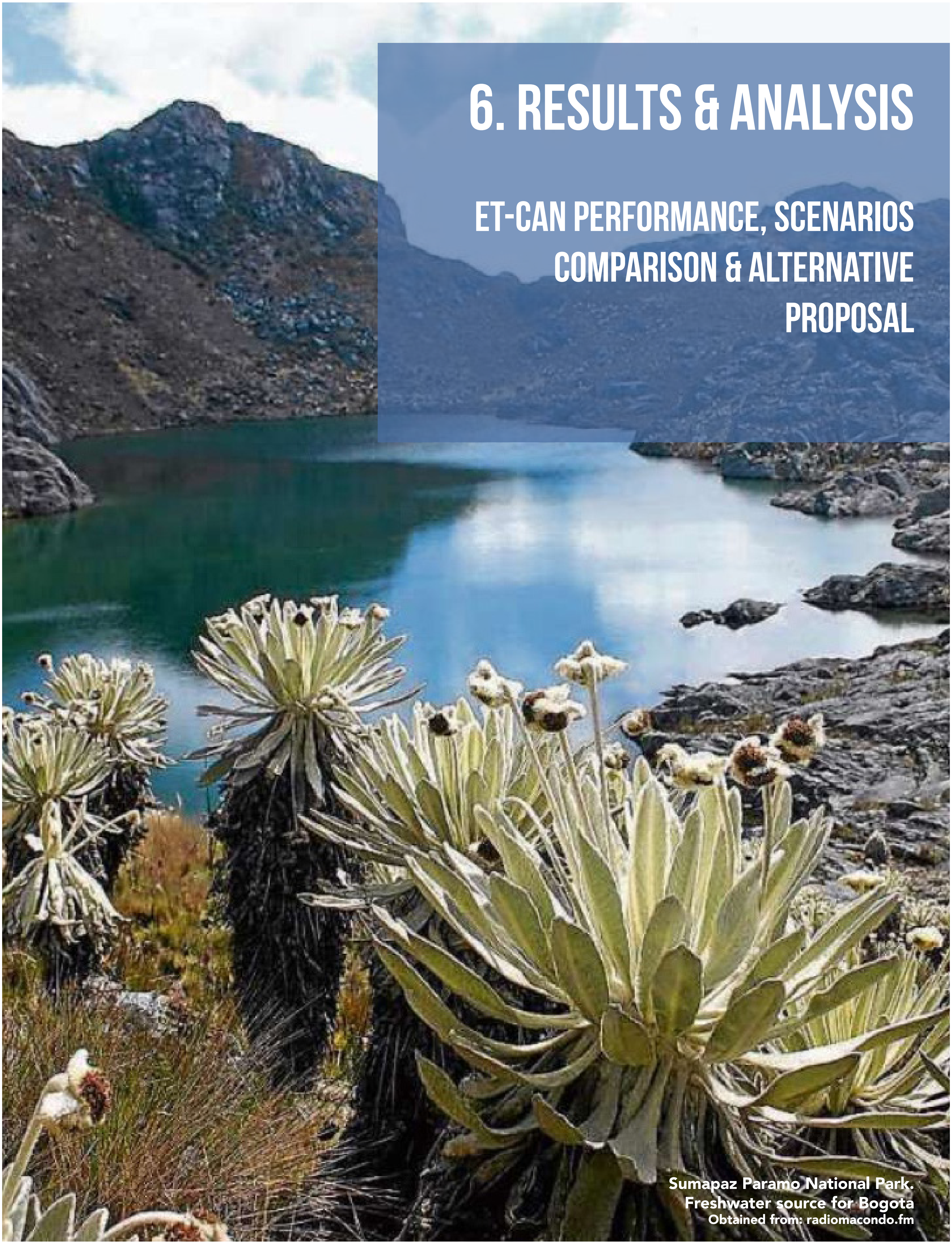


Figure 38
Average Daily Internal Demand Profile. Own compilation using info from (Aquacraft, 2011)

6. RESULTS & ANALYSIS

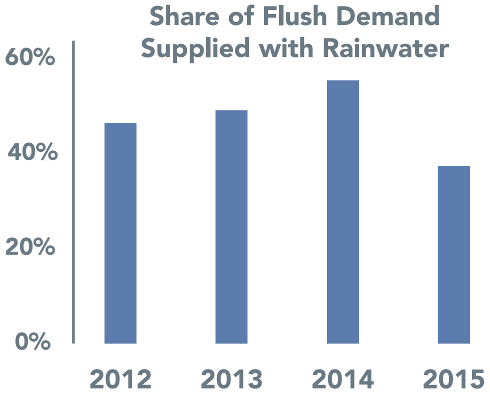
ET-CAN PERFORMANCE, SCENARIOS COMPARISON & ALTERNATIVE PROPOSAL



Sumapaz Paramo National Park.
Freshwater source for Bogota
Obtained from: radiomacondo.fm

In order to evaluate the performance of the Sustainable Water Management strategies proposed for the ET-CAN project, the aforementioned methodology was followed using the information obtained from the design proposal and the available precipitation data gathered by the chosen meteorological station. A complete flow analysis was performed for every 3-hour gap of the analyzed period: January 1st 2012 – December 31st 2015

The followed process allowed estimating the volume of all of the relevant Water Flows previously described for each 3-hour period and at both interaction spaces. This level of detail permits a thorough analysis in which the performance of each implemented strategy can be evaluated at different periods of time, whether for a specific rain event, as well as week, a month or a year time period.



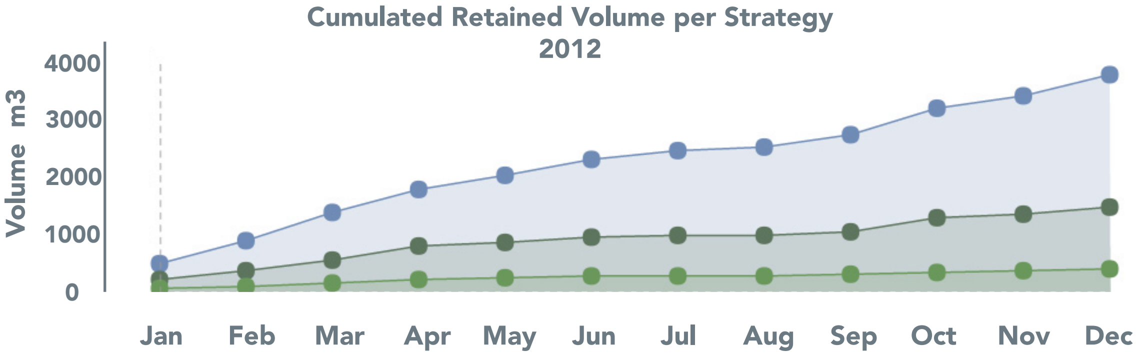
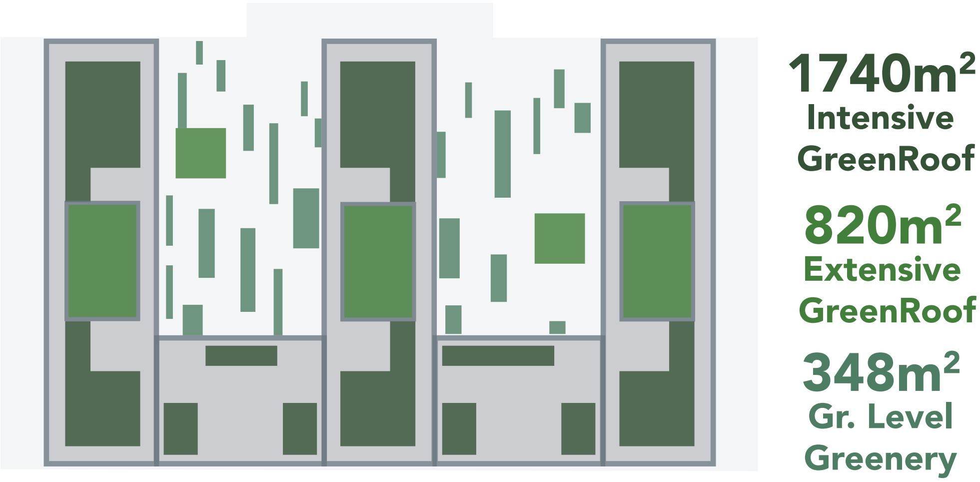


Figure 39
Example of possible analysis time frames and scales



6.1. ET-CAN ACTUAL DESIGN

As previously mentioned in Chapter 4, the ET-CAN design team has considered various strategies regarding Sustainable Water Management. However, the present study focuses exclusively on Green Roof systems and Rain Water Harvesting systems for which a short summary is provided next:

GREEN ROOF SYSTEMS:

Large roof surfaces of both towers and building platform will be covered with Intensive and Extensive Green Roof systems. Also, given that the complete analyzed area is located above underground parking; vegetated areas placed on the exterior ground level of the project were considered to perform as Intensive Green Roof systems.

- Intensive Green Roofs: 1740.7 m2
- Extensive Green Roofs: 820.8 m2
- Green Open Ground-floor: 348.55 m2

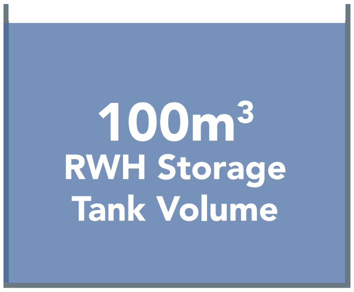


Figure 40
Summary of WSUD strategies design for ET-CAN

RAINWATER HARVESTING:

In order to collect rain water and have this volume available for the building's internal use, 3 underground retention tanks will be built. The tree tanks together add up a total retention volume of 100 m3.

A complete water flow balance was performed imputing the aforementioned design information in the calculation tool created for the purpose of this study. Using the 3-hour precipitation data for the complete evaluation period, results were gathered to analyze the performance of the project in the two fields of interest: Freshwater Use Reduction and Rainwater Runoff Discharge.

6.1.1. Freshwater Use Reduction

The evaluation performed over the 2012 – 2015 period shows that a yearly average of 47.1% of the internal water demand for flushing devices could have been supplied by harvested rainwater. This means a yearly average freshwater use reduction of 3790.5 m3. The share of water demand that could be supplied varied considerably from one year to another as the total yearly precipitation volume was not at all homogeneous during the analyzed period. The year 2014 experienced a total precipitation of 10587.7 mm and 55.4% of the relevant water demand could have been supplied with harvested rainwater. In comparison, in 2015, a total precipitation of 6056.9mm could have only help supply 37.3% of the demand.

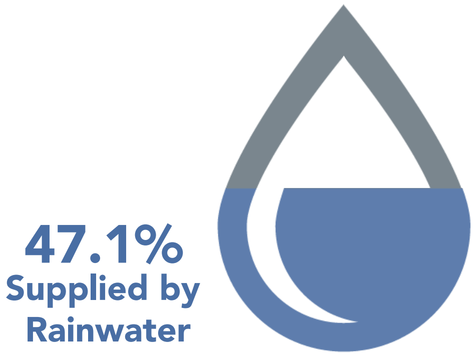


Figure 41
Average Flushing Demand Supplied with Rainwater ET-CAN

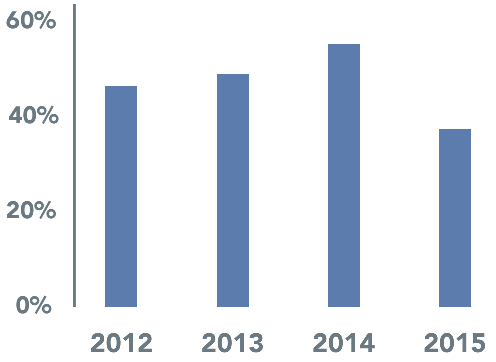


Figure 42
Share of Flushing Demand Supplied by Rainwater by Year. ET-CAN

When looking at a monthly scale, the pattern of percentage of demand supplied by rainwater matches Bogota's precipitation profile. During highest precipitation months such as March and November, almost 70% of the demand is supplied by rainwater. On the contrary, during August which counts with the lowest precipitation volume throughout the year, only 16.5% of the demand could be met with harvested rainwater. However, it is already possible to perceive that the potential water savings do not exclusively depend on the total monthly precipitation volumes. The results show that during October the RWH system could have only provided 58.0% of the demand, a share which is 10% lower than that of November which on average counts with slightly lower precipitation volumes.

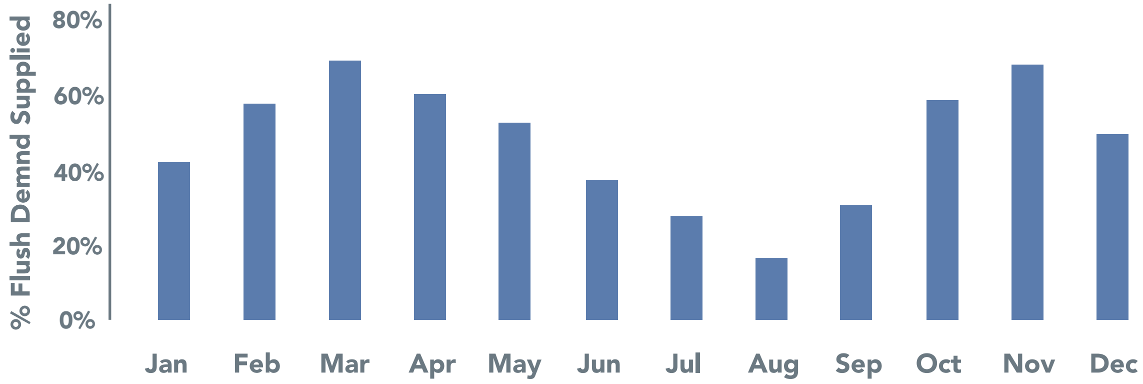


Figure 43
Average Flushwater Demand supplied with RWH by Month

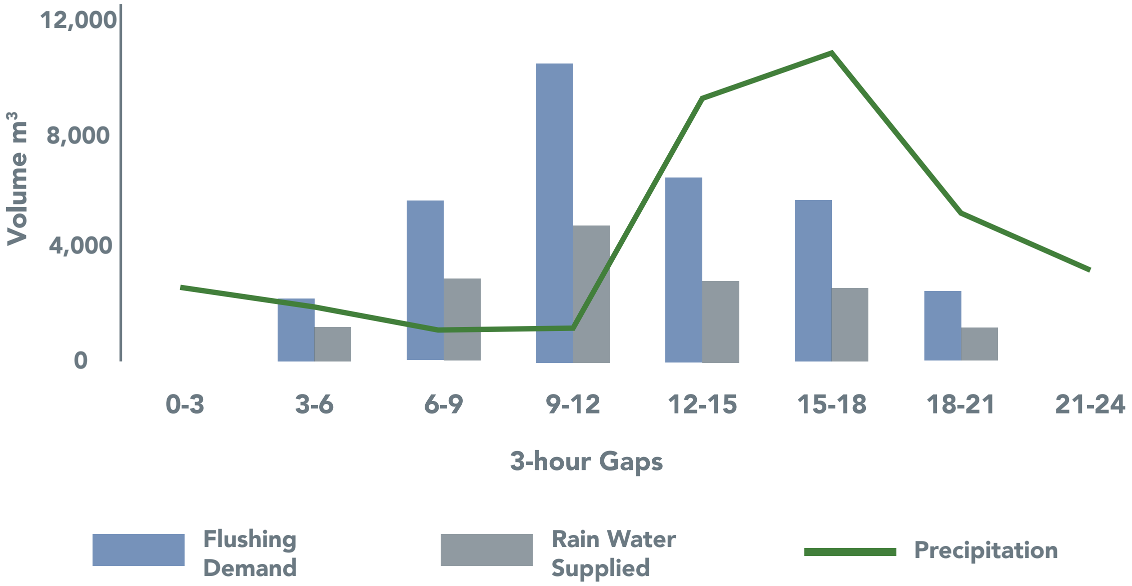


Figure 44
Average ET-CAN RWH System Daily Perfomance Profile

When analyzing the results at a daily scale, it is evident that during hours of high demand, larger volumes of rainwater would be supplied into the building. However, the total demand share supplied by rainwater remains rather constant throughout the day, varying only from a lowest of 43.5% during the 12-15hr period to a highest of 53.7% during the 03-06hr period. These figures are reasonable when compared to the precipitation or water offer profile. After an average dry morning time, stored water volume is on average lower of 22.36 m3 at 12:00 hours, explaining the minimum demand share supplied by RWH during the 12-15hour period.

The resulting daily profiles of internal demand and actual rainwater supply suggest that, if the precipitation and internal demand profiles in the particular case of the project where more corresponding, the total volume of rainwater supplied for internal demand could be higher, resulting in lower freshwater use. Nevertheless, considering the slight variation of the average tank level throughout the day, the additional potential savings would not be so significant.

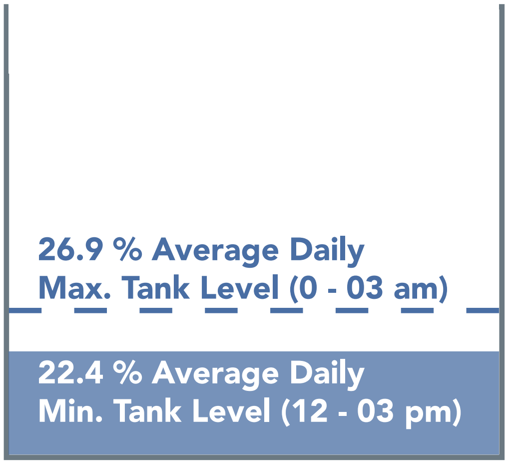


Figure 45
Average Storage Levels of ET-CAN RWH System Retention Tank

FINANCIAL BENEFITS:

Considering Bogota's water utility fees system which has been previously introduced in the present document, annual freshwater volume consumption reduction would represent an economic benefit throughout the building operation lifespan. As previously explained, the local fee system considers two different tariffs: Water Supply and Water Discharge. However, for the actual utility fee collection, the payable amounts for both items are calculated based exclusively on water supply volumes. Although not precisely accurate, for the purpose of payable water fees, freshwater use volume reduction would also translate to the same reduction in volume of water discharge.

Table 16 provides information on payable tariffs for both utility services for the year 2015. Provided that tariffs are established in Colombian Peso COP, they have been converted to Euro using the 2015 yearly average exchange rate 1 Euro = 3045.97 COP obtained from (DW, 2016). A yearly average was used due to the high fluctuation of the exchange rate during the previous months.

Service	COP / m^3	Eu m^3
Fresh Water Supply	4,016.46	1.32
Water Discharge - Sewage	2,461.01	0.81

Table 16
EAAB Utility Tariffs 2015 (EEAB, 2016)

Based on the provided tariffs and the average yearly freshwater volume reduction due to rainwater use, the actual building design would save an average of 8,060.8 Euro yearly on water utilities. From this total, 4,998.21 Euro are direct savings for lower fresh water demand and 3,062.55 Euro would be saved on an inaccurate discharge volume reduction.

6.1.2.Rainwater Runoff Discharge

If the performance of the project and its individual strategies is analyzed on an over the 4 year data available period, the outcome is rather positive. However, it does not meet the stringent standards set under Ciudad CAN Master Plan. At the end of the studied period, a total of 8.763 m3 would be actually discharged into the sewage system. This represents 25.0% of the total precipitated volume. However, when comparing it to the total runoff volume generated within the project, the share of water discharged into the sewage increases to a value even further above from the 20% benchmark stablished on the Ciudad CAN Master Plan requirements. When comparing to runoff generated volumes, only the retention performance of the RWH system can be taken into account as the water retained on the project surfaces, whether green or hard surfaces, are volumes which are not converted into stormwater runoff.

When looking at the individual performance of each strategy, the results show that a volume of 15.162m3, 43.3% of the total precipitated volume, would be supplied into the building by the RWH system. On the other hand, 11.115m3, 31.7% of the precipitated water would be retained on the building surfaces. The share of this retention would be divided as follows: 16.7% by Intensive Green Roof systems; 7.1% by hard surfaces; 4.6% by Extensive Green Roof systems; and 3.3% by garden areas on the ground level.

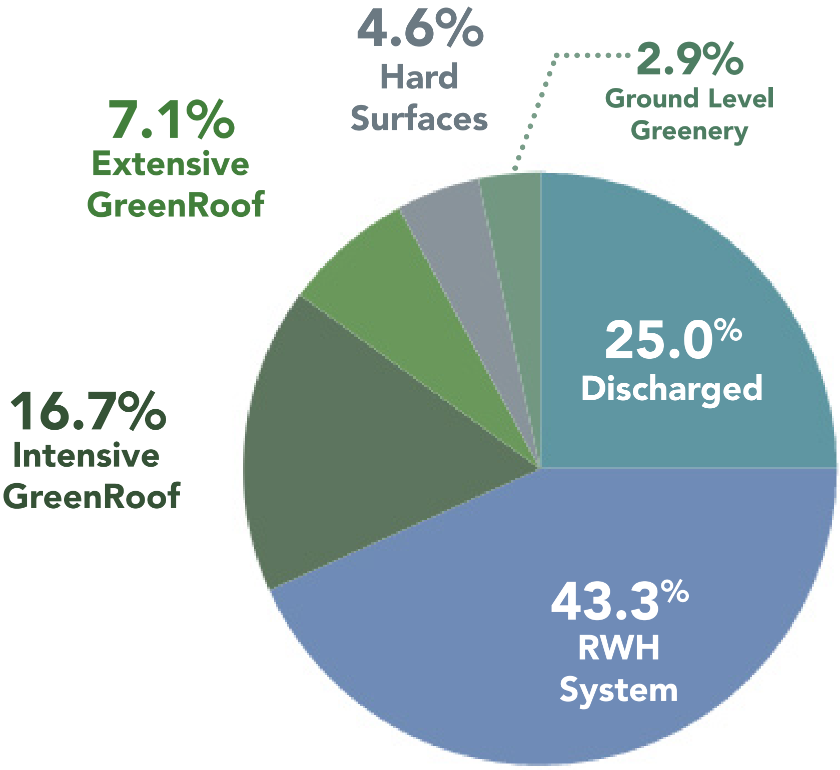


Figure 46
Average Precipitation Retention Share by Surface / Strategie in ET-CAN

However, the performance of each type of surface regarding total retention cannot be assessed with the aforementioned figures as the areas of each type of surface are by no means equivalent. When taking the areas of each type of surface, the results over the 4 year period show that Intensive Green Roofs or garden surfaces (for the purpose of this study they have been considered as the same type) retain 96.7% of the water precipitated on them; whereas Extensive Green Roofs retain 56.0%; and hard surfaces, which in the present study were considered to have a static runoff coefficient, retain only 10%

If the analysis is taken to the results of each individual year, the percentage of stormwater that is effectively discharged into the sewage system does not vary greatly. Regardless of the large difference of total precipitation volumes between years, the share of discharged volume, as well as the share of the volume retained by the RWH system and the building surfaces, remain rather constant. Only for the year 2015, during which the total precipitation was considerably lower, the percentage of discharged volume was reduced to little under 20%.

Nevertheless, when observing the results for rainwater discharge reduction, looking into overall yearly figures might not be as relevant as it is for the freshwater use reduction analysis. Flooding, which is the negative consequence related to excessive rainwater discharge occur during specific strong storm events. For this reason, the performance of the product should be assessed exclusively for this type of events.

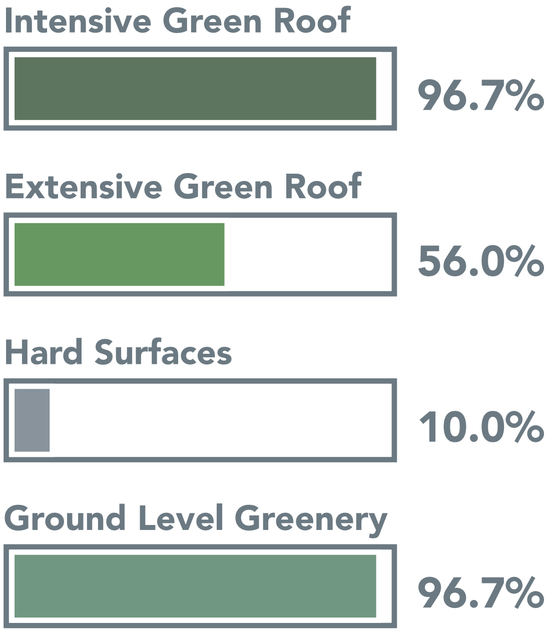


Figure 47
Avg. Share of Rainwater retained when fallen on each Surface Type.
ET-CAN

In order to fulfill the water related sustainability requirements of the Ciudad CAN Master, the runoff and discharge volumes should be estimated for a 2hour duration and 2 year return period event. This is the event requested by the U.S. Green Building Council in order for the project to obtain the LEED Certification (USGBC, 2008). On the other hand, the EAAB specifies that public drainage infrastructure which serve areas no larger than 3ha should be designed for a 5 year return period event and leaves it to the expertise of the design engineers to determine the duration which would represent the peak water flow.

Nevertheless, neither of the aforementioned approaches take into account the situation prior to the design event. As it has been observed on the freshwater use reduction assessment, the performance of the RWH system at any specific time gap does not exclusively depend on the precipitation volume during this period, but it also depends greatly on the water balance during previous hours which determine the actual storage level of the tank. Regardless the size of the storage tank, if already full at the moment of a precipitation event, it would not be able to retain any additional water volume. If performance were to be assessed based on the requested events, the water level of the RWH system retention tank at the time of the event would have to be assumed.

Following this premise, it has been decided to assess Rainwater Runoff Discharge performance based on the real daily events with the largest precipitation volume during the 4 year period of available data. Additionally, the complete water balance which was performed for the present study would allow to assess the system performance using the real storage level of the RWH system tank for the selected events.

Table 17 displays the 10 days with the highest precipitation amounts during the analyzed period. Coincidentally, these are the only days with a total precipitation exceeding 30mm. Results show that 10% of the total 4 year precipitation volume falls during the top 10 rainiest days. Table 17 also indicates the performance of the project by providing total daily runoff volume discharged information.

Date	Precipitation mm	Precipitated Volume m³	Runoff Discharge	
			Vol. m³	% of Precip. Vol.
28 / Oct / 2013	45.4	457.3	237.2	51.9
07 / Mar / 2014	44.1	444.2	293.5	66.1
23 / Feb/ 2014	36.8	370.7	258.4	69.7
03 / Apr / 2014	36.2	364.6	177.6	48.7
19 / Mar / 2015	33.1	333.4	196.3	58.9
12 / Oct / 2013	31.6	318.3	129.5	40.7
21 / Jan / 2012	31.5	317.3	206.2	65.0
12 / Oct / 2012	31.2	314.3	208.5	66.3
15 / Apr / 2012	30.9	311.3	205.8	66.1
26 / Nov / 2013	30.3	305.2	195.2	64.0
10 Days Total	**351.1**	**3536.6**	**2108.2**	**59.6%**
Complete Period	**3478.6**	**35040.0**	**8762.6**	**25.0%**
% Of Comp. Per	**10.1%**	**10.1%**	**24.1%**	

Table 17
Summary Info for the 10 Days with the most Precipitation

During the 10 rainiest days, 8762.6m3 of runoff water are discharged to the sewage infrastructure, a quarter of the total volume discharged over the 4 year analyzed period. Furthermore, during these days, the average share of daily precipitated volume discharged is 59.6%, a value considerably larger than the 25.5% average for the 4 year period which was previously indicated. Taken this last remark into account, the actual performance of the project is far lower than the initial assessment, and even further away from meeting compliance benchmark required by the Ciudad CAN Master Plan.

Table 17 also evidences that daily precipitation volume is not the single variable affecting the runoff volume generation. During Oct 12th 2013, the retained volume was almost 15% higher than that of Jan 21th 2012, despite receiving almost exactly the same precipitation volumes. Figure 48 shows how the retention performance of the project is strongly affected by two aspects: the previous water level of the storage tank; and the precipitation distribution throughout the day.

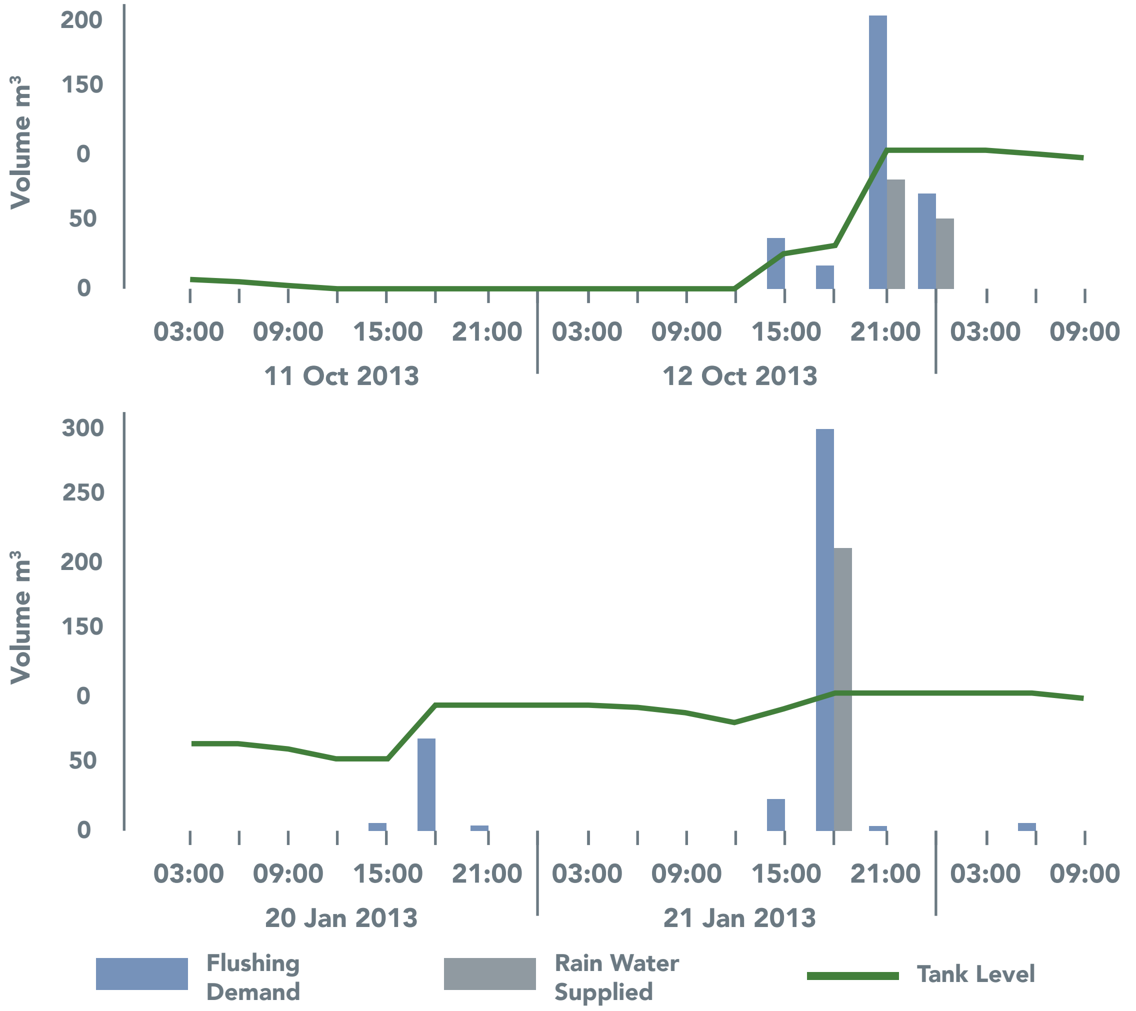


Figure 48
Effect of prior precipitation and tank level conditions on ET-CAN Retention Performance for specific strong rain events. Example

Additionally, when looking at the performance for each of the 10 selected events, it is possible to observe that the lowest retention values do not coincide with the highest precipitation volumes. From all 10 events, with a discharge share of 51.9%, the performance during 28/10/ 2013 was the second best, despite being the day with the highest precipitation volume during the complete analyzed period. Actually, results show that days with the highest precipitation volumes are not necessarily those with the largest generated runoff generated volume, nor those with the largest retained volume.

Finally, when analyzing the performance during the 5 days with the largest precipitated volumes, the results show that the volume retained on the building surfaces is considerably larger than that retained by the HRW system (See Figure 49). In fact, the percentage of water retained by the Intensive Green Roof Surfaces is almost the same as the one retained by the HRW, accounting 14 % and 15 % respectively. These values vary greatly from those resulted when analyzing long term periods (See Figure 46). These values allow to conclude that, during strong storm events for which runoff volume reduction is indeed desired, both systems perform equally for the ET-CAN case study.

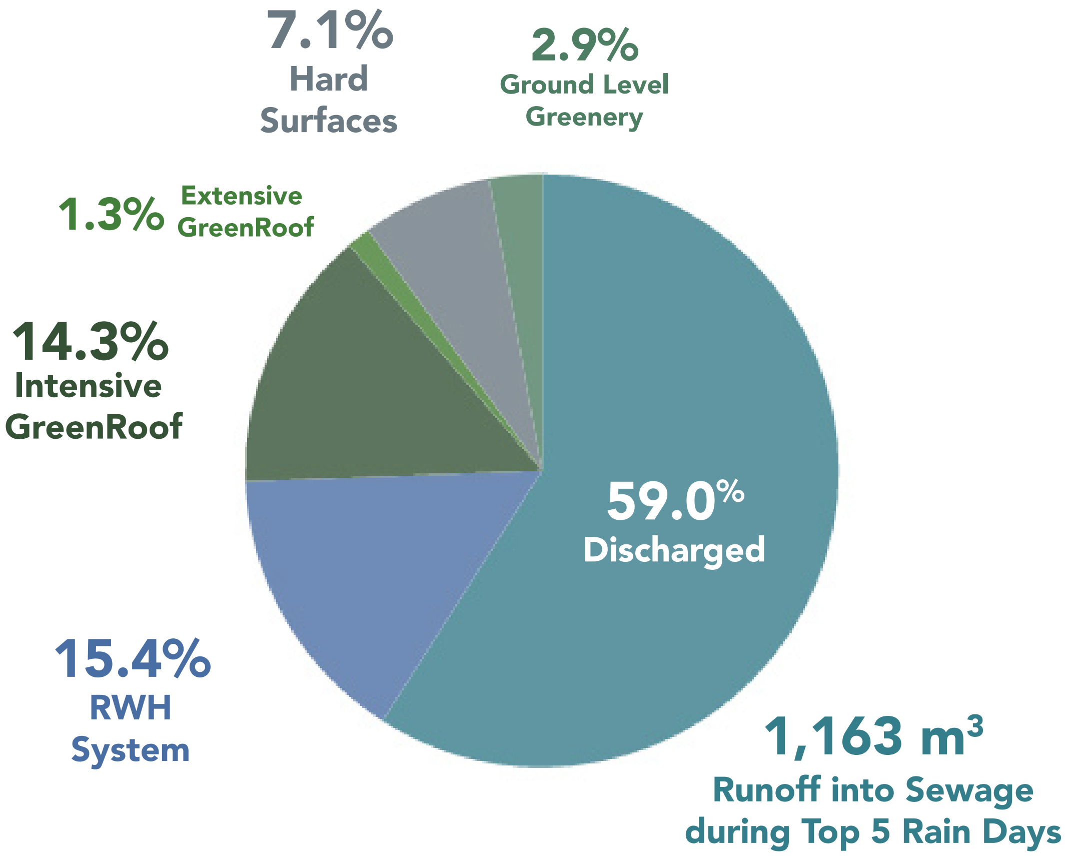


Figure 49
Precipitation Retention Share by Surface / Strategie during Top 5 Rainiest Days

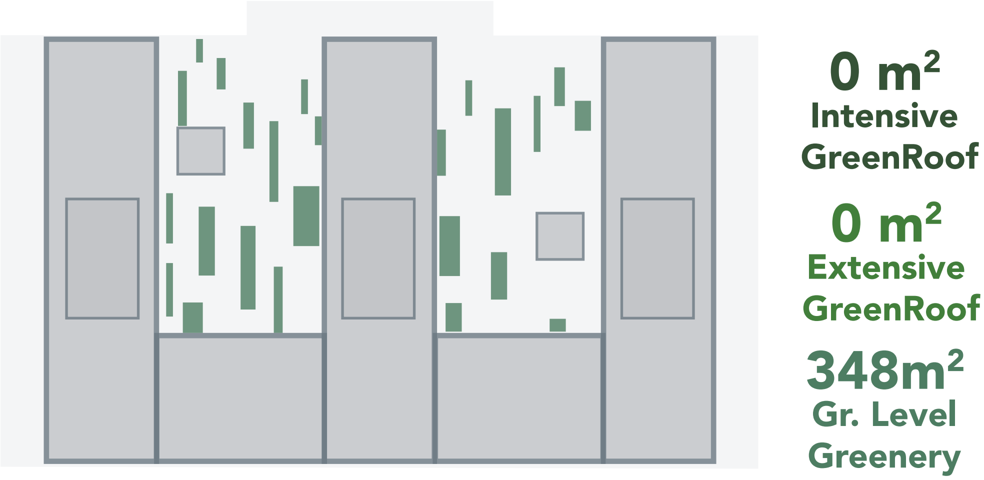
6.2. ALTERNATIVE SCENARIOS

The previous analysis allowed to observe how both systems, under the specific design characteristics of ET-CAN, work together and perform in terms of freshwater use and runoff discharge reduction. However, in order to accomplish a more thorough performance assessment, 3 alternative scenarios were created, analyzed and compared. The scenarios to evaluate were chosen and created in order to achieve two purposes: First, to observe the improvement of the Design Proposal for both analyzed aspects when compared to a typical building design in Bogota; and secondly, to observe how both systems would perform independently in the case they were not affected by each other. The three proposed scenarios are the following:

1. **Bogota Standard Design**

2. **Exclusive Implementation of Green Roof systems**

3. **Exclusive Implementation of RWH system**



6.2.1. Bogota Standard Design

As it has been previously stated, the use of either Green Roof or RWH systems is not a common practice in Bogota, or any Colombian urban settlement for that matter. Typical building practices in Bogota constitute: Hard material roof areas which are seldom accessible to building occupants; no rainwater harvesting practices; and a low share of green open space on the project ground level area. For this reason, the analyzed scenario considered the same size and occupancy figures of the ET-CAN design proposal, however implementing the following variations:

- Total roof surface covered by impervious hard materials (C = 0.9)

- No RWH system

As normal construction standards do not completely eliminate greenery on ground floor open areas, the garden surfaces on these spaces were not altered.

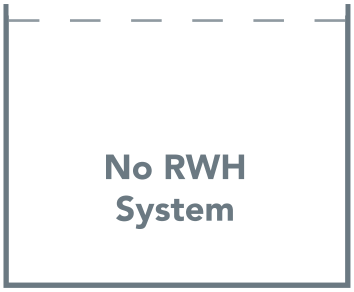


Figure 50
Summary information of the Bogota Standard Scenario

After performing the water flow balance methodology proposed in the present study and taking into account the same analysis principles which were used for the assessment of the Design Case; the performance results of the Bogota Standard Design Scenario were as follows:

- 0% Freshwater Use Reduction

- Average 87.0% of total precipitated volume discharged to sewage

- 87.5% of precipitated volume discharge during 5 rainiest days

- Total 1,723.6 m3 discharged to sewage during 5 rainiest days

In terms of Water Use Reduction; the Standard Scenario cannot supply water from alternative sources as it does not count with a RWH system, thus there is no possibility for reduction. As for Runoff Discharge; the total discharge volume of the Standard Scenario is 48.2% larger than that of the actual project design, which means an extra 560.6m3 discharged into the sewage during the 5 rainiest days of the analyzed period.

FINANCIAL BENEFITS:

View that no freshwater volume saving would be achieved, and that there are no direct benefits due to stormwater runoff reduction contemplated in the utility tariff scheme of the city, there would be no direct financial benefit in this scenario.

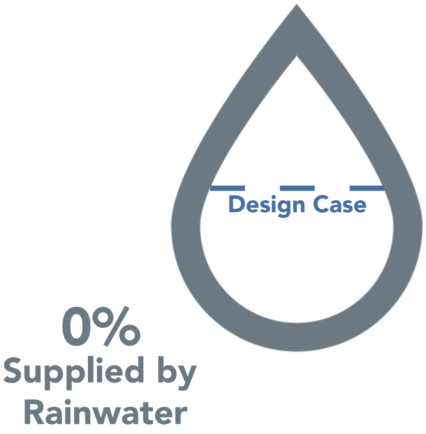


Figure 51
Average Yearly Freshwater Use Reduction for Flushing Devices
Bogota Standard Scenario

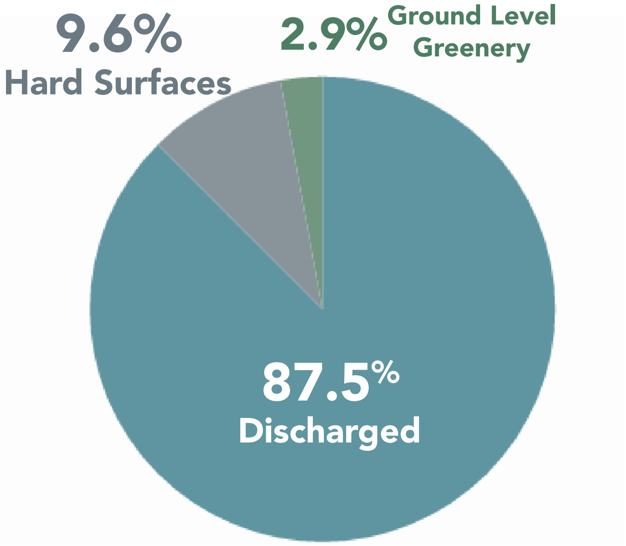
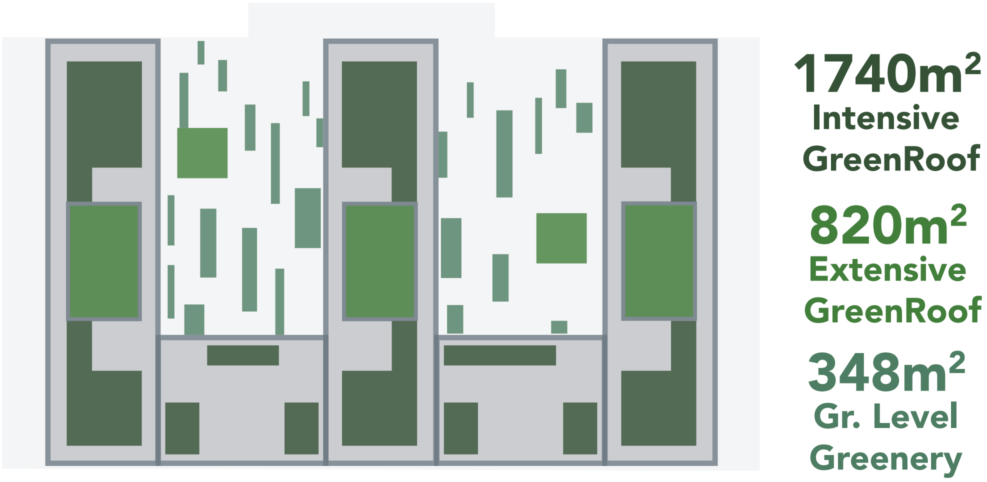


Figure 52
Precipitation Retention Share by Surface / Strategie during Top 5 Rainiest Days - Bogota Standard Scenario

1,724 m^3
Runoff into Sewage during Top 5 Rain Days

Figure 53
Discharge Volume during Top 5 Rainiest Days Comparison: Bogota Standard Scenario vs. ET-CAN Design



6.2.2. Green Roof Systems

In order to assess the actual weight of Green Roof systems on the performance of the project for Runoff Discharge reductions, it is necessary to analyze a scenario where rainwater collection and use does not play a role. For this reason, the current scenario considers the same size and occupancy figures of the ET-CAN design proposal, however implementing the following conditions:

- No RWH system

The materiality of the building surfaces, both on roof and ground level areas remain unaltered from those in the design proposal.

After performing the water flow balance methodology proposed in the present study and taking into account the same analysis principles which were used for the assessment of the Design Case, the performance results of the Green Roof Systems Scenario were as follows:

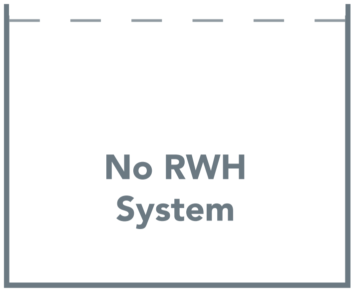


Figure 54
Summary information of the Green Roof Systems Scenario

- 0% Freshwater Use Reduction
- 74.4% of precipitated volume discharge during 5 rainiest days
- Total 1,466.4 m3 discharged to sewage during 5 rainiest days
- 14.3% of precipitated volume (282.1m3) retained by Intensive Green Roofs
- 1.3% of precipitated volume (25.2m3) retained by Intensive Green Roofs

In terms of Water Use Reduction, the Standard Scenario cannot supply water from alternative sources as it does not count with a RWH system, thus there is no possibility for reduction. As for Runoff Discharge, the total discharge volume of the Standard Scenario is 26.1% larger than that of the actual project design, which means an extra 303.4m3 discharged into the sewage during the 5 rainiest days of the analyzed period.

FINANCIAL BENEFITS:

View that there are no direct benefits due to stormwater runoff reduction contemplated in the utility tariff scheme of the city, there would be no direct financial benefit in this scenario. However, the implementation of Green Roof systems is proven to carry indirect benefits which have been previously mentioned in the present document and could be translated to financial savings. Unfortunately, those savings are not easy to estimate and would certainly not be considered by local developers.

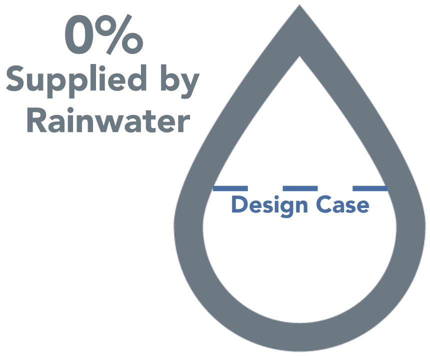


Figure 55
Average Yearly Freshwater Use Reduction for Flushing Devices - Green Roof Systems Scenario

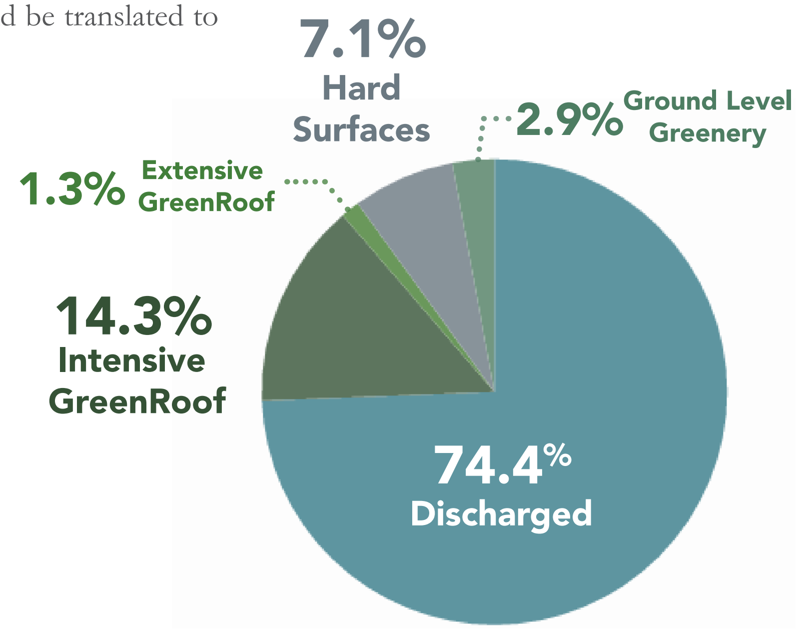


Figure 56
Precipitation Retention Share by Surface / Strategie during Top 5 Rainiest Days - Green Roof Systems Scenario

$1,466\ m^3$
Runoff into Sewage during Top 5 Rain Days

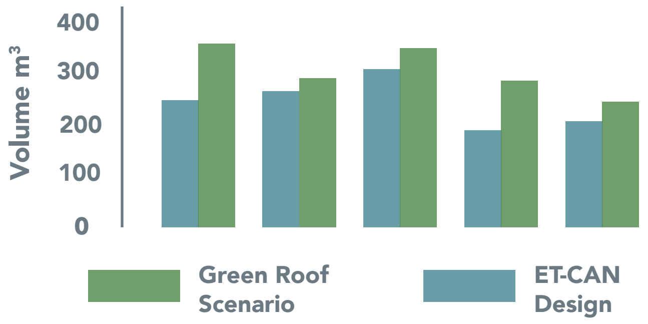
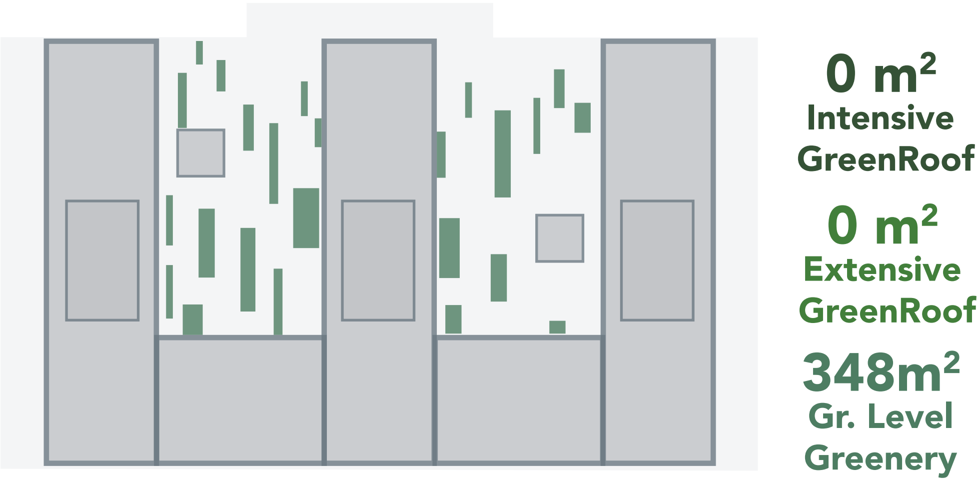


Figure 57
Discharge Volume during Top 5 Rainiest Days Comparison: Green Roof Systems Scenario vs. ET-CAN Design



6.2.3. Rainwater Harvesting System

Rainwater Harvesting systems do play a role on both analyzed topics. Given that the contribution of this system in the water flow balance takes place after the effect of the building surfaces, the use of Green Roofs or any alteration of the building materiality has an effect on the performance of the RWH system. In order to assess the actual weight of the RWH system on the performance of the project for Water Use and Runoff Discharge reductions, it is necessary to analyze a scenario considers the same size and occupancy figures of the ET-CAN design proposal, however implementing the following conditions:

- No Green Roof Systems

- Standard Materials = Total roof surface covered by hard materials (C = 0.9)

As normal construction standards do not completely eliminate greenery on ground floor open areas, the garden surfaces on these spaces were not altered.

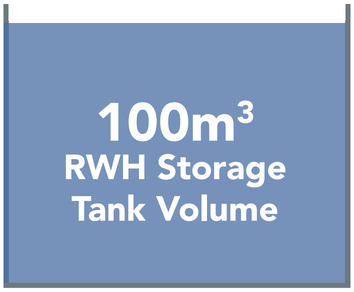


Figure 58
Summary information of the Rainwater Harvesting System Scenario

After performing the water flow balance methodology proposed in the present study and taking into account the same analysis principles which were used for the assessment of the Design Case, the performance results of the Rainwater Harvesting System Scenario were as follows:

- 52.0% Yearly average Freshwater Use Reduction
- 4182.6 m3 average yearly demand supplied with rainwater
- 73.1% of precipitated volume discharge during 5 rainiest days
- Total 1,439.6.6 m3 discharged to sewage during 5 rainiest days
- 14.4% of precipitated volume (284.0m3) retained by RWH system

- 12.5% of precipitated volume (246.7m3) retained by building surfaces

In terms of Water Use Reduction, the Rainwater Harvesting System Scenario is able to supply an additional 392.1m3 for internal demand. This represents an increase of 4.87% when compared to the volume supplied by the designed project. The larger water use reductions are due to a lower volume retained on the building surfaces and thus, a larger volume reaching the RWH system retention tank.

As for Runoff Discharge, the total discharge volume of the Standard Scenario is 23.8% larger than that of the actual project design, which means an extra 276.6m3 discharged into the sewage during the 5 rainiest days of the analyzed period.

FINANCIAL BENEFITS:

The annual average 392,1m3 additional volume which could be supplied to the internal building demand would make total annual savings due to lower fresh water consumption increase to a total 8.894.52 Euro. From this total, 5,515.2 Euro are direct savings for lower fresh water demand and 3,379.53 Euro would be saved on an inaccurate discharge volume reduction. These values represent an additional annual saving of 833.8 Euro when compared to the real project design.

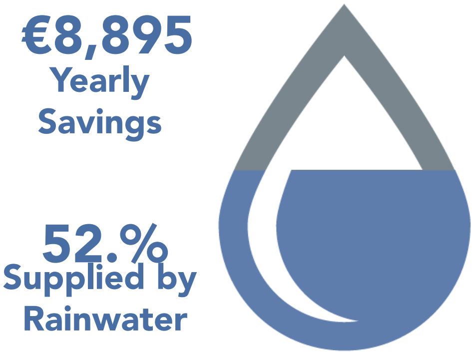


Figure 59
Average Yearly Freshwater Use Reduction for Flushing Devices - RWH System Scenario (Left)

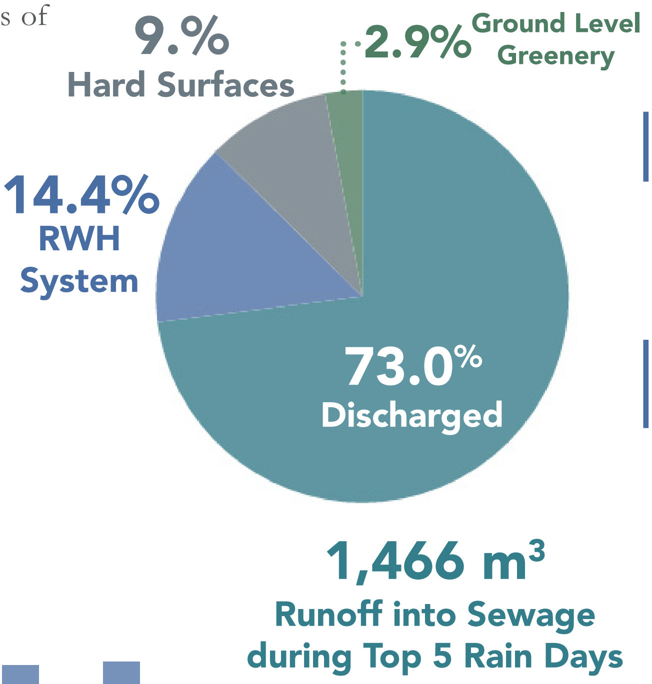


Figure 60
Precipitation Retention Share by Surface / Strategie during Top 5 Rainiest Days - RWH System Scenario. (Right)

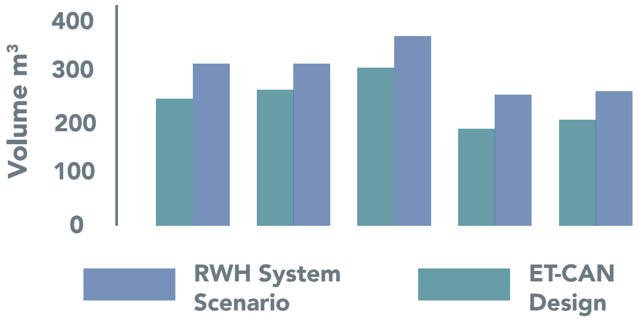


Figure 61
Discharge Volume during Top 5 Rainiest Days Comparison: RWH System Scenario vs. ET-CAN Design

6.3. SCENARIOS COMPARISON

6.3.1. Freshwater Use Reduction

Only two of the analyzed scenarios count with a Rainwater Harvesting and Use system which would allow the project to reduce the freshwater extraction from the city's water supply infrastructure. Thus, neither the Standard nor the Green Roof scenarios would represent a freshwater use reduction within the project.

An initial rough conclusion is that, for the very specific characteristics of both the internal demand and the precipitation patterns and quantities in Bogota, the projected water retention tank volume of 100m3 would on average suffice to supply 50% of the yearly internal demand for flushing devices of the ET-CAN building. It is important to remark that the relation between storage tank volume and yearly rain water supply is not linear.

Furthermore, altering the building surfaces resulted on a variation of only 5% of the water volume that the system would be able to supply into the building. Taking this rather small variation into account, it is possible to reach a more meaningful conclusion: Contrary to various assumptions regarding the use simultaneous implementation of Green Roof and RWH systems, the use of the former did not greatly affect the performance of the latter in terms of internal demand volume supply.

The ET-CAN design proposal considers the implementation of Green Roof systems on approximately 44% of the total roof surface and it only reduces the RWH system performance by less than 5% when compared to a scenario which considers no Green Roofs.

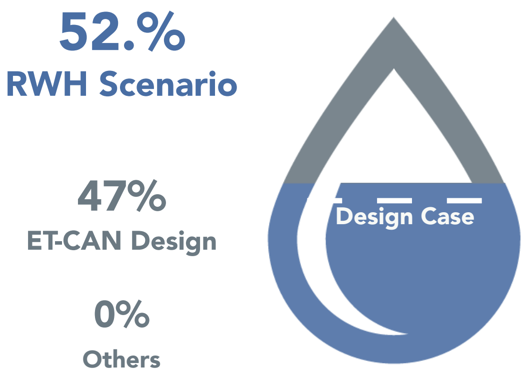


Figure 62
Share of Flushing Demand Supplied by Rainwater. Scenarios Comparison

6.3.2. Rainwater Runoff Discharge

The total discharge volumes during high precipitation days vary significantly between the analyzed scenarios. Whilst the total discharge volume has already been provided for all scenarios separately, Figure 63 allows to observe two important situations: First, adding up the results from the top 5 rain events, the actual design proposal would allow the project to discharge approximately 560 m3 less than if followed a standard local design, 28% less of the total precipitated volume. Secondly, if the project developer were to implement only one of the strategies comprehended in the design proposal, both Green Roof or HWR system scenarios would perform very similarly, retaining 26% and 27% of the precipitated volume, respectively.

Previously, when analyzing how separately individual elements affect the retention performance of the ET-CAN design proposal, it was concluded that both Intensive Green Roofs and HRW systems retained each almost equal shares which averaged between 14%-15% of the precipitated water during the 5 rainiest days. Nevertheless, the performance of the systems does not remain equal when analyzing the events separately. In Figure 64 it is possible to observe how, whilst retention share of building surfaces remains almost invariable, that of the RWH system varies greatly. More importantly, it allows to observe how for some events it exceeds the retention already obtained on Green Roofs and other the building surfaces (April 3rd 2014), whilst for others, its retention capacity is almost non-existent (February 23rd 2014).

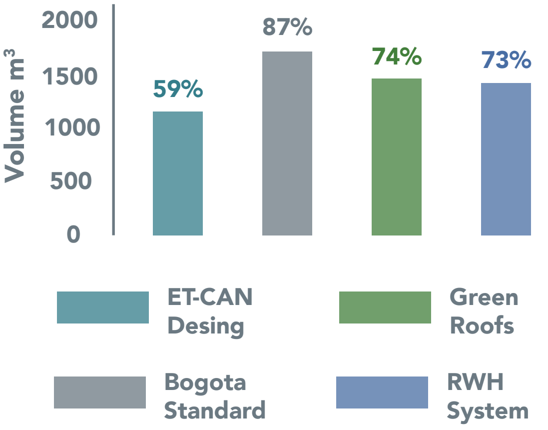


Figure 63
Total added Discharge Volume and % of Total Precip. Vol. during Top 5 Rainiest Days by Scenario

This behavior is clearly due to the dependence that the RWH system has on the water storage level conditions prior to the storm events. The results leads to conclude that both Green Roofs and RWH systems work as complementary retention strategies. Ideally, the RWH storage tank would be at a low level when a strong storm event arrives, however, if it is not the case, Green Roof systems would always contribute to reduce stormwater runoff discharge.

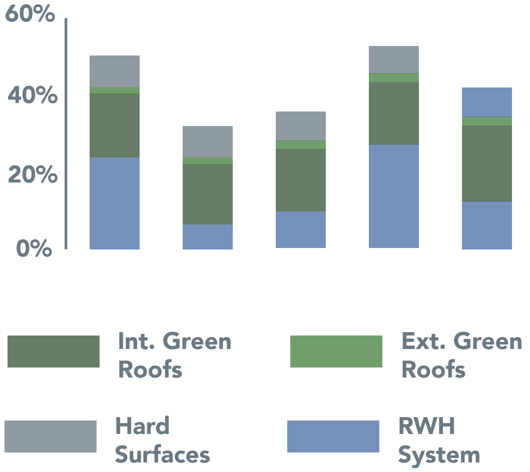


Figure 64
% of Precip. Volume Retained per Strategy during Top 5 Rainiest Days

Moreover, when analyzing the retention performance of the RWH system, results show that it is positively affected by the presence of Green Roof systems. Figure 65 illustrates the share of stormwater retained by the RWH system on both scenarios that considered one. Although for 4 of the 5 selected events RWH retained volume does not vary on much between both scenarios, during April 3rd 2014 this volume was larger when for the scenario that also considered Green Roof systems. Moving from 21.5% for the RWH scenario to 26.8% for the actual design proposal.

Figure 66 illustrates how the presence of Green Roof systems contribute to obtaining a lower RWH tank storage level after a smaller rain event, thus allowing the RWH system to be able to retain a larger volume 2 days afterwards during the strong rain event.

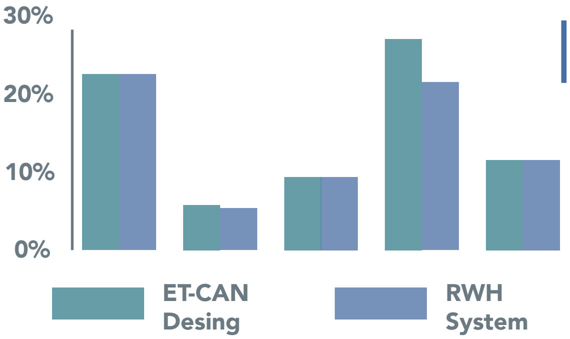


Figure 65
% of Precip. Volume Retained by the RWH System during Top 5 Rainiest Days

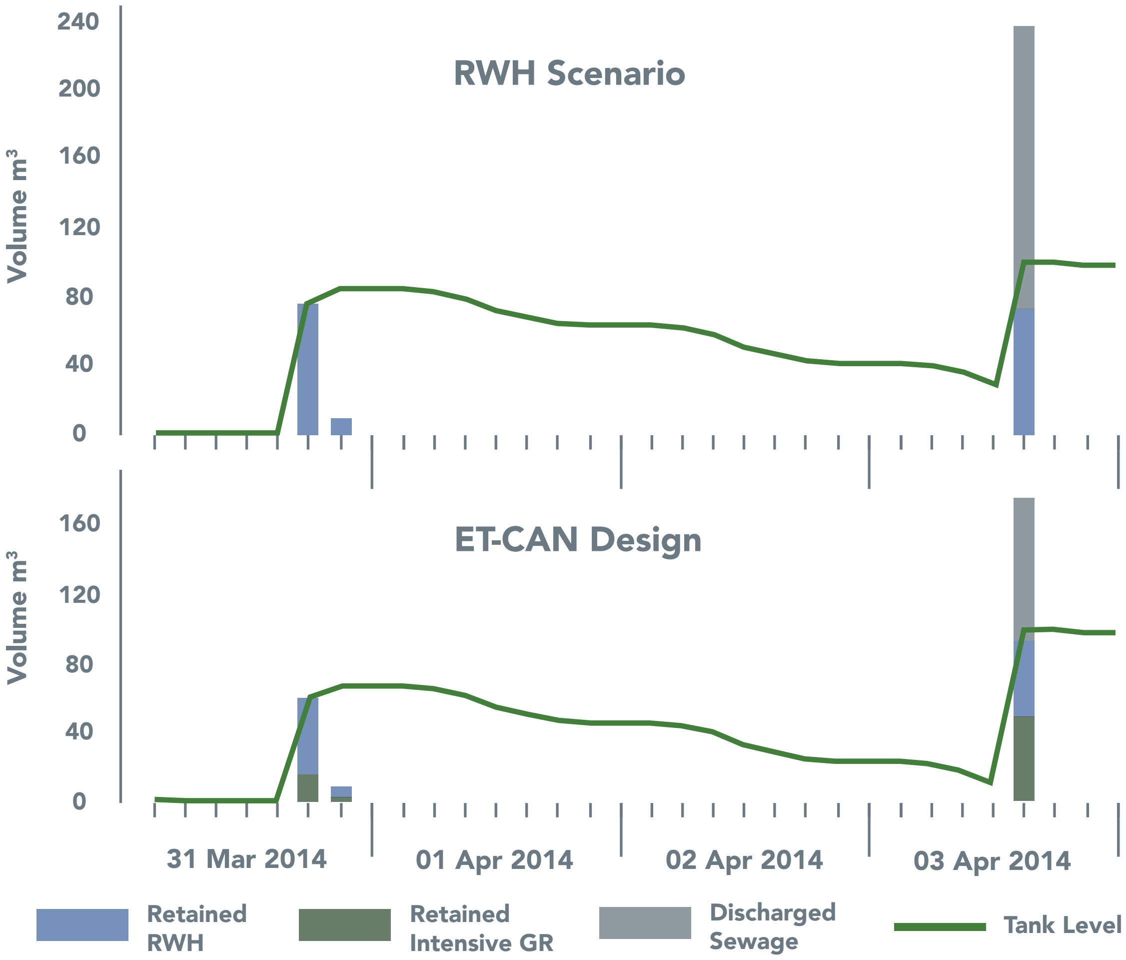


Figure 66
How Green Roof Surfaces Improve RWH System Retention Performance. Example 03 Apr 2014

6.4. Additional Criteria

The implementation of WSUD practices and strategies indirectly carries benefits beyond sustainable water management. Recreating a more natural hydrological cycle also results in improvements on other environmental topics such as air quality, biodiversity and temperature regulation. Additionally, according to (Hoyer, Dickhaut, Kronawitter, & Weber, 2011), a successful WSUD project implementation should follow certain principles under 5 categories: Water sensitivity; Aesthetics; Functionality; Usability; and Public perception and acceptance. This considered, it has been decided to assess all previous scenarios under 5 additional criteria.

AIR QUALITY AND BIODIVERSITY:

The assessment of this criteria has been based on the total green surfaces comprised in the project which help absorb CO2 from the air whilst providing a habitat for local species. As it was stated in Chapter 02 of this document, Intensive Green Roofs have on average the capacity to absorb more than double the amount of CO2 than Extensive systems (IASP, 2012). Thus, total Intensive Green Roof systems surfaces and Garden Areas on the ground level, plus half of Extensive Green Roof surfaces were considered to contribute for this criterion.

HEAT ISLAND EFFECT REDUCTION:

The assessment of this criteria has been based on the total non- heat-absorbing surfaces comprised in the project, meaning Intensive and Extensive Green Roof systems and Garden Areas on the ground level.

THERMAL INSULATION:

The assessment of this criteria has been based on the total vegetated surface installed on the roof area of the project, meaning Intensive and Extensive Green Roof systems.

PUBLIC GREEN AREAS:

Chapter 03 provided an insight of Bogota's situation regarding the ratio of urban trees per inhabitant and the availability of vegetated areas accessible to all citizens. For this reason, providing green vegetated surfaces on spaces which are accessible to everybody and not building users exclusively signifies an improvement towards the city's livability. Thus, the assessment of this criteria has been based on the total vegetated surface installed on the ground level of the project.

FINANCIAL COST:

A thorough and precise assessment on the actual financial costs and benefits related to the implementation of WSUD strategies is far too complex for the scope of this study. Aside from the initial investment related to the implement infrastructure, there are various additional costs which have already been mentioned in the introduction of both analyzed technologies. Such additional indirect costs or benefits, as for example; larger structural requirements due to the use of Intensive Green Roofs; savings due to a longer lifespan of roof materials thanks to Green Roof systems; or energy costs of pumping devices for internal rainwater use, cannot be taken into account for the current assessment. Thus, the assessment of these criteria has been based on a subjective appreciation of the immediate initial investments and direct tangible financial return related to each strategy.

	Air Quality Biodiver.	Heat Island Effect	Thermal Insulation	Public Green Areas	Cost	Freshwater Use Reduc.	Runoff Discharge
Scenario	IGR+GA +0.5EGR m^2	IGR+GA +EGR m^2	IGR+EGR m^2	Garden Areas m^2	#	RWHW supplied m^3	Discharged Volume m^3
Design	**2,499.7**	**2,910,1**	**2,561.5**	**348.6**	4	3,790.5	**807.3**
Standard	348.6	348.6		**348.6**	7	0	246.7
Green Roof	**2,499.7**	**2,910,1**	**2,561.5**	**348.6**	2	0	503.9
RWH	348.6	348.6		**348.6**	**10**	**4182.6**	530.7

Table 18
Scenario Evaluation per Criterion

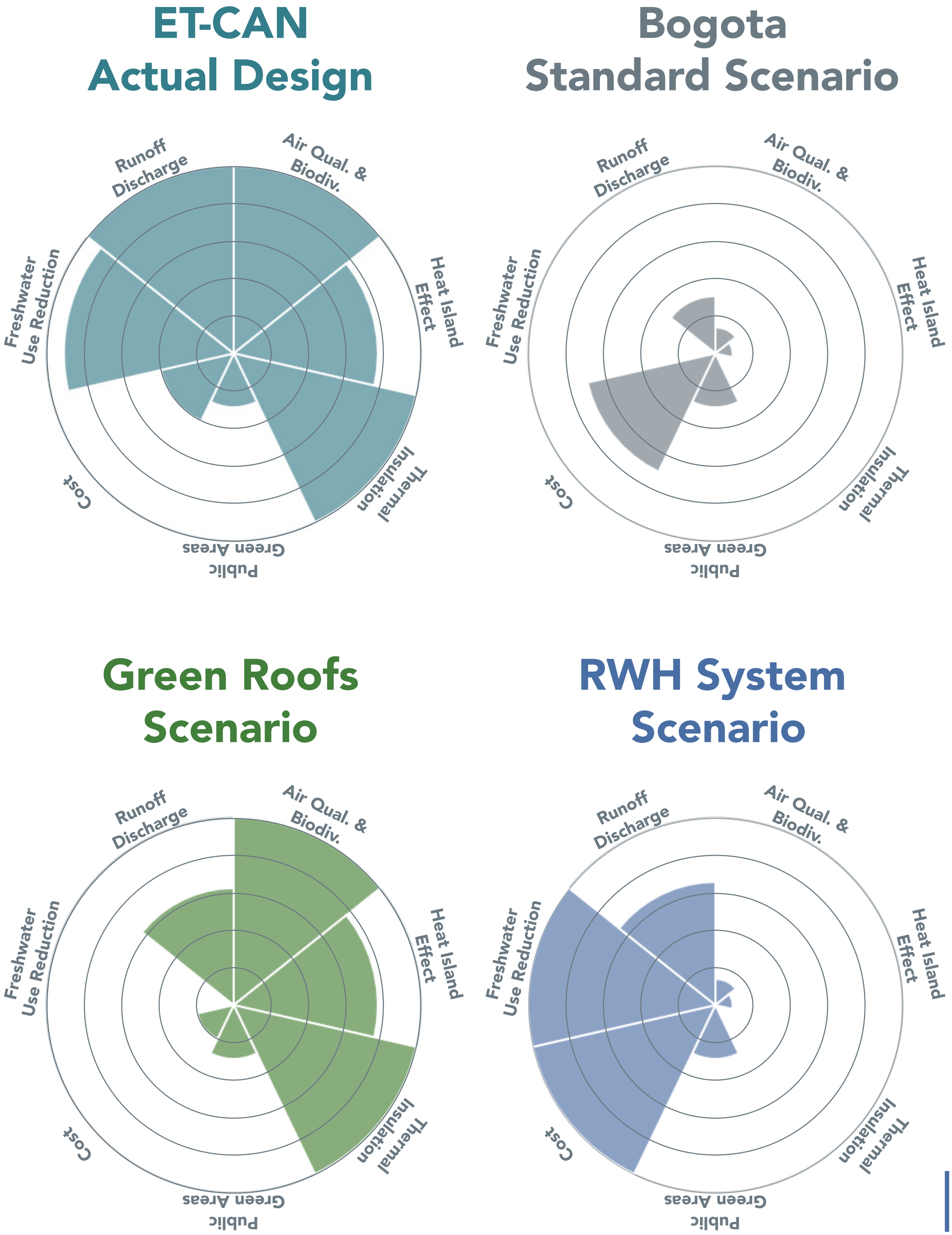
In order to compare all considered scenarios, a score has been assigned for each analyzed criteria. As previously described, each criterion is valued on a specific indicator. The score for each criteria has been calculated dividing the indicator value of each individual scenario by the highest indicator value from all scenarios on each criteria. The score has been expressed in percentage, thus the best performing scenario for each criterion obtaining a 100% score. Table 18 displays the indicator values obtained under each criterion for all scenarios.

From Figure 67, it is quite clear that the Design Proposal is the top performer in most of the considered criteria. Being the only one implementing both WSUD strategies, except for cost, it performs well on both water and non-water related categories. As previously discussed, the Design Proposal performance in terms of Freshwater Use Reduction is lower than that of the RWH Scenario, however it is not too significant when taking into account the improvements on all other categories.

The performance of the Standard scenario is very poor on all environmental related criteria, and yet, it would not be the most economical option given that, despite counting with the lower initial investments, it would not benefit from the yearly savings due to lower freshwater consumption.

When comparing the performance of both single strategy scenarios, Green Roofs and RWH system, it is very clear that Green Roofs scores much better in all non-water related environmental categories due to the inherent additional benefits of vegetated surfaces. Furthermore, in terms of stormwater retention, performance of both scenarios is very comparable. However, the far greater initial investment costs and the non-existence of a rainwater use infrastructure make the Green Roof scenario the lowest performant on the remaining two categories.

The obtained results can be used to create alternative proposals. Taking into account the individual effect of each indicator on the considered criteria, it is possible to make variations which could lead to an overall better performing alternative.



ET-CAN Actual Design

Bogota Standard Scenario

Green Roofs Scenario

RWH System Scenario

Figure 67
Scenarios Performance Comparison.
Overall Score

6.5. ALTERNATIVE PROPOSAL

Despite the different impact that both WSUD strategies have on each selected criterion, from the results obtained during the scenarios comparison it can be affirmed that both Green Roof and Rainwater Harvesting systems contribute to Stormwater Runoff Reduction. Moreover, initial results show that when performing the analysis under the actual ET-CAN design parameters, both systems contribute to reduce almost equivalent shares of the total precipitated volume for the chosen strong events.

The Design Scenario assessment indicated that both Green Roof and RWH systems would retain 15.6% and 15.4% of the total precipitated volume respectively. The share retained by Green Roof areas is almost entirely due to Intensive systems (14.3%), as saturation height for these elements (60.0mm) is never reached during the analyzed period. On the contrary, saturation height for Extensive systems (17.5mm) is reached during all 5 events which are taken into account.

It is then evident, that any increase on installed Intensive Green Roof surfaces or RWH retention tank volume capacity would directly signify a reduction on the project's runoff volume generation. The relation between these variables, IGR surface/RWH tank volume, and the total runoff volume reduction is however not linear, nor it is easily determined by a single formula. However, for the purpose of this study, a retention percentage of total precipitated volume has been estimated per relevant strategy unit. See Table 19.

For the specific ET-CAN design characteristics, each m2 of installed Intensive Green Roof would on average retain 0,008% of the total precipitated volume during the 5 events chosen for the analysis. On the other hand, each m3 of total tank retention capacity of the RWH system would on average retain 0,154% of this total precipitated volume. Thus, in order to achieve a 50% retention goal, the total added generated runoff volume for the analyzed events should be reduced 177,3 m3.

	Intensive Green Roof	Rainwater Harvesting System	Total Retention
Avg. Retention	**14.3%**	**15.4%**	**41%**
Tot. Surface / Capacity	1740.7 m2	100 m3	**Goal Retention**
Avg. Retention per Unit	**0.008%**	**0.154%**	**50%**
Increased Required Separately	1095,5 m2 **62.9%**	58.4 m3 **58.4%**	

Table 19
Retention per Strategy Unit and Required Increases to achieve 50% Retention

On broad numbers, achieving this reduction would require either an increase of at least 63% of the total installed IGR surface; a minimum increase of 60% of the total RWH retention tank capacity; or a combined increase of both. It is worth to remind that the actual increases should in fact be larger, given the non-linear relation of the system units and total volume retention.

Nevertheless, the comparative assessment between scenarios has shown how altering either SUWD strategy would have effects on many other aspects besides stormwater runoff volume reduction.

An increase of the total Intensive Green Roof surface would signify:

- An increase of total vegetated roof areas of the project, improving its performance in terms of air quality and biodiversity; heat island effect reduction; and thermal insulation.

- Significant additional financial direct and indirect costs.

- A low decrease on the project´s water use reduction performance.

- No impact in terms of public green areas.

An increase of the RWH storage tank capacity would signify:

- A direct increase of the project´s water use reduction performance.

- Very low additional direct investment which is likely to be returned.

- No impact in terms of neither air quality & biodiversity; heat island effect reduction; thermal insulation; nor public green areas.

Taking these conclusions into account, it has been decided to create an example of an alternative proposal for the ET-CAN, altering the basic variables of both SUWD strategies already considered. This proposal would theoretically have a better performance, not exclusively on water-related aspects, but on all criteria.

6.5.1. Proposed Variations:

Given the integrated and holistic approach that SUWD advocates, the following aspects were taken into account when considering the possible variations:

- Intensive Green Roof technology, with an average local market price above 50 euro/m^2, remains very expensive in the local context.

- Private developers, who will not own the project after its completion, do not consider financial benefits during the building operation. Higher direct and indirect initial costs inherent to IGR system would without doubt discourage their implementation.

- For the current ET-CAN design proposal, the share of vegetated areas of the open ground level is only 8.2%, whereas the share at the roof level is 44.1%.

RAINWATER HARVESTING SYSTEM:

- **Increase the retention tank volume capacity by 50% reaching a total of 150m3.**

This proposed alteration would have a direct positive effect on both water related aspects. As for the remaining environmental indicators, it would not have any positive nor negative affectation.

Regarding direct financial costs, the storage increase would most likely take some space usable for parking. Other extra direct investments such as water treatment and pumping devices would not be required. As for indirect costs, it would not signify any increase as the system operation costs depend on the maximal desired supply flow and not the storage capacity. On the contrary, an increased share of water demand supplied by rainwater would result in lower annual water utility costs.

GREEN ROOF SYSTEMS:

- **Replacement of all Intensive Green Roof Surface by Extensive Green Roof systems.**

- **Transfer 50% of the previous IGR surface to the open ground level area.**

Reducing the IGR surface would evidently have a negative effect on the stormwater retention of the project, however, this effect is expected to be compensated through the increased RWH tank capacity. A larger average runoff coefficient for the project would increase the harvested rain volume and theoretically, also the share of internal demand supplied by it. As for the remaining environmental indicators, the total vegetated surface of the project would actually be increased, improving its performance on both Air Quality & Biodiversity and Heat Island Effect indicators. Moreover, the share of roof vegetated area would not be changed, causing no affectation on the Thermal Insolation performance. Furthermore, the share of vegetated surface at the ground level would also be increased, improving the performance on the Public Green Areas indicator.

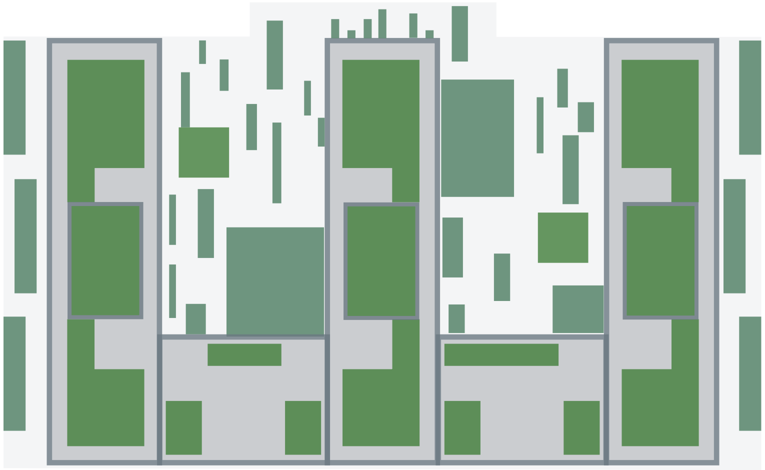
Regarding the financial aspects, replacing IGR surfaces by EGR systems would significantly reduce direct investment from the developer, whilst maintaining the benefits during the building operation. Additionally, the cost of increasing the vegetated areas at ground level is much lower than that of installing IGR systems at the roof level.

6.5.2. Results:

The proposed variations result in the following project characteristics:

- Intensive Green Roofs: 0 m2
- Extensive Green Roofs: 2561.42 m2 (44.1% of Roof Surf. and 25.4 % of Project Surf)
- Vegetated Areas on Open Ground-level: 1218.89 m2 (28.6% Open Groundlevel Surf and 12.1 % of Project Surf)
- RWH system storage tank capacity: 150 m3

After performing the water flow balance methodology proposed in the present study and taking into account the same analysis principles which were used for the assessment of the Design Case, the performance results of the Alternative Proposal were as follows:



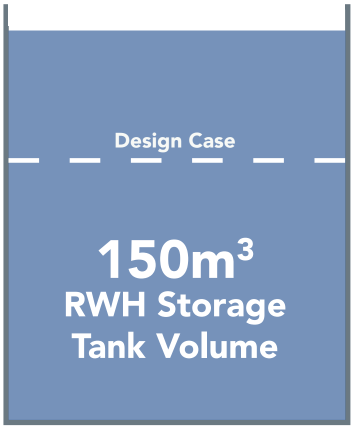
0m^2
Intensive GreenRoof

2561m^2
Extensive GreenRoof

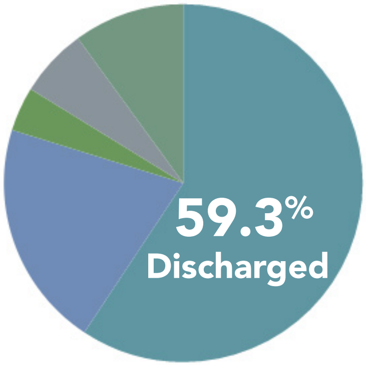
1218m^2
Gr. Level Greenery

50.9%
Supplied by Rainwater

€8,720 **Yearly Savings**



150m^3
RWH Storage Tank Volume



1,168.3 m^3
Runoff into Sewage during Top 5 Rain Days

Figure 68
Alternative Proposal Performance. Summary Info

When comparing the example alternative with the current ET-CAN design proposal it is possible to see that there would not be an extreme variation regarding both sustainable water management indicators.

The example alternative would have positive results on freshwater use reduction, as the rainwater volume use for internal demand would increase by approximately 10%. On the other hand, stormwater runoff volume generation would remain almost invariable. However, it is on the other indicators where greater performance differences can be seen. Taking all criteria into account, the example alternative would outperform the ET-CAN design proposal.

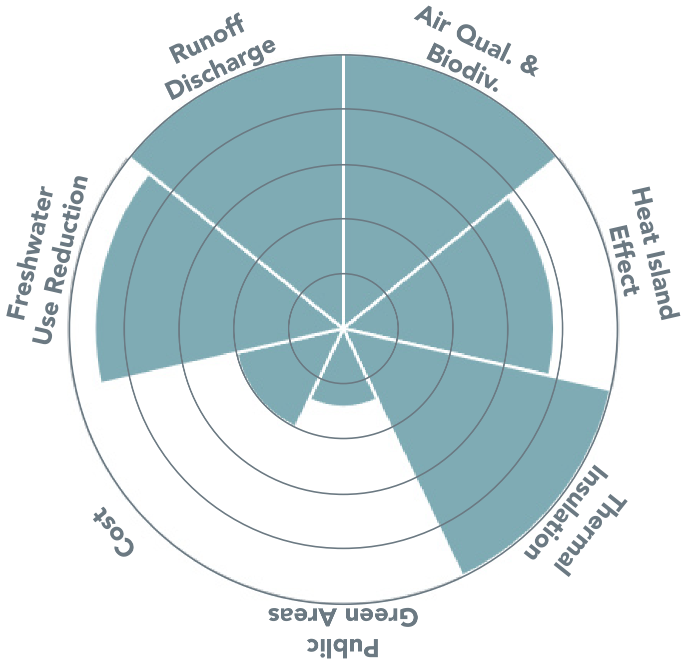
The proposed alternative is by no means a thoroughly optimized one. For example, the analyzed alternative example shows that increasing vegetated surfaces on groundlevel open areas would improve the performance of the project on several criteria. It does so at a larger extend than vegetated roof areas.

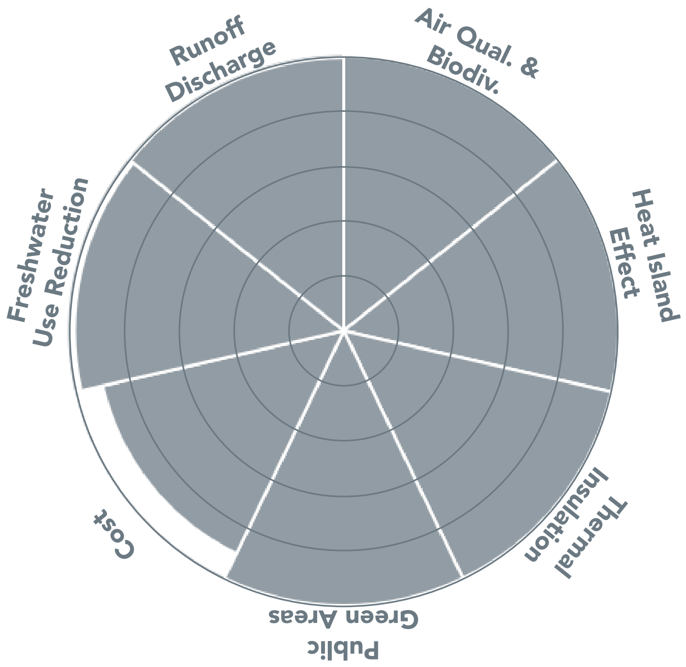
The 28% share of groundlevel open area covered by this type of surface could be easily increased at a not too significant cost. This share is also far below the 80% minimum vegetated coverage required for roof areas. However, the Ciudad CAN Master Plan does not state any minimal requirement for vegetated coverage for groundlevel open areas.

Furthermore, a very limited cost information for both direct investments and long term savings and costs related to SUWD practices in the local context does not allow to make a precise financial assessment. A much more detailed and thorough financial analysis on the implementation of SWUD practices on private developments is needed in order to find solid arguments which can encourage developers.

However, it is possible to conclude that considering a holistic approach on the current analysis leads to propose variations which would allow the project have an overall better performance on various environmental indicators. This would be possible to do whilst, at the same time, maintaining the performance on stormwater runoff generation and reducing the initial financial costs which would normally discourage developers to implement WSUD strategies.

ET-CAN Actual Design





Alternative Proposal

Figure 69
Performance Comparison. ET-CAN vs Alternative Proposal

Tequendama Fall. Bogota River after flowing through Bogota

Obtained from: soachaenimagenes.blogspot.co

7. CONCLUSIONS

Bogota's local hydrological structure has been terribly damaged by an ever accelerated and disorganized urbanization process. Indicators such as green permeable surfaces and trees/ inhabitants ratios, as well as the conditions of water bodes such as creeks, rivers and wetlands, are far below international recommended standards. This situation has placed the city and their inhabitants under great risks related to water management. A water scarcity situation has been reached, compromising the ability of the administration to provide permanent sufficient potable water resources for the entirely population. Simultaneously, strong rain events continue to result in flooding and land slices which almost exclusively affect the most economically vulnerable population.

Lately, local policy has started to steer towards sustainable water management practices in terms of public infrastructure. However, provided the large share of surface which is under private owners, policy also has to address private developments and include them into the sustainable water management scope. Current typical construction practices do not take into account a responsible water management, and this thesis has proven the enormous affectation this represent in terms of generated storm runoff volumes and freshwater extraction. Construction standards have to be revised and updated in order to incorporate WSUD practices and obtain the benefits that these carry. However, a sensible analysis has to be made in order to assess which practices are the most beneficial and go more accordingly to the local meteorological context and the current state of the local market.

The Ciudad CAN Master Plan, and more specifically, the ET-CAN Building project, represent the first large scale effort that the city has made to incorporate WSUD practices into both public infrastructure and private developments. The current analysis has showed that the implementation of the strategies projected for the ET-CAN building would allow the project to reduce almost thousands of cubic meters of freshwater extracted volume from endangered natural water bodies every year. Additionally, when compared to normal practices, the ET-CAN design would greatly reduce the share of precipitation that is discharged to the sewage infrastructure during strong storm events, thus significantly reducing the risk of flooding of areas located near the rivers receiving the city's sewage discharge.

The present analysis also concluded that, in the case of ET-CAN design and demand conditions, and for the local precipitation trends, Green Roof and Rainwater Harvesting systems act as complementary strategies in terms of water retention purposes. Using either one of the strategies separately would result in a lower retention performance for the project. Furthermore, the results show that the use of Green Roofs would in certain cases improve the performance of the Rainwater Harvesting system without having a major alteration in terms of the total rainwater volume supplied into the building. The implementation of both strategies would allow the project to have better resilience taking into account the heterogeneity of rain events in Bogota.

The actual performance of a Rainwater Harvesting and Use system will at a very great extend depend on the end-use which can be given to the harvested rainwater. The more uses it can supply, the less freshwater needs to be extracted from natural sources and also, the more stormwater can be diverted from direct discharge during strong rain events. Additionally, this analysis showed that daily local precipitation profiles, as well as daily consumption profiles play a major role on the system's performance. Unfortunately, alterations to either of those profiles are not likely, however, the results allow to conclude that a detailed analysis is needed for every specific location where such systems will be implemented. Average daily precipitation volumes would not provide enough and accurate information to estimate the performance of a Rainwater Harvesting and Use system.

Furthermore, the inclusion of additional environmental criteria in the present analysis allowed to show how a more holistic and sensible approach when determining the actual requirements for implementation of WSUD strategies would result in larger benefits, not only in terms of water management, but also in a range of environmental topics which are also currently affecting the city.

The Ciudad CAN Master Plan, although a great step towards sustainable water management, has opted for either Command and Control, and Indirect Performance Standards instruments when looking to encourage the implementation of SWUD practices. For the local context of Bogota, these type of instruments may not be the most effective as, whit them, private developer do not see any benefits from the implementation of such practices. The local market for Green Roofs, although is growing rapidly, is still not competitive enough to create affordable prices so that the technology becomes common practice. Especially in the case of Intensive Green Roof systems which cost in Colombia between 2 or 3 times more than what they cost in the European market; opposite to a much lower prices of common construction materials. Unfortunately, experience has shown that Command and Control instruments tend to fail in Colombia given the lack of Control. Private developers, not seeing the economic benefits of SWUD practices, would hardly meet the requirements set on the Ciudad Can Master Plan.

Additionally, local entities have mostly looked at Green Roof systems when promoting SWUD practices. Whereas no effort has been done to promote Rainwater

Harvesting systems which are actually much more affordable and easily implementable in Bogota as it is not a novelty and does not represent excessive additional investment. Still, given the apparent local low prices and high availability of freshwater, they are seldom used.

Alternatives such as both direct and indirect economic incentives should maybe be considered; using international examples as references and assessing which one is more suitable for the financial situation of the city. Options such as indirect incentives would most certainly be appropriate considering Bogota's current finances. However, it would be ideal to perform a thorough study of the financial benefits related to the implementation of these practices in the local context. This could provide stronger arguments when considering the use of economic incentives.

The Ciudad CAN urban renovation project and the ET-CAN building are the perfect opportunity to test WSUD practices performance, as well as the possible tools to encourage their use. Hopefully, this project will serve as a milestone for policy creation and project development at a national level.

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I hereby declare that I have written this thesis with the title:

Evaluation of sustainable water management strategies for urban renovation projects in Bogota, Colombia. Green roof and rainwater harvesting systems in ET-CAN. Case study.

Without any help from others and without the use of documents and aids other than those stated above and that I have mentioned all used sources and that I have cited them correctly according to established academic citation rules.

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