THE CULTURAL-SOCIAL BENEFITS OF DEVELOPING GREEN CHANNELS: CASE STUDIES AND DEMONSTRATION IN JEDDAH CITY, SAUDI ARABIA

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Thesis
Submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Master of Landscape Architecture
In
Landscape Architecture

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5/7/2015
Blacksburg, VA

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Keywords: Green stormwater channel, Green infrastructure, Ecological wastewater treatment, Sense of place, Greening arid countries

ABSTRACT

"… Creative Thinking about the future requires tension – the tension of holding both the need and the possible in our awareness at the same time." – Milenko Matanovic

Constructing concrete open channels can provide a quick, efficient solution to help prevent an area from flash floods and water accumulation. However, such a solution does not take into consideration the increased land needs for housing and public open spaces, in addition to missing the opportunity for benefitting from rainwater and reusing the municipal water of cities in greening sustainable stormwater channels. The United Nations (2014) reported that 54% of the world's population is living in urban areas, and it is predicted to increase to 66% by 2050. Jeddah City, Saudi Arabia already struggles from both lack of open spaces while consuming spaces in constructing concrete open channels, only made worse by the rapid growth of population and urbanism. Although the rate of precipitation in arid regions is low, studies and evidence show that even in arid regions turning the majority of urban areas into impervious surfaces is restrictive and the result of doing so is devastating.

This thesis aims to find an environmental alternative solution for an open drainage channel designed to function as a stormwater management facility as well as a central green finger for Jeddah City. It will take into consideration international and regional precedent design and future development of green channel case studies, to provide efficient design recommendations to planners and designers, who aim to redevelop constructed or proposed stormwater channels using sustainable green infrastructure practices to improve a city's livability.

ACKNOWLEDGMENTS

"Whoever does not thank people (for their favor) has not thanked Allah (properly)."

– Prophet Mohammad (peace be upon him)

All thanks goes first to Allah the most merciful and the most generous, followed by the people who helped me to achieve this work. This achievement would have been mere thoughts, scratches, or even a dream without the great guidance and support from my committee members, my parents, friends, and King Abdulaziz University.

I would like to express my deepest gratitude to my advisor, Dr. Patrick Miller, for his excellent guidance, caring, patience, and creating an academic atmosphere conducive to finishing this work by supporting me. This came mostly in the form of a number of digital and textbook sources that helped me understand how to do academic research, and most importantly, taught me how to narrow down a thesis question and problem, which I could have spent another ten years before finishing. It is my honor that such a well-known, excellent, and humble professor had me as one of his students.

A special thanks to Professor Dean Bork for his immense courage, delicate comments and advices, and letting me experience the different ways of designing a landscape project for better water quality during the hydrology class that he teaches. I also would like to thank Professor Brian Katen for the great opportunity he provided me with by "investing" my skills in improving my general personal knowledge and this thesis. Also, I would like to thank Dr. Mintai Kim who had excellent influence in forming the thesis problem. There are no words that are enough to thank these individuals. If I have power to turn these words into gold I will do so and they deserve more than that.

I will never forgot the great support, guidance and the constant courage by Dr. Abdulmohsen Farahat, who improved my critical thinking and design, and always treated me as one of his sons by making me an example of an outstanding hard worker to encourage every new student he taught.

I would also like to thank my dear friend Dr. Adel Alzahrani for helping me a lot in my professional career as a designer and as an academic. A special thanks to my colleague Jessica Hajek for her editing suggestions.

Thanks also to my step-brother Talal Al-Aidaroos, for heling me with my writing, and great thanks to my brother Anas, for the pictures he took of Tahlia Channel. Last but never least, the deepest and most sincere appreciations tor my mom Dr. Najat Bugis and dad Mr. Mohammed Bogis for their infinite support, teaching me important life lessons, and implanting noble ethics inside me especially when seeking to help the weakest people by giving them a hand literally and figuratively, which was the basis of my career and landscape project intentions including my intentions in creating this thesis.

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THESIS TERMINOLOGY AND ALPHABETS

First: Green Infrastructure (Source: Greening Cities: A review of Green Infrastructure)

GI asset or procedure	Definition
Green Channel	Green Storm Water Channel
Permeable paving	“Permeable pavements are hard surface paving systems that reduce stormwater runoff flows and improve runoff water quality. The porous surface of permeable pavement allows stormwater to soak through to an underlying coarse gravel layer, before slowly draining away. They are used in low traffic areas such as carparks, driveways and footpaths” (Auckland Council, Permeable Pavement Operation and Maintenance Guide)
Bio-retention systems: Rain gardens and bio-swales	Bio-retention systems such as rain gardens can be applied to small sites including parking lots, residential swales, highway medians, etc. A rain garden is “a man-made depression in the ground that is used as a landscape tool to improve water quality” (Virginia Department of Forestry, 2012). They serve multiple functions such as reduction of water pollution, carbon sequestration, etc. depending on the species of plants utilized.

Urban forests	Auckland Council (2008) defines urban forest as all vegetation, including habitats and ecosystems, on the Auckland isthmus. This includes vegetation in private properties, parks, reserves, street trees, etc. Urban forests serve multiple functions including pollution amelioration, temperature regulation, carbon sequestration and storage, as well as providing aesthetic appeal.
Green streets	"A green street is defined as a streetscape designed to: integrate a system of stormwater management within its right of way, reduce the amount of runoff into storm sewers, make the best use of the street tree canopy for stormwater interception as well as temperature mitigation and air quality improvement" (Odefey et al., 2012)
Street trees	According to Odefey et al., (2012), "when properly designed, traditional tree plantings along street and road edges can capture, infiltrate, and transpire stormwater. These virtues can be expanded by incorporating trees into more extensively designed "tree pits" that collect and filter stormwater through layers of mulch, soil and plant root systems, where pollutants can be retained, degraded and absorbed". Additional functions provided by street trees include air pollution reduction, climate change mitigation via carbon sequestration and storage.

Second: Flood Types (Source: from Flood Risk Assessment and Management by Han, Dawei)

Flood Type	Definition
Flash Flood	"Occurs in mountain streams and upper tributaries with relative small catchment areas. Small catchment has smaller storage hence water move out of the catchment faster (most within 6 hours) and in greater volume per unit area than larger catchments. Flash floods are more dangerous to human lives because they are harder to forecast."
Pluvial Flood (i.e., rain flood)	"Occurs when the intensity of rainfall exceed the capacity of drainage system or during prolonged periods of wet weather. The soil is so saturated such that it cannot accept any more water."
Urban Flood (i.e., urban pluvial flood)	"Urbanization destroy vegetation cover on the ground and replaces the ground cover with concrete, asphalt and roofing materials. These impervious areas prevent rainwater absorption into the soil profile, causing rapid runoff into drainage systems. When an intense storm generates runoff that is greater than drainage capacity, urban flooding occurs. This is a special case of pluvial flood when it occurs in an urban area. "

Third: Stormwater

Stormwater Management	“Stormwater is rainwater and melted snow that runs off streets, lawns, and other sites. When stormwater is absorbed into the ground, it is filtered and ultimately replenishes aquifers or flows into streams and rivers. In developed areas, however, impervious surfaces such as pavement and roofs prevent precipitation from naturally soaking into the ground. Instead, the water runs rapidly into storm drains, sewer systems, and drainage ditches and can cause: -Downstream flooding Stream bank erosion -Increased turbidity (muddiness created by stirred up sediment) from erosion” (EPA, 2014a)
Rainwater Harvesting	“The accumulation and deposition of rainwater for reuse before it reaches the aquifer. Uses include water for garden, water for livestock, water for irrigation, and indoor heating for houses etc.. In many places, the water collected is just redirected to a deep pit with percolation. The harvested water can be used as drinking water as well as for storage and other purpose like irrigation. “ (Anonymous, 2015).
Watershed	“that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community.” (Wesley Powell)

100-Year Flood (or 100-Year Storm)	"A one-hundred-year flood is a flood event that has a 1% probability of occurring in any given year. The 100-year flood is also referred to as the 1% flood, since its annual exceedance probability is 1%." (Anonymous, 2015)

CHAPTER 1

INTRODUCTION

Due to the explosion in the world's urban population and the fact that so many cities are located near bodies of water, flooding has become one of the top devastating natural disasters on Earth. Some countries have taken steps towards implementing green stormwater channels in order to reduce urban flooding and create multiple social, environmental, and economic opportunities, while others have chosen to create efficient but non-generative stormwater channel designs. These non-generatively designed channels have been widely used in Saudi Arabia in the form of concrete channels. However, I intend to demonstrate that green solutions can be more beneficial in improving the quality of life of Saudi cities in addition to controlling flooding.

1.1 Background

Saudi Arabia is located in an arid region, where natural water resources are a serious problem and the alternative man-made resources are incredibly expensive. Overall, 55% of the country water resources are provided by twenty-seven desalination stations along the Red Sea and the Arabian Gulf, while the remaining 45% are renewable (precipitations) and non-renewable resources (ground water) (see Figure 1) (Al-Ibrahim, 2012). However, the general desert climate of Saudi Arabia is also characterized by sporadic pluvial floods caused by excessive precipitation, and thus, incompatible stormwater infrastructure is still the number one cause of most natural disasters in the country (see Table 1) (EM-DAT, 2015).

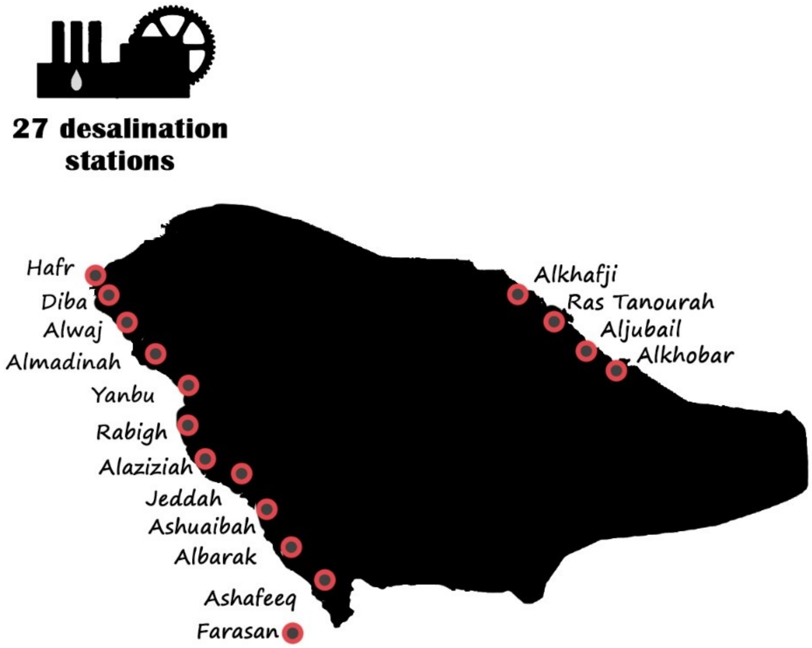


Figure 1 Water resources & consumption per capita in Saudi Arabia (Source: author)

Disaster	Date	No Killed
Flood	24-Nov-2009	161
Epidemic	11-Sep-2000	76
Epidemic	Mar-2000	57
Epidemic	9-Feb-2001	35
Flood	28-Apr-2005	34
Flood	24-Dec-1985	32
Flood	22-Jan-2005	29
Flood	4-Apr-1964	20
Flood	8-Apr-2002	19
Flood	14-Apr-2012	19

Disaster	Date	No Total Affected
Flood	8-Aug-2003	13,000
Flood	24-Nov-2009	10,000
Flood	24-Dec-1985	5,000
Flood	4-Apr-1964	1,000
Flood	14-Apr-2004	430
Epidemic	11-Sep-2000	529
Epidemic	Mar-2000	168
Flood	10-Jul-2010	85
Epidemic	9-Feb-2001	74
Flood	22-Jan-2005	67

Table 1 Top 10 natural disasters in Saudi Arabia for the Period 1900 to 2013, sorted by number of those killed & affected (Source: EM-DAT The International Disaster Database - Center of Research on the Epidemiology for Disasters-CRED) http://emdat.be/country_profile/index.html

Jeddah is a city in Saudi Arabia that was previously prone to floods, and witnessed two pluvial flooding crises as a result of unexpected heavy rain in 2009 and 2010. Another important factor that contributed to these floods was the high rate of impermeable urban surfaces and the low capacity of the constructed drainage system in holding or draining stormwater effectively (Al Saud, 2010). This problem is not unique to Jeddah, and has caused losses in life and property in twenty-eight cities throughout the Kingdom. The most recent urban flood disasters that also caused great damages to property were in Riyadh and Tabouk in 2013 (Alghamdi, 2013). In response to this, the Saudi government is now expending its resources to gather crews of engineers, economists, and other parties to solve this issue. However, the efficiency of environmental or landscape solution and numerous benefits in many green channel cases around the world has already been proven—has not yet been considered by the Saudi government (see Figure 2).

On the one hand, ignoring environmentally sensitive solutions to remove stormwater could become expensive, as well as causing other issues in both the short and long term. On the other hand, integrating environmental and heavy construction solutions in designing stormwater channels can generate extraordinary benefits that go beyond improving the economy, and overflows into the other pillars of sustainability.

Figure 2 Jeddah's flood consequences, & dumping raw black-water close to urban areas & environmentally sensitive areas (Source: author)

Within the balance between land shortages and need of land for recreation or residency, it was found that the prepared strategic plans for Jeddah's stormwater management had been developed to solve only flooding issues (Isnasious, 2014). Not taking into consideration the need for public open spaces and the waste of gray-water makes redeveloping green stormwater channels a rational decision to maintain the security of the channels. Having these spaces (stormwater channels) used by people will reduce, and hopefully prevent, any irresponsible human behaviors like disposing black-water into these channels or other unethical, unauthorized actions. In 2010, a health warning message issued by environmental experts to the municipality of Jeddah urged the city to take action regarding the dumping of raw black-water by sewage trucks (vacuum truck) into drainage channels (see Figure 3) (Badwylan, 2010).

Figure 3 Dumping black-water & solid waste at the drainage channel of Prince Fawaz district, Jeddah City (Source: Al-Madinah Newspaper, 2010)

However, this suitable, urgent flood prevention plan for Jeddah is not considered a multi-benefits solution for three reasons. These reasons include that the channels occupy vast lands in Jeddah are dry most of the year, that the city has a significant need of land for open spaces, and that this plan would have an environmental and social impact as a result of paving huge spaces with concrete. While a great percentage of the city's waste water is not recycled or reused as reported by the municipality (Municipality, 2014c), this valuable source could be used as an advantage to turn the concrete open channels into sustainable parks, which in turn it can help reduce the pressure and traffic from the northern and southern coastal parks in addition to the multiple benefits that it can add to the city's quality of life. Currently, Jeddah is a city starving for open spaces. From the domestic to the international experiences in green stormwater channels, Jeddah's open channels could be seen as great opportunities for creating linear or segments of parks. This phenomenon can be conspicuously seen when you visit the developed recreational parks in the city at the Northern and Southern Corniche (coastal parks) that are overwhelmed with crowds during weekends and holidays (see Figure 4).

Figure 4 The crowd of the Northern Corniche during weekends & large land occupation by Tahlia stormwater channel (Source: Al-Madinah Newspaper, and Riyadh Newspaper)

As a resident of Jeddah City, the continuous weekly and seasonally crowds in public parks discourage Jeddah's residents from enjoying outdoor activities, which in turn affects both man's ability to enjoy the natural environment and people's health. As a matter of fact, traveling outside the country has become a trend that many Saudi families follow for multiple reasons. The reasons include the lack of high quality of recreational activities that encourage domestic tourism. Last year, "10 million Saudi refused domestic tourism and are turning to travel overseas, instead" (Athynian, 2012). Moreover, a comprehensive literature review of studies on the prevalence of obesity in Saudi Arabia reported that there was a progressive increase in obesity prevalence among adults in the Kingdom from 22% in 1990-1993 to 36% in 2005, with a rate of 43.8% in women and 28.3% in men (Al-Quwaidhi, Pearce, Critchley, Sobngwi, & Flaherty, 2014). Avoiding the high risk of poor health for those who are obese or overweight requires an important combination of exercise and diet (Austin, 2014). It is expected that by increasing the number of open spaces could stimulate more physical activities, which could help mitigate the rate of obesity.

The hypothesis of this thesis is that converting stormwater open channels to green channels is very beneficial and applicable for arid cities. It provides to researchers, planners, and designers a guide of how green infrastructure could be implemented in arid regions' stormwater channels, since green infrastructure has thus far only been tested and researched in wet climate regions. Considering the current gap in the literature, the potential and future preparations in Jeddah City were chosen to be the example of a comprehensive vision for future green channel planning and design in Saudi Arabia and/ or the rest of the world.

The thesis was developed to answer the following questions. (1) What are the benefits of applying green principles to the redevelopment of stormwater drainage channels in Jeddah? (2) What are the differences between developing sustainable green open channels approached globally and domestically in Saudi Arabia? (3) How can landscape architects bridge the gap between the traditional engineers' approach of designing channels and the green approaches in order to create a sense of place and improving a city's livability? The objectives of this work are: (a) to illustrate the benefits of transforming stormwater channels to green open channels; (b) to increase open spaces per capita; (c) to emphasize the role of landscape architects in improving environmental, social, economic qualities; (d) to reduce the cost of using sewage treatment plants by using the proposed green open channels as a part of the treatment process (and maintain the landscape and the running stream of the channel); (e) to build a present and future water stockpile that can create a balance between the production and consumption of desalinated water currently used for drinking or irrigation; and (f) to create an ecosystem that can serve both ecological, social, and economic purposes.

1.2 Thesis Organization

The thesis begins by raising the environmental concerns and problems of Saudi Arabia and, in particular, Jeddah's unbalanced future expansion—compared to the population growth rate and the available and the needed rate of open spaces per capita. In order to magnify the unnoticed future issues, this thesis presents green channel approaches that can be developed instead in accordance with Jeddah's huge consumption of lands, which can provide pure engineering solutions (concrete drainage channel) that can eliminate developing flooding issues only.

Chapter 2 contains the literature review that is dedicated to illustrating the benefits of incorporating green infrastructure practices within the concrete channels in terms of the ecological performance, biodiversity, and city's quality of life. It will also describe Green Infrastructure as a broad base of knowledge, and the ways to justify the principles and concepts of this system for coastal arid regions. Moreover, it will cover the practices encompassed within this knowledge base and specifically the ones that are dedicated to open channels. Later, the chapter will shed light on the barriers that prevent arid countries like Saudi Arabia from having such a system, and how to overcome these obstacles by highlighting additional opportunities or alternatives.

Chapter 3 illustrates the methodology that was developed to test the feasibility and benefits of transforming Jeddah's stormwater channels into green channels. The methods consist of international and domestic case study analysis, using Jeddah City to demonstrate the learned knowledge and lessons from both the literature (see Chapter 2) and the selected case studies, followed by a feasibility study dedicated for Jeddah. The results collected using these methods are presented in chapters 4, 5, and 6 respectively.

Chapter 4 demonstrates Jeddah's issues and opportunities regarding the current stormwater drainage channels. This is done in order to emphasize the opportunities that can be generated by incorporating the gray channels into sustainable stormwater drainage channel from economic, social, environmental, and tourism point of views. The chapter will also stress the climate and resources challenges that stand in front of making these channels "green." The chapter will draw a historical timeline of the stormwater management development in Jeddah, from the first time it was first inhabited until the present, to highlight the sustainable used-stormwater management practices in the past that contributed to reducing flooding issues. General information including the urban and population growth, the city's future expansion, and the available rate of open spaces per capita will also be included in order to evaluate and argue against the currently proposed concrete open channels that the government has developed. The levels of water consumption and recycling compared to the rate of daily production will be also presented to support the feasibility studies in rationalizing the objectives of this proposed project (greening the concrete open channels) in such a climate zone.

Chapter 5 contains the methods used in this thesis in order to study the chosen sustainable open channel cases. These methods are presented in order to generate lessons learned that could be adapted for Jeddah, followed by the focus area of the study supported by feasibility studies. Chapter 6 contains the findings of the thesis and future research questions.

1.3 Research Significance

In most Saudi cities and particularly in Jeddah City, the existing stormwater management plan and design strategies are unsustainable due to global climate changes, the limitation of natural resources and/or the water scarcity situation, and shortages/need of land for recreation or residency. However, incorporating the traditional techniques of stormwater management coupled with contemporary technologies of green infrastructure practices could support sustainable achievements in developing green open channels. The green open channels would provide "biological machines" that appear as "green fingers" of a city, but can function beyond the actual designed-physical appearance (i.e. also as linear parks). They function as "green fingers" that could provide multiple ecological, social and economic services. They may provide arid cities with an additional water supply and even productive landscape "urban agriculture." This would help improve environmental quality, public health, and enhance overall the image of arid cities. Therefore, this thesis can be seen as relevant to governments, practitioners, and researchers who are interested in ways of implementing green infrastructure practices in arid regions—in other words, to help those who are looking to implement a multifunctional and "resilient" system. Green open channels are expected to help improve the quality of life of those countries who face water scarcity issues as well as low rate of public open space per capita like in Saudi Arabia, by recycling the wasted spaces (i.e. concrete channels) and less resilient wastewater.

CHAPTER 2
LITERATURE REVIEW

This thesis aims to answer research questions related to the multiple benefits of incorporating green infrastructure practices within concrete stormwater channels in arid regions like Saudi Arabia. It is the intent of this researcher to demonstrate how a deeper understanding of these benefits will help landscape architects and decision makers (i.e. governments) reconsider "green principals" in future planning and/or redeveloping of stormwater channels for better, more livable urban spaces and societies. However, to answer these research questions, it is vital to begin with a thorough understanding of the theory and methodology underlying research on green infrastructure principles and practices and its influence on environment, society and economy.

Many scholars and organizations have defined GI in both slightly different and quite similar ways. Yet, one of the most significant gaps in this subject is due to the fact that the knowledge covered in all the reviews represent wet regions. This means that none of them demonstrate the knowledge or provide possibilities of this system in arid regions. Therefore, this thesis demonstrates the feasibility of implementing the principles of GI in arid regions, with this chapter more specifically covering the knowledge needed to understand the feasibility (which will be discussed in more detail in Chapter 6). To do so, first, a list of definitions bellow were collected precisely in order to explore and modify a definition to be adapted for arid regions like Saudi Arabia.

2.1 What is Green Infrastructure?

"…We need creative urban design and planning that makes nature the centerpiece, not an afterthought." – Timothy Beatley

Green Infrastructure (GI) is a broad subject, for which much research has illustrated the multiple benefits that can be generated from it regarding the environment, society and the economy. This section covers an overview of the knowledge, practices and benefits of GI to demonstrate the opportunities and barriers of implementing such a system in arid regions in regard to green channels.

GI has been defined in different resources as an integrated system with the built environment, which combines natural and ecologically engineered systems that promote various ranges of ecological, social and infrastructure services (Boyle et al., 2012). It is an adapted term that represents a group of products, technologies, and practices that implements natural or engineered systems to improve the quality of environment with provision of utilities services by mimicking natural process (EPA, 2011). A network of multi-functional green space that includes both new and/or existing networks, and rural and urban spaces is integral to the health and quality of life of sustainable communities (PPS12, 2008). According to Benedict and McMahon, these open spaces represent a "strategically planned and managed networks of natural lands, working landscapes and other open spaces that conserve ecosystem values and functions and provide associated benefits to human populations" (Benedict & McMahon, 2006). This can include waterways, garden, woodlands, green corridors, street trees, and open countryside that benefit local people socially, economically, and environmentally (TEP, 2005). According to Mitchell and Smith, "Green infrastructure practices are very flexible and can be integrated into many different development contexts, including new development, redevelopment, and retrofit of public and private properties." (Partnership, 2013). Therefore, a concept of recreating a system must supports species and their communities to move and adjust (WWF, 2011).

Based on these definitions, GI can be also implemented in arid regions. Highlighting the main ideas of this concept, there are no major differences between arid regions compared with wet region—except the part that describes the water bodies. Therefore, GI in arid regions can be defined as the physical environment within and between our cities or villages, which uses an engineered ecosystem that mimics the natural process. In other words, it consists of an array of products and flexible practices that can be integrated into many development contexts to enhance overall environment quality to human populations like social, economic and ecological benefits. However, for arid regions in particular, "green" as a word in this matter is a big concern due to limited or scarce water resources, and so it is used as a concept rather than an actual organism or living being. However, plants are still the main living machines that assure efficient performance of a newly created system of GI in arid regions. Citing Boyle et al., "In fact, the role of vegetation in improving climate, air, hydrology and the quality of life were documented in the 1980s (e.g. Bernatzky, 1982 and Rowntree, 1986)" (Boyle et al., 2012). Therefore, regardless of the water scarcity situation of arid regions, plants are still the most important material of implementing green infrastructure, and so the provision of vegetation is not an option, however it should follow the provision of plants as laid out by green (sustainability) principles.

2.2 Green Infrastructure Scales

The Landscape Institute (2009) has developed typology based on scale where GI practices are classified according to: 1) Local, neighborhood and village scale; 2) Town, city and district scale; and 3) City-region, regional and national scale (EEA, 2011). In this way, this section classifies GI assets according to a scale of open channels suggested by this thesis, which vary from neighborhood, town to regional scale as given in Table 2. Some of the elements might not be applicable to arid regions like Saudi Arabia due to the limitation of water resources.

Local, neighbourhood and village scale	Town, city and district scale	City-region, regional and national scale
■ Street trees, verges and hedges ■ Living roofs and walls ■ Pocket parks ■ Private gardens ■ Urban plazas ■ Town and village greens and commons ■ Local rights of way ■ Pedestrian and cycle routes ■ Cemeteries, burial grounds and churchyards ■ Institutional open spaces ■ Ponds and streams ■ Small woodlands ■ Play areas ■ Local nature reserves ■ School grounds ■ Sports pitches ■ Swales (preferably grassed), ditches ■ Allotments ■ Vacant and derelict land	■ Business settings ■ City/district parks ■ Urban canals ■ Urban commons ■ Forest parks ■ Country parks ■ Continuous waterfronts ■ Municipal plazas ■ Lakes ■ Major recreational spaces ■ Rivers and floodplains ■ Brownfield land ■ Community woodlands ■ (former) mineral extraction sites ■ Agricultural land	■ Regional parks ■ Rivers and floodplains ■ Shorelines ■ Strategic and long distance trails ■ Forests, woodlands and community forests ■ Reservoirs ■ Road and railway networks ■ Designated greenbelt and strategic gaps ■ Agricultural land ■ National parks ■ National, regional or local landscape designations ■ Canals ■ Common lands ■ Open countryside

Table 2 GI assets classified according to scale (Source: from Landscape Institute, 2009)

2.3 Centric and De-centric Green Infrastructure in Arid Regions

This thesis claims that a centric GI system (i.e. linear parks and linkages) is more beneficial and sustainable than de-centric GI systems (i.e. neighborhood parks). According to the Dallas Park & Recreation Department, neighborhood parks

> …serve a variety of age groups within a limited area or neighborhood. They range in size from 1 to 15 acres and generally serve residents within a quarter- to half-

> mile radius. *The neighborhood park* includes areas for active recreation activities such as field games, court games, playgrounds, etc. Passive recreation activities may include walking, viewing, sitting, and picnicking. Facilities are generally unlighted and off-street parking is not recommended. (2015)

This definition points to the salient features of neighborhood parks as “passive” rather than “active” spaces for social activities. Conversely, Dallas Park & Recreation defines *linear parks and linkages* as

> …built connections or natural corridors that link parks together. Typically, the linear park is developed for one or more modes of recreational travels such as walking, jogging, biking, in-line skating, hiking, horseback riding, and canoeing. Linear parks may include active play areas. The NRPA does not stipulate specific standards for linear parks other than they should be sufficient to protect the resource and provide maximum usage. (Parks, 2013).

This distinction between active and passive uses of open green spaces is one of the primary claims that this thesis makes for why centric GI systems are potentially more beneficial for arid regions.

Adults need two and a half to five hours of activity with involvement of forty minutes of aerobic activity five times a week, with of course some variation between people in terms of how active a person already is. Regardless of how beautiful the landscape is, no one would find satisfaction in walking day after day in a neighborhood parks of 1.7 acres with only 0.15 miles parameter for 17 circuits per day of speed of 4 miles per hour. A single 40-minute circuit around a park requires 278 acres, which means a typical neighborhood park is too small to meet this size need. Unless this park was also equipped with a stationary exercise equipment, it would be difficult for residents to meet their weekly activity needs. Despite the fact everyone can walk around a neighborhood, there are number of unanticipated barriers that confront or discourage walking in neighborhoods. The absence of sidewalks (or being in poor condition if available), traffic noise, fumes and hazards, steep or hazardous terrain, lack of shading by trees, dogs, absence of benches, and/or sometimes crime risk make it unsafe to walk in a neighborhood (Austin, 2014). Many of these factors were all actually found in some typical neighborhoods of Saudi cities.

Therefore, the most important requirement to support daily physical activity is a walkable neighborhood and a nearby path that is separated from the road and designed for walking and/or biking (Austin, 2014). For the case study of Jeddah presented in this thesis, the researcher will design an urban green channel that can provide these requirements for daily physical activity in neighborhood—besides other benefits can be generated out of it, due to the fact that a green channel that crosses through a neighborhood is considered a very good asset for an road-safe pedestrian walkway and connection for separated neighborhoods (a result of roads, streets and stormwater channel). Moreover, green channels promotes are also in line with what linear parks promotes to communities (see Figure 5).

Figure 5 Two different examples of linear parks created a new sense of place & have been encouraging daily physical & social activates (Source: the left photo was taken by author, & the right from http://m.thanglongtravel.vn/tin-tuc/seoul-trung-tam-du-lich-mice-cua-the-gioi.html)

2.4 Green Infrastructure Assets, Multi-Functions and Benefits

While gray stormwater infrastructure is mainly designed to serve the singular purpose of moving urban stormwater out of urban areas, GI provides many other environmental, social, and economic benefits in addition to treating and reducing stormwater at its source. According to the Environmental Protection Agency (EPA), "These benefits not only promote urban livability, but also add to the bottom line" (EPA, 2014c).

The natural elements are the major assets of GI which provides social, environmental and economic benefits. These assets include a network of green spaces and other natural elements (i.e. rivers and lakes) that are interspersed between and connect villages, towns and cities. Connectivity of these GI assets is the key behind generating maximum benefits from them. A connectivity can be visual or notional; however the biggest impact is a result of physical connections. The result of this connectivity fosters the engagement of the public with nature, and assists in encouraging sustainable forms of travel and migration that improve biodiversity (Institute, 2009). The multiplicity of functionality and benefits of GI are some of its major assets, and the provision of healthy open spaces for example can mitigate and adapt to climate change. In terms of adaptation, GI increases ecosystem resilience by: managing high temperatures, water supply, riverine flooding, coastal flooding, and surface water—in addition to reducing soil erosion, helping other species to adapt, and managing visitor pressure (WWF, 2011). The value of GI is based on the multiple functions that GI offers where the primary functions can be categorized under: 1) Water and storm water; 2) Land use; 3) Energy; 4) Communications; and 3) Transport (Boyle et al., 2012).

Research and reports have covered multiple benefits that can be generated from implementing GI practices for the benefits of ecology, community and economy. For instance, Gary Austin in his book about “Green Infrastructure for Landscape Planning: Integrating Human and Natural Systems” (2014), illustrates multiple functions or “services” that can be performed by GI, and so multiple benefits follow that as a result. Maintaining the health of the ecosystem was found to be very important in generating multiple human services (or benefits), where GI plays the key link of this beneficial relation between them (see Figure 6 & Table 3).

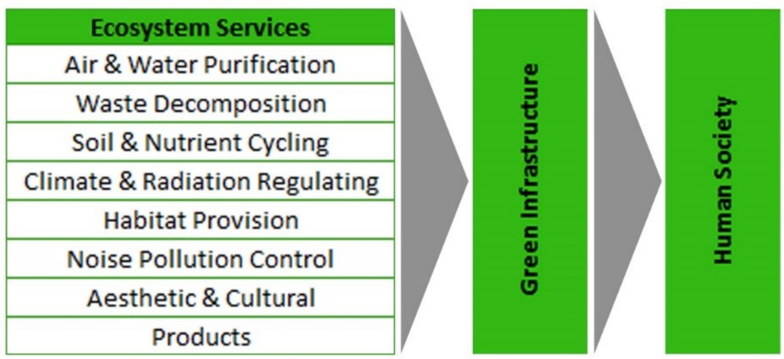


Figure 6 Ecosystem services & products are provided through GI to humans. The services flow to human society only when the vability maintained. In every case, the components listed here are not independent; insteade they are embaded and interact within an ecosystme. (Source: Austin, 2014)

Economic value	Social value	Environmental value
▪ Water and flood risk management. ▪ Water quality, supply and function of hydrology. ▪ Sustainable energy use and production – saving energy and cost. ▪ Sustainable waste management. ▪ Sustainable food production. ▪ Micro-climate adjustment and adaptation to climate change. ▪ High-quality environment to attract and retain a quality workforce. ▪ Rising property values. ▪ Boosts to the local economy. ▪ Links between town and country.	▪ Recreation, enjoyment and health benefits. ▪ Community development and cohesion. ▪ Provision of space for public art, concerts, etc. ▪ Non-motorised transport systems. ▪ Exposure to nature and increased awareness of environmental issues. ▪ Education and training. ▪ Visual screening of unsightly buildings or infrastructure. ▪ Heritage preservation and cultural expression.	▪ Biodiversity protection and enhancement of habitat and species – preserving ecosystems. ▪ Landscape restoration and the regeneration of degraded sites. ▪ Protection of significant geological sites. ▪ Reductions in the ecological footprint. ▪ Carbon sequestration.

Table 3 Economic, social & environmental functions and values of GI (Source: from TCPA, 2008)

2.4.1 The Cost-Effectiveness of Green Infrastructure

As reported in "BANKING ON GREEN: A Look at How Green Infrastructure Can Save Municipalities Money and Provide Economic Benefits Community-Wide" (2012), GI has been realized and appreciated lately over the past few decades by many American communities for the considerable financial and water quality benefits that are generated by implementing GI practices or "approaches" to reduce and manage stormwater. These practices include roof gardens (i.e. stormwater control and energy reduction), wetlands restoration (i.e. floodwater retention), mimicking natural "hydrologic functions" by installing permeable pavements, and harvesting and reusing water on site. Infiltration and evaporation are elements of hydrologic functions and through them, stormwater management receives a volume reduction out of surface run-off reduction or prevention. According to the report, these practices are often provide a cut in cost, meaning that they are more "cost-effective" than traditional stormwater management (or "gray infrastructure") because these traditional methods "rely heavily on heavily engineered and structural solutions" (2012). Additional benefits can be also generated out of GI practices like air and water quality improvements, habitat and green spaces of communities' quality of life, as well as property values is a consequence of enhancing locals' environment and aesthetic. The reduction of runoff "can provide healthier aquatic habitats and water supplies, becoming resources that provide environmental and public health benefits to all residents." The report illustrated classifications of efficiency as the following:

> • ***Green infrastructure can be cost-effective —***
> *Green infrastructure can provide less expensive, and more cost-effective, approaches to managing runoff.*
> *Municipalities and developers may benefit from lower capital costs, land acquisition requirements, operational expenses and other financial burdens when green infrastructure is integrated into new*

construction, redevelopment projects, or programs to reduce combined and sanitary sewer overflows.

• ***Green infrastructure increases energy efficiency and reduces energy costs —***
Stormwater management practices built around natural hydrologic functions and increased use of vegetation can dramatically reduce energy consumption. Green roofs, street trees, and increased urban green spaces have the effect of making individual buildings more energy efficient by reducing heating and cooling demands. On a neighborhood or community level, the shading and insulation provided by these techniques cools urban heat islands, again reducing the energy required to cool indoor spaces during summer months. Additionally, by re-using harvested rainwater, some green infrastructure approaches decrease the need to use potable water for landscaping, toilet flushing, or other industrial uses. In turn, this reduces municipal and utility expenditures to transport, treat, and deliver potable water.

• ***Green infrastructure can reduce the economic impacts associated with flood events —***
Poor stormwater management can be a significant factor in many localized flooding events, increasing damage to property and public infrastructure. Federal Emergency Management Agency (FEMA) estimates that 25% of the $1 billion in annual damages from caused by flooding are linked to stormwater.[5] *By increasing infiltration and retention, green infrastructure can substantially reduce the overall amount of water entering local storm sewers or surface waters and reduce flooding-related impacts, including decreased property values and tax revenues associated with flooding, damages to public infrastructure and associated repair costs and damages to private and public property.*

• ***Green infrastructure protects public health and reduces illness-related costs —***
The pollutants delivered by stormwater runoff are a major source of contamination of drinking water supplies, recreational waters, and productive fish and shell fishing areas. The medical and lost productivity costs associated with water-borne illnesses can be considerably reduced by preventing harmful bacteria and other pollutants from entering these waters. The EPA estimates that CSOs and separate sewer overflows (SSOs) cause at least 5,576 illnesses every year from recreational exposure at recognized recreational beaches across the country. The number of illnesses caused by recreational exposure to waters contaminated by CSOs and SSOs is likely much higher because EPA's analysis was limited to gastrointestinal illness alone and did not evaluate illness at inland or unrecognized beaches.[6]
Clean waters are essential to the vibrancy and success of local businesses that depend on beachgoers and other recreational water users. Green infrastructure reduces the pollutants that enter our waters and can help to reduce the impact of these economic losses. (A.Rivers et al., 2012)

2.5 Green Infrastructure and the Livability of Physical Environment

"Livable cities" is a term first used back in the 1980s that aims to describe quality of life and the characteristics of cities that make them livable. According to the International Making Cities Livable LLC., "The term has become so widely, if not overly used, that its meaning is becoming lost" (Maggie, 2014). Typically, the term has been used in countless ways to describe standards of living, rather than quality of life. "Most livable," is a title that every city wants to be recognized as, in order to attract new business and investments, boost local economies and real estate markets, and foster community involvement and pride. There are a number of conditions that can encourage these outdoor activities and by extension, community involvement. Jan Gehl, in *Life Between Buildings: Using Public Space* (2011), demonstrates and classifies outdoor activities and demonstrates a number of the physical conditions that influence them. Gehl classifies outdoor activities into three categories, each differing in demands on the physical environment—necessary, optional, and social activities or "resultant."

First, the "necessary" activities are those which require less degrees of participation that are "more or less compulsory," like going to school or to work, shopping, waiting for a bus or a person, running errands, distributing mails. The "physical framework" of the environment has a slight influence on these kind of activities, due to the nature of these type of activities as a "necessity," and that the participants have no choice to do them or not. According to Gehl, "When outdoor areas are of poor quality, only strictly necessary activities occur" (2011). Second, "optional" activities represents all of those for which a person has of a choice to whether to do them or not. However, the consideration of time and place are in the preference of making these activities possible is another matter. Example of these types of activities are talking and walking for a breath of fresh air, standing to enjoy life, sitting, and sunbathing. Usually these activities are fostered by optimal conditions of the exterior environment, and also when whether a place is inviting. As Gehl claims, "This relationship is particularly important in connection with physical planning," and this can be conspicuously seen over most of the recreational activities that are “epically pleasant to pursue outdoors,” which are found precisely within this category of activities (2011).

Third, “social” activities are fostered where the presence of other people (as in more than one person) in public spaces is required. According to Gehl, this includes “children at play, greeting and conversations, communal activities of various kind, and finally – as the most widespread social activity – passive contacts, that is, simply seeing and hearing other people” (2011). These social activities could also be described as “resultant” activities, “because in nearly all instances they evolve from activities linked to the other two activity categories” (Ibid.).

The quality of the environment will have an impact on both necessary and optional activities. When outdoor areas are of high quality, necessary activities take place approximately for the same duration and at the same frequency, and though they tend to be more prolonged if the physical condition are better. Furthermore, optional activities will also occur because the place and situation are now inviting for people to stop, sit, eat, and play, and so on. Whenever necessary and optional activities are given better conditions in public spaces, social activities occur as a result (see Figure 7) (Gehl, 1996). In poor exterior conditions, people may hurry home and only the “bare minimum of activity takes place” (Ibid.). In contrast, a broad of spectrum of human activities are possible in a good environment.

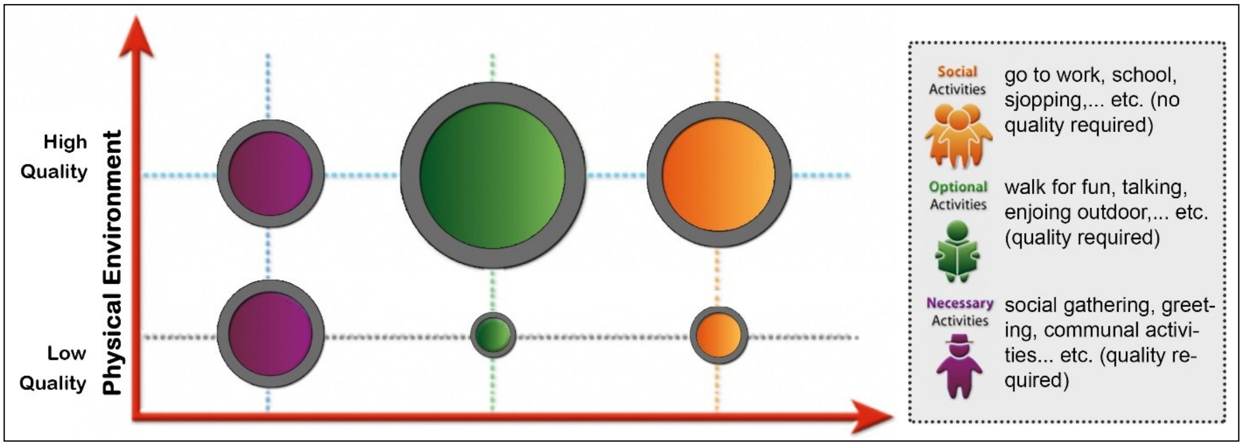
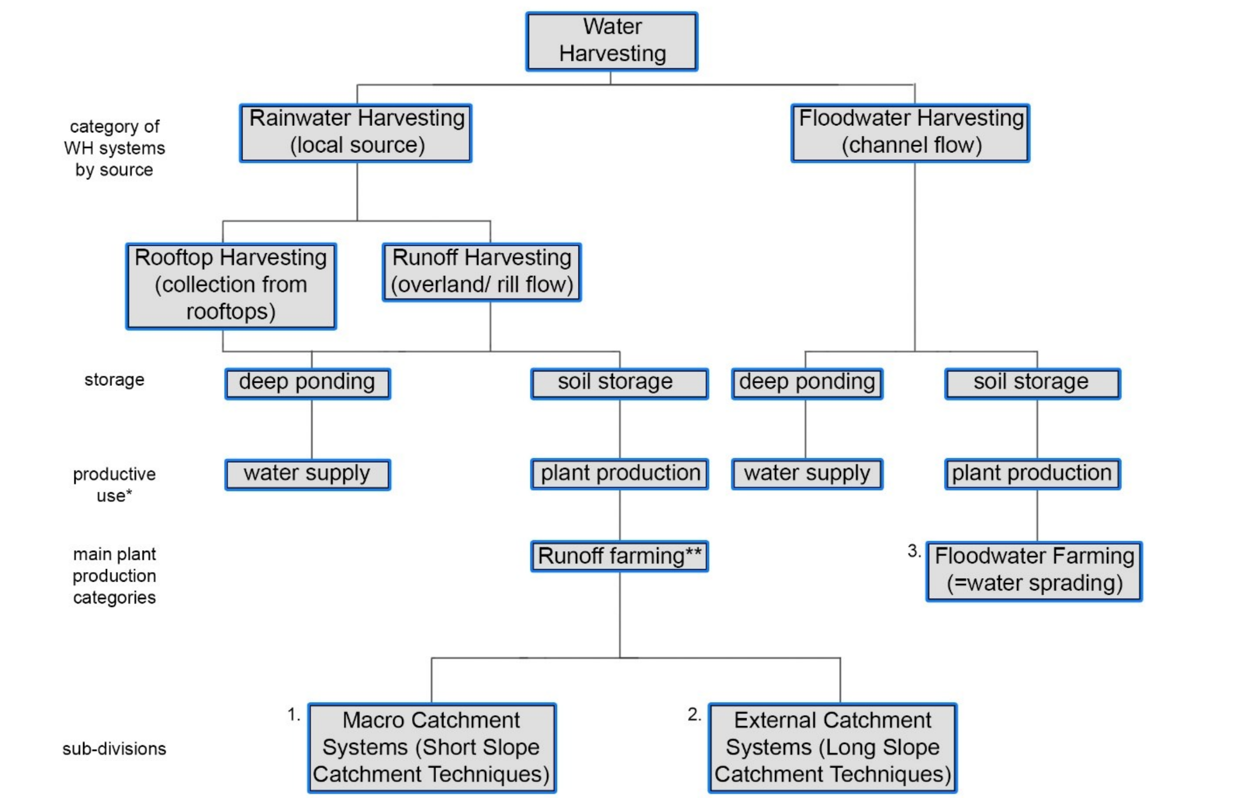


Figure 7 The nature of the relationship between environmental quality & human activity (Source: adapted from Gehl, 2011)

2.6 Rainwater Harvesting

As cited in "A Review of Rainwater Harvesting" by Boers & Ben-Asher (1982), the first definition of water harvesting (WH) appeared in Myers seminal article (1975). Here, Myers quotes the definition of WH suggested by Geddes as "the collection and storage of any farm waters, either runoff or creek flow, for irrigation use" and by Currier as "the process of collecting natural precipitation from prepared watersheds for beneficial use." Moreover, Myers himself offers the following definition, or "the practice of collecting water from an area treated to increase runoff from rainfall or snowmelt" (Boers & Ben-Asher, 1982). Therefore, rainwater harvesting (RWH) is a process of catching, moving, and storing rainwater for uses by humans (i.e. cultivation, food and drinking) and/or other non-humans (i.e. animal needs), and that requires a catchment area, transference, storage, and a system for distribution. According to the United States Environmental Protection Agency (EPA), RWH is also recognized as one of the most important GI practices or elements. This is because it helps "slow and reduce runoff and provide a source of water" when a system of RWH is designed appropriately (EPA, 2011).

However, according to Brauch et al., “The natural aridity is a major constraint on productivity, and very little can be done to change it” (2003) (see Figure 8). Thus, in arid and semi-arid regions like Saudi Arabia and other Middle East and North Africa (MENA) countries, RWH is considered to be attractive. This is primarily because RWH used to be and is still in use in some of the MENA countries, as most of them are classified as “water-scarce countries” (precipitation below 300mm).



Notes:
* Water supply systems (i.e. ponded water) used for a variety of purposes, mainly domestic and stock water but also some supplementary irrigation.
** The term “farming” (as in “”Runoff Farming”) is used in its broadest sense - to include trees, agroforestry, rangeland, rehabilitation, etc.
*** Deep ponding often also referred to also long term storgae includes dams, reserviors and all kind of tanks.
Source: Siegert, K.: Introduction to water harvesting: some basic principals for planning, design and monitoring, in: The FAO Proceedings of the Export Conclusion about “Water Harvesting for Improved Agriculture production”, Water Report No. 3, Rome, 1994

Figure 8 Classification of water harvesting techniques (Source: Brauch et al., 2003)

As described by Kinkade-Levario (2007), there are many reasons that RWH has proven to be attractive to MENA countries. These reasons, according to the authors, include:

> 1) It provides a self-sufficient water supply located close to the user; 2) It reduces the need for, and hence the cost of, pumping groundwater; 3) It provides high-quality soft water that is low in mineral content; 4) It augments the supply and improves the quality of groundwater when it reaches the aquifer after it has been applied to the landscape or crops; 5) It reduces and may even eliminate soil salts as it dissolves and moves the salts down through the soil; 6) It mitigates urban flooding and, as a result, reduces soil erosion in urban areas; 7) Roof top rainwater harvesting is usually less expensive than other water sources; 8) Roof top rainwater harvesting systems are easy to construct, operate, and maintain; 9) In coastal areas where salt water intrusion in to the aquifer is a problem, rainwater provides good quality water, and when recharged to groundwater, reduces groundwater salinity while helping to maintain a balance between the fresh and saline water interface; 10) On islands with limited fresh-water aquifers, rainwater harvesting is the preferred source of water for domestic use; 11) Occasionally, there are economic advantages such as rebates from municipalities for a reduction in use and dependency on municipal water.

These benefits are some of the most obvious reasons why RWH is not only popular among MENA countries in the present, but also why RWH was present in these countries for thousands of years.

As reported in "Assessing Desertification and Water Harvesting in the Middle East and North Africa: Policy Implications" (1999), the first signs of WH practices in history were found in the MENA region. Remnants of early WH structures in the Edom Mountains in southern Jordan are believed to have been constructed over 9,000 years ago. Moreover, many cultures around the world have also harvested rainwater including in the Middle East, Asia, Ancient Rome, and Mexico. As far back as 3,000 BC in India, simple stone-rubble structures were used for capturing rainwater. As early as 2,000 BC, other civilization in the Negev Desert survived by storing hillside run-off in cisterns (Kinkade-Levario, 2007).

Other signs of early WH structures have been discovered along the routes used at the time by caravans in Iraq and the Arabian Peninsula. More recently, catching rainwater and storing was also practiced in North Africa beginning in the 11th and 12th centuries and continuing into the present. For instance, it was estimated that in Morocco alone in 1990, there were over 360,000 cisterns that still supplied domestic water to 10% of the population throughout the country (Nasr, 1999). In Saudi Arabia WH is also extant in different regions throughout the country in different ways. Asir, the southwestern region of Saudi Arabia (north of Yemen) receives surprisingly up to 20 inches (500 mm) of rain annually, is considered one of the kingdom's wetter and more temperate climates, and is an important agricultural region. The steep terraces cut into the mountainous landscape for agricultural use have the added benefit of providing a source of passive RWH (see Figure 9). Historical evidence also shows that in arid-coastal regions in Saudi Arabia like Jeddah City, RWH had been practiced by individuals for years within the old city limits (now called Albalad) in a form of underground cisterns that stored stormwater that used to be harvested from the roof tops of many ancient building there (see Figure 10).

Figure 9 Most cultivation in the Asir region, Saudi Arabia takes place on steep, terraced mountainsides, and the main crops include wheat, coffee, cotton, indigo, ginger, vegetables, and palms. Moreover, passive RWH occurs because of these terraces (Source: from the Arabshare website)

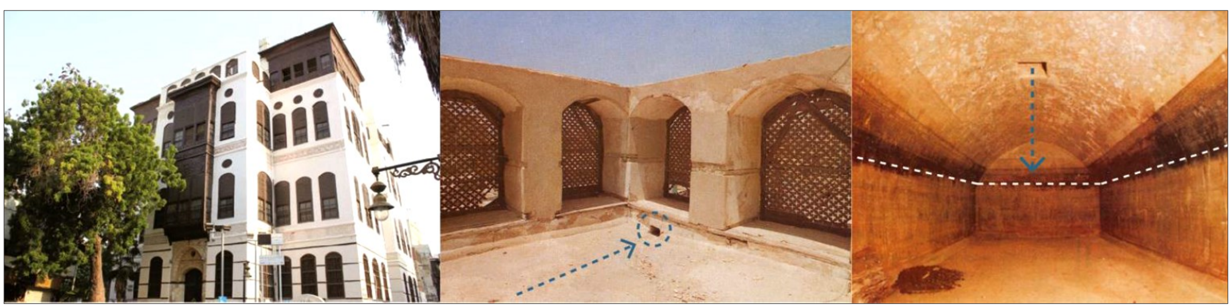


Figure 10 Traditional rooftop rainwater harvesting with underground cistern (Source: Image of Nasif House, from The National Center for Research and Documentation at Jeddah City)

2.6.1 Active and Passive Rainwater Harvesting Systems

Active and passive are two classified systems of RWH. Active RWH refers to systems of collecting, filtering, and storing in tanks or cisterns for future use (Pushard, 2015). In contrast, passive RWH refers to systems of collecting rainwater from low infiltration surfaces and directing it to irrigate a designed landscape area, like rain-gardens, bio-swales, constructed wetlands, tree-boxes, and green-streets (Kinkade-Levario, 2007). Luckily, all the buildings in Saudi Arabia—whether residential or commercial—have constructed cisterns that were made to receive the potable water of the municipalities. Therefore, it is possible to collect rainwater by harvesting from the rooftops of buildings and storing it in these cisterns (after a process of infiltration and proper cleaning before the deposit).

Compared to the passive RWH systems, active RWH systems are more complex and more expensive in general. Active RWH systems require electricity to operate pumps and filters that are needed for the system, which means constant maintenance is required. Passive RWH systems on the other hand, require only areas to contain waters to be naturally absorbed into the land. With the ability to store huge quantities of winter rainfall and summer monsoon rains, passive systems can also move water to exact spots when needed; although generally, they are related to irrigation systems, they are also applicable for residential uses. Both active and passive RWH systems contribute to a significant overall water consumption, with a major distinction of active RWH used primarily for indoor water consumption. In contrast, passive RWH systems can be added to most new or existing landscapes without major changes or expensive treatment and they require little maintenance, since as Pushard explains, "Both are valid methods of harvesting rainwater and neither should be neglected as an option" (Pushard, 2015).

2.6.2 Rooftop Stormwater Harvesting

There are many RWH practices that can help reduce a city's total surface runoff and is associated with buildings like *green roofs, blue roofs, cisterns* and *rain barrels*. This section briefly explains each system, with a particular emphasis on the system that is associated with this thesis (i.e. cisterns or rain barrels).

Green roofs are gardens or vegetation constructed on rooftops and consist of multiple layers of specially-designed soil that provides a growing medium for plants. The requirements and complexity of such a system are more costly than a conventional roofs. However, they provide multiple economic, social and environmental benefits like cooling rooftops by reducing UV radiation absorption, improving quality-of-life for residents, and providing a habitat for birds in addition to the valuable contribution of absorbing and retaining a great volume of stormwater (NYC, 2015) (see Figure 11).

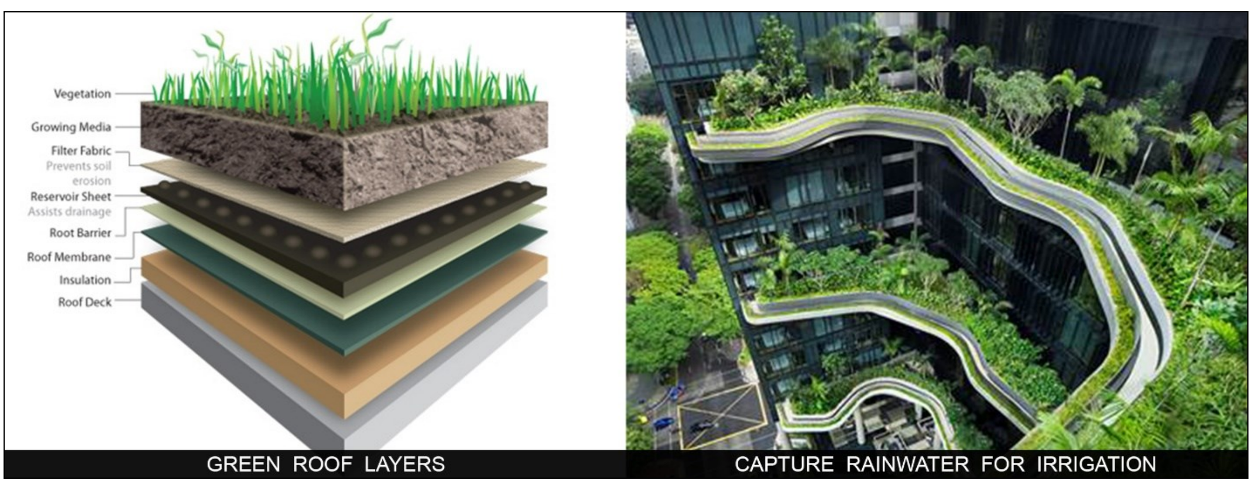


Figure 11 Green roofs for water management and aesthetic and productive purposes (Source: the left picture model from http://www.hazenandsawyer.com/, and the right picture from http://www.greenrooftechnology.com/)

Blue roofs consist of light colored material that reduce building heat, although vegetation is not part of the materials of these systems. They offer environmental services like controlling stormwater, which they detain stormwater for a period of time and gradually release it to the drainage system (NYC, 2015) (see Figure 12).

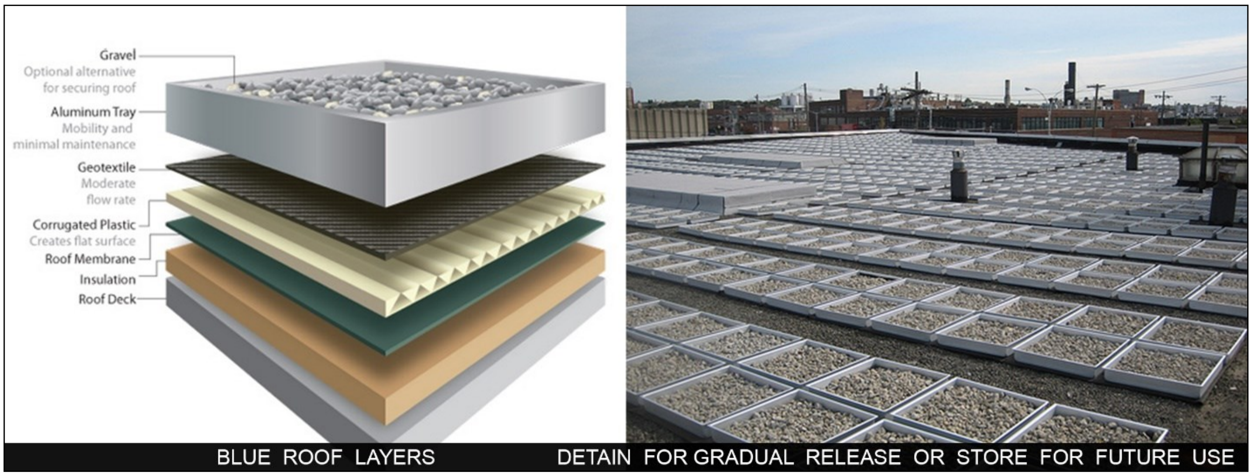


Figure 12 Blue roofs system of detain to gradually release or store future uses (Source: the left picture model from http://www.hazenandsawyer.com/, and the right picture from http://reducerunoff.org/)

According to Clark & Acomb (2008), cisterns and rain barrels are "storage tanks that capture runoff water from a catchment area like rooftops." Usually, cisterns can store more water than barrels because of the significant different size comparing with barrels (see Figure 13). Rain barrels can only be placed outside of a building and must be attached to the downspout; they are usually made to suit single-family houses. In contrast, cisterns can be constructed above or underground. Both storage tanks help reduce water consumption and considered a good source of non-potable uses and/ or irrigation. They are also effective to in reducing stormwater runoff (Uf, 2008).

Figure 13 Rain barrel & underground mega cistern (Source: left picture from http://prairieform.com/blog/wp-content/uploads/2011/02/rain_barrel.jpg, right picture from http://www.istanbuldiary.com/Turkey/Destinations/Istanbul/Sites/Cisterns/Theodosius-Cistern.html**)**

Figure 14 shows a diagram of a stormwater catchment system of a rooftop in Jordan. In most cases, the roof of a house or a building is the collection area. The used material in roof construction affects the collection efficiency and also the water quality. As a roof surface texture is cleaner and smoother, this means that more impervious roofing materials are preferred, and a higher quality and greater quantity of water is expected to be generated. The most preferable and easiest way to use and give the cleanest water was found by implementing "tiled roofs" or roofs sheeted with corrugated mild steel (Abdulla & Al-Shareef, 2009).

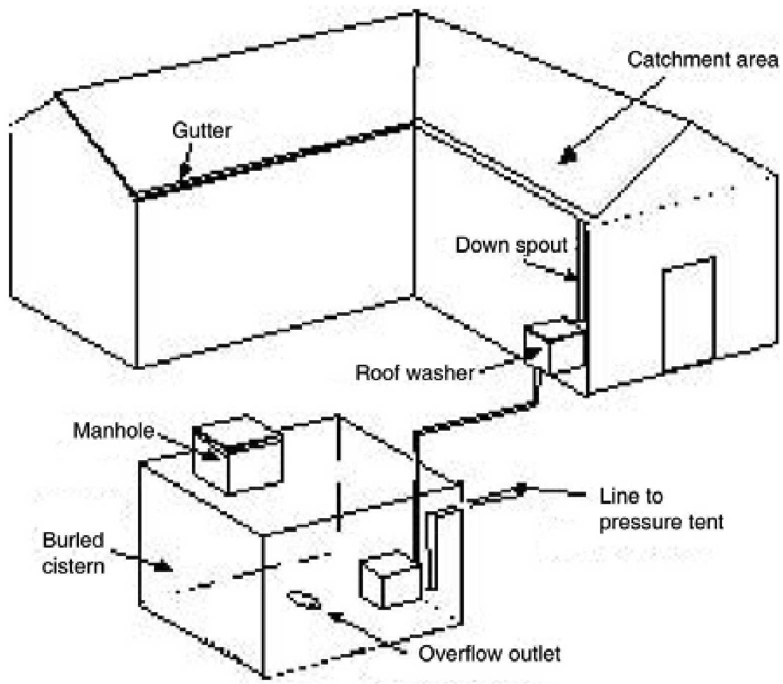


Figure 14 Typical roof water harvesting system in Jordan (Source: from Abdulla & Al-Shareef, 2009, P. 199)

2.7 Green Infrastructure and Water Quality

Water quality can be achieved by many green infrastructure practices. Each practice is designed for specific level of quality-results as needed. Some of these strategies are discussed below.

There many strategies that are designed to capture and control, then release storm water runoff and/or improve runoff water quality as a part of storm water management systems. These include: filtration, infiltration, detention and retention systems. Infiltration is a process of capturing storm water runoff and slowly putting it back into the ground, rather than leaving it to run-off the surface of the ground, and causing as result some damages to infrastructure and/or flooding in some flood prone areas. There are many systems that can implement the strategy of infiltration, like bio-swales, rain gardens, trenches, and permeable pavement.

Conversely, the filtration strategy is a process of removing sediment and other contaminants from storm water by implementing natural filtering layer using sand, gravel and plants. Detention systems is the process of capturing storm water runoff in a chain of ponds for storage and slowly releasing the water to be treated in sewer systems. A retention system is the process of improving water quality using layers of filtration system and other mechanisms (SARP, 2015). Therefore, the retention strategy presents captured storm water runoff and permanently holding the water through a system of pipes or tanks.

2.7.1 Wastewater Treatment Wetlands

Another function can be added to the multiple functions and benefits of GI, which is the *biological treatment* of wastewater (Austin, 2014). There are other different terms that are similar to the idea of *biological treatment*, including *bioremediation* and *bio-treatment*, and many techniques can be classified under these terms. *Biological treatment* means a "process in which wastewater is treated with aerobic bacteria to remove or reduce organic contaminants such as animal and human excreta, ammonia, nitrates, and plant tissue" (Dictionary, 2105). *Bioremediation* means "the treatment of pollutants or waste (as in an oil spill, contaminated groundwater, or an industrial process) by the use of microorganisms (as bacteria) that break down the undesirable substances" (Merriam, 1986)et al. *Bioremediation* was also defined in "Wadi Hanifah Restoration Project" (2010), as

> a general term applied to the use of natural biological functions for the remediation of a variety of environmental damages. It's nature's way of cleaning water. This naturally occurring process can be augmented in wastewater systems through the establishment of an ecologically efficient food web consisting of not only primary

producers (algae and higher plants) but also consumer organisms (fish, birds, insects, etc.) (ADA et al., 2010).

This thesis focuses on centralized wastewater treatment techniques that create wetlands and habitat within public spaces, which can add new value to desert culture and communities.

Treatment wetlands can be situated within a neighborhood scale and can be implemented throughout the watershed. Wetlands that are located at higher altitudes can serve neighborhoods and provide a wildlife habitat, meanwhile the cleaned water can serve different uses at lower elevations without the need for a pumping system (Austin, 2014). Biological treatments of wastewater is estimated to cut the cost to 33% of the price of a conventional wastewater treatment plant. The bio-cells in Wadi Hanifa, Riyadh City, Saudi Arabia for example "…is already performing beyond expectations and at a capital cost of 1/3 of a mechanical treatment plant" (ADA et al., 2010).

There are many techniques to treat wastewater ecologically. In his book *Green Infrastructure for Landscape Planning: Integrating Human and Natural Systems* (2014), Austin demonstrates different types of wetlands and their performance, including: 1) horizontal subsurface flow (HSF); 2) vertical subsurface flow (VSF); 3) mix of HSF and VSF. For more details about these systems performance, requirements and benefits refer to Chapter 11 of Austin (2014) (see Figure 15). The focus of the thesis is concentrated on the bio-remediation techniques that was used in Wadi Hanifa bio-cells. A successful examined system in one of the most arid regions in the world (Saudi Arabia), and "…the first of its kind in the world." (ADA et al., 2010).

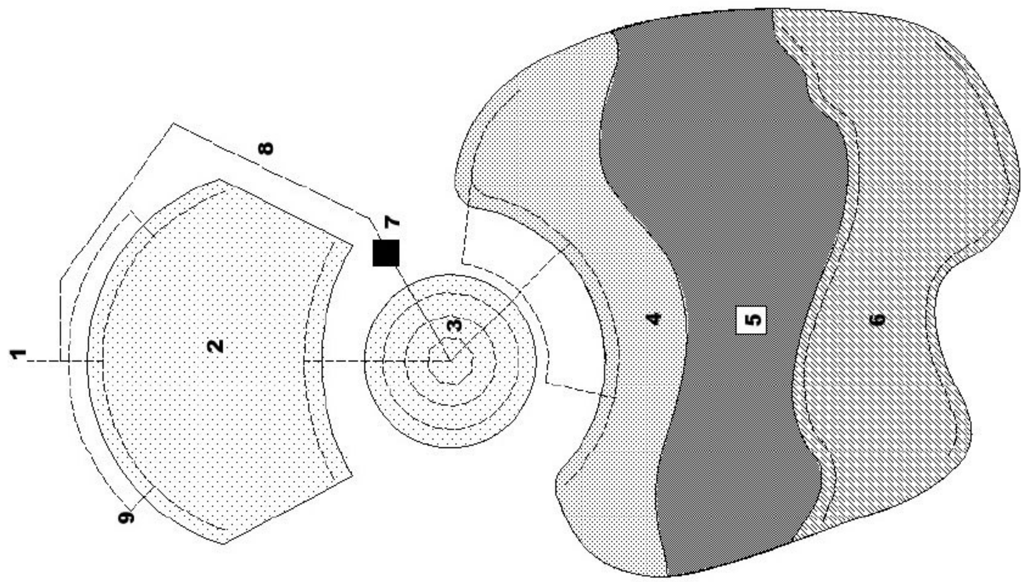


Figure 15 This plan view is a schematic of the three wetland types combined for high water-quality improvement and habitat value in green infrastructure. 1, inflow from septic tank; 2, HSF wetland; 3, VSF wetland; 4, FWS wetland cell (shallow marsh); 5, FWS wetland cell 2 (open water); 6, FWS wetland cell 3 (shallow marsh); 7, recirculating pump; 8, distribution piping; 9, uniform inflow distribution. (Source: Austin, 2014)

2.7.2 Example and Benefits of Hybrid Treatment Wetlands

Koh Phi Phi is a 1.5-acre city park and wastewater treatment wetland that is located on Koh Phi Phi Island, Thailand. The design of the treatment facility resembles a butterfly sitting on a flower, with a symbolic reference to the butterfly-shaped contour of Koh Phi Phi itself (see Figure16). Three thousands residents occupy the island and more than one million tourists visit annually. After the devastating consequences of tsunami in 2005, a relief fund was given to Thailand by the Danish Government to re-establish the wastewater management services at Koh Phi Phi. The constructed park presents the potential for "aesthetical integration of constructed wetland systems in the built environment" (Brix et al., 2010). The island experiences regular water, energy and land scarcity, where the freshwater resources are limited and expensive. Therefore, a multifunctional landscape design was developed The design received the municipal government and major stakeholders. With local hands of labor hired by local contactor the project cost $700,000 (see Figure 17) (Brixa, Koottatepb, Frydc, & Laugesen, 2011). The benefits of wastewater treatment wetlands follow the GI practices benefits.

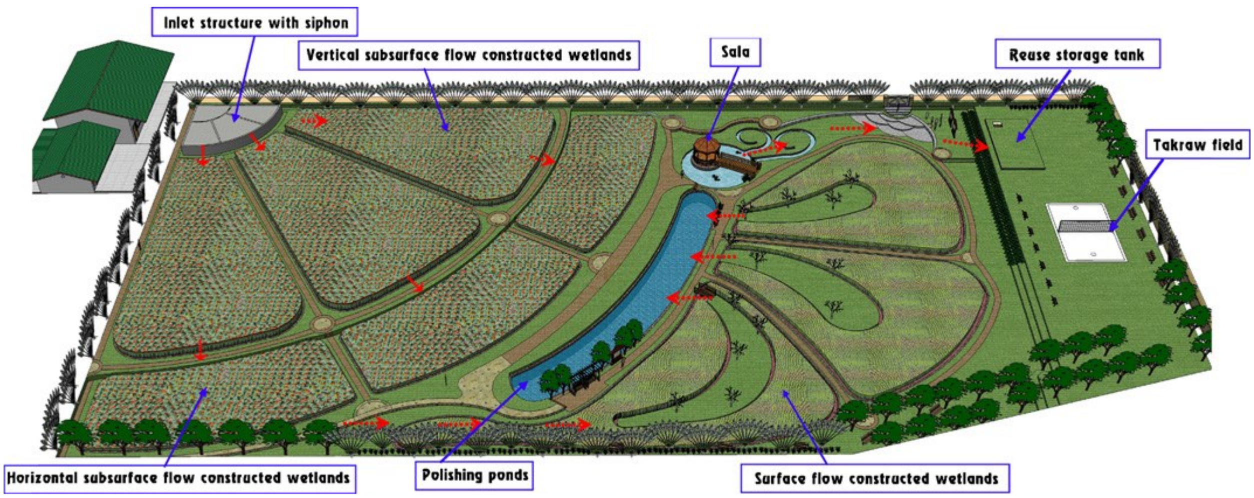


Figure 16 Artist drawing of the 'Flower and Butterfly' wastewater management system. Wastewater enter the system at the distribution tank with three elevated siphons (the center of the flower), which distribute the wastewater in intervals to three vertical subsurface-flow wetlands (the first petal of the flower). The flow is then directed via pipelines to three horizontal subsurface flow wetland cells (second petal of the flower). From there, the wastewater flow to three surface flow wetlands (the wings of the butterfly), and then enter the polishing ponds (the butterfly body), the last stage of treatment through which the effluent pass before it is stored for irrigation purposes (Source: Laugesen et al., 2010)

The process of treatment is as follows. First, wastewater pretreatment at the business and residence site, where free public septic tanks with sewer networks are provided. Using solar energized pumps, 105,670 gallons pass through 0.6 acres of three parallel cells of VSF wetlands. The cells are two feet and four inches deep and contain three layers of gravel (10 mm top, 25 mm middle and 44 mm bottom), and Canna and Heliconia plants. Then, the water comes out of the VSF cells and flows through another three parallel of HSF wetlands of 0.2 acres, two feet deep and occupied by 25 mm gravel and Canna plants. Next, the water flows into 0.2 acres of FWS three pools. With Papyrus plants and two-foot deep pools, the FWS wetlands direct the water to flow into the two feet and four inches deep linear polishing pond that is sized 0.5 acres. Finally the water is stored in a reservoir to be used later for irrigation (see Figure 18 & 19) (Brixa et al., 2011). The park is found to be very beneficial to the public and the environment alike, offering basic services like recycling the wastewater and reusing it to create a sense of place for the community and the tourists (Austin, 2014).

Figure 17 The park like appearance of the Koh Phi Phi wastewater management system showing (from upper left to lower right): The free-water surface flow wetlands (the wing of the butterfly), the Sala with benches (head of butterfly), benches along the pond constituting the body of the butterfly, and luxurious growth and flowering of Canna lilies in the vertical flow beds (Source: Brix et al., 2010)

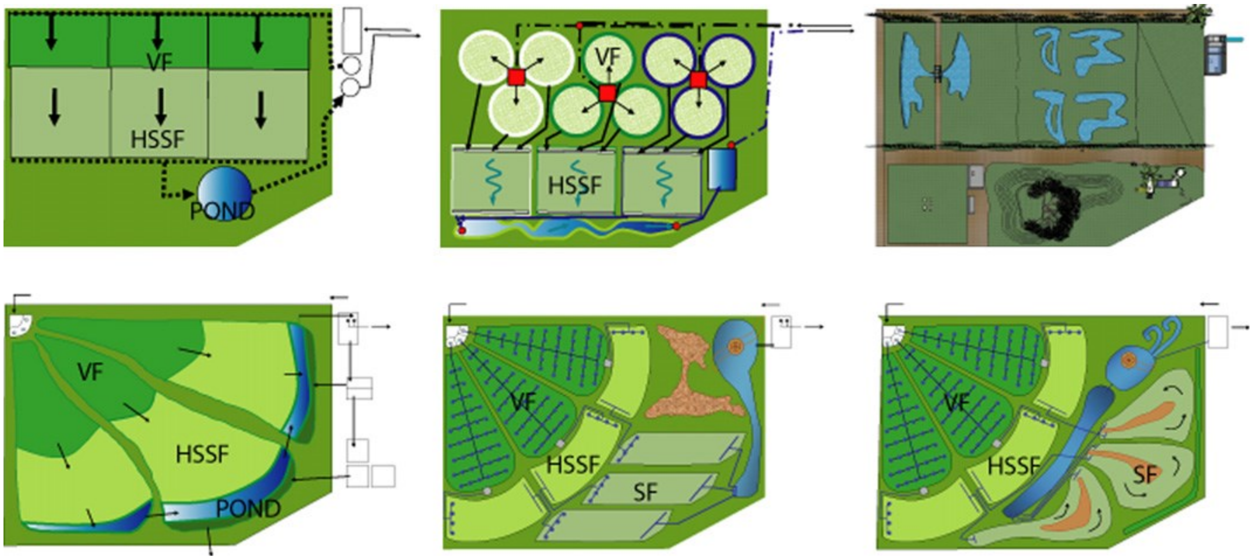


Figure 18 Examples of layouts developed and discussed in the design process: (from top left) (i) conceptual engineering design with square wetland beds, (ii) circular batch loaded circular vertical flow beds optimized for water distribution, (iii) artistic landscape design with contours of the Phi Phi Islands, (iv and v), combined functional and landscaped designs, and (vi) the final 'Flower and Butterfly' wetland system. VF, vertical flow beds; HSSF, horizontal subsurface flow beds; SF, surface flow beds (Source: Laugesen et al., 2010)

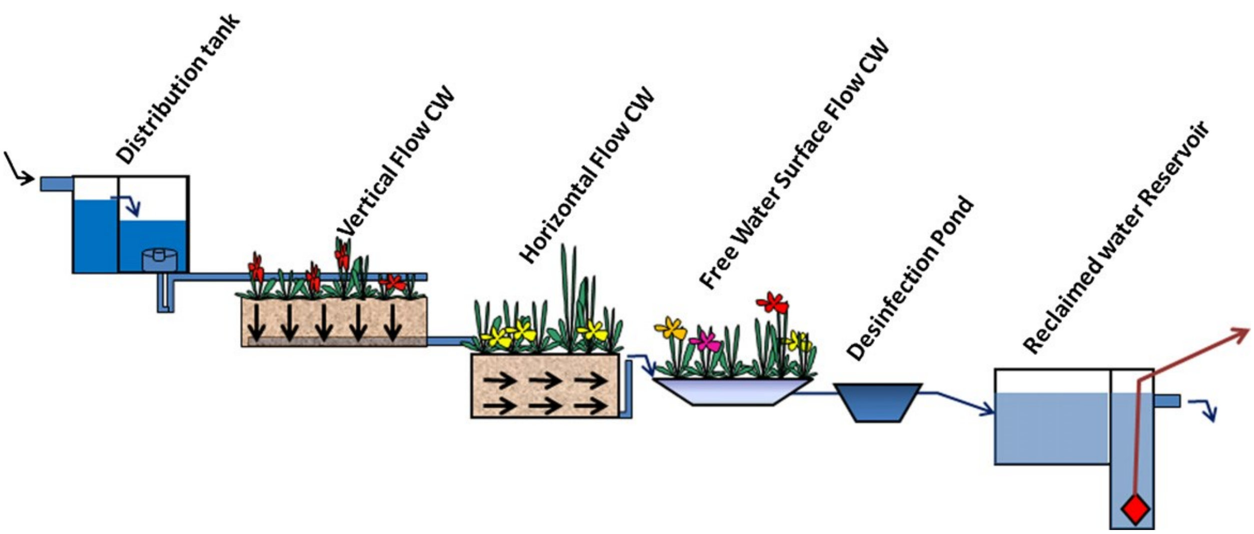


Figure 19 Concept for the treatment system as a series of vertical flow, horizontal flow and free water surface flow constructed wetlands followed by a pond and reservoir (Source: Brix et al., 2010)

2.8 The Impact of Green over Health

Much research has reported the positive influence of “green elements” on public general health and how important it is the daily interactions between humans and nature. Many studies also support the notion that green elements are very important and that they are associated with mental health—and that a reflection of this can affect the performance of employees and even patients in how quickly they recover. As reported in the “Biophilic Cities: Integrating Nature Into Urban Design and Planning” (2011), there are substantial relationships between green elements in built environment and higher levels of self-reported physical and mental health, where people report fewer symptoms and living generally in a healthier condition at greener environment (Beatley, 2011). People’s mental health also appears better in greener environment, so much so that “10% more greenspace in the living environment leads to a decrease in the number of symptoms that is comparable with a decrease in age by 5 years.” (De Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003).

Also reported by Beatly (2011), a Danish study in 2007 demonstrated how important is to have an access and proximity to parks and nearby greenspaces, and how these greenspaces are associated with both lower stress levels and reduced likelihood of obesity. Likewise, Beatly reported another example of the positive influence of green elements in the speed of healing process of gallbladder patients (Ibid.). He presented that a study by Roger Ulrich, of Texas A&M University, where the “postoperative recovery” of those patients of gallbladder in hospital rooms with view-window access to landscape and natural scene “recover easily and more quickly” than those whose rooms views face walls (Beatley, 2011).

2.9 Green Infrastructure and Creating Sense of Place

Often at a fraction of the cost, GI performs many of the same functions as conventional gray infrastructure. These assets improve public quality of life that deliver clean water, agricultural soils, public parks and trails. According to the EPA, "Successful projects have demonstrated that an interconnected landscape system also provides a unique sense of place that attracts people, jobs and investment" (EPA, 2014a). Stedman (2002) stated that "landscape characteristics matter" in the making of "place meanings" and subsequently "place attachment" and "attitudes" (Davenport & Anderson, 2005). In arid regions where landscape resources are rare due to the water scarce situation, providing a well-designed landscape area with proper utilities, social, aesthetic and economic services with a special "place identity" can easily create sense of place to public and then giving the place "meaning" and therefore establishing "place attachment" (see Figure 20).

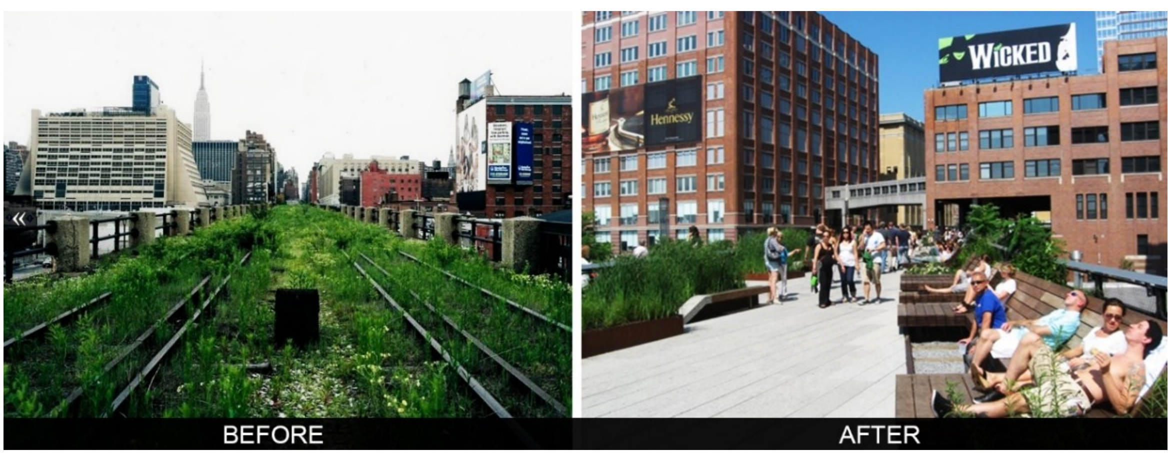


Figure 20 Creating a new sense of place at The Highline project, New York - before and after development
(Source: from http://littletrip.diary.to/archives/34985173.html, and http://allovertheus.ru/wp-content/uploads/2012/05/High-Line-NYC.jpg)

2.10 Barriers Confronting Green Infrastructure in Arid Regions

Despite the growing in number of evidence stemming from research and reports of the multiple benefits of implementing GI practices, they are still not within the radar of preferences of practitioners, stakeholders, and cities' municipalities and developers. According to the Clean Water American Alliance report, four barrier categories can be generally identified (2014). These categories include technical and physical; legal and regulatory; financial; and community and institutional barriers (which are cited below). The thesis selects among these barriers what might be confronting implementation of GI practices in arid regions like Saudi Arabia:

Technical and Physical Barriers

- *Lack of understanding and knowledge of what green infrastructure is and the benefits it provides.*
- *Deficiency of data demonstrating benefits, costs, & performance.*
- *Insufficient technical knowledge and experience.*
- *Lack of design standards, best management practices, codes and ordinances that facilitate the design, acceptance, and implementation of green infrastructure.*

Legal and Regulatory Barriers

- *Local rules can be lacking, conflicting, or restrictive.*
- *State water and land-use policies and property rights can be complicating factors.*

Financial Barriers

- *Not enough data about upfront and ongoing maintenance costs and economic benefits.*
- *Perceived high cost over short and long term.*
- *Lack of funding at all levels coupled with poor coordination or integration of programs and funds.*
- *Too much risk - not enough incentives.*

Cultural, Community and Institutional Barriers

- *Insufficient and inaccessible information about green infrastructure and its benefits for political leaders, administrators, agency staff, developers, builders, landscapers, and others, including the public.*
- *Community and institutional values that under-appreciate green infrastructure aesthetics and characteristics."*
- *Lack of inter-agency and community cooperation.* (UWA, 2011).

2.11 Regulations and Adaptations of Green Infrastructure for Arid Regions

For arid regions, greening a city might be considered a luxurious decision due to the water scarcity issue. However, the spreading of "green patches" is one of the Saudi government's strategic plans that it is enacting all over the cities of the Kingdom. To do so, a lot of research and many studies have been taking place to fulfill this ambitious plan with absolute consideration to the limitation of water resources. For example, the Municipality of Jeddah City has an irrigation guideline titled "Irrigating Plants Guide in Afforestation Projects within Cities" (2015). This guideline explains and compares different irrigation techniques with plant water needs per month per species. This thesis focuses only on sustainable methodologies of irrigating and planting that is mentioned in that manual. The guideline does not recommend on relying on harvesting rainwater for irrigation purposes due to the unreliable precipitation rates and patterns in the kingdom. And as quoted by the Municipality of Jeddah City (2015), "Saudi Arabia falls under the regions of 'evaporate' not the 'infiltrate' (or saving water), since rainwater rarely falls, it is not a reliable source for irrigation, and when that happens (or rain falls), the average does not exceed 200 mm per year (7.8inch) (Eizudeen Alfarraj, 1986)" (translated from Arabic by the research). The recommended irrigation methodology for this thesis is "dripping irrigation" due to the high value of efficiency-factor of the system which is 90% (Stryker, 2015). Local plants are recommended for the landscape design especially if the intention was to spread the "green patches" all over a city (or de-centric). However, if the intention was concentrated on a specific site or location (or centric), then a mix of local and adapted foreign plants design should be applicable with the condition of an appropriate low-cost and affordable water-source. A list of "Water requirements for most of the aesthetic plants in Jeddah" is suggested by the Municipality of Jeddah City that is implemented in this thesis (see Table 4).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Palms g/day	13.2	13.2	17	17	17	26.4	26.4	26.4	17	17	17	13.2
Big Trees g/day (> 65 ft2)	10.5	10.5	13.2	13.2	13.2	21	21	21	13.2	13.2	13.2	10.5
Small Trees g/day (< 65 ft2)	7.9	7.9	10.5	10.5	10.5	15.8	15.8	15.8	10.5	10.5	10.5	7.9
Small Shrubs g/day	2	2	2.64	2.64	2.64	3.96	3.96	3.96	2.64	2.64	2.64	2
Ground Covers g/10 ft2/d	1	1	1.3	1.3	1.3	2	2	2	1.3	1.3	1.3	1
Bermuda Grass g/10 ft2/d	1.5	1.5	2	2	2	3	3	3	2	2	2	1.5

Table 4 Water requirements for most of the aesthetic plants in Jeddah (Source: Jeddah Municipality, 2015)

CHAPTER 3

METHODOLOGY

According to currently available literature on the subject, green principles can improve social life within open spaces by increasing what Gehl (2011) refers to as "optional" and "social" activities. This chapter demonstrates the methodology that was developed to test the feasibility and benefits of transforming Jeddah's stormwater channels into green channels. The methods consist of international and domestic case study analysis, using Jeddah City to demonstrate the learned knowledge and lessons from both the literature (see Chapter 2) and the selected case studies, followed by a feasibility study dedicated for Jeddah. The results collected using these methods are presented in chapters 4, 5, and 6 respectively.

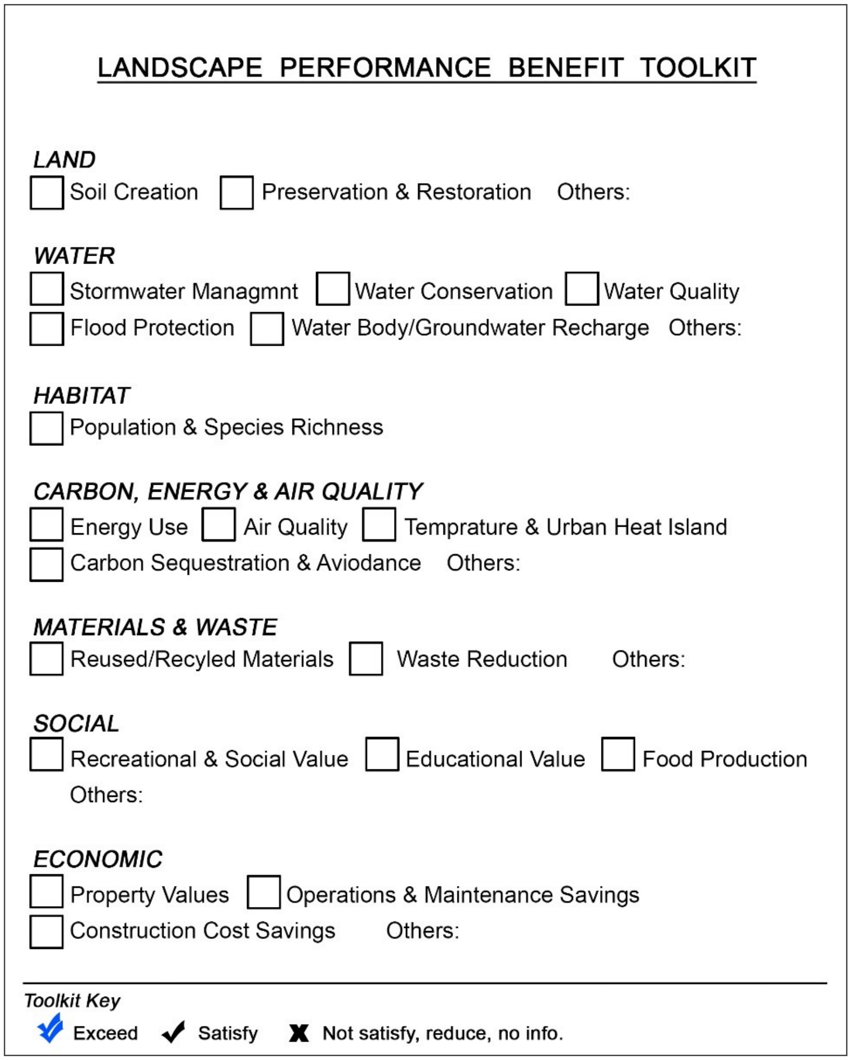
3.1 Method One: Case Study Analysis

The first method was used to demonstrate the social, environmental and economic benefits of developing green channels within an urban context by studying selected precedent designed green channels and identifying the implemented design solutions and strategies. This process helped to determine the influence of embracing green principles in redeveloping these urban channels on improving a city's health and livability. Six case studies were selected for this study to address a variety of issues, solutions, and cultural diversity. Therefore, a number of criteria were developed to select these case studies. These criteria are that a project must: (a) be situated within an urban context; (b) have implemented green principles; (c) represent different cultural and geographical locations;

(d) present sustainable redevelopment that was motivated by environmental, social, and economic issues; and (e) have been developed to serve social and environmental services.

To achieve the main goal of this chapter, a model of comparison was devolved. The model was dived into the following sections:

- Project background: a brief section with information about the project name, location, size, developer, cost, and project before and after development.
- Project goals
- Design implementations: design solutions that were used to solve the problem and to achieve the goals.
- Optional and social activities: the resulting activities that help to improve the livability of each site location of these projects and their cities in general.
- Landscape performance benefits toolkit: a toolkit developed by the Landscape Performance Series: The benefit were categorized as – land, water, habitat, carbon, energy & air quality, materials & waste, social, or economic (see Figure 21).
- Comparison table: a summarized table of the selected channel, consisting of – project name, location, climate information, issues, solutions, general benefits, and benefit of water. The table was developed to illustrate the relationship between the solutions and the generated benefits.



LANDSCAPE PERFORMANCE BENEFIT TOOLKIT

LAND

☐ Soil Creation ☐ Preservation & Restoration Others:

WATER

☐ Stormwater Managmnt ☐ Water Conservation ☐ Water Quality

☐ Flood Protection ☐ Water Body/Groundwater Recharge Others:

HABITAT

☐ Population & Species Richness

CARBON, ENERGY & AIR QUALITY

☐ Energy Use ☐ Air Quality ☐ Temprature & Urban Heat Island

☐ Carbon Sequestration & Aviodance Others:

MATERIALS & WASTE

☐ Reused/Recyled Materials ☐ Waste Reduction Others:

SOCIAL

☐ Recreational & Social Value ☐ Educational Value ☐ Food Production

Others:

ECONOMIC

☐ Property Values ☐ Operations & Maintenance Savings

☐ Construction Cost Savings Others:

Toolkit Key

Exceed ✔ Satisfy ✘ Not satisfy, reduce, no info.

Figure 21 Landscape performance benefit toolkit (Source: retrieved from LAF)

3.2 Method Two: Jeddah as a Case Study

This second method of this thesis illustrates the reasons for selecting Jeddah City as the case study for implementing the green-design principles and implementations learned from the selected international and domestic (Saudi) case studies. At first, this section presents the environmental issues of Jeddah in regard to stormwater channels, flood prevention plan, water and public open spaces, and the city strategic plan to order to discuss the opportunities and barriers of redeveloping a green channel in Jeddah. It also briefly explores Jeddah's historical development in terms of water management. This is done in order to locate Jeddah among other global green trends in and approaches to constructing open channels and to emphasis the multiple benefits that can be generated from developing green channels.

3.3 Method Three: Feasibility Study

This third method actually consists of three steps to illustrate different ways to develop a green channel in Jeddah. The *first step,* selecting one of the four channels in Jeddah to be the subject of any future green channel development in Saudi Arabia or the worldwide, as well as a subject of an environmental and urban analysis. For this thesis, the Northern Channel (Tahlia Channel) was selected to be an example of any future green channel development. The value of this channel stems from its strategic location, the land's values, and the intensive activities and/or investments in the area—in addition to the future vision of redeveloping the western part of the channel to be a linear park and running stream by the municipality—making Tahlia Channel the best choice for this study. The *second step,* analyzing the selected channel using a color-coding technique to divide the channel into homogenous zones and units via an analytical site map and sections. Moreover, categories of different zones and units presented in sections, based on the channel changing in physical, social and other characteristics, were developed to analyze the opportunities and obstacles in each homogeneous area. This step then redevelops the quality of the physical environment diagram originally defined by Danish architect Jan Gehl in order to categorize the current situation of each area. Each analysis include four parts: positive and negative analysis, measurements, the category of the section based on the redeveloped diagram from Gehl, and an activities matrix that connects each area to the other case studies. Based on the findings of these analyses and the lessons learned from the evaluating the selected case studies, recommendations of green infrastructure practices, design implications and motivational utilities were demonstrated and located on a map and table.

The *third step,* calculating the water supplies, plant and irrigation needs by utilizing scientific calculations to prove the feasibility of greening the selected channel. The feasibility of greening the channel and providing running stream utilized the guidelines, tables of coefficients, and rainwater calculations that are explained in Patricia H. Waterfall's book *Harvesting Rainwater for Landscape Use* (2006). "Scenario one" is developed to measure the potential volume of harvested rainwater per square foot from selected surfaces that drain to the watershed within the selected area. It includes calculation for the water requirement per square foot of the proposed landscape of that model, taking into consideration the plant water needs and the dripping irrigation efficiency. Multiple government agencies databases and published research were used to achieve the technical analysis for Scenario one. The scenario also includes the monthly plant water requirements table that was provided by the Municipality of Jeddah, and taking into consideration the number of plants that can be planted after applying the efficiency factor of dripping irrigation. Although "Scenario two" relies on the rain water that is harvested by the dam, it follows the same basic steps of the first scenario. Finally, according to the outcomes of each argument, the author suggests if the system can rely on one source of water or mix of sources.

The calculations presented in this section include the water budget to assist greening the channel in these two scenarios from three water sources; (1) graywater and (2) harvested rainwater from the roof tops of the selected locations or (3) the harvested rainwater by the dam. The first scenario is demonstrated via a model of hydrology cycle design system to irrigate the landscape of this model. A plant-species list were selected from Table 4, with a number of recommended plants to be irrigated per house (model) from the collected rainwater and graywater per house (model). This model is suggested to be applied only on the buildings that face Tahlia Channel. The second scenario, suggests greening the channel by relying on the harvested rainwater by the dam. The two scenarios (or arguments) also considered calculations of the required constant water deposits to create a running stream. Moreover, the two scenarios also demonstrate a supportive supply of water with a presence of black-water from the surrounding neighborhood of the whole channel and the selected area of that channel if needed. Finally, the two scenarios also provide cost estimations of constructing residential or mega cisterns to store the required water for irrigation and/or the suggested running stream.

The data regarding the average monthly rainfall in Jeddah City that is issued by the Ministry of Defense and Aviation-National Meteorology and Environment Center of Saudi Arabia (DANMEC) was calculated in the annual climatological report for Jeddah during the period from 1981 to 2011 (see Table 5). The evapotranspiration ETo data that is based on the Jeddah climatological reports from 1966 to 1982 was obtained from Geoff Ricks' *Landscape Plant Manual for Saudi Arabia* (1992) (see Table 6). The Plant Water Use factors were obtained from Waterfall's *Harvesting Rainwater for Landscape Use* (2006), which categorizes plants based on water tolerance that ranges from low, medium, to high water use (see Table 7). One equation used from the book of *Harvesting Rainwater for Landscape Use* serve as the basis for Scenario one:

Scenario one: The potential rainwater harvesting volume (Supply) using the following equation:

(1) $VR \text{ (in Gallons)} = P \text{ (inches)} \times \text{Area } (ft^2) \times C \times 0.623$

Where P is the average annual rainfall that falls in Jeddah City. The parameter C is a runoff coefficient based on the Rational Method. The conversion factor 0.623 is used to measure the supply in US gallons.

The irrigation system suggested for the methodology of the thesis is the dripping irrigation system. The efficiency factor of dripping irrigation system is 90% or higher (Stryker, 2015).

Scenario one: Calculating the Flow Rate of Open Channel using the following equation:

(2) $Q \ (m^3/\text{day}) = V \ (\text{m/day}) \text{ x } A \ (m^2)$

Where Q is the average flow rate (m^3/day). The velocity V of an average flow at cross section (m/day). And A is the area of the cross section (m^2).

The cost of residential concrete tank was estimated based on an estimation cost of tank per cubic meter by an entrepreneur at a cost of $0.13 per gallon (AqarCity, 2007). The cost of constructing mega concrete tank was estimated by calculating the estimation of constructing the new suggested strategic tanks for Jeddah by the government, which cost $0.37 per gallon (Gazzawi, 2013).

Avg. Preciptation from 1981 to 2011 mm			
Months	M	Ex.t	YEAR
Jan	10.8	75.9	2011
Feb	3.2	45.2	1995
Mar	2.4	26	1998
Apr	2.4	45	2005
May	0.2	4.4	1987
Jun	0	0	0
Jul	0.2	7.2	2010
Aug	0.5	10	1998
Sep	0.1	2.2	2010
Oct	0.9	26	1997
Nov	22.3	285.1	1996
Dec	11	65.6	2010

Table 5 Average precipitation in Jeddah from 1981 to 2011 (Source: Ministry of Defense and Aviation-National Meteorology and Environment Center of Saudi Arabia)

MONTH	Avg. Precipitation	POTENTIAL EVAPORATION - ET_O	
	Inch	mm	Inch
Jan	0.42	8.3	0.32
Feb	0.12	10	0.4
Mar	0.09	10.7	0.42
Apr	0.09	12	0.47
May	0.007	12.5	0.49
Jun	0	12.6	0.49
Jul	0.007	12.8	0.5
Aug	0.01	13.1	0.51
Sep	0.003	12.5	0.49
Oct	0.03	10.8	0.42
Nov	0.87	9.8	0.38
Dec	0.43	7.9	0.31

Table 6 Evapotranspiration ETo data (Source retrieved from Ricks, 1992)

RUNOFF COEFFICIENTS		
Land Use Type	High	Low
Roof		
(A) Metal,asphalt, shingle,fiber glass	0.95	0.9
Paving		
(B) Concrete ,asphalt	1	0.9
(C) Gravel	0.7	0.25
Soil		
(D) Flat,Bare	0.75	0.2
(E) Flat,with vegetation	0.6	0.1
Lawns		
(F) Flat,sandy soil	0.1	0.05
(G) Flat,heavy soil	0.17	0.13

Table 7 Values of runoff coefficient (C) (Source: Waterfall, 2006, p. 14)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Palms g/day	13.2	13.2	17	17	17	26.4	26.4	26.4	17	17	17	13.2
Big Trees g/day (> 65 ft2)	10.5	10.5	13.2	13.2	13.2	21	21	21	13.2	13.2	13.2	10.5
Small Trees g/day (< 65 ft2)	7.9	7.9	10.5	10.5	10.5	15.8	15.8	15.8	10.5	10.5	10.5	7.9
Small Shrubs g/day	2	2	2.64	2.64	2.64	3.96	3.96	3.96	2.64	2.64	2.64	2
Ground Covers g/10 ft2/d	1	1	1.3	1.3	1.3	2	2	2	1.3	1.3	1.3	1
Bermuda Grass g/10 ft2/d	1.5	1.5	2	2	2	3	3	3	2	2	2	1.5

Table 4 Water requirements for most of the aesthetic plants in Jeddah (Source: Jeddah Municipality, 2015)

CHAPTER 4

GREEN CHANNEL CASE STUDIES

This chapter illustrate the benefits of developing green channels by drawing a comparison between the six green channels. Five international and one domestic (Saudi Arabian) channel were selected for the study. After taking into consideration the criteria of selection that were mentioned in the Methodology Chapter (see Chapter 3.1), the following are the most suitable projects that were found: (1) Los Angeles River, California; (2) Buffalo Bayou Promenade, Houston, Texas; (3) Wadi Hanifa, Riyadh, Saudi Arabia; (4) Zhanjiagang Town River, China; (5) Shenzhen Qianhai Water City, China; and (6) Cheonggyecheon Stream, Seoul, S. Korea (see Figure 22). The goal of this chapter is to illuminate—using different cases around the world—how transforming stormwater channels to green channel creates a significant impact on a city's livability.

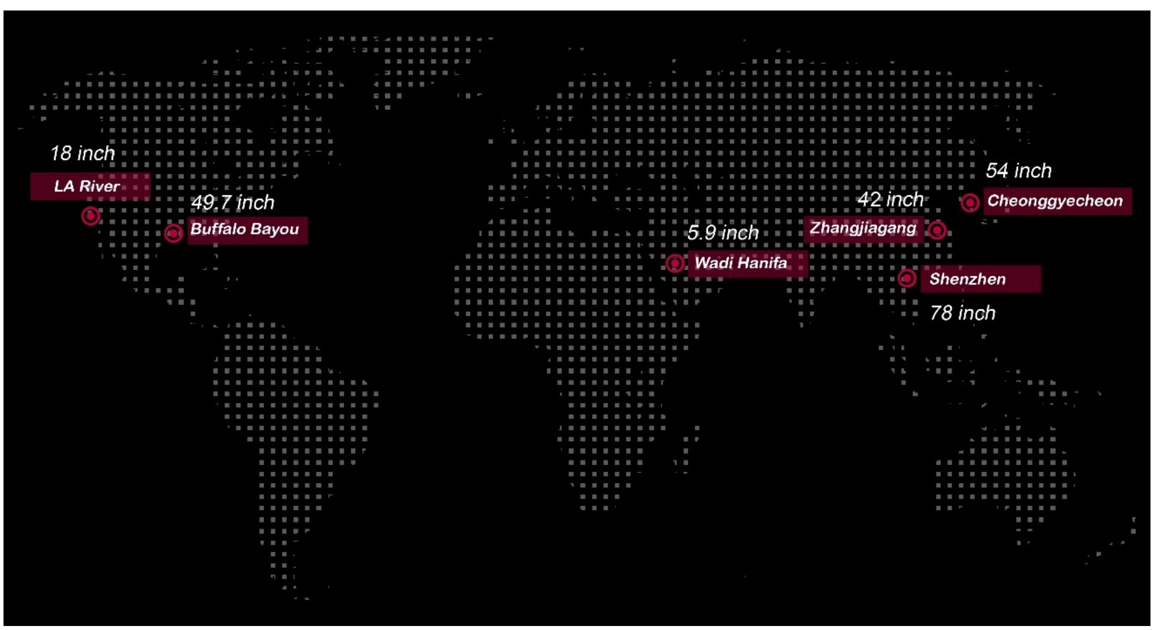


Figure 22 Locations and annual precipitations of the selected case studies (Source: author)

The purpose of this chapter is to provide a comparison of landscape performance of six selected green channel projects, relying on a developed model as explained in the Methodology Chapter (see Chapter 3.1). Quantitative and qualitative research that was conducted by university researchers and/or experts was used to fulfill a comparison based on the following criteria:

- Project background
- Project goals
- Design implementations
- Optional and social activities
- Landscape performance benefits

Each selected channel depends on information availability to qualify the purpose of the comparison. All the information is summarized at the end in Table 8. The summarized table aims to determine if there is a relationship between the design solutions and any generated general benefits. The goal of this chapter is to address the following concerns:

1) What are the influence of green practices and principles on encouraging both optional and social activates?

2) What are the green practices that were used?

3) What are the reasons for selecting each project beyond fulfilling the criteria of selection (which is answered within in the "Design Implementations" of each case study)?

4.1 Case Study 1: Revitalizing the Los Angeles River, California, 2007

Design Team

by The County of Los Angeles

Project Highlights

Location: Lose Angeles, California
Year: 2007
Main goal: flood control & connecting neighborhood
Sub-goal: recreational amenity,
Size: more than-750 acres
Cost: $1 billion

4.1.1 Project Background

The 32-miles of concrete-paved river (or channel) that flows within the very heart of the city of Los Angeles is serving a vital function as a flood control measure for the City and County of Los Angeles. However, this singular function has limited the vast potential of the river as a focal point for economic growth, community revitalization, environmental stewardship, and recreational opportunities (Villaraigosa, 2007). The river represents more than 750 adjacent contiguous acres of real estate. Altering part of that land for multiple-benefit uses could indeed revive the river. This could include restoring the natural system, treating of storm water runoff, creating continuous river greenways, and interconnecting a network of parks and trails. These changes eventually could restore the ecological function of the river and the river's identity, which celebrates the past and the future of Los Angeles. Once the quality of life for Angelinos is being enhanced, the next arena that becomes most important is the status of visitors' attractions, which appears as a symbol of natural resilience and revival for the city itself (County of Los Angeles, 2007). Like many rivers around the world, the Los

Angeles River speaks presents a case against channelizing natural streams by reviving instead a part of it natural appearance in some part of its watershed, fostering wildlife to flourish again in a way to teach us designers and engineers the proper way to redevelop such a river or an urban channel (see Figure 23).

Figure 23 Los Angeles River restoring its ecosystem (Source: from http://www.lamakerspace.com, http://lawaterkeeper.org/)

4.1.2 Project Goals

The project goals were classified into the following four main aspects:

1) Revitalize the River
    - Enhance Flood Storage
    - Enhance Water Quality
    - Enable Safe Public Access
    - Restore a Functional Ecosystem
2) Green the Neighborhood
    - Create a Continuous River Greenway
    - Connect Neighborhoods to the River
    - Extend Open Space, Recreation, and Water Quality Features into Neighborhoods
    - Enhance River Identity
    - Incorporate Public Art Along the River

3) Capture Community Opportunities
    - Make the River the Focus of Activity
    - Foster Civic Pride
    - Engage Residents in the Community
    - Planning Process and Consensus Building
    - Provide Opportunities for Educational and Public Facilities
    - Celebrate the Cultural Heritage of the River
4) Creative Value
    - Improve the Quality of Life
    - Increase Employment, Housing, and Retail Space Opportunities
    - Create Environmentally-Sensitive Urban
    - Design and Land Use Opportunities and Guidelines
    - Focus Attention on Underused Areas and
    - Disadvantaged Communities (County of Los Angeles, 2007).

4.1.3 Design Implementations

To achieve the aforementioned goals, the proposed master plan were developed first to restore riparian vegetation in order to support birds and mammals, and create fish passages and riffle pools to allow for the restoration of steelhead trout habitat. This will only be made possible by replacing the channel pavement and dividing it into multiple constructed wetlands, which will function as reservoirs, and replacing the channel walls with terraced landscapes and creating a sequence of wetlands for wildlife habitat. Reducing the flow velocity of the river by increasing the channel capacity will also help protect the river bed and the public safety. This can be achieved by constructing storage outside the channel, underground flow diversions, and most importantly land acquisition including purchase of private property to allow for channel widening. Moreover, this design will reconnect neighborhoods to the Los Angeles River via a network of green paths and streets for pedestrian and bike riders. The channel was developed to serve as a green spine for the city, and this will foster more optional and social activities at the channel. It will also create a green corridor that connect habitats and green patches throughout the city (County of Los Angeles, 2007). Frankly, the implementation of this design will allow the people of Los Angeles to once again enjoy and observe the natural environment of the river—an activity that has been absent for quite some time.

4.1.4 Optional and Social Activities

By implementing the developed master plan, more optional and social activities are expected to be enjoyed at the channel. Already, some of the optional activities have become popular again since the river ecosystem has begun restoring itself over the last few years. For instance, some of these activities include canoeing, observing wildlife, fishing and hunting, and even educational program activities for trainees and school students. The master plan will provide additional activities to channel life, such as long river waterfront promenade, parks, hiking and bike trails, public arts, nature watching, social gatherings and events, controlled fishing, playing in soccer fields, skating at skate parks, and more (see Figure 24).

Figure 24 Green ideas with atractive design both foster wildlife & recreational activties for the public to thrive (Source: from http://www.lariver.org/index.htm)

4.1.5 Landscape Performance Benefits

LAND

☑ Soil Creation ☑ Preservation & Restoration Others:

WATER

☑ Stormwater Managmnt ☑ Water Conservation ☑ Water Quality

☑ Flood Protection ✓ Water Body/Groundwater Recharge Others:

HABITAT

☑ Population & Species Richness

CARBON, ENERGY & AIR QUALITY

☒ Energy Use ☑ Air Quality ☒ Temprature & Urban Heat Island

☑ Carbon Sequestration & Aviodance Others:

MATERIALS & WASTE

☒ Reused/Recyled Materials ☑ Waste Reduction Others:

SOCIAL

☑ Recreational & Social Value ✓ Educational Value ☒ Food Production

Others:

ECONOMIC

☑ Property Values ☑ Operations & Maintenance Savings

☒ Construction Cost Savings Others: Improve tourism

Toolkit Key

☑ Exceed ✓ Satisfy ☒ Not satisfy, reduce, no info.

4.2 Case Study2: Buffalo Bayou Promenade, Houston, Texas, 2006

Design Team

by SWA Group

Project Highlights

Location: Houston, Texas
Year: 2006
Main goal: flood control & water cleaning
Sub-goal: recreational park,
Size: 23-acre
Cost: $58 million

4.2.1 Project Background

Buffalo Bayou Promenade (also known as Sabine-to-Bagby Promenade) has been a focal point in Houston's history since the Allen brothers founded the city in 1836 (Thompson Design Group, 2002). The 23-acre impenetrable edge was redeveloped as an urban and recreational park by the SWA Group and completed in 2006. The bayou had suffered for years from trash-soaked overgrowth that ruined flood control efforts and caused cityscape distortion (see Figure 25). After a period of segregation, the midtown and the downtown of Houston are no longer separated from each other. Transforming an impervious urban grey field into a functioning green channel, the park now serves as a thriving urban waterfront promenade.

Figure 25 Buffalo Bayou before revitalization (Source: by Mike Garver)

4.2.2 Project Goals

The goal of redeveloping the bayou can be categorized into the following:

1) Environmental

- Create “Green Fingers” to detain, filter and clean stormwater.
- Reduce erosion by stabilizing bayou banks.
- Organize trash cleanup program.
- Transform brownfields to parks.
- Promote the use of low-impact development practices.
- Increase and create wildlife habitat areas.
- Initiate demonstration projects to test long-term impacts of Bayou-related improvements.
- Develop a regional Eco-Park to expand rehabilitation efforts beyond Buffalo Bayou.

2) Flood Management

- Creating additional canals to improve downtown floodwater flow that is carried by Buffalo and White Oak bayous.
- Reduce impedance to the flow of floodwater by consolidating bridge crossings.
- Improve the bayou conveyance capacity along critical reaches, particularly from Allen’s Landing to McKee Street (Thompson Design Group, 2002).

4.2.3 Design Implementations

Revitalizing a portion of Buffalo Bayou as a green channel that previously occupied a marginalized space beneath the freeway, the promenade has introduced urban amenity for the citizens that improved the image of Houston (see Figure 26). The promenade was developed to serve its visitors with a variety of physical activities, gathering events, and both passive and active recreation opportunities along the banks—as well as in the water—year around. To achieve this, the area underwent a process of gentrification, which included adopting gentle sloping banks, water bio-remediation, trash removal, extensive use of native plants, and spreading green practices around the channel. This was done for two reasons, both to achieve the predevelopment condition as much as possible and to moderate the time required for stormwater to reach the bayou. Green practices were included in this process in order to pin the bayou at the center of the map of top must-see attractions. The bayou now boasts twelve street-to-bayou gateways, the first pedestrian bridge which connects the north and south sides of the bayou, and over twenty miles of paved hiking and bike-trail systems, public art, dramatic lighting, and interpretive signage (Ozdil, Modi, Stewart, & SWA, 2013).

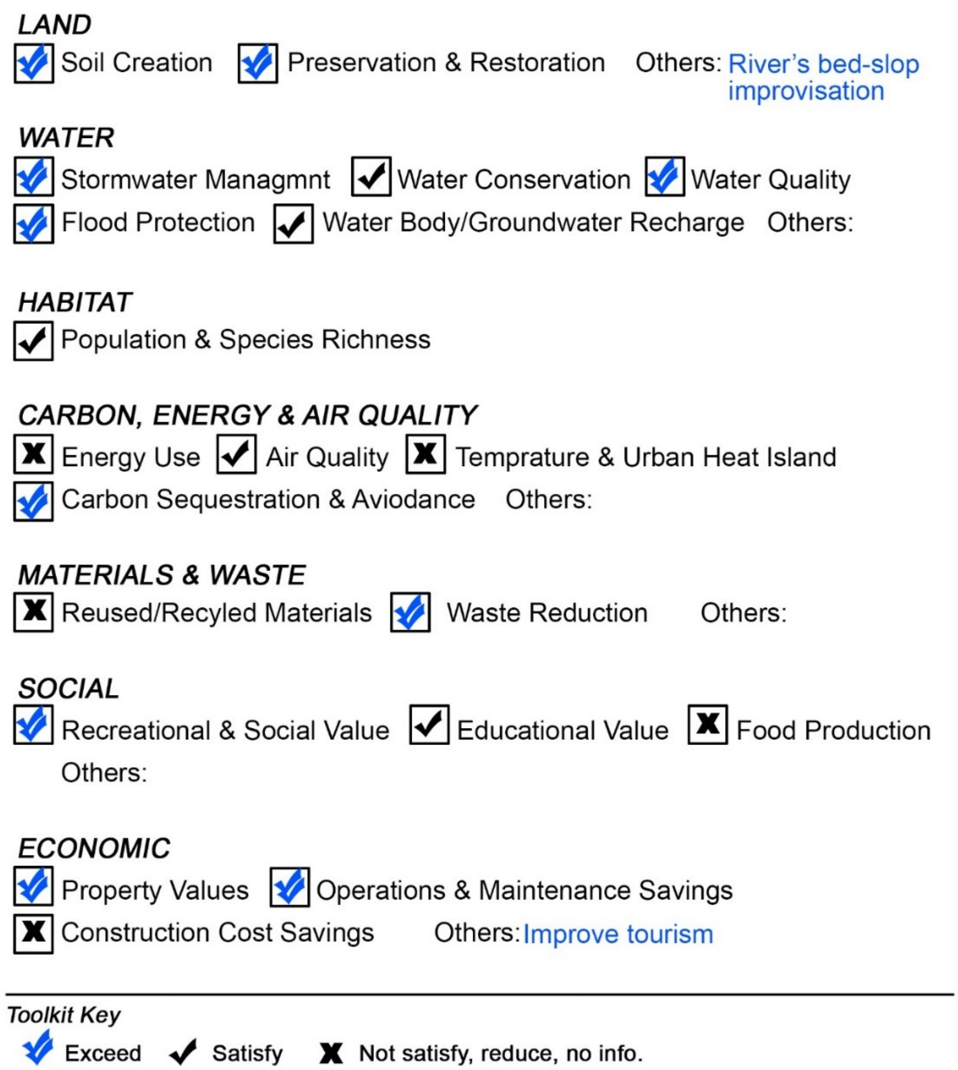
Figure 26 Buffalo Bayou, Houston, Texas (Source: from left to right photo taken by Bill Tatham, the 2nd & 3rd pictures by Tom Fox, http://www.asla.org/2009awards/104.html)

4.2.4 Optional and Social Activities

The bayou recreated a new sense of place for city residents and visitors. The high quality of the physical environment that resulted from the implementation of green practices has also encouraged the return of multiple optional and social activities. As in many other cases, both blue and green infrastructure are the key elements in encouraging optional and social activities. Some of these activities used to be part of the history of the promenade, but others have only more recently been introduced to the area. Some of these activities include biking and walking on trails, canoeing, boat tours (private and public), picnicking, spectating public art, attending social events, and so on (see Figure 27) (Ozdil et al., 2013).

Figure 27 Optional & social activities (Source: from left to right, top to bottom pictures were taken by Tom Fox, http://archidose.org/, Bill Tatham, http://www.downtownhouston.org/, http://archidose.org/)

4.2.5 Landscape Performance Benefits



4.3 Case Study 3: Wadi Hanifa, Riyadh, Saudi Arabia, 2007

Design Team

by Moriyama & Teshima, and Buro Happold

Project Highlights

Location: Riyadh, Saudi Arabia
Year: 2007
Main goal: flood control & water cleaning
Sub-goal: recreational park,
Size: over 1 million acre
Cost: $160 million

4.3.1 Project Background

Wadi Hanifa is a major natural landmarks in the city of Riyadh, representing a very wide natural drain area for surface water. Overall, 70% of the city is located within the catchment area of the Wadi (or valley), where the watershed of Hanifa passes through the city (Alhamid, Alfayzi, & Hamadto, 2007). In 2001, Wadi Hanifa was occupied by a highly-polluted running river, caused by the direct dumping of industrial and municipal waste water—to the point that animals and fish floated dead in its waters. The river was so polluted that the entire eco-system along its shores was dangerously close to extinction, and the surrounding environment was totally damaged within a 1,111,974 acre catchment area (see Figure 28).

Through a visionary Master Plan, Restoration Program and ongoing enhancements, The Arriyadh Development Authority (ADA) as the client, working closely with Canadian architecture and planning firm Moriyama & Teshima, in partnership with the UK engineering firm Buro Happold, have had Wadi Hanifa living and thriving once again. A restored eco-system and continuous sustainable source of life for the city in turn restored the great natural identity of the Wadi that once was (ADA et al., 2010).

The comprehensive plan for the development of Wadi Hanifa was internationally recognized for its pioneering role in the field of environment and water resources management and development. The project has received worldwide recognition, such as the first prize award by the Water Center in Washington amongst seventy-five projects in 2003 (submitted by twenty-one countries), and the Golden Award from the International Award for Livable Communities amongst 160 project submitted in the field of environment and water resources conservation in 2007 (ADA, 2010).

Figure 28 Wadi Hanifa before development (Source: from ADA)

4.3.2 History

Following the rapid population growth at the early 1970s, Riyadh has been expanding westward toward Wadi Hanifa, alongside with the valley, exploiting the Hanifa valley to meet the increase of water demand and the massive construction needs for the mineral resources. By the 1980’s the Wadi could not cope with the water demand, leading to a drastic drop in the water table levels below sustainable limits. An alternative water supply of piping in water from the nearest desalination station along the eastern coast was founded to cope with the growing demand. Unfortunately, the solution brought the problem of rising contaminated groundwater that was mixed with raw sewage, which naturally drains through the Wadi, and caused environment and public health hazards (Alhamid et al., 2007). This all occurred with the onset of widespread dumping and quarrying, which also resulted in extensive environmental destruction that negatively influenced the surrounding real estate investment and the cost of revitalizing the dead Wadi. Ultimately, after proper redevelopment plans approved by ADA and lots of effort by the government, the Wadi is now considered one of the top attractions to be visited in both Riyadh and in the entire Kingdom.

4.3.3 The Water Budget of Wadi Hanifa

In such an arid region, it is important to know the water budget needed to maintain the flow of life (green, wildlife, and visitors) through the Wadi. The budget for this project was reported in Khan (2007), stating that (see Figure 29):

> Approximately 450,000 cubic meters of water (dry weather flow) continually flowed at that time out of the city each day into the Wadi Hanifa from various side wadis and channels. The main sources of flow into the Wadi are:
>
> | | |
> |---|---|
> | The North Diversion Channel | 24,000 m^3/day |
> | Wadi Gudwannah | 3,600 m^3/day |
> | Wadi Umm Qassar | 9,000 m^3/day |
> | West Ship | 19,300 m^3/day |
> | Batha Channel (Manfouha STP outfall) | 250,000 m^3/day (average) |
> | | 450,000 m^3/day (peak) |
>
> These flows are expected to increase two-fold by the year 2021. (Khan 2007, pp. 7-8)

Figure 29 Bio-remediation facilities cost one-third of a mechanical wastewater treatment plant & foster wildlife (Source: from the Bioremediation of Surface Water in Wadi Hanifa presentation by ADA, http://www.akdn.org/architecture/project.asp?id=2258)

4.3.4 Project Goals

• Protection and preservation of the Wadi Hanifa valley.

• Rehabilitation of floodplain and drainage basin.

• Maintenance and preservation of historical and heritage sites.

• Creating a sustainable balance between the Wadi ecosystem and the City's needs.

• Improving the quality of life.

• Use of Wadi as an open space for the City (ADA, 2015).

4.3.5 Design Implementations

A "Living Wadi" is the main concept that fully integrated health and sustainability into the life of Riyadh. An inspired client and a team of planners, landscape architects and engineers, over a period of almost ten years, succeeded in saving Wadi Hanifa through a completely organic, yet ground-breaking process of naturalization and bio-remediation. Daily bio-remediating a great volume of municipal water of the city, using 134 bio-remediating cells, makes the idea of a running river in one of the most arid places in the world what the author would consider a "dream come true" and makes Wadi Hanifa a special case study among the others. The restoration project includes:

- Open spaces and parklands along the Wadi and extended into surrounding residential areas.
- Magnificent cultural resource in the Al Masani district, the Old Dam and Old Al Hair.
- Natural landscape and rangelands at the catchment area of the Wadi, including constructed check dams.
- Private sector investments to renew the Seyah mixed-use development area.
- Private sector investment opportunities for recreational and leisure facilities.
- Private sector investment opportunities for tourism development.
- Private sector investment for innovative agricultural development.
- Reconstructing the downstream of Al Hair to meet the future reserve capacity needs for water recycling in Riyadh.
- Constructing water recycling and treatment facilities, to meet the future water recycling needs of Riyadh.

To achieve this, a series of landscaping and other features were implemented:

- Including rock features to introduce an interesting natural feel to the Wadi.
- Planting of palm trees at some of the gateways to Riyadh.

- Regenerating indigenous species of flora that spread throughout the Wadi.
- Developing interpretative trails to direct public to places of interest.
- Providing lighting on interpretive trails and roads for safe access at night.
- Implementing an attractive lighting design.
- Embracing the existing landscape features in the design.
- Constructing recreational parks and lakes.
- Providing public utilities like prayer areas, restrooms and more. (Khan, 2007)

4.3.6 Optional and Social Activities

Having a clean running river and a well-designed natural park fostered the increase of many optional activates that improved the livability of the city and created a unique sense of place in the region. This new identity was promoted with the area's interpretative hiking trails, twenty-seven miles of foot paths, fishing, society contribution agriculture and cleaning programs, camping, animal releasing activities, livestock grazing, wildlife observation, landscape scenic spots, and so on (see Figure 30).

Figure 30 Optional & social activates a provision of rehabilitating the Wadi (Source: from ADA)

4.3.7 Landscape Performance Benefits

LAND

☑ Soil Creation ☑ Preservation & Restoration Others:

WATER

☑ Stormwater Managmnt ☑ Water Conservation ☑ Water Quality

☑ Flood Protection ☑ Water Body/Groundwater Recharge Others: Bioremediate municipal water

HABITAT

☑ Population & Species Richness

CARBON, ENERGY & AIR QUALITY

☒ Energy Use ☑ Air Quality ☒ Temprature & Urban Heat Island

✓ Carbon Sequestration & Aviodance Others:

MATERIALS & WASTE

☒ Reused/Recyled Materials ☑ Waste Reduction Others:

SOCIAL

☑ Recreational & Social Value ☑ Educational Value ✓ Food Production

Others:

ECONOMIC

✓ Property Values ☑ Operations & Maintenance Savings

☑ Construction Cost Savings Others: Improve tourism

Toolkit Key

☑ Exceed ✓ Satisfy ☒ Not satisfy, reduce, no info.

4.4 Case Study 4: Zhanjiagang Town River, China, 2014

<u>Design Team</u>

by Botao Landscape

<u>Project Highlights</u>

Location: Zhangjiagang, China
Year: 2014
Main goal: City Parlor
Sub-goal: pollutant removal
Size: 6.4 acre
Cost: no info.

4.4.1 Project Background

The Town River is located at the south of an urban core commercial-pedestrian-street, extending from Gudu Harbor to the east all the way to Gangcheng Boulevard to the west. The overall length is more than 1.36 mile with average width of almost thirty-nine feet. Before the project, the river water quality was seriously polluted due to direct rainwater discharge from the surrounding neighborhood into the river without treatment. During the early 1990s, nearly half of the river used to be covered by residential buildings and streets, leading to an increase in the amount of polluted water caused by surface water run-off during the rainy seasons—affecting the environment and eco-system of the river as a result (ArchDaily, 2014).

4.4.2 Project Goals

The comprehensive reconstruction of Town River considered the following:

- Creating the "City Parlor" of core commercial area.
- Implementing pollution control and water import.
- Recovering the natural ecology of the river.
- Constructing the landscape to provide a more pleasant environment.
- Implementing a comprehensive development to improve infrastructure functions of the entire region. (ArchDaily, 2014)

4.4.3 Design Implementations

A modern Chinese urban river style was developed with a strong water town style and features. The modern design included constructing a pavilion and wall to improve the drab scenery to the south of the Yangtza River for the people who live near river, and repairing the most familiar Tsing Lung Bridge (Longyin) for the people living along the banks of the Old Yangshe. The two sides of the Gudu Harbor River were embellished by the Green Fragrant Pavilion, the bamboo raft dock, the ship dock, the Jiyang city wall, the "Eight Forbiddens" stela, and the eight original cultural elements in the history of Old Yangshe. The northern and southern area of the river are linked by central bridges that benefit the daily lives of the general public, forming a wonderful piece of landscape-art over the river (ArchDaily, 2014).

The comprehensive plan of the Town River also included water purification plan by utilizing bio-retentions and tree planters installed on both sides of the river, and growing floating plants like water lilies (nymphaea spp.) and other water-purifying grass and plants along the edges of the stream. The floating plants have proven their abilities to serve multi-ecological functions in addition to increasing the aesthetic values of the environment.

Ecological services like purifying the water by absorbing nutrients results in clearer water and less algae, and absorbing carbon dioxide and releasing oxygen into the water can improve the ecosystem of freshwater environments. Both of these conditions were eventually achieved in this project. Additional water purification methods used in this case were intake-and-out river-water filters that were designed to clean the polluted water within the river through a capture and release process (see Figure 31).

Figure 31 Pollutant removals and water purification through and ecological process (Source: by Botao Landscape)

4.4.4 Optional and Social Activities

The Quality of the physical environment of the Town River was improved by the wise design decisions that fostered new optional and social activities in the area. For instance, creating a center stage, providing waterfront footpaths, providing a coffee house, and designing cascades and other water features, sculptures, and a social bridges have increased both the livability of the overall city public square and the flow atmosphere within the square. Meanwhile, the design copes with the overall planning and design goals of municipal government. For example, bus stations were properly arranged throughout the area, which can be considered another source of visitors flowing to and from the area on daily basis (ArchDaily, 2014) (see Figure 32).

Figure 32 Optional & social activities (Source: by Botao Landscape)

4.4.5 Landscape Performance Benefits

LAND

✓ Soil Creation ✓ Preservation & Restoration Others:

WATER

✓ Stormwater Managmnt ✓ Water Conservation ☑ Water Quality
✓ Flood Protection ✗ Water Body/Groundwater Recharge Others:

HABITAT

✓ Population & Species Richness

CARBON, ENERGY & AIR QUALITY

✗ Energy Use ✓ Air Quality ✗ Temprature & Urban Heat Island
✓ Carbon Sequestration & Aviodance Others:

MATERIALS & WASTE

✗ Reused/Recyled Materials ✗ Waste Reduction Others:

SOCIAL

☑ Recreational & Social Value ✓ Educational Value ✓ Food Production
Others:

ECONOMIC

☑ Property Values ☑ Operations & Maintenance Savings
✗ Construction Cost Savings Others: Improve tourism & investments

Toolkit Key

☑ Exceed ✓ Satisfy ✗ Not satisfy, reduce, no info.

4.5 Case Study 5: Qianhai Water City, Shenzhen, China, 2010

Design Team

by JCFO

Project Highlights

Location: Shenzhen, China
Year: 2010
Main goal: new urban center
Sub-goal: water & green parks
Size: 4,500 acre
Cost: $102 billion

4.5.1 Project Background

James Corner Field Operations (JCFO) was awarded First Prize in the International Competition for the Planning of the Qianhai Region of Shenzhen, a major new city in Qianhai, Shenzhen, China in 2010. The 4,500 acres of reclaimed land was designed to accommodate 1.5 million people, surrounding Qianhai Harbor on the western coast of Shenzhen. A new compact, mixed, sustainable "Water City" is what the JCFO scheme envisions to emphasis the most important culture identity and source of life – water.

4.5.2 Project Goals

To link Hong Kong to Shenzhen and Guangzhou, Qianhai is to be the "major new urban center" and is envisioned to be the financial, logistics and service hub of Shenzhen. To achieve, this the city has to develop a reliable infrastructure. The JCFO scheme as a result developed a creative masterpiece of green channels (or "fingers") for flood protection and stormwater management purposes (see Figure 33) (Cilento, 2010).

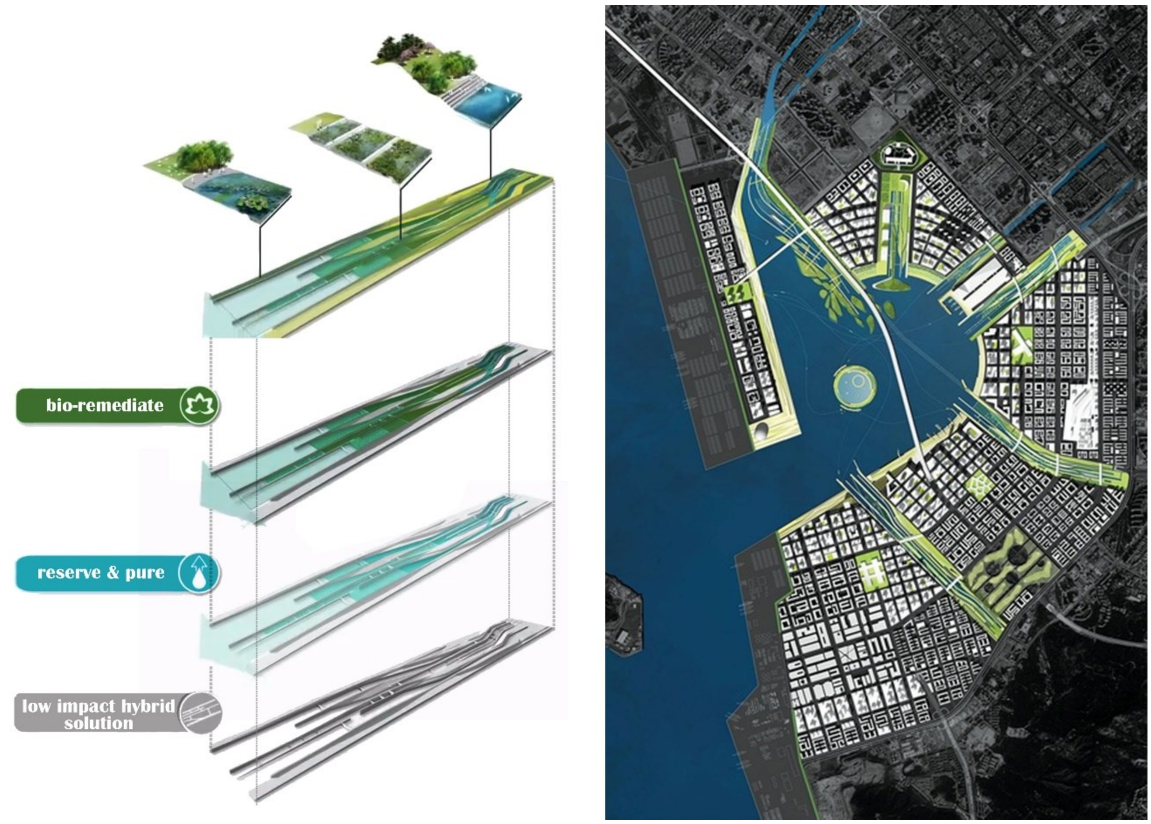


Figure 33 Five green channels designed in a 3-D "muscular way" to process and treat the inland water (Source: JCFO)

4.5.3 Design Implementations

The proposed master plan met the decision makers and stakeholders' envision of a new urban center to attract huge investments. The master plan proposes five development sub-districts, circumvented by five "Water Fingers" that spread along the existing rivers and channels. The five rivers and channels are currently polluted and exposed to flooding (refer to Figure 33). The singularity of this project is illuminated by the idea of developing the master plan based on the landscape amenities—the Water Fingers—first, rather than streets and urban blocks. The Fingers serve multiple functions, including providing ecological and social services as an innovative hydrological infrastructures and new public parkland (central parks), materializing what could be described as “big biological machines(Corner, 2012)” (USC Architecture 2011) These fingers were designed, sculpted, and shaped in a “muscular way” (meaning layered in three dimensions) to process and treat the inland water before releasing to the bay, using basins and terraces of plants and fish ponds (see Figure 34). The structure of these Fingers make them able to function as reservoirs to slow down and control flood in the bay in different levels (Corner, 2011).

The master plan provides an ecological sensitive urban fabric of hyper-dense zones, with diverse building stock, cultural and recreational features, and series of unique, inter-connected public open spaces that creates an iconic waterfront. Each development sub-district is in the scale of the typical Shenzhen block with a diverse range of inter-connected urban neighborhoods (Cilento, 2010). Each district is a home to a monumental building that represents its identity, like the Cultural Forum, Financial Tower, Mediatheque, Athletic Club, and the Eco Sphere. Each is connected to a public transit hub that, in turn, is connected to a regional train which connect them with Pearl River Delta, Shenzhen, and Hong Kong megalopolis.

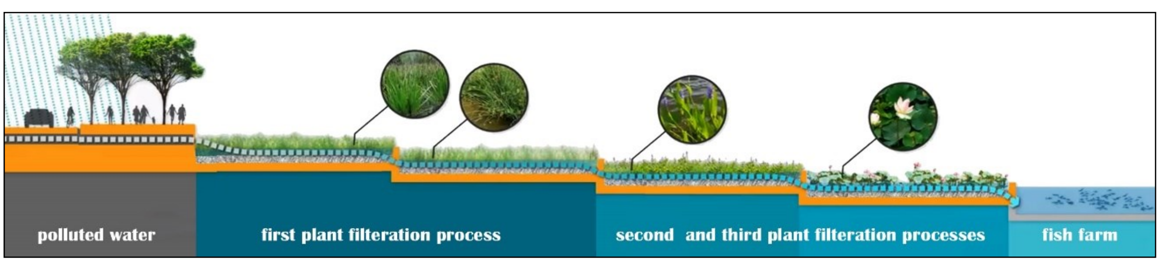


Figure 34 Bio-remediation process through basins of wetlands & fish farms (Source: JCFO)

4.5.3 Optional and Social Activities

The Water Finger parks are expected to improve the livability of the city by the promoting more social and optional activities. The proposed five linear river parks (or the Fingers) provide one-of-a-kind amenities that integrate large scale urban infrastructure with the active and passive recreation with ecology, habitat, and cultural programs in order to create new productive urban citizens. The master plan also proposes a constructed island in the middle of the harbor to help process and filter the water and to be a special destination of a new water park for resident and tourists (Corner, 2011) (see Figure 35).

Figure 35 A new creative, iconic & unique waterfront that will rival major destination waterfront cities around the world (Source: JCFO)

4.5.4 Landscape Performance Benefits

LAND

Soil Creation Preservation & Restoration Others:

WATER

Stormwater Managmnt Water Conservation Water Quality

Flood Protection Water Body/Groundwater Recharge Others:

HABITAT

Population & Species Richness

CARBON, ENERGY & AIR QUALITY

Energy Use Air Quality Temprature & Urban Heat Island

Carbon Sequestration & Aviodance Others:

MATERIALS & WASTE

Reused/Recyled Materials Waste Reduction Others:

SOCIAL

Recreational & Social Value Educational Value Food Production

Others:

ECONOMIC

Property Values Operations & Maintenance Savings

Construction Cost Savings Others: Improve tourism & investments

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Toolkit Key

Exceed Satisfy Not satisfy, reduce, no info.

4.6 Case Study 6: Cheonggyecheon Stream, Seoul, South Korea, 2005

<u>Design Team</u>

by MYKD

<u>Project Highlights</u>

Location: Seoul, South Korea
Year: 2005
Main goal: restore the water-way
Sub-goal: green corridor
Size: 12592 acre
Cost: $ 281 million

4.6.1 Project Background

Cheonggyecheon is a creek that was covered with concrete for roads and an elevated highway that was built over it in 1968 (see Figure 36). The creek flows west to east through downtown Seoul, and then meets the Jungnangcheon tributary, which in turn connects to the Han River and empties into the Yellow Sea. In 2003, Mr. Lee Myung-bak, the mayor of Seoul, initiated the Cheonggyecheon Restoration Project to remove the elevated highway and restore the stream. This project was meant to create an ambitious modern recreational public space in downtown Seoul, South Korea, that would stand as the epicenter of the seven-mile green corridor, beginning in the central business and commercial district of the city. The design of this project was the winning project in an international competition that was designed by Mikyoung Kim Design (MYKD). The project met the requirements of the competition by highlighting the future reunification of North and South Korea and symbolized this political effort by using donated local stones that were collected from eight provinces in North and South Korea.

Figure 36 Cheonggyecheon before & after development (Source: from http://landscapeperformance.org/case-study-briefs/cheonggyecheon-stream-restoration)

4.6.2 Project Goals

The restoration of the Cheonggyecheon Stream design is highly symbolic. It has been developed to achieve the following services:

- Create a public space to integrate the hydraulic infrastructure and many other urban services.
- Restore the history and culture of the region, which had been lost for thirty years.
- Mitigate the contaminated condition.
- Construct a green channel that promotes purification and retention services.
- Create the ability to accommodate a 100-year storm.
- Help to convey water from the central wastewater treatment plant by pumping daily 75,000 tons of water from the Hangang River during the dry season and moves it through the city all the way back into Hangang.
- Drain 22,000 ton of underground water per day from subway stations through the channel to Hangang.

4.6.3 Design Implementations

The channel was designed to cope with the water levels—hour by hour and season to season—while also addressing the catastrophic flooding that occurs during in the rainy season. The channel functions as a vessel by storing the water during the height of monsoon season before releasing it back to Hangang River. It was also designed to purify the water conveyed from the treatment plant—with water quality of Class II in order to be safe for public reengagement with the river (Kim, 2007) (see Figure 37). The velocity of the stream was regulated by national stones that were installed over the stream bed. More importantly, the restoration reestablished connections between three waterways. The Cheonggyecheon runs into Jungraechon stream then discharge into the Hangang River. Their meeting point was designated for designed wetlands and then classified as an ecological conservation area (LAF, 2015a). During the dry season, the river flow is maintained by 97,000 tons of daily water pumping and draining to the stream from Hangang River and the underground water from subway stations.

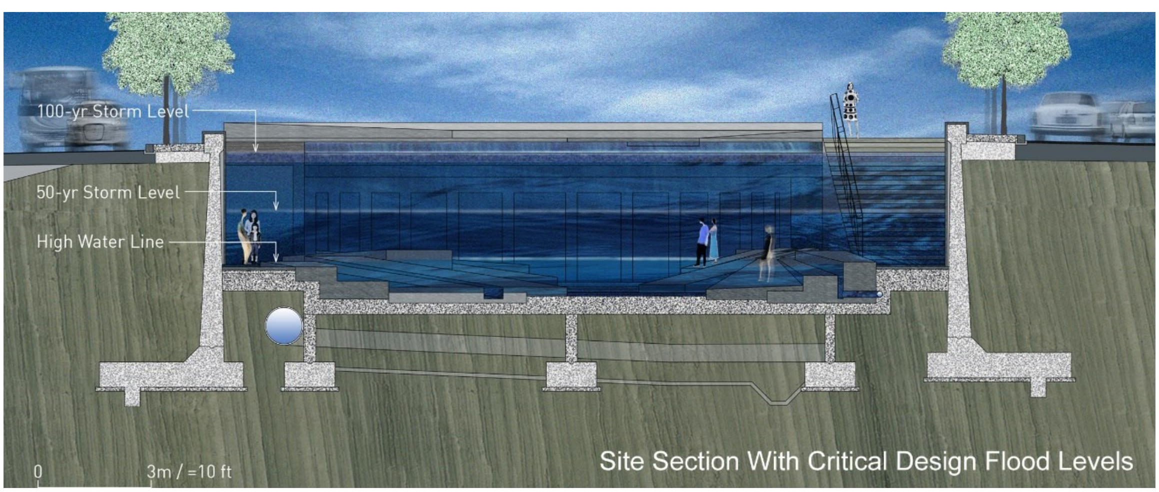

Figure 37 Site section showing design flood level (Source: MYKD)

4.6.4 Optional and Social Activities

The restoration of the Cheonggyecheon Stream created a new sense of place and has improved the livability of the neighborhood and the city of Seoul. This urban channel provided the city with a very long green corridor. Greening the channel and bringing an abandoned, dead stream back to life has increased the overall biodiversity by 639% between the pre-restoration works in 2003 to 2008. Moreover, 308 species of plants, twenty-five of fish, thirty-six of birds, fifty-three of aquatic invertebrates, 192 of insects, four of mammals, and eight of amphibians have now been observed in this reclaimed area. The channel became the focal point of an annual interactive festival in Seoul, fostering multiple socio-cultural events. The 3.6-mile continuous east-west green corridor for pedestrians, bicyclists, and wildlife attracts an average daily of 64,000 visitors. The vertical terraced walls create seasonal interests as water levels change, and protect the city from floods. The natural stones link the two banks and create an adventurous walkway for pedestrians over the stream, giving them a chance to engage and interact with nature (LAF, 2015a) (see Figure 38).

Figure 38 Festive channel promotes cultural events, social interactions, public art contributions (Source: http://kuonnanao1.blog.fc2.com/blog-entry-198.html, https://www.pinterest.com/pin/30047522488923932/, http://pixgood.com/cheonggyecheon-stream.html)

4.6.5 Landscape Performance Benefits

LAND

✓ Soil Creation ☑ Preservation & Restoration Others:

WATER

☑ Stormwater Managmnt ✓ Water Conservation ☑ Water Quality

☑ Flood Protection ✓ Water Body/Groundwater Recharge Others:

HABITAT

☑ Population & Species Richness

CARBON, ENERGY & AIR QUALITY

✗ Energy Use ☑ Air Quality ☑ Temprature & Urban Heat Island

☑ Carbon Sequestration & Aviodance Others:

MATERIALS & WASTE

✗ Reused/Recyled Materials ☑ Waste Reduction Others:

SOCIAL

☑ Recreational & Social Value ☑ Educational Value ✗ Food Production

Others:

ECONOMIC

☑ Property Values ☑ Operations & Maintenance Savings

☑ Construction Cost Savings Others: Improve tourism & investments

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Toolkit Key

☑ **Exceed** ✓ **Satisfy** ✗ **Not satisfy, reduce, no info.**

4.7 Conclusion

Redeveloping green channels has been proven as a valuable source of opportunities that can improve the overall quality of life and livability of a city by providing multiple optional and social activities. This is because human health and city livability are both effected by the quality and health of the ecosystem. By revitalizing a lost ecosystem or developing a new one, wildlife can thrive and increase, resulting in more biodiversity of native and/or new species.

The case studies presented in this chapter show how green channels can result in a very good improvement in people's daily life and their perception and appreciation for nature. This chapter also demonstrates the importance of open spaces, since they reward their residents with such opportunities that accompany well-developed and interactive green channels. Regardless of the availability or rarity of vegetation and water among different geographical locations and cultures identities, people tend to appreciate the provision of green channels with clean running water—especially in dense urban development areas, where the rate of open spaces does not keep up with the population, and where the interaction with nature often requires a car trip. Table 8 illustrates the differences and similarities, in addition to the generated benefits of the case studies, in order to see if there is relation between the provision of green practices and the general benefits that were reported in this chapter for each case. The table shows no major differences in the generated benefits of developing or revitalizing green channel or river. All the green channel cases show a very good improvement in people's life and a great bond and/or creation of a distinctive sense of place between people and nature.

The role of landscape architects in redeveloping an abandoned or polluted area into an urban green channel is not an option anymore, especially with the challenges and scarcity of natural resources (i.e. water and food) that the whole world faces due to the rapid growing in population and the urbanism phenomenon. Landscape performance (or design solutions) in all cases have helped to generate general benefits and distinctive benefits in all of the cases—all based on its design solutions. The general and special benefits or services (what I will refer to as "opportunities") of developing green channels that were reported in this study are:

1- **Environmental services:**

- Effective flood control system
- Environmental water management services
- Municipal water biological treatment
- Recharged groundwater.
- Increased biodiversity

2- **Social services:**

- Historic restoration and/or preservation
- Neighborhood connectivity
- Educational activities
- Urban agriculture or food production
- Increased aesthetic values
- Public health and activities (biking, hiking or walking, public education, public art, social gatherings, cultural events, water activities, fishing, etc.)

3- Economic services:

- Increased land value
- Increased mixed-use developments
- Increased investments
- Increased job opportunities
- Waste water and water management cost reduction
- Medical bill reduction (due to overall health improvements)

Although some cases cannot be compared or placed at the same level of "sustainability or green solutions" that distinguish some cases (discussed in more detail below), general benefits can be found among them all, and they have all resulted or will result in improving the quality of life of their citizens. This study highlights some of these distinctive green solutions, and the optional and social activities that were fostered by implementing these solutions. For example, Wadi Hanifa is distinguished by its arid condition plus the alternation between scarce precipitation and considerable rainfall, but showed a promising solution and actually an ideal lead in manipulating the municipal water source in order to revive its lost nature and revitalize its urban life. In short, it is physical concrete proof and evidence of the possibility to have a river running constantly in the middle of a desert. Remediating the municipality water of Riyadh naturally through the body of the Wadi via bio-cells and other biological treatments brought back both wildlife and human social life to the valley. Implementing this natural process generated economic benefits due to the reduction in treatment plant costs and increased opportunities for investments by neighboring lands. This natural process also fostered some optional-social activates that were previously considered impossible or unimaginable in the middle of a desert. For instance, using tilapia fish basins as part of the bio-remediation process developed fishing activities that was never before conceivable in the minds of the people of Riyadh. In general, the beauty of waterfront of Wadi Hanifa (along with similar projects in Jeddah and Khobar) completed the beauty of the waterfronts in Saudi Arabia and its unique desert landscape design (see Figure 39).

Figure 39 Examples of manmade waterscapes in the Saudi desert; from left to right, the waterfront of the cities of Jeddah, Khobar & Riyadh (Source: http://www.j44j.net, http://www.alkhobargate.com, ADA)

The provision of vegetation and water both combined in creative modern designs of green channels are the main reason behind the successes of these selected projects. It is highly recommended when developing a green channel to have a combination of both blue and green infrastructure. However, in such an arid region like in Saudi Arabia, the percentage of water bodies (i.e. blue) compared to green infrastructures should take into consideration the existing potential and water sources of a site. Although some case studies—like the Cheonggyecheon Stream project—provided unsustainable (green) solutions (because of the daily pumping of water from Hangang River to maintain the flow of the stream all the year except the rainy seasons), these case studies have all created uncountable sustainable social behavior that justify the means—benefits that include an increase in public transportation use, walking, biking, and so on.

Project			Revitalize Los Angeles River	Buffalo Bayou Promenade	Wadi Hanifa	Zhanjiagang Town River	Shenzhen Qianhai Water City	Cheonggyecheon Stream
Location			Los Angeles, U.S.	Houston, Texas, U.S	Riyadh, Saudi Arabia	Zhanjiagang , China	Shenzhen , China	Seoul, South Korea
Stream surface			Pervious	Pervious	Pervious	Pervious	Pervious	Pervious
Function(s)			* Storm water management * Public Park	* Storm water management * Public Park	* Storm Water Management * Public Park * Bioremediate polluted water	* Storm water management * Public Park * Bioremediate polluted water	* Storm water management * Public Park * Bioremediate polluted water	* Storm water management * Public park
Climate			***General:*** Warm is the predominant weather, mild temperatures throughout the year due to the moist of the Pacific air. Dry and sunny in summers with averages of 329 sunny days per year. Precipitation mostly occurred in winter months. ***Temperature:*** January, 13.8 C (57.0° F); August, 22 C (72.0° F); annual average, 17.7 C (63.9° F) ***Precipitation:*** averages 431.8mm (17 in).1	***General:*** humid subtropical. ***Temperature:*** August normally ranks as the warmest month at 93 °F (33°C) and January the coldest month at 44 °F (6°C). ***Precipitation:*** average 1066.8 mm (45 in).2	***General:*** Hot desert climate. ***Temperature:*** In summer extremely hot, approaching 50 °C (122 °F), Winters are warm with cold, windy nights can reach as low as −2°C (28 °F). ***Precipitation:*** avrage 150mm (5.9in).3	***General:*** warm and temperate ***Temperature:*** The temperature here averages 15.2 °C. In a year. ***Precipitation:*** There is significant rainfall throughout the year in Zhangjiagang. Even the driest month still has a lot of rainfall. the average rainfall is 1037 mm (42in).4	***General:*** Subtropical climate, weather is mild with plenty of sunshine and rainfall all year round and relatively dry in Winter. ***Temperature:*** A long mild summer and short relatively warm winter, 22 C (72 °F) on average ***Precipitation:*** averages 1,970 mm (78 in).5	***General:*** Humid continental climate with severe, dry winters, hot summers and strong seasonality.1 ***Temperature:*** In summer hot, humid weather with temperatures soaring as high as35 °C (95 °F), in winter temperatures dropping as low as -13 °C (7 °F).2 ***Precipitation:*** averages 1370.5 mm (54in).6
Channel width (m)		20 - 40s						
		40 - 50s						
		Over 50						
Previous/ Current Issues		flood	Yes	Yes	Yes	No	Yes	Yes
		pollution	Yes	Yes	Yes	Yes	Yes	Yes
		covering stream channel	No	No	No	No	No	Yes
		gray solutions only	Yes	No	Yes	No	No	Yes
		env. degradation	Yes	Yes	Yes	Yes	Yes	Yes
		lost culture	Yes	No	Yes	Yes	No	Yes
		lost habitat	Yes	Yes	Yes	Yes	No	Yes
		waste land	Yes	Yes	Yes	Yes	No	Yes
		neighbor segregation	Yes	Yes	No	Yes	Yes	Yes
Solution Practices		dam	Yes	Yes	No	No info.	No	No
		check dams	Yes	Yes	Yes	No	Yes	Yes
		concrete channel	No	No	No	No	Yes	Yes
		wet/ dry pond/ river	Yes	No info.	Yes	Yes	No	No
		recycle waste water	Yes	No	Yes	No	No	No
		bio-(re/de)tention	Yes	Yes	No	Yes	Yes	No
		rain garden	Yes	No info.	No	Yes	Yes	No
General Benefits		100Y flood prevention plan	Yes	Yes	Yes	No info.	Yes	Yes
		restore ecology	Yes	Yes	Yes	Yes	Yes	Yes
		increase biodiversity	Yes	Yes	Yes	Yes	Yes	Yes
		increase land value	Yes	Yes	No info.	Yes	Yes	Yes
		improve air quality	Yes	Yes	Yes	Yes	Yes	Yes
		remediate water pollution	Yes	Yes	Yes	Yes	Yes	Yes
		recycle waste water	No	No	Yes	No	No	No
		reduce energy consum.	Yes	Yes	Yes	Yes	Yes	Yes
		encourage walking	Yes	Yes	Yes	Yes	Yes	Yes
		encourage bicycling	Yes	Yes	Yes	No	Yes	No
		increase socialzation	Yes	Yes	Yes	Yes	Yes	Yes
		encourage tourism	Yes	Yes	Yes	Yes	Yes	Yes
Water and landscape design preparation benefits	society	aesthetic attraction	Improve	Improve	Improve	Improve	Improve	Improve
		social gathering	Improve	Improve	Improve	Improve	Improve	Improve
		events	Improve	No info.	Improve	Improve	Improve	Improve
	economy	investment	Improve	Yes	Improve	Improve	Improve	Improve
		reduce water production	Improve	No info.	Improve	No info.	Improve	Improve
		reliable water resource	Improve	Improve	Improve	Improve	Improve	Improve
	environment	mitigate temp.	Improve	Improve	Improve	Improve	Improve	Improve
		biodiversity	Improve	Improve	Improve	Improve	Improve	Improve
		agriculture	No	No	Improve	No	Improve	No
		open space	Improve	Improve	Improve	Improve	Improve	Improve

Table 8 Summary of the cases' information, issues, and practices (Source: developed by author **A) climate information** collected from 1. http://www.citydata.com 2. http://www.usclimatedata.com, 3. ADA, 4. http://www.en.climate-data.org, 5. http://www.travelchinaguide.com, 6. http://www.regaltravel.co.uk. **B) table data information** retrieved by author from google earth & 1.Los Angeles River Revitalization master Plan, 2007. 2. Landscape Performance Series. 3. http://watercanada.net. 4. http://www.archdaily.com. 5. http://www.fieldoperations.net, table data from the sources of each case study)

CHAPTER 5

JEDDAH CITY INVENTORY

This chapter demonstrates Jeddah's issues, obstacles and opportunities regarding the current stormwater management plan to emphasize the opportunities that can be generated from converting the stormwater channels to green channels. This chapter will also overview the timeline of developing stormwater management in Jeddah from the first time it was inhabited until the present. The chapter will also include figures regarding the urban and population growth, future city expansion, and the available open space per capita in order to evaluate the current and proposed stormwater channels that the government had constructed. Moreover, the chapter will present the current water sewage and treatment plant strategy to support the feasibility studies in rationalizing the solutions proposed by this thesis in order to redevelop green channels in such an arid zone.

5.1 Overview of Jeddah's Geographical and Climate Characteristics

Jeddah is a city-port and the gateway to the two Holy Mosques, Makkah (Mecca) and Medina (Al-Masjid Al-Nabawi), which is located at the middle of the western coast of Saudi Arabia (see Figure 40). Affected by its geographical location, Jeddah is characterized by a semi-tropical climate, where there are high temperatures and humidity in the summer and a mild temperature and low humidity in the winter (Municipality, 2014a). Average temperatures range from 9.8°C (49.64°F) to 52°C (125.6°F) during winter and summer, respectively (WWCI, 2015). The annual climatological reports from 1981 to 2011 were obtained from the Ministry of Defense and Aviation-National Meteorology and Environment Center of Saudi Arabia (DANMEC). The highest average annual precipitation of 285.1mm (11.2in) was recorded on November 1996, with highest average mean of 22.3mm (0.8in) in the same year. The driest weather on record is consistently from May to September, during the years 1981 to 2011, with an average annual precipitation of 0-2.2mm (0-0.08in) (DANMEC, 2011) (see Table 9).

Figure 40 Location of Jeddah City (Source: reproduced by author from google earth maps)

Jeddah is known as “Bride of the Red Sea,” where the name here refers to its location. Jeddah’s location has obtained for the city a significant economical and religious reputability. The Red Sea coral reefs and marine life are well known as one of the most beautiful of all the world’s marine habitats and one of the most iconic natural attractions for local and international divers (Bremner, 2012). The city is also located terrestrially within the Tehama plains. The landscape units of Jeddah are defined by the eastern mountains that are known as the Sarawat Mountains, the Red Sea from the west, and the urban area in between. The city is affected by fifteen valleys fluctuating in size from big to small, which reflects the size of the impact in the event of a flood. Due to the historical drought conditions of the past, Jeddah had no gardens or vegetation except for a few date palms adjoining a mosque. Besides these palms, Jeddah’s landscape consists mostly of natural barren desert. In contrast, Jeddah’s landscape image in recent years has drastically changed from brutal drought and barren desert into a top tourist destination in the Arabian

Peninsula, due to the massive water supply that is mainly generated by the desalination stations and the recycling of water sewage (see Figure 41). The drastic change in gardens and economy would not have been possible before the wealth accumulated from the oil discovery in 1938. This wealth helped to operate the desalination stations which eventually led to an increase in the number of open spaces per capita.

Figure 41 Northern costal park, Jeddah (Source: from http://www.sainternational.us/)

	Precipitation from 1981 to 2011 mm																																	
Months / Years	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	M	Ex.t	YEAR
Jan	0.7	0	0	0	5.4	0	0	0	0	2	7	40.2	6.8	0.5	0.3	2.5	13	45.7	70.9	0	13	0	0	10	32	0	3.3	5.3	0	0	75.9	10.8	75.9	2011
Feb	1.9	0	0	0	0	0	0	1	0.6	0	0	0	0.5	0	45.2	0	0	0	19	0	0	1	3	0	0	0	0	0	4	25	0	3.2	45.2	1995
Mar	0.1	0	0	0	0	0	4.4	0	0	1	6	14.8	1	0	0	0	0	26	5	0	5.6	11	0	0	0	0	0	0	0	0	0	2.4	26	1998
Apr	0	0	0.7	0	0	0	0	0	19	2	0	0	1	0	0	0	0	0	0	0	0	0	0	1	45	0	0	0	0	0	0	2.4	45	2005
May	0	1	0	0	4.5	0	4.4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0.2	4.4	1987
Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.2	0	0.2	7.2	2010
Aug	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	10	0	0	0	2	0	0	0	0	0	0	1	0	0	0.5	10	1998
Sep	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.2	0	0.1	2.2	2010
Oct	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	22	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0.9	26	1997
Nov	0.6	0	0	0	39.5	0	0	0	2	0	7.2	67.5	6	8.7	31.5	258.1	6	22	0	65	0	20	60.6	0	0	0	0	22	70	0	4.6	22.3	285.1	1996
Dec	0	0	2	0	22	0	1.5	27.9	50.8	0	0	22	58	0.3	0	24	3	0	19	0	25	0	0	0	0	0	0	0	20.3	65.6	0	11	65.6	2010

Table 9 Precipitation data of Jeddah (Source: The National Meteorology & Environment Center, Saudi Arabia)

5.2 The Catastrophic Flood

In November 2009, Jeddah witnessed a severe event, when a flood inundated the urban areas, which resulted in the deaths of many people and destroying the infrastructure and residential zones. The lack of appropriate infrastructure exacerbated the problem. A study by Mashael Al Saud titled "Assessment of Flood Hazard of Jeddah Area 2009, Saudi Arabia" (2010), has identified many influencing factors at different levels of effects in all the zones that were subjected to the flood. The study used different tools of assessment like IKONOS satellite images that can identify terrain features by embracing its high resolution images, in addition to the Geographic Information System (GIS) to supports the IKONOS results (see Figure 42). The study aims to identify the flood prone areas in order to avoid them in the future city expansion plan:

> Analyzing the produced map, in combination with field verification, resulted a number of findings related to the mechanism of flood process, as well as it helped inducing the influencing factors of impact. The major findings are:
>
> 1) The geographic distribution of flooded zones within a certain domain reflects the location where rainfall has taken place.
>
> 2) There is an obvious coincidence between the geographic distribution of flooded zones and the existing valleys courses.
>
> 3) The entire figure of the flooded zones composes a funnel-like shape with a maximum width of about 32 km and an outlet of about 8 km (*i.e.*, 4:1).
>
> 4) There is abrupt discontinuity along some flooded zones, which is almost attributed to human influence, such as the presence of a dam along Wadi El-Assla, and existing of a concrete channels in Kilo-8 region.
>
> 5) Even though, some valley systems are vulnerable to floods; however, they did not witness a flooding process, and this is due mainly to the low rainfall rate. (Al-Saud, 2010)

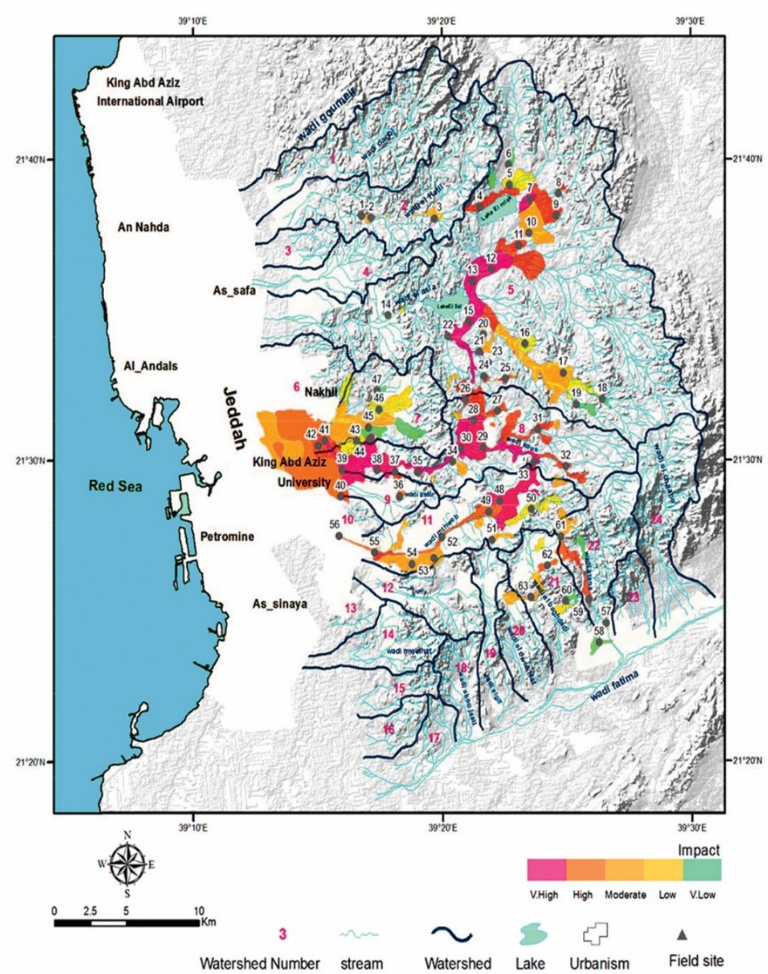


Figure 42 Flooded zones in Jeddah region (November 2009) with five damage categories. (Source: Al-Saud, 2010)

5.3 Jeddah's Hydrologic Cycle

The process where the atmosphere and the ground are constantly exchanging water in a form of precipitation and evapotranspiration is called the "Hydrologic Cycle." The natural water cycle is simply when rain falls into the ground and then water flows finding its way into creeks and valleys (drainage lines) all the way to the sea. During this natural journey, rainwater either infiltrates underground and recharges an aquifer or evaporates to the atmosphere—most often because of the erosion factors like winds, ambient temperature, and other factors. In many urban areas around the world including Jeddah, this natural process has been inextricably altered due to urbanization (see Figure 43). Urbanizing the city turns a large number of the pervious surfaces into impervious surfaces, including those in the floodplain areas. This in turn has increased the velocity of rainwater surface run-off, which in turn has caused flooding, torrents, and large pools of accumulated water in different spots in the city. This untreated water goes directly to the sea, which can affect the condition of the marine life as well (see Figure 44).

5.3.1 Water Resources of Jeddah

Desalination is the only reliable source of water for Jeddah City. It provides the city with the daily water needs of 972,400,000 L/day (256,880,904 gallons) for 3.4 million residents. The process of desalinating costs in Saudi Arabian Riyal (SAR) 7/m^3 (US$0.007/gal) at a total daily cost of 6,806,800 SAR. Only 142,800 SAR (2% of the total cost) is what the users pay for the entire daily desalination cost, at a rate of SAR 0.15/m^3 (US$0.04/$m^3$) (Al-Ibrahim, 2012). Recently a new strategic tanks project located at Bryman is under construction to help cope with the future increase in water needs. The capacity of these tanks is 6,000,000m^3 (1.5B gal) of desalinated water at an estimated cost of US$586,666,667 (US$0.37/gal) (Gazzawi, 2013).

Following the high cost of desalination and high rate of water consumption per person (75gal/d/person) an excessive daily waste of a valuable source of the municipal water is dumped to the sea. An approximate 45% of the population is served by the main sanitary sewerage (see Figure 43 and 44). Only 70,000m^3 (20%) of the treated wastewater of Jeddah is recycled for irrigation (Municipality, 2014c).

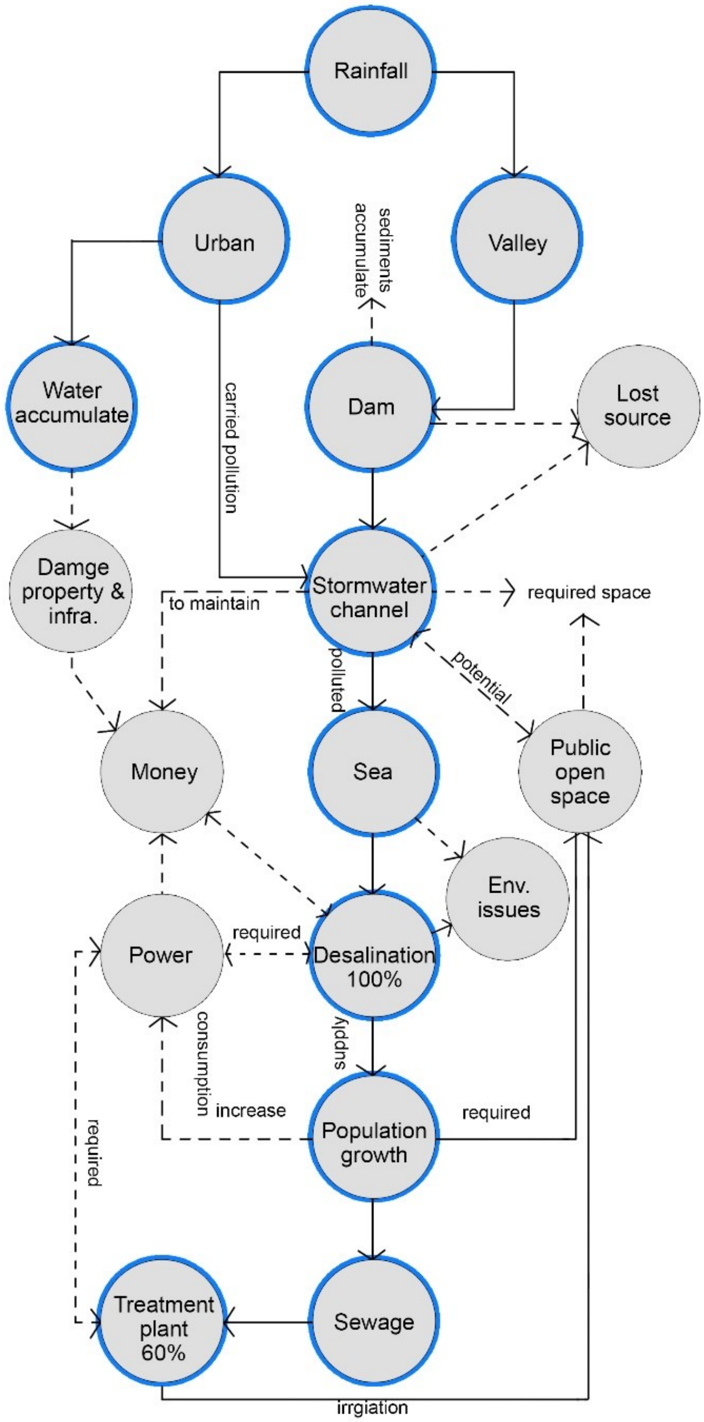


Figure 43 The current hydrology cycle of Jeddah (Source: author)

Figure 44 Jeddah's underwater garbage & pollution accumulation (Source: Azmi Awari a Saudi dive master)

5.4 Jeddah's Stormwater Management Development between Past and Present

This section provides an overview of Jeddah's storm water management practices that helped or are helping to reduce the volume of surface run-off and eventually reduce any chances of developing a severe flood (see Figure 45).

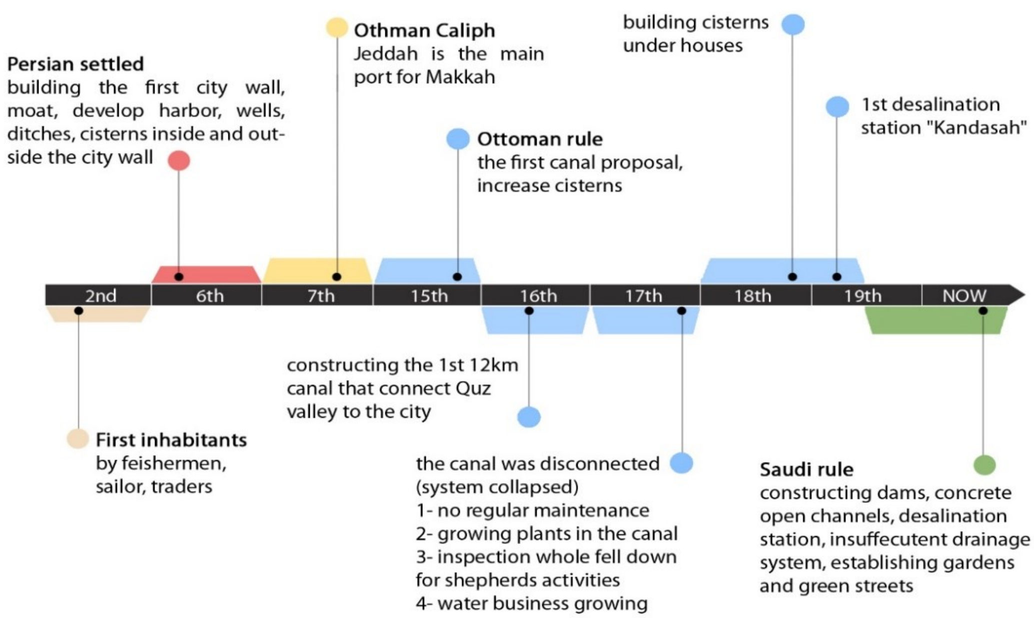


Figure 45 The stormwater-management-development timeline of Jeddah (Source: Author)

Comparing the influences and benefits of both old and current practices in terms of which one is more sustainable, our understanding of the fundamental concept of sustainability supports that idea that the old practices are apparently more sustainable than the currently used practices in Jeddah (see Figure 46).

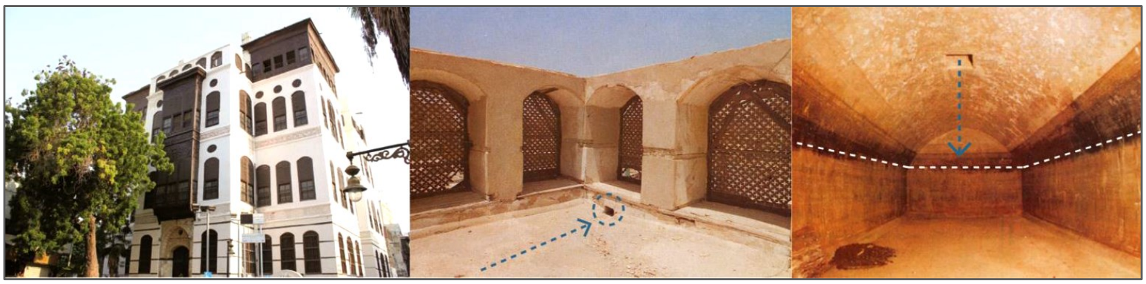


Figure 46 Traditional rooftop rainwater harvesting with underground cistern (Image of Nasif House, Source: The National Center for Research and Documentation at Jeddah City)

Jeddah was first inhabited in the second century BCE by fishermen settlements and traders. Its location plays an important role in making Jeddah the center of trading and sailing in the region (Municipality, 2014c). As rainfall was the only water resource for Jeddah at that time, the city had witnessed a number of projects and practices of rainwater harvesting and flood protection strategies due to the growing number in population and the needs for potable water. It was recorded that some of these practices were first founded by Persians in the sixth century CE. Persians were the first who built the city wall and moat to protect the city from its enemies and also from any sporadic flood or invading torrents. They also developed a harbor, constructed wells, ditches, and built a number of cisterns inside and out of the city wall (see Figure 47) (Azhar, Al-Shoail, & Al-Okazi, 1996).

Flooding is not a new threat in Jeddah. It was also an issue in the past since it was first inhabited in the second century BCE (Municipality, 2014c). Yet, the magnitude of damages by flooding in recent years has significantly increased. As in many other cities in the world, rainfall was the only fresh water resource for Jeddah's first inhabitants. Therefore, these first inhabitants constructed a number of what we nowadays describe as "sustainable practices" or "green infrastructures" such as harvesting rainwater from roofs and storing it in cisterns under buildings—unlike the current practices that have been developed to discharge surface run-off as quickly as possible to the sea. As demonstrated in old photos of the city, Jeddah used to have a balance between impervious and impervious surfaces, where the impervious surfaces did not affect the infiltration process when rain fell or floods struck (see Figure 48).

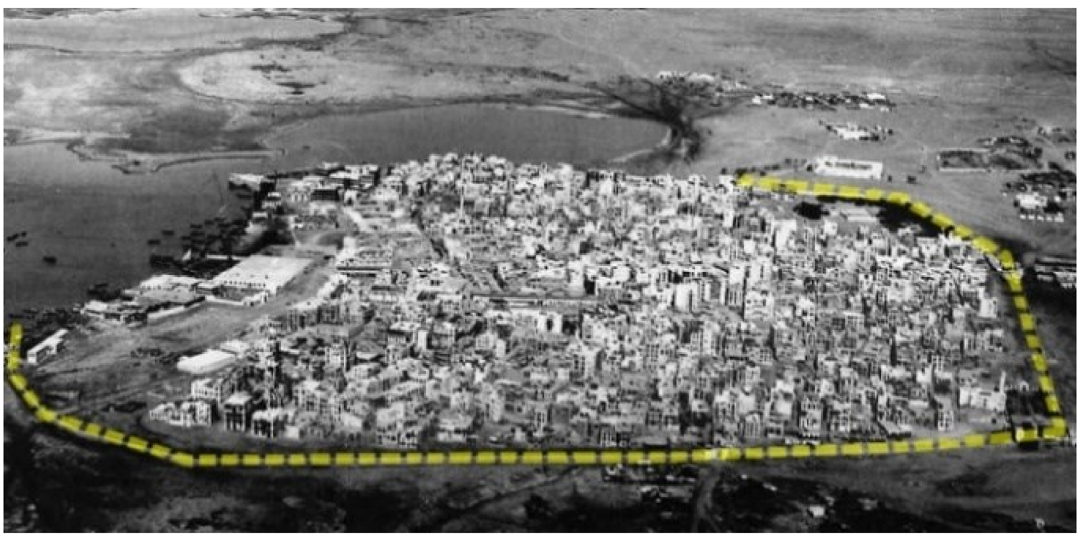


Figure 47 The Old City Wall surrounding the old city for protection (Source: Azahar, Al-Shoail, and Al-Okazi, 1996)

During the Ottoman rule, between the fifteenth and nineteenth centuries CE, the Ottomans also greatly contributed to the methods and techniques of bringing fresh water to the city. These techniques are still appreciated due to their contribution to reducing the volume of surface run-off during the infiltration process, and therefore reducing the chances of having flood issues. The first time a canal was proposed to bring fresh water from a nearest valley to Jeddah was during the mid-fifteenth century CE. However, issues and obstacles that arose at that time made the idea of building a canal system an impractical option. Instead, Ottoman rule provided more cisterns instead to create some balance (Burckhardt, 1829) (refer Figure 46).

Figure 48 Ancient Jeddah (Source: The National Center for Research and Documentation database at Jeddah City)

Jeddah nowadays is more protected and safe in terms of threats from flood tor drought. The Saudi government has spent billions of dollars to secure the city from a 100-year flood event. They have constructed fourteen dams and four main concrete open channels both before, but especially after the last catastrophic sporadic flood events that struck twice in a row in 2009 and 2010 (Isnasious, 2014) (see Figure 49). Since these events, the government has become more cautious and aware of the importance of developing stormwater management facilities in Jeddah and across the country. The government committed to spend about 20.7 billion Saudi Riyal (approximately US$5.52 billion) (Alghamdi, 2013).

Figure 49 Jeddah Floods (Source: Alsharif, Mo. (photographer) (2009) Jeddah floods. Retrieved May 05, 2013, from: https://www.flickr.com/photos/7336409@N07/4159870202/)

5.4.1 Jeddah's Stormwater Management Strategic Plan

Jeddah's municipality has developed and constructed certain projects in the last ten years in order to control flood and stormwater. After the US-based AECOM Company was assigned to continue this effort, the number of constructed dams rose to fourteen, and these dams were strengthened with four main open channels, which makes Jeddah now resistant to a 100-year storm (see Figure 50). The dams were designed to control a 100-year storm with a time frame of eight to fifteen days for accumulated storm water to evaporate, infiltrate or discharge directly to the sea. The dams were not designed to harvest water because of the unreliable precipitation pattern as mentioned by Mr. Zack Isnasious, former director of design and engineering of Jeddah Stormwater Drainage Program-AECOM (see Table 9). He added "constructing a heavy engineered solution for rainwater harvesting is an expensive option" (2014). However, the constructed and proposed plan are still considered unsustainable compared to the traditional practices that were mentioned earlier in this chapter. While there is no major urban flood threat anymore, the city is still suffering from water accumulation in different spots and locations due to the replacement of pervious surfaces with impervious urban surfaces and the absence of an appropriate drainage system (green or gray-infrastructure). As Jeddah's residents have experienced for years, the accumulation of stormwater on streets and roads can easily kill the traffic flow and produce traffic jams. This issue has an obvious economic impact, as it wastes the time of commuting employees and affects the productivity of the city and the country as a result. This issue also has a negative influence on the city infrastructure as well, particularly streets and walkways, where untreated accumulated stormwater can damage property if it is left for long time without any treatment (see Figure 51).

Figure 51 From left to right, picture of infrastructure, properties damages & traffic jam caused by stormwater accumulation in Jeddah (Source: website, Almadina News Paper)

The following map describes the depth of the catchments area from high to low (indicated by shades of red to yellow, respectively), where the highest depth reaches up to 50cm and the lowest is about 20cm and below (see Figure 52). The neighborhoods that surround the main channels suffers the most from the accumulation of the water, which makes it difficult for pedestrian to walk to mosques during heavy, rainy season. Despite the obligation for all Muslim men to pray five times a day at mosques (also known as "masajid"), Imams (or the mosque leaders) ask people to pray at home instead because of the difficulties to walk through the accumlation of rainwater and the poor walkway systems throughout the city in general—especially when rainwater is mixed with municipile water, which can cause other health concerns (see Figure 51).

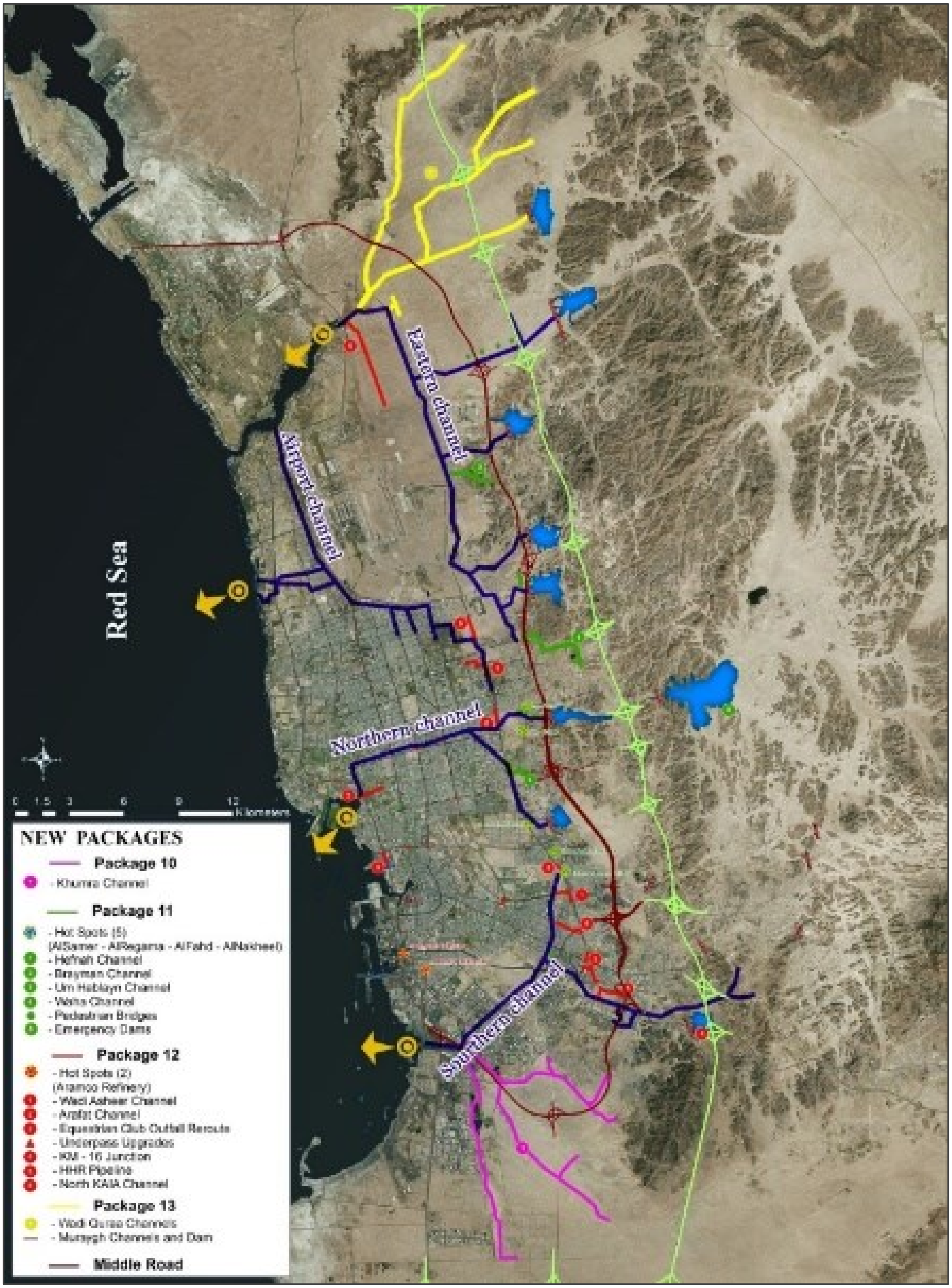


Figure 50 Locations of the constructed dams & channels (Source: AECOM, 2014, http://www.aecom.com/)

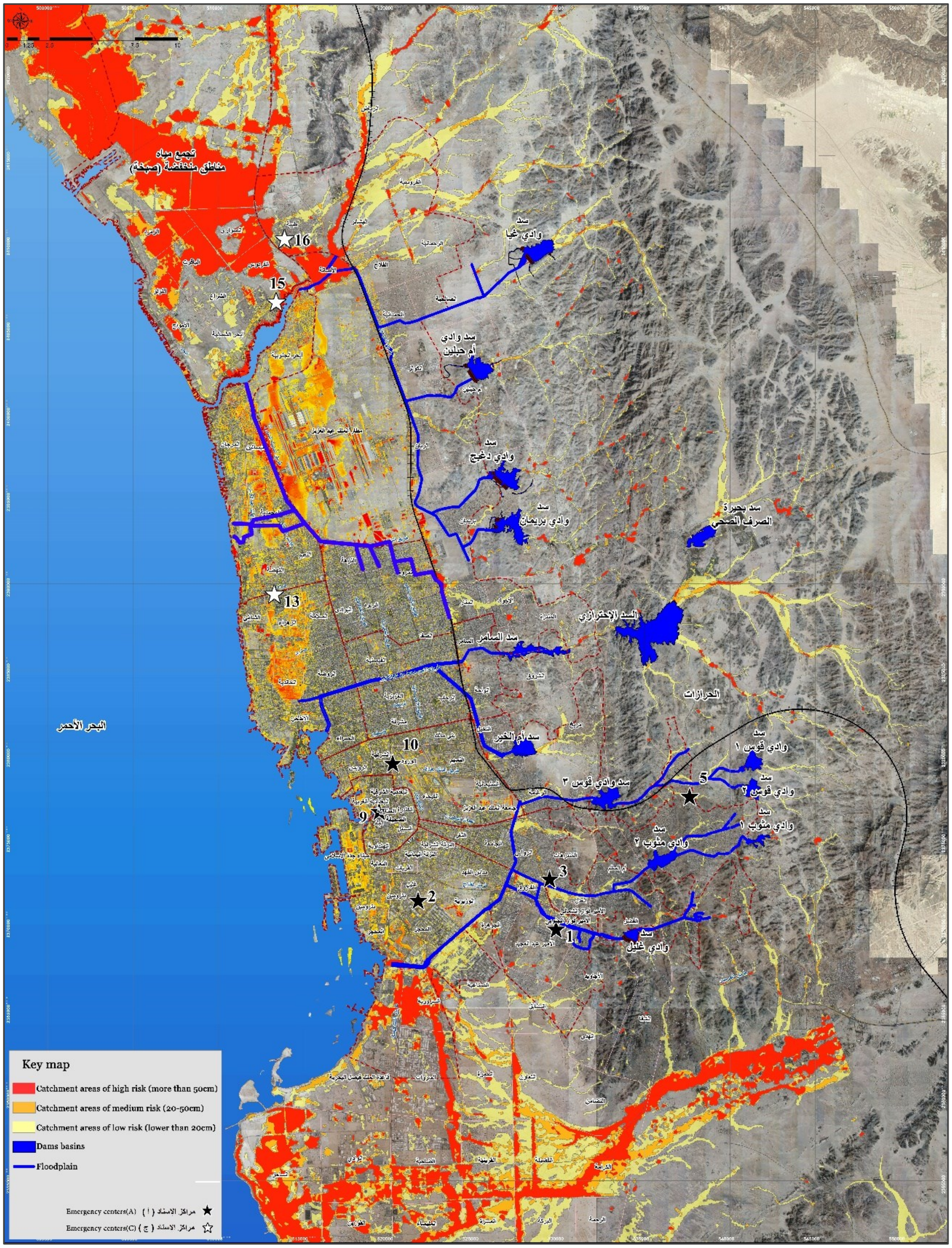


Figure 52 Locations of catchment areas classified by high (>50cm), medium (20-50cm), and low risk (<20cm), & the constructed channels (Source: AECOM, 2014, http://www.aecom.com/)

5.5 Environmental Issues Affect Infrastructure

Greening stormwater channels in Jeddah may solve many issues and improve quality of life, but also it could cause another environmental issue in return. Therefore, understanding the environmental issues is an important step in order to make a strategic decision like developing parks at the regional scale of the city. To avoid any environmental issues during the planning of such an undertaking, this section studies Jeddah's water table issue and soil characteristics.

5.5.1 The Rise of Water Tables in Jeddah

According to Dr. Kofi Awumah, a former senior civil engineer with Jeddah Stormwater Drainage Program-AECOM, the level of the water table in Jeddah is not a cause for concern. Therefore, according to Awumah, greening a channel should not cause a rise in the water table. However, this issue was also discussed in an article by Peter Vincent (2003) called "Jeddah's Environmental Problems," which claims that in some parts in the city (and in the north areas in particular) are damp due to the 60 cm-deep water table. This water is not good for drinking because of its saltiness taste, which results as advisable salty efflorescence crust known as *sabkha*. According to Vincent, this phenomena may have been caused by

> …remnants left over from higher sea levels, but the majority are probably due to deflation by wind of sand and silts more or less down to the water table. Evaporation then concentrates the salt at the surface, and, if these concentrations are not washed away by rainwater or floodwater, they accumulate and develop a crust that is often 5 centimeters thick. (2003, p. 398)

The weak structure of *sabkha* has little load-bearing capacity, which means it is unsuitable for construction. As shown in the map, the level of water table is fluctuated between 1 to 8 meters below the surface (see Figure 53) (Vincent, 2003). Overlapping the channel location map over the water table depth map illustrates that the location of the channels are located over 4 to 5 meters for the eastern channel, 2 to 4 meters water table depth for the northern and the airport channels, and from 1-6 meters for the southern channel (see Figure 53). The reasons for the rise in the water table are the absence of an effective sewer system, leaky drinking-water pipes and tanks, and effluent lakes in the foothills east of the city. Another important reason for this rising water table in locations that are close to the coast line in particular is the rising of the sea level as consequence of global warming (Vincent, 2003).

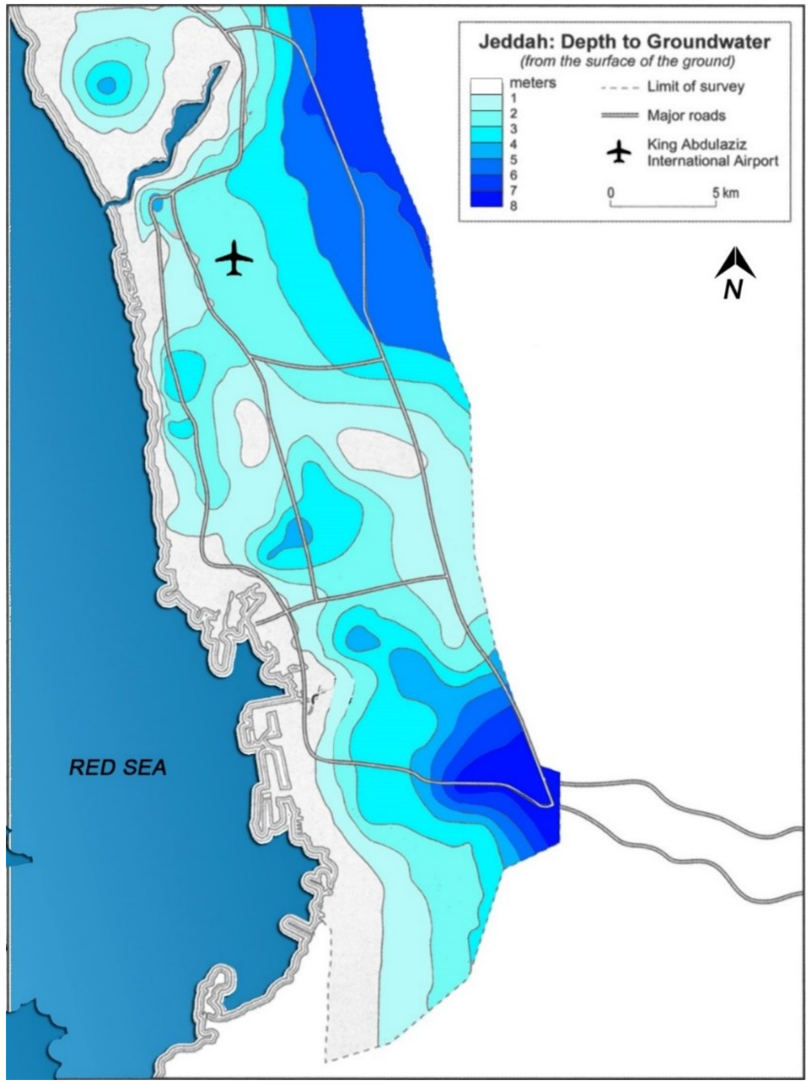


Figure 53 Depth from the surface of the ground to the groundwater, Jeddah (Source: redeveloped by author from unpublished data from the Saudi Geological Survey)

5.5.2 Soil Types and Land Classification and Soil Type

In general, land classification describes the capability of lands to be used for irrigated cultivation as shown in the following table in degrees from one to six, where soil group number one is considered the best group soil for agriculture (see Table 10). Figure 54 shows the grouping of soils into capability units that is coded in numbers. Each number represents different types of soil. Depending on the soil characteristics, each is classified under a group number from one to six. The classification includes information about each soil's suitability for agriculture, production and other characteristics that affects soil's behavior and response toward any factors like the capability to hold or infiltrate the water during rainstorm. The degree of capability scaled from 1 to 6 to represents the best and worst agriculture lands. The best lands for agriculture are those lands that were graded from 1 to 4 with differences in the degree of suitability. All lands that were graded 5 requires land-reclamation to be good for cultivation. Finally, all lands graded 6 is unsuitable lands for agriculture.

Degree of Capability							
1	2	3	4	5	6		
soils capability units							
26	10	14	12	11	13	33	46
	22	27	19	15	16	34	47
		43	25	20	17	36	50
			30	29	18	37	51
			35		21	38	52
			44		23	39	53
			48		24	40	54
			49		28	41	55
					31	42	56
					32	45	57
							58

Table 10 Degree of capability of lands, Jeddah (Source: Ministry of Agriculture and Water, Saudi Arabia)

As shown in Figure 54, Jeddah's mainly consist of soil group number 30, which is classified as "4" under the degree of capability. This type of sandy loam deep soil covers almost 3,000 to 100,000 hectares of Jeddah, and ranges in slopes from 0 to 5%. It consists of two type of soils – 45% Camborthids, 45% Torripsaments, and 10% secondary types of soil and areas of rocky outcrops. Camborthids are a deep loam soil, non-saline to extremely salinity, medium permeability with high ability to store water. It can be found in coastal plains or in slightly convex lands. Torripsaments are a deep, sandy, non-saline to slight salinity soli, with high permeability and low ability to store water. It can be found in small sand dunes and coastal plain areas (Ministry of Agriculture and Water, 1986). Overall, 85% of the lands are suitable for agriculture.

Figure 54 Soil groups & classifications, Jeddah (Source: Ministry of Agriculture and Water, Saudi Arabia)

5.6 City Growth and Public Open Spaces

According to the municipality of Jeddah the number and size of active and passive open space and leisure facilities currently insufficient to meet the demands of residents, stating that“…the World Health Organization (WHO) recommends 8 square meters of open space per person as a minimum provision. With an average provision of only 2square meters of open space per person in most districts, Jeddah currently falls significantly short of this target” (Municipality of Jeddah) (see Figure 55). The often-used leisure facilities and open spaces are beyond the capacity and though the municipality is actively pursuing to increase the amount of open space by providing various range of recreational opportunities. One of its future visions is to increase the number of leisure facilities and open spaces by turning the northern concrete channel into a green park, which is timely for this thesis (Municipality, 2014c) (see Figure 56). This means the Municipality has a vision about redeveloping left over spaces and creating a sense of place to improve the city’s quality of life. However, with future expansion and the expected population growth of the city, the rate of open spaces will certainly decrease (see Figure 57).

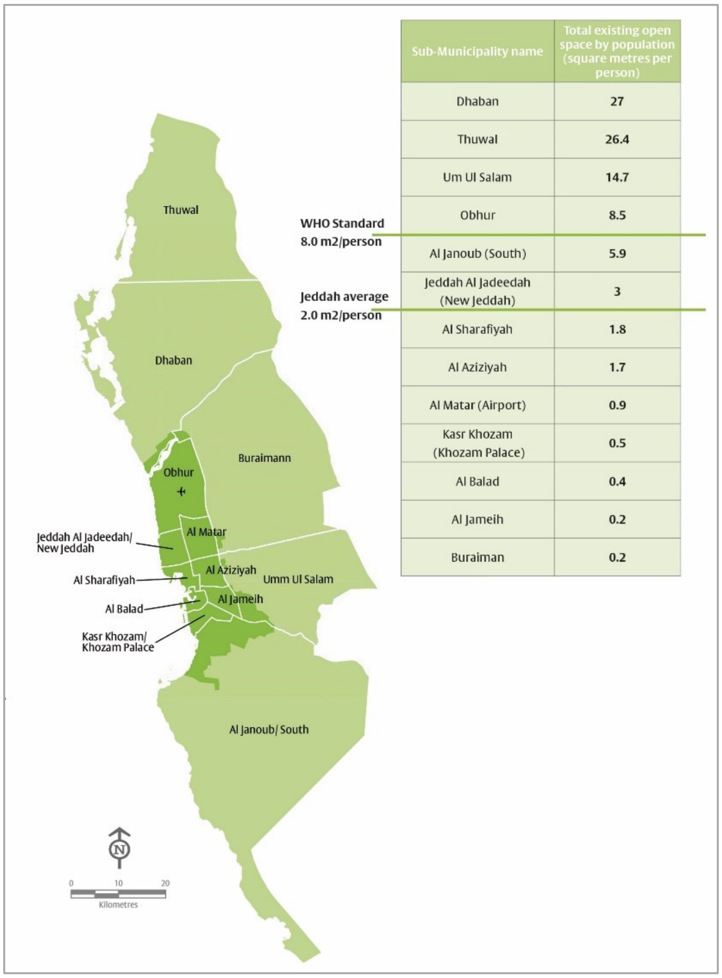


Figure 55 The available open space system, Jeddah (Source: Jeddah's Municipality)

Figure 56 Future envisioned of the northern part of Tahlia Channel by the Municipality of Jeddah City (Source: Jeddah's Municipality)

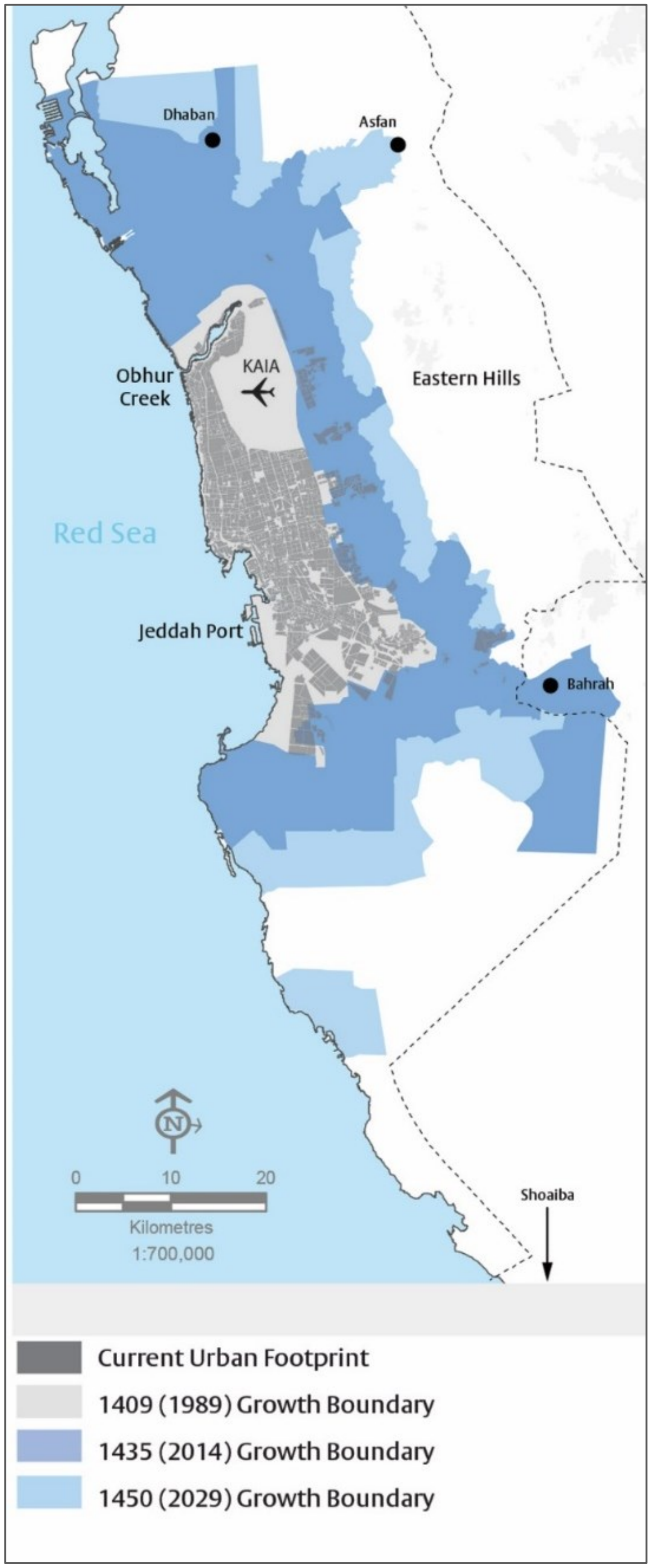


Figure 57 City's future urban expansion, projects, and vacant spaces (Source: Jeddah's Municipality)

CHAPTER 6

FEASABILITY STUDY

This chapter discusses the feasibility of developing a green channel in the city of Jeddah, supported by analytical graphics for feasible optional and social activities, and scientific methodologies for Rainwater Harvesting (RWH), water quality, plant and irrigation needs as were explained in Chapter 3 (Methodology). This chapter is dedicated to study one channel as a guiding example for developing the other channels as well. The chapter outlines the feasibility study in three steps: Step 1, environmental and urban analysis for the selected channel; Step 2, color-coding analysis that divides the channel into zones-units areas; and Step 3, demonstrating the water supply and plant needs. Three arguments (or scenarios) were developed to answer these concerns as explained earlier in the Methodology chapter (see Chapter 3.3.1). In conclusion, the author recommends one and/or mix of these arguments as feasible for this case.

6.1 Step One: Channel Selection Assessment

This step was intended to analyze and assess the selected channel. The Northern Channel (Tahlia) was selected for the feasibility study to be an example of how to redevelop other channels in Saudi Arabia and other arid cities in the world. The reasons behind selecting this channel among the others are; (a) the Municipality has expressed a future vision of Jeddah that involves part of this channel being a green channel, (b) it is close to the most active streets in Jeddah, where there is a huge business and investment infrastructure, where most important mixed-use developments and luxurious shopping centers (attraction points) are located, and where neighborhood have high land values, (c) it is located on the largest watershed in Jeddah, and (d) it is the first partly developed, yet underdeveloped channel in terms of optional and social activities. The study undertaken here included an urban analysis (land use, open spaces, attraction points and land values) and environmental analysis (topography and drainage lines, water consumption from the neighborhoods of the channel, soil and geology, and the levels of water table (see Figure 58 and 59).

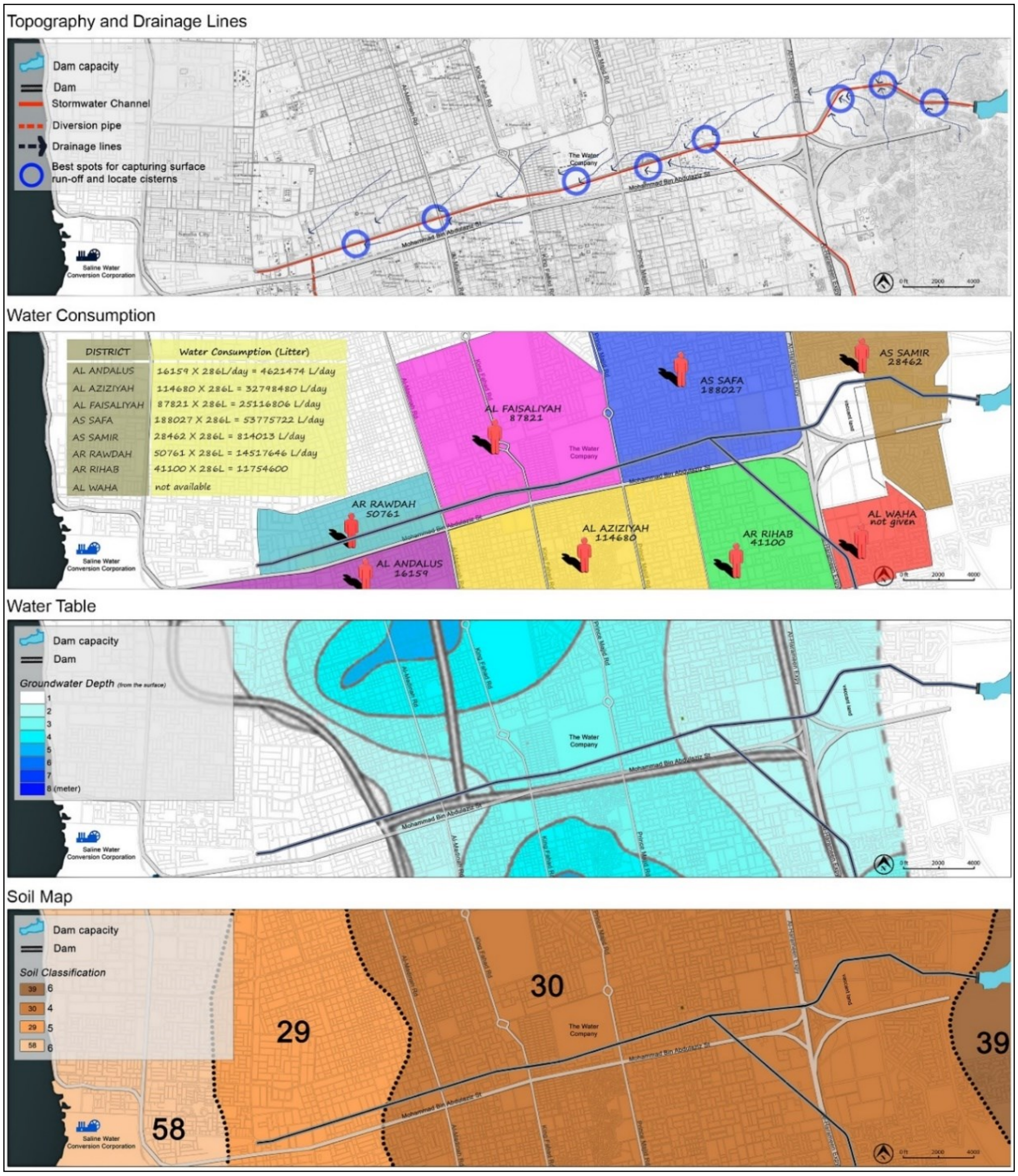


Figure 58 Environmental analysis for Tahlia Channel (Source: author)

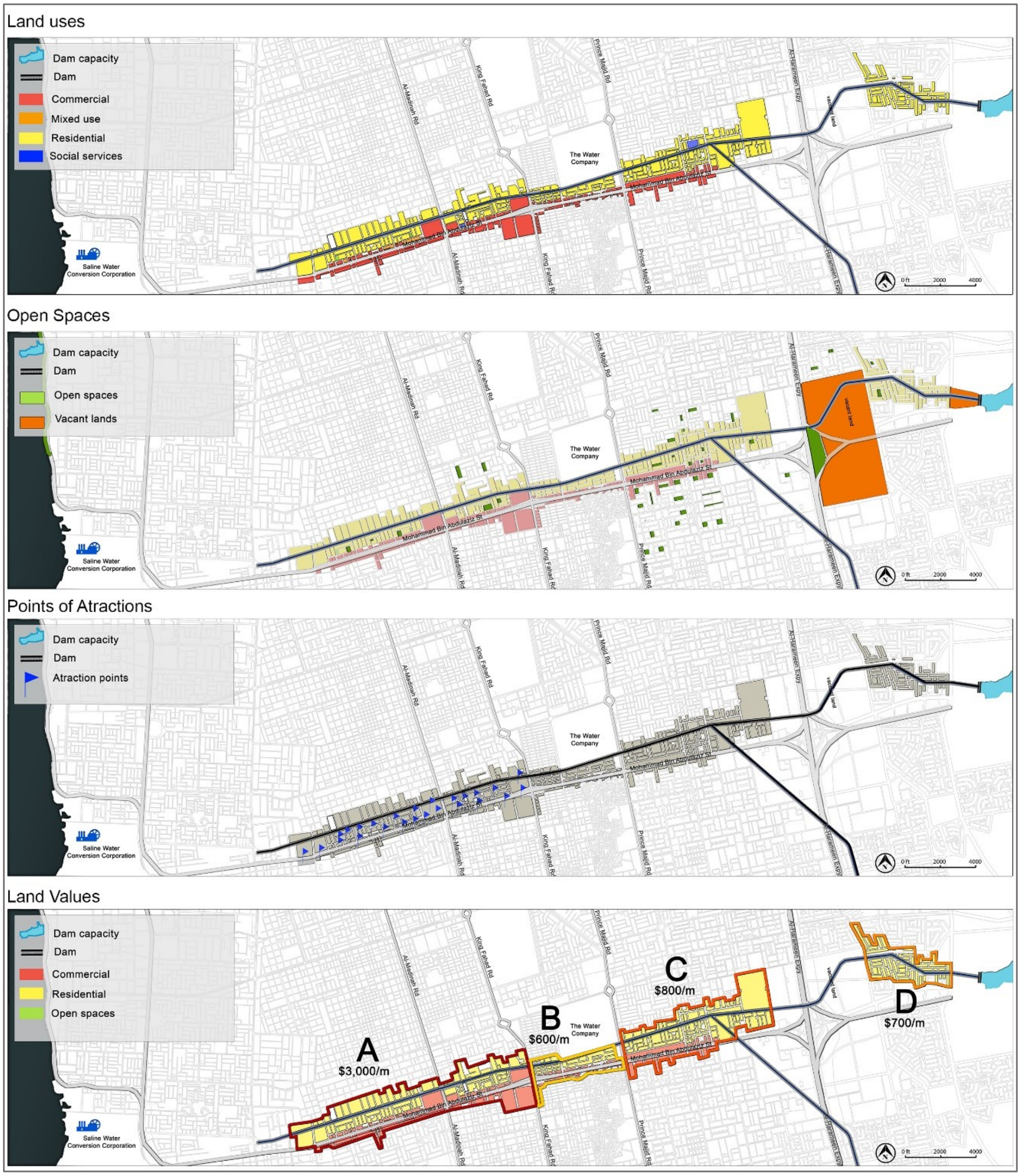


Figure 59 Urban analysis for Tahlia Channel (Source: author)

The urban and environmental analysis shows good potential and opportunities to convert the current channel to a green channel that encourages optional and social activities, especially the parts of the channel that are close to the points of attraction. The environmental analysis shows the potential for multiple water resources (RWH by the dam and the municipal water of the surrounding neighborhood), that the soil types that are suitable for irrigated cultivation categorized as number 29 (required land reclamation) and 30 (very good for agriculture), and that the drainage lines drain to the channel, and create the best spots to capture rainwater or to locate underground cisterns. Meanwhile, the urban analysis illustrates the vacant lands that are located within the watershed of the channel. These lands can be seen as opportunities for reclamation as wetlands and natural parks that can help naturally remediate municipal water supply of the neighborhood and create an attractive and recreational environment for the public and wildlife (see Figure 59).

The urban analysis also shows potential of the necessity to develop a linear park, due to the significant location of the channel that is a result of its relative closeness to the most active spots in the city (i.e. shopping malls). The Land Values and Points of Attraction maps demonstrate the most important business hub in the city in the western part of Tahlia Street in particular. Therefore, developing a green channel, within just five-minutes walking distance from the shopping malls, stores, coffee houses, and other business-social services that are located in and around Tahlia Street will improve the business circulation in this area and will attract other new activities, especially during the month of Ramadan, Eid, and discount seasons. During these seasons, Tahlia Street becomes very crowded because of the traffic jams caused by the number of cars and shoppers (before Eid) and worshipers, who like to pray in the two famous mosques in Jeddah (Masjid Al-Lami and Ataqwa) located nearby. Converting Tahlia Channel into a green park and stream channel, served with all the amenities and utilities of parks, walkways and avenues and of course with proper parking lots and buildings, will help reduce the traffic during the shopping seasons and rush hour. It will also create new business from the parking services, similar to other big crowded cities like Chicago and New York. Providing parking meter spots might also foster a new kind of business that might help those who cannot afford renting a kiosk in such an expensive area, but a spot to park their trucks that serve food and hot and cold drinks. All in all, converting Tahlia Channel to a green channel will improve the economy of the livability and economy of the city as a whole.

6.2 Step 2: Color-Coding Analysis

This step was developed to analyze and assess the selected channel by dividing the channel into homogenous zones and units, using the color-coding technique of an analytical site map and sections. According to the map, Tahliah Channel can be divided into five zones and seven units. These zones-units are coded by according to an assigned letter and number, where the first letter represents the zone with a color code and the number represents the units. These zones-units are: A-1, B-2, C-3, D-4, E-6, and A-7. Each coded zone-unit is located in the site map and is followed by an analytical section that describes the physical characteristics and opportunities of that zone-unit. The five different zones were coded by five different colors and letters, where the red zone (A) represents a day-lit stormwater channel, the green zone (B) represents a covered channel by a designed walkway, the yellow zone (C) represents a covered channel by an undeveloped sandy-vacant land, the gray zone (D) represents a covered channel by asphalt pavement, and finally the orange zone (E) represent a day-lit channel within undeveloped vacant land (see Figure 60).

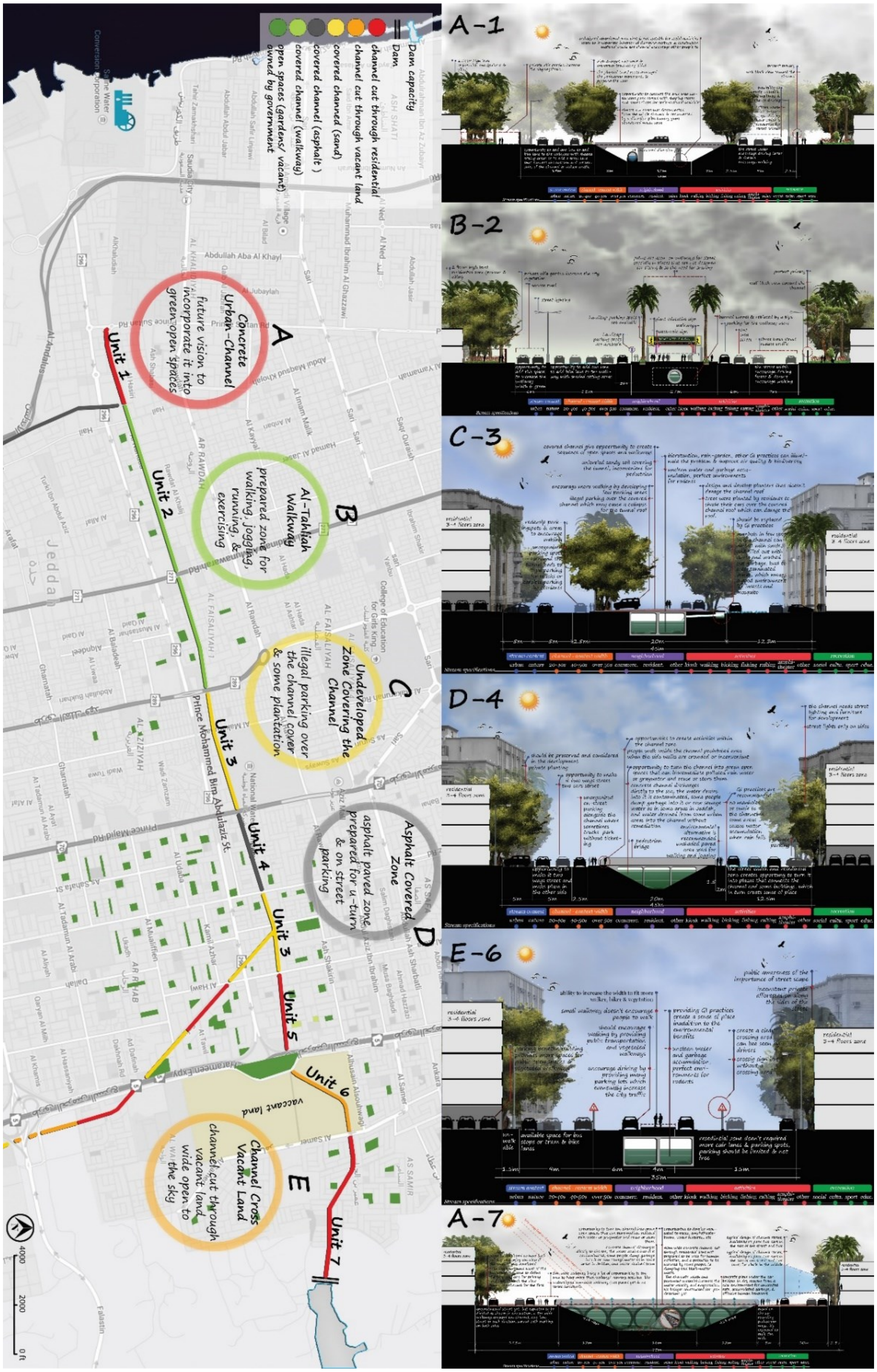


Figure 60 Tahlia zones & units (Source: author)

6.2.1 The Analytical Sections

Each zone-unit was described by an analytical section. Each section describes the physical characteristics (channel, pedestrian and street width, buildings heights, etc.), the current condition of the channel and neighborhood (positive and negative descriptions), the currently available activities and activities that can be created with the category of each one based on Gehl's classification for activities (necessary, optional or social). This information was arranged in a matrix that matches them with the selected case studies (see Figure 61 A, B & C). The matrix then compares the case studies with each other, and the described section with the cases. The sections were also developed to classify each zone-unit under a measurement of the quality of the environment based on an adapted quality of physical environment diagram that was developed by Gehl (see Figure 62). This categorization helps to illustrate what kind of activities are currently absent in order to increase the quality of life in each section (zone-unit).

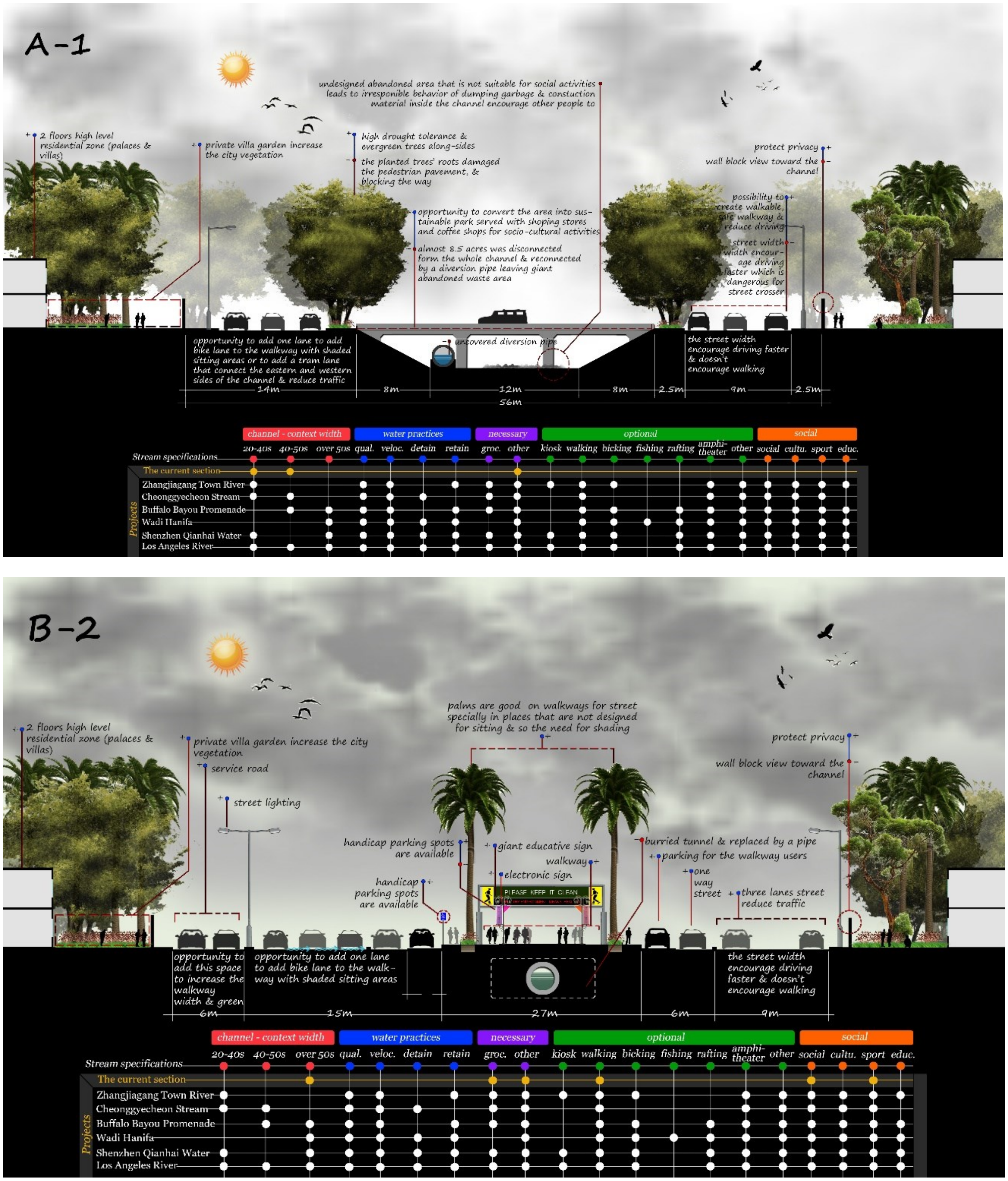


Figure 61-A Analytical sections zones-units: A-1, B-2 (Source: author)

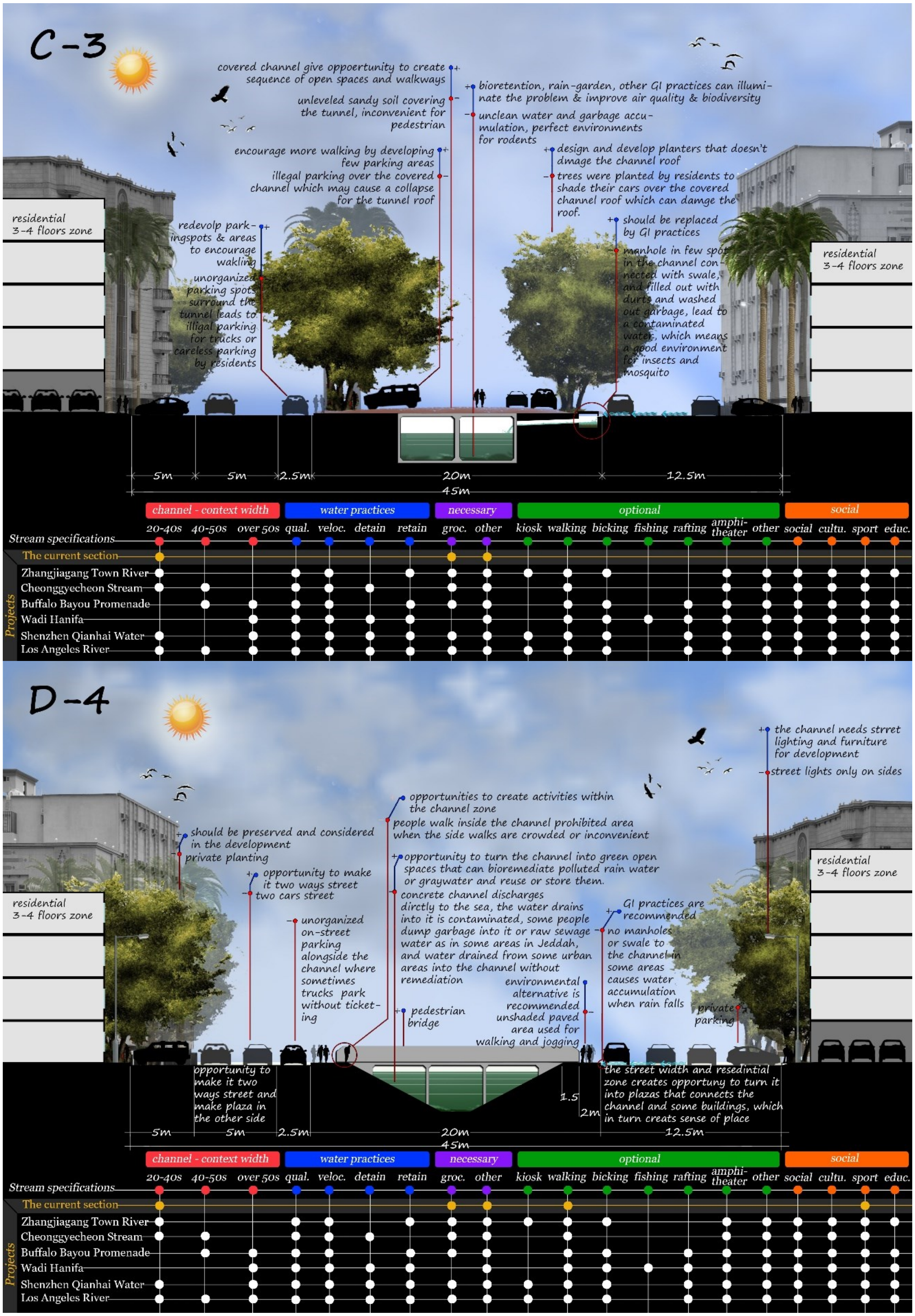
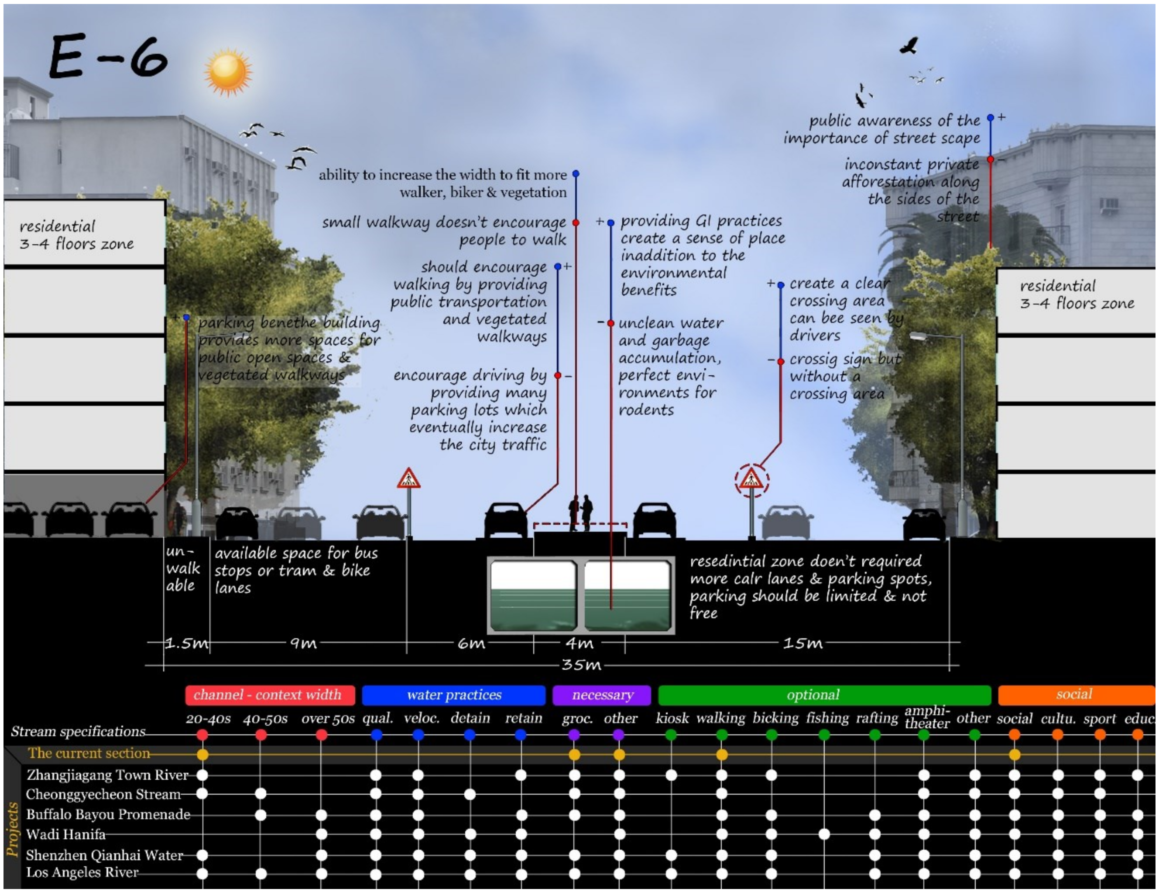


Figure 61-B Analytical sections zones-units: C-3, D-4 (Source: author)



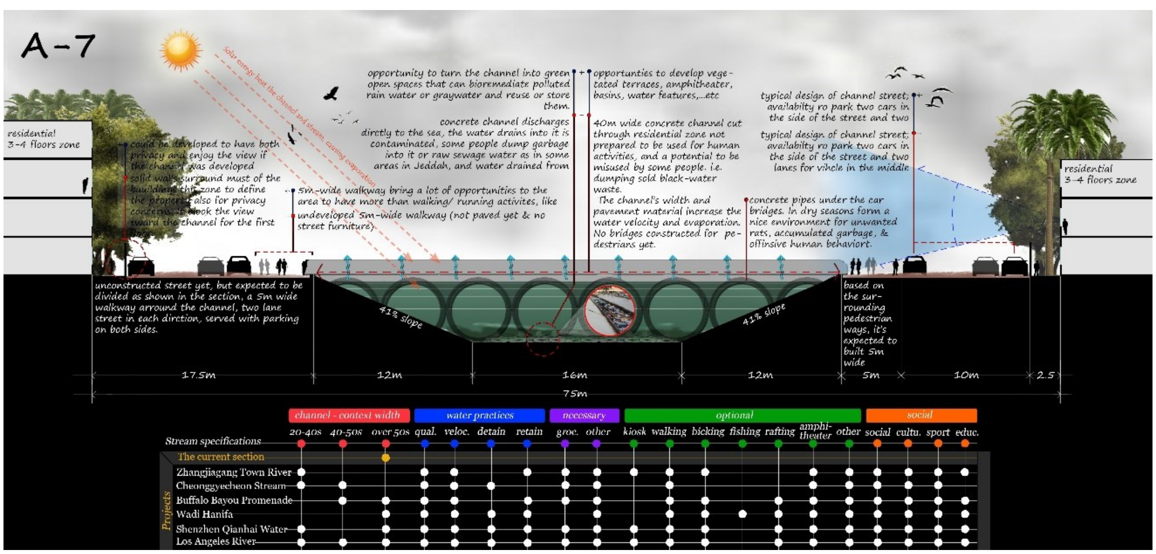


Figure 61-C Analytical sections zones-units: E-6, A-7 (Source: author)

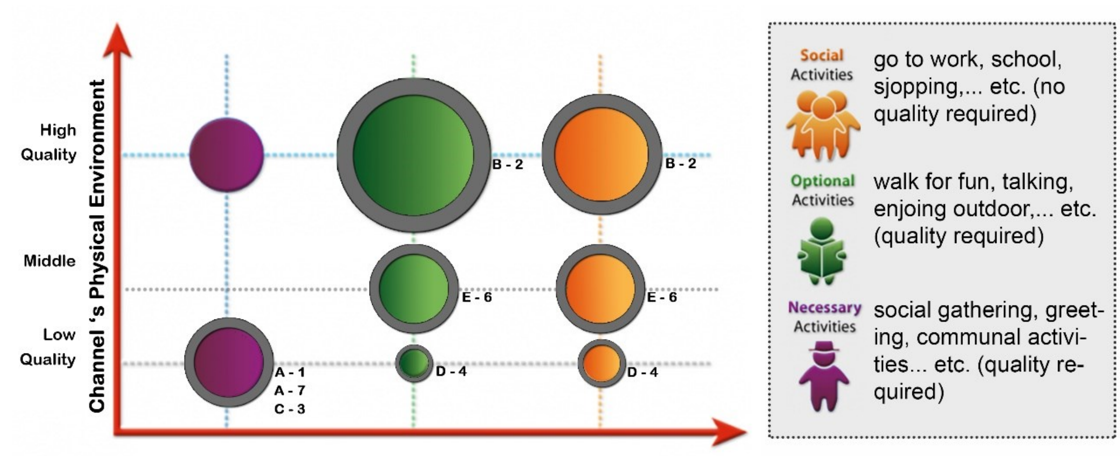


Figure 62 The quality of the physical environment of each zone-unit (Source: adapted by author from Gehl, 2011)

Figure 62 illustrates the quality of each zone-unit. In addition to Gehl's high and low qualities of the channel's physical environment, a middle quality was added to this table to describe an additional category that falls between the high and low quality. After analyzing the zone-units by the analytical sections, the quality of physical environment of each zone-unit was categorized as the following:

1- High Quality Physical Environment includes: B-2. Provides new recreational amenities that foster optional and social activities that did not exist before the development (see Figure 63).

Figure 63 B-2 zone (Tahlia Walkway) & attractive recreational amenity (Source: Anas Bugis)

2- Middle Quality Physical Environment includes: E-6. Provides unsafe walkways because of the width. It requires significant further development to improve the quality of this zone-unit and to encourage more optional-social activities (see Figure 64).

Figure 64 Unsafe walkways, too many cars, & unattractive environment for optional-social activities (Source: Anas Bugis)

3- Low Quality Physical Environment includes: A-1, A-7, C-3, and D-4. These zones are characterized by environmental pollution, neighborhood disconnection, and waste of their potential (see Figure 65).

Figure 65 Unsafe environment for social activities & accumulated pollution in the channel drain to the Sea (Source: Anas Bugis)

6.2.2 Analytical Section Findings

By analyzing the zones-units of Tahlia Channel, general and specific design implementations per zone-unit are recommended. These design recommendations represent a necessity and feasibility to can be developed to foster optional and social activities in the area. These recommendations are:

1- Creating safe sidewalks along the channel and providing the surrounding buildings with safe crossing areas.
2- Reduce the car lanes to a maximum of two to three lanes.
3- Reduce the speed limits of the attached street to the channel to 25 mph posted on signs.
4- Provide metered spots for parking alongside the channel and construct parking structures/garages, especially near the main points of attraction on Tahlia Street.
5- Develop safe walking and bike trails.
6- Develop tram lanes that connect the eastern part with western part of the channel.
7- Develop different types of vegetation densities; low density for the areas or spots that are dedicated for walking, jogging and running, and high density for the area or spots that foster social gatherings and other activities that require remaining in one spot for leisure and recreation.
8- Provide the public with open-space amenities and utilities, like kiosks, shaded sitting areas, restrooms, amphitheaters, public art, educational activities, and so on.
9- Create a running stream and water activities that are safe for social interactions.

10- Create wetlands with fish bonds to treat the municipal water, and improve the biodiversity of the city as well as creating water activities, like fishing and canoeing.

11- Design a water quality volume treatment system to treat the surface run-off that drains from the urban areas to the channel by embracing green infrastructure practices, like bio-retention, bio-swale, rain-gardens, permeable pavement, bio-cells, green parking, green streets, infiltration trenches, and so on.

Figure 66 illustrates the recommended green infrastructure practices to perform water quality volume purposes all based on the best location for each practice in the typical channel section (a building, sidewalks, street, stream side, and stream bed). Each practice was preceded by a color code that match a color in the typical section to define the best place for each practice. Following that, a best location at the map were determined for some special green infrastructure practices that require large spaces (like bio cells and/or wetlands). The figure also demonstrates the recommended optional and social activities based on applicability and/or necessity. In addition, the figure shows some planning recommendation that could increase the level of livability of the channel. For example, suggesting a public transit system that connects the east and west sides of Tahlia Channel served with multiple parking buildings along the channel to reduce the traffic from the west part of the channel and encourage people to walk to work, or for shopping and social gathering and so on.

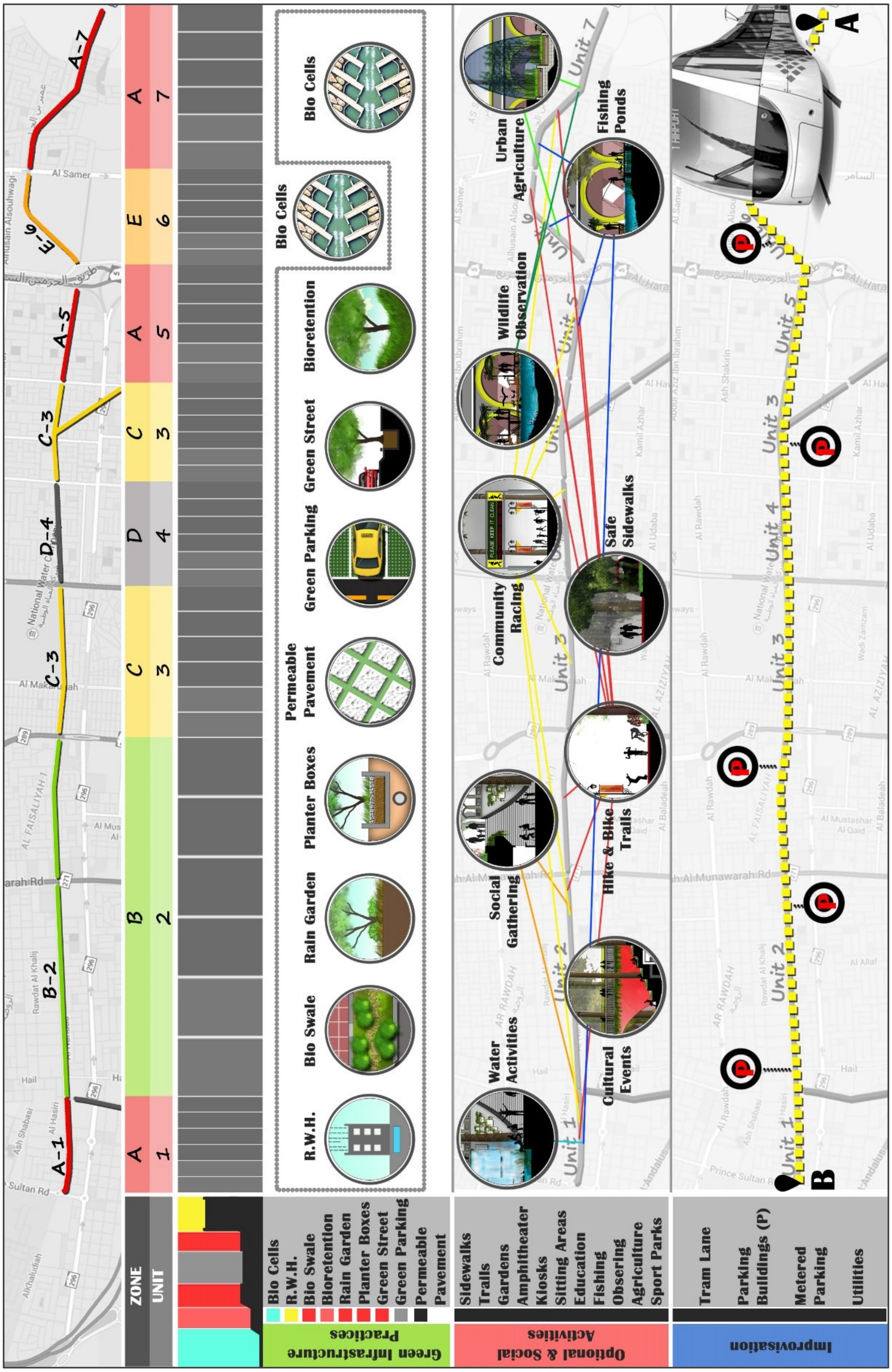


Figure 66 Green practices, optional social activities, public transportation & parking services (Source: author)

6.3 Step 3: The Water Supplies, Plant and Irrigation Needs

This step demonstrates the current water supply and plant needs in order to present the feasibility and barriers of greening Tahlia Channel and create a running stream. Two arguments (or scenarios) were developed to answer these concerns as explained earlier in the Methodology chapter (see Chapter 3.3.1), of which the authors recommend one and/or a mix of them.

6.3.1 First Scenario: Water Supply from Channel-Front Buildings

This part of study develops an argument of whether or not including an RWH system as part of the building-code regulations of Jeddah for the existing and future constructions that are located in front of Tahlia Channel is feasible. A model of RWH collecting from roofs and other surfaces and municipal water supply per house was developed in order to simulate the annual potential water supply per house to the channel for existing and future developments. This model is a suggested hydrology cycle design system, not a final channel design (see Figure 67). Following this model, a plant-species list were selected from Table 4, with a number of recommended plants to be irrigated per house from the collected rainwater and graywater (see Table 12). The table illustrates the daily water requirements to irrigate the suggested model.

Next, the number of segments of this model that are needed to cover both sides of the channel to achieve a green channel were counted. Approximately eighteen segments of an average of thirty-seven models per segment (666 models in total) should be sufficient to cover both sides of Tahlia Channel (see Figure 68). Following this, an estimation cost of constructing storage tanks for rainwater and graywater per model was also included, each with specific tank size necessary to cope with the daily water needs for irrigation and running stream. The recommended tank size for rainwater harvesting per house (model) is 4,735.5 gallons/year, which equals the average annual rainwater harvesting from an average roof top area of 3,659.73 ft2. This water can account for 44% of a person's needs of water for drink, food, and cooking. The recommended tank size to collect graywater per house for daily irrigation needs of the recommended model is 1,767 gallons/month, which equals the highest irrigation needs during the months of July and August (see Table 12) (refer also to Method A).

Although this scenario was developed to collect the rain water from the roof tops of the buildings that are located in front of the channel, there are other surfaces that also drain into the watershed of this channel (see Figure 68). Some of these surfaces are contaminated and therefore, some type of water quality treatment is required to protect the health of environment of the aforementioned stream, the marine life of the Sea, and the people. A calculation of potential rainwater catchment from different surfaces was calculated to treat the volume of the polluted water before draining to the channel (see Figure 69).

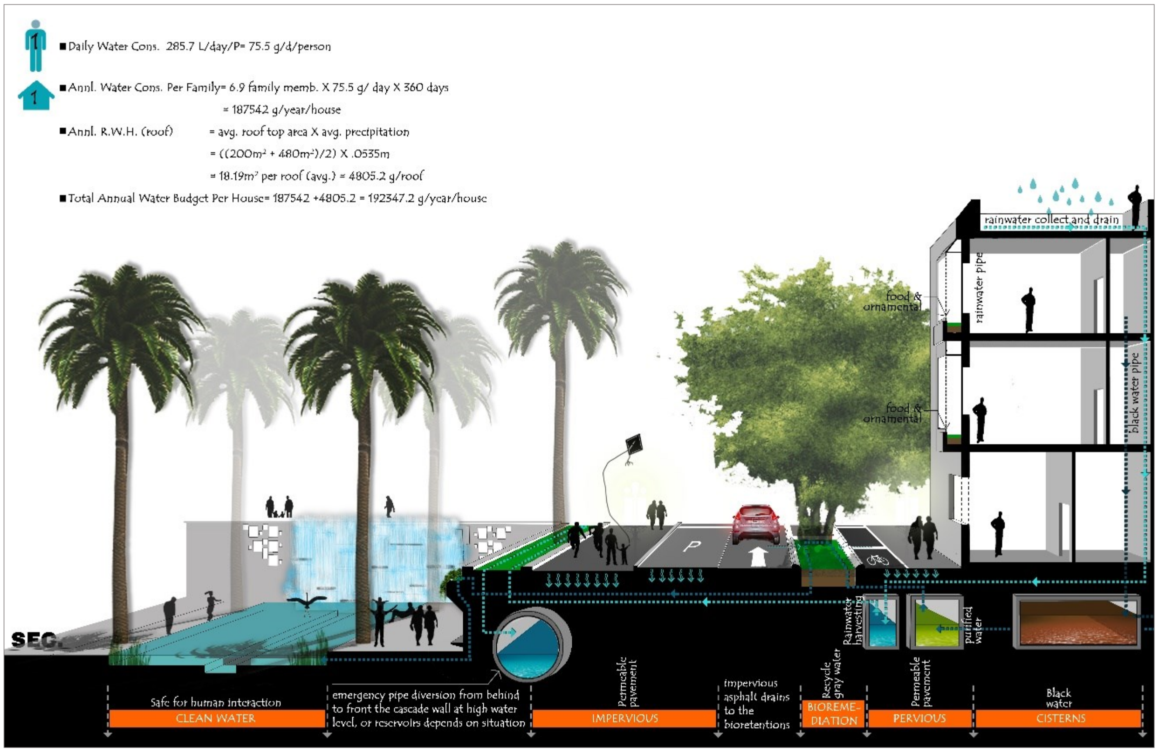


Figure 67 A model of R.W.H. collecting from roofs & other surfaces, bio-treatment planters for graywater, & daily deposit of clean water in the suggested stream per house (Source: author)

Figure 68 From left to right, the number of possible segments (18) & models (37) (Source: author)

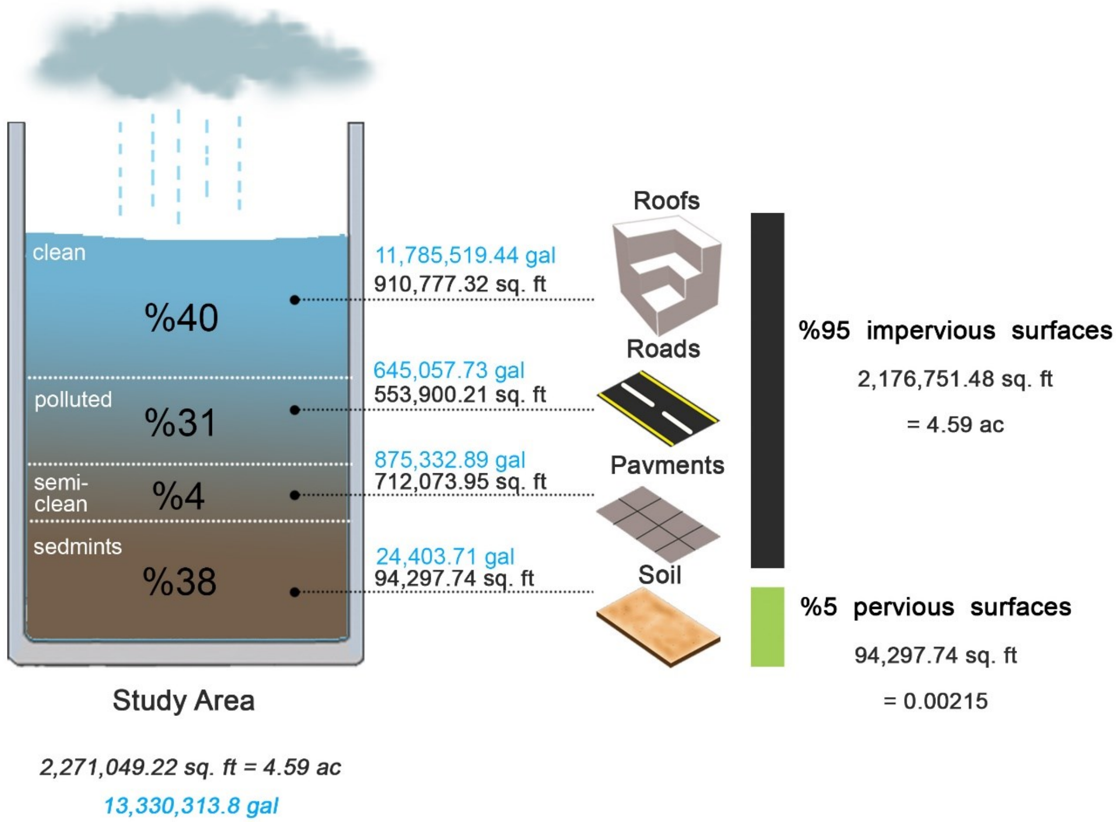


Figure 69 Required water quality volume based on different catchment surfaces in the selected area for study (Source: author)

6.3.1.1 Given Information:

- Average Saudi family members is 6.9 people/house
- Average daily water consumption per person is 75.5 gallons/person/day (520.95 gal/day/house).
- Daily water usage is 25gal (flushing), 20gal (bathing), 10gal (laundry), 2.9gal (food & drink), 2.9gal (cooking), and 2.9gal (faucets)
- Average annual precipitation is 1.294 gallons/year
- Average roof top area in the selected area is 3659.73 ft^2
- Roof top coefficient (C) is 1
- Annual ETo is 5.2 in
- Dripping irrigation efficiency is 90%

- Plant water requirements in Table 4 (see Methodology Chapter)
- Residential concrete cistern cost is \$0.13 per gallon
- Tertiary treatment cost is \$0.005 per gallon, and desalination cost is \$0.007/gal
- 40% of the channel area is a running stream with a depth of 50cm (1.6ft), with an average cross-section area of 3.5m^2 (37.6ft^2)

6.3.1.2 Method (A):

(1) Annual Water Consumption Per House = 6.9 x 75.5 (g/person/day) x 360 (days)
= 187542 g/year/house

(2) VR (in Gallons) = P (inches) × Area (ft2)× C× 0.623
= 2.077 (in) x 3659.73 (ft^2) x 1 x 0.623

= 4735.5 g/year/roof = 44% of water needs per person per year for drinking, food, and cooking.

(3) Annual Potential Generated Water Per House = Annual Water Consumption + VR
= (187542 + 4735.5)
= 192277.5 g/year/house

(4) Table 12 illustrates the recommended plant-species that were selected from Table 4, number of plants, and the annual irrigation needs using the dripping irrigation system. The total annual water requirement to irrigate 4 palms, 4 big trees, and 20 small shrubs per model (house) is 76,180 g/year. The decided tank size to collect graywater to cover monthly irrigation requirement is 1767 g/month (the highest water requirement per month), taking into consideration the irrigation efficiency (see Table 12).

(5) Now, a calculation of the daily-monthly water deposit requirements per house (model) can be made. To do so, 40% of the channel area with a 50cm (1.6ft) depth was calculated for a 24/7 running stream for this study. The total area of Tahlia

Channel is 346,429m^2 (85.60447acre). The stream volume = 40% x 346,429m^2 x 0.5m = 69,285.8m^3 (18,227gallons). Table 13 illustrates a basic estimation of the daily-monthly water deposit requirements to keep the stream running, taking into consideration only the monthly water loss by evapotranspiration. However, to design a running stream, there are other factors should be considered—such as the slope of the stream bed, the type of soil, other climate consideration, and the constant flow. The daily water deposit requirement per house (model) for the stream is 18,227gal/day ÷ 666 (models) = 27gal/day/house, which is higher than the daily supply from the annual potential rainwater harvesting per model of 12gal/day (4735.5/house/year ÷ 365days). However, the required daily water deposit for the stream can be covered from the graywater production of the Tahlia Channel neighborhoods. The total graywater of the surrounding neighborhood was estimated at 37,881,939 gal/day (refer to Figure 58), which equals five and a half times the volume of the required daily deposit for the running stream (18,227 gal/day).

(6) Calculating the velocity of flow (V) at the average cross section of the stream of 3.5m^2 (37.6ft^2) (A) and an average flow rate (Q) (daily graywater deposit) of 0.068m^3 (18,227 gal/day):

$V = Q/A = 0.068m^3 \div 3.5m^2 = 0.019m/day$

(7) The total cost of two separate concrete tanks for (rainwater and graywater) per house is \$0.13/gallon x (4735.5 + 1767) (g) = \$845 (S.R. 3169)

(8) The total cost of two separate concrete tanks of 666 applied model is

\$845 x 666 = \$562,770 (S.R. 2,110,387).

(9) The total cost reduction of Tertiary water treatment of 1767 gal/month of graywater that is used for irrigating the plants of the model is \$0.005/gal x 1767 gal = \$9/ month/ model = \$109/ year/ model = \$72748/ year/ 666 models (houses).

(10) The total reduction of desalinate 4735.5 gal/year is \$0.007/gal x 4735.5gal/year = \$33/gal/year/house = \$22,299/gal/year/666 models (houses).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual (g)/plant	Number of Plants	Annual Irrgiation (g)
Palms g/day	13.2	13.2	17	17	17	26.4	26.4	26.4	17	17	17	13.2	6727.8	4	29871
Big Trees g/day (> 65 ft2)	10.5	10.5	13.2	13.2	13.2	21	21	21	13.2	13.2	13.2	10.5	5292.6	4	23499
Small Shrubs g/day	2	2	2.64	2.64	2.64	3.96	3.96	3.96	2.64	2.64	2.64	2	1027.44	20	22809
Gallons	884	884	1130	1130	1130	1767	1767	1767	1130	1130	1130	884	13,048		76,180

Table 11 The water requirements for most of the aesthetic plants per unit in Jeddah City (Source: retrieved by author from Jeddah's Municipality)

Month	Number of Days	ETo evapotra	Proposed Stream Capcity (in3)	Req. Daily Deposit (in3/d)	Req. Daily Deposit (g/d)	Tertiary Treatment Cost	Annual Req. Deposit (g/y)
Jan	31	0.32	4210437	4210437	18227	\$91	565036
Feb	28	0.4	4210437	4210437	18227	\$91	510356
Mar	31	0.42	4210437	4210437	18227	\$91	565036
Apr	30	0.47	4210437	4210437	18227	\$91	546810
May	31	0.49	4210437	4210437	18227	\$91	565037
Jun	30	0.49	4210437	4210437	18227	\$91	546810
Jul	31	0.5	4210437	4210438	18227	\$91	565037
Aug	31	0.51	4210437	4210438	18227	\$91	565037
Sep	30	0.49	4210437	4210437	18227	\$91	546810
Oct	31	0.42	4210437	4210437	18227	\$91	565036
Nov	30	0.38	4210437	4210437	18227	\$91	546810
Dec	31	0.31	4210437	4210437	18227	\$91	565036
Total					Cost	\$1,094	6,652,849

Table 12 The total daily-monthly water-deposit requirements for a 50cm-deep stream (Source: author)

6.3.1.2 Results

This scenario (approach) failed to supply water for a running stream per model that is located only in front the Channel. However, the RWH and daily graywater deposit to irrigate the number of plants per model seem to create a very good opportunity to green the Channel by constructing two separate tanks—one for RWH to collect 4735.5 gal/year/roof, and the other tank to collect only 1767 gal/month of graywater. This method succeeded in reducing the treatment cost of tertiary graywater treatment by $72748/year for 666 models (houses). This method also succeeded in reducing the water supply need from the desalination station by providing 44% of a person's water needs per year for drinking, food, and cooking, which costs $22,299/gal/year for 666 models (houses). To cope with the daily water-deposit requirements for a running stream, an additional source of water is required. This water is actually available if the development included water deposits from the entire neighborhood of Tahlia Channel. However, wetland and bio-cell treatment areas should be developed to treat that water before being released into the channel. This method can green 40-50% of the channel context. This resulting 40-50% of vegetation cover can be achieved by using only 76,180gal/year/house, thus leaving an additional 111,362gal/year/house of unused water. This amount (111,362gal) can irrigate twenty big trees from the selected plant-species list. However, using this additional amount will increase the cost of the graywater tank from $9,903 to $23,664.

6.3.2 Second Scenario: Greening the Channel by Dam Rainwater Harvesting

This argument illustrates the feasibility of irrigating the landscape of Tahlia Channel using the harvested rainwater from the dam. The total rainwater harvesting is 55,185,594,235 gal/year. This amount of water can easily cover the irrigation needs for the 666 models, which is 50,735,709 gal/year, and creates a running stream of 6,652,849 gal/year—with a remainder of 44,082,860 gal/year (see Table 14). However, this amount is not guaranteed because of the monthly rate of evapotranspiration (see Method B in the follow section). Table 14 also illustrates the amounts of potential RWH per month. Although the given amounts of rainwater harvesting per month can cope with the irrigation requirements and even more, the rate of ETo per month shows the potential to lose this amount in only a few days.

The only way to preserve this valuable amount of water is by storing it in mega-tank structures. The cost to construct such a tank is very expensive. The cost of constructing mega-tanks is more expensive than a house-sized tank. The house-sized tank (as mentioned previously) costs $0.13/gallon while a mega-tank can cost about $0.37/gallon. The cost of a tank to store 55,185,594,235 gal/year is $20,418,669,866. However, the cost of constructing a tank for 50,735,709 gal (the annual irrigation water requirements for the 666 models) is $18,772,212. This amount of money can be returned within fourteen years by renting fifty kiosks spread along the sides of the channel at a cost of $26,666/kiosk/year. This cost is an average of the highest rental kiosk rates of $53,333/kiosk/year (the rental cost of kiosks at the costal parks), and $13,333/grocery store/year (the average rental cost of grocery stores surround Tahlia Channel).

Month	Number of Days	Avg . P (in)	ETo evapotrans	Dam Catch Area (ft2)	Dam Capacity (ft3)	Dam Capacity (gallon)	Total Eto / day (gallon)	Number of Days for Total Eto (gallon)
Jan	31	0.42	0.32	3,552,120,000	1,491,890,400	11,159,340,192	1,136,678,400	10
Feb	28	0.12	0.4	3,552,120,000	426,254,400	3,188,382,912	1,420,848,000	2
Mar	31	0.09	0.42	3,552,120,000	319,690,800	2,391,287,184	1,491,890,400	2
Apr	30	0.09	0.47	3,552,120,000	319,690,800	2,391,287,184	1,669,496,400	1
May	31	0.007	0.49	3,552,120,000	24,864,840	185,989,003	1,740,538,800	0
Jun	30	0	0.49	3,552,120,000	-	-	1,740,538,800	-
Jul	31	0.007	0.5	3,552,120,000	24,864,840	185,989,003	1,776,060,000	0
Aug	31	0.01	0.51	3,552,120,000	35,521,200	265,698,576	1,811,581,200	0
Sep	30	0.003	0.49	3,552,120,000	10,656,360	79,709,573	1,740,538,800	0
Oct	31	0.03	0.42	3,552,120,000	106,563,600	797,095,728	1,491,890,400	1
Nov	30	0.87	0.38	3,552,120,000	3,090,344,400	23,115,776,112	1,349,805,600	17
Dec	31	0.43	0.31	3,552,120,000	1,527,411,600	11,425,038,768	1,101,157,200	10
Total	365	2.077			7,377,753,240	55,185,594,235		
Tank Cost						$ 20,418,669,867		

Table 13 Dam capacity & daily potential of ETo (Source: author)

6.3.2.1 Method (B):

- Potential to irrigate the landscape of 666 models = 55,185,594,235 gal/year (dam) – 50,735,709 gal/year (plants need of 666 models) = 55,134,858,526 gal/year.
- Potential to create a running stream = 55,134,858,526 - 6,652,849 (stream) = 55,128,205,680 gal/year (remaining).
- Tank cost of harvested rainwater by dam = $0.37/gallon x 55,185,594,235 gallon = $20,418,669,866.
- Tank size 50,735,709 gallon cost = $0.37/gallon x 50,735,709 gal = $18,772,212.
- Returning construction cost of tank size 50,735,709 gallon by providing 50 kiosks, each annual rental cost is $26,666 = $18,772,212 ÷ ($26,666 x 50) = 14 years.

6.3.2.2 Results

The amount of potential RWH from the dam demonstrates that there is a good opportunity to irrigate the landscape of 666 models and to create a running stream. However, capturing the whole amount of water necessary and storing it in mega tanks will cost the government a lot of money. It has been determined that using the first scenario is more sustainable than the second scenario. Although wasting this amount of clean and free water by allowing it to drain to the sea or to evaporate can be considered unsustainable, from another perspective, the amount of money to construct a tank in order to capture every drop of rainfall to harvest rainwater from the dam can be spent on constructing other multi-benefit and sustainable projects. For instance, constructing wetlands to bio-remediate the municipal water can generate multiple environmental, social, and economic benefits as explained in the Literature Review (see Chapter 2) and the Case Studies (see Chapter 4). Moreover, draining fresh water to the sea might create an important balance between the desalination operations and the amount of freshwater deposit that drains from different sources, which hopefully can reduce the increase of salinity of the sea as a cause of the daily desalination process.

6.3.3 Conclusion

The feasibility study shows very good opportunities to convert the existing stormwater channels in Jeddah to green channels with additional, multiple functions assigned to each channel instead of one function (i.e. drain stormwater). Transforming Jeddah's stormwater channels into "green-fingers" could function as linear parks, a bioremediation facility for the municipal water of the city, socio-cultural attractive spaces, and also a potential for urban agriculture activities. Tahlia Channel revealed very promising opportunities and benefits of green channels that could change the world perception of public open spaces, especially in arid regions. The new trend of transforming stormwater channels into green channels can provide a new chapter of professional and research careers in new approached to what is landscape architecture. The feasibility of implementing green infrastructure practices in arid region shows there much left to be discovered and many questions left unanswered.

The thesis highlighted that a green centric open space system in arid regions is more sustainable, durable, and beneficial than a de-centric system. That is due to the scarcity of water resources in these regions. Centric open space systems can foster more optional and social activities, plus improve the city's health and economy, than a de-centric system. The trend of Jeddah's Municipality of "having a garden every week" can improve the health of neighborhood and might foster some social and optional activities. However, having these patches scattered inconsistently over Jeddah cannot generate the health and economy benefits of green channels. Currently, the walkway system of Jeddah's is below any sustainable standards (i.e., it does not exist or does exist in some places, but with poor conditions and/or an inconvenient environment) and does not encourage occupying these green patches (i.e. neighborhood gardens). Unlike these patches, which are considered a final destination (or they do not encourage active movements through the space), green channels would foster multiple moving activities (running, jogging, and walking) with an interactive landscape and physical environment (or scene changing). Neighborhood gardens require maintenance with low to minimum chances of investment activities around. On the other hand, linear parks are a combination of multiple gardens or patches linked together and could mean a variety of space activities and investments (see Figure 70 and Table 15) (see also Section 6.3.3.1 below).

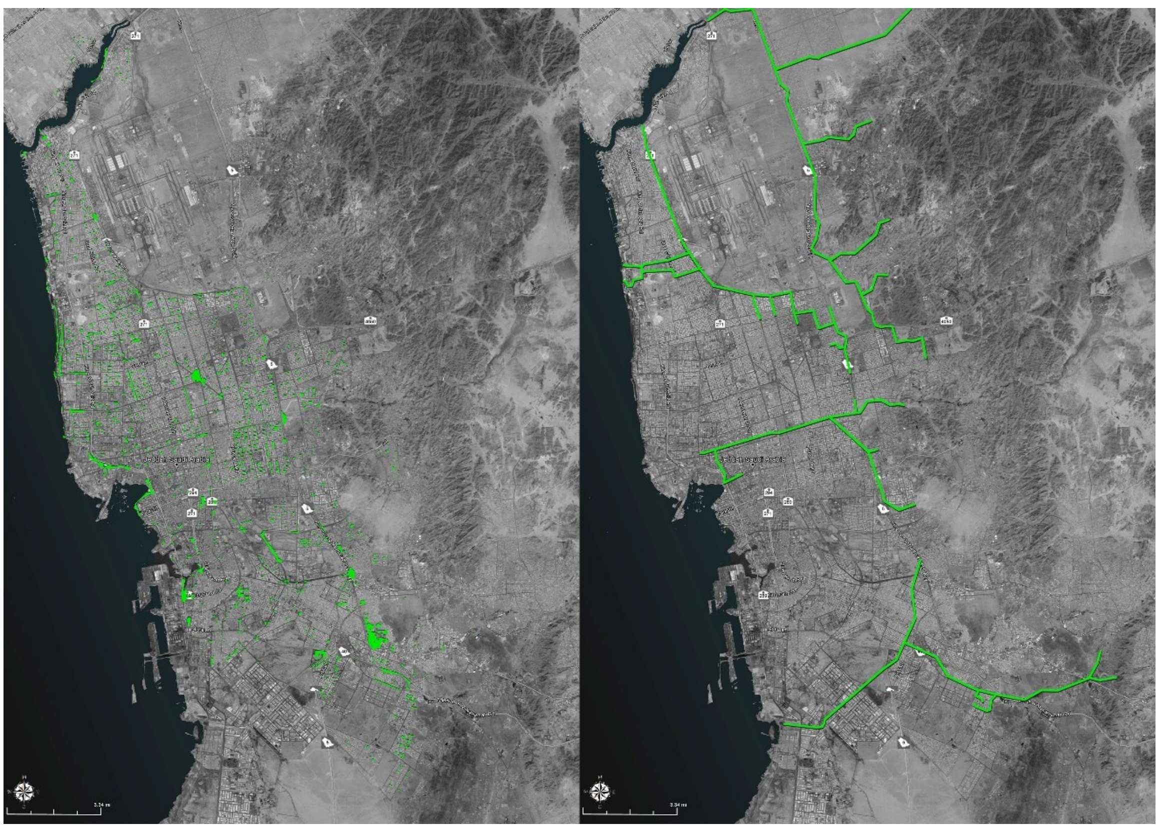


Figure 70 Centric & de-centric open spaces system efficiency comparison – open spaces owned by the government

(Source: author)

	Neighborhood garden	Green channel	Comparison factor
Society	low public health improvisation	high public health improvisation	movements rates
	low job opportunities	high job opportunities	investment opportunities
	low educational opportunities	high educational opportunities	space, activities, sources
	low food production opportunities	high food production opportunities	soil type, space, water source
Economy	low investment opportunities	high investment opportunities	space, activities, close attractions
	no tourism contribution	tourism contribution	space, activities attraction
	less activities	more activities	space, attraction
	slight increase in land value	great increase in land value	general potentials
	required many labor for maintenance for all gardens	required less number of labor to maintain	concentration of effort
	difficult to manage	easy to manage	concentration of effort
	more expenses	less expenses	labor number, maintenance
Environment	scattered patches	connected habitat	physical characterstics
	less sustainable	more sustainable	multiple benefits
design	does not motivate creativity	motivate creativity	potentials

Table 14 Comparison between centric (green channel) & de-centric system (neighborhood garden) (Source: author)

6.3.3.1 Expected Landscape Performance Benefits for Tahlia Channel

LAND

☑ Soil Creation ☑ Preservation & Restoration Others:

WATER

☑ Stormwater Managmnt ☑ Water Conservation ☑ Water Quality

☑ Flood Protection ✓ Water Body/Groundwater Recharge Others: Bioremediate municipal water

HABITAT

☑ Population & Species Richness

CARBON, ENERGY & AIR QUALITY

☒ Energy Use ☑ Air Quality ☑ Temprature & Urban Heat Island

☑ Carbon Sequestration & Aviodance Others:

MATERIALS & WASTE

☒ Reused/Recyled Materials ☑ Waste Reduction Others:

SOCIAL

☑ Recreational & Social Value ☑ Educational Value ✓ Food Production

Others:

ECONOMIC

☑ Property Values ☑ Operations & Maintenance Savings

☑ Construction Cost Savings Others: Improve tourism & tourism

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Toolkit Key

☑ **Exceed** ✓ **Satisfy** ☒ **Not satisfy, reduce, no info.**

6.3.3.2 Results and Reflection

Redeveloping a green channel requires symbiosis and synergy of different parties, in addition to collaborative regulations and work. Government, practitioners, ministries, and the public are all involved in the process of developing green channels before and after their construction. This section divides the duties and obligations of governments and individuals who aim to develop green channels. It represents executive, legislative and judicial authorities as summarized in Table 16. Recommendations in Table 16 were classified under two parts for existing and future developments surround the channels. The recommendation were adapted for the case of Jeddah City.

As part of the process of thinking and analyzing, a number of envisioned designs for possible activities and design implementation were developed during the process of completing this thesis, to give readers of what the author was thinking of during the whole journey of project (see Figures 71, 72 & 73). However, these envisioned designs are not a suggested final design to be constructed. Rather, they are a brainstorming of what might be done.

		Existing Development	Future Development	Comments
Policies & Physical Planning	Building Codes	All buildings close or far from channels must implement system to harvest water from roof tops.	Same implementations	To reduce the rates of water consumption.
		At the first phase of developing green channels, those buildings that are located in front of channels must provide separated system of gray & blackwater. This idea might be generalized for all the city in the future.	All future buildings must implement pipe system that separate gray from blackwater.	To help reduce the cost of wastewater treatment.
		All the existing buildings that are located in front of the channel must provide two separate cisterns to store the harvested rainwater by roof tops & the required graywater to supply the channels with needed water volume to maintain constant stream flow. These cisterns may be located over or underground depends on the need & potentials.	All future buildings must include two separated cisterns. One for graywater & the other for the harvested rainwater by roof tops.	To help reduce the cost of wastewater treatment & sea water desalination.
	Street	Provide metered parking spots & public parking buildings all over the channels sides based on needs.		To reduce urban run-off & cars gas & noise pollution chances, & to protect resident & pedestrians to increase walkability.
		Reduce the speed limits of the attached street to the channel to 25 mph posted on signs.		
	Vegetation	The planting of the channels must be designed based on requirements of shading, purification, ornamental or productive functions. A part of a channel may combine all, some or singular functions.		To reduce the required water-volume fro irrigation
		Develop different types of vegetation densities; low density for the areas or spots that are dedicated for walking, jogging and running, and high density for the area or spots that foster social gatherings and other activities that require remaining in one spot for leisure and recreation.		
		All channels must be protected by green buffer that helps remediate polluted water before release it to a stream of a developed green channel.		To protect the sea & stream marine lives from the temperature & pollution of urban run-off water.
		Using low water requirement plants in as much as possible, especially in areas where design dose not require ornamental & high-water-requirement plants.		
	Pavement	Taking into consideration impervious and light-colored materials.		To reduce surface run-off and increasing micro-temperature.
	Location	The wastewater treatment wetlands must be located in a higher altitude of a developed green channel in order.		To benefit form the gravity & avoid pumping system.
	Design Form	Any future design-proposal of water way in the green channels must implement design-lines that help reduce flooding velocity to the safe rate, process and treat the inland water before releasing to the proposed stream, using basins and terraces of plants and fish ponds.		The structure of these green channels will make them able to function as reservoirs to slow down and control flood in the bay in different levels.
	Standard	Create safe sidewalks along the channel and providing the surrounding buildings with safe crossing areas.		To protect, maintain & improve the performance & the health of green channels & community.
		Develop safe walking and bike trails.		
		Reduce the car lanes surround the channels to a maximum of two to three lanes, especially near resident & pedestrian crossing areas.		
		Provide the public with open-space amenities and utilities, like kiosks, shaded sitting areas, restrooms, amphitheaters, public art, educational activities, and so on.		
		Create a running stream and water activities that are safe for social interactions.		
		Create a running stream and water activities that are safe for social interactions.		
		Design a water quality volume treatment system to treat the surface run-off that drains from the urban areas to the channel by embracing green infrastructure practices, like bio-retention, bio-swale, rain-gardens, permeable pavement, bio-cells, green parking, green streets, infiltration trenches, and so on.		
	Universities	Researchers must contribute to all the required research of these green channels from all the aspects of environment, society & economy.		
		Practitioners & public must be educated about the importance of protecting these green channels and their important contribution & services that are provided to communities by academic & professional research & reports. Universities must provide programs that involve public in this educational process or system by providing public workshops & volunteer work for the cleaning & other missions related to the health of these channels.		
	Practitioners	A professional exam must be taken by all those who aim to work professionally right after achieving their degree that is related to the majors that are associated with green channels. For example, landscape architects and urban designers must pass qualification-exams of the profession, plus an additional exam for applicable GI practices in arid regions.		
	Schools	Educational programs & field trips to educate students and schools all based on proper knowledge for their ages.		To raise & educate the community from early ages about green principals & individual commitments toward protecting our environment
	H.Edu.	Scholarships & higher-education programs must encourage those research topics that are related to green channels		To create job opportunities.
Tourism	Program	Green channel protection & tourism activities programs must be also provided & sponsored by the Saudi Commission for Tourism & Antiquities		To create job opportunities & improve economy.
Organizations	Support	Founding & encouraging all the environmental, social or communal & other important organizations that are associated with green channel systems. For instance, the government can fund & help found the Saudi Society for Landscape Architects (SSLA) & Friends of Green Channels of Jeddah City (FGCJC) following the model of FoLAR (Friends of Los Angeles River) & so on.		To provide public proper knowledge about green channels & public commitments toward them
Economy	Investment	The government must provide activities & utilities that foster & encourage investment by all of economy levels of the community. For instance, creating social activities, providing stores, kiosks, & metered parking spots to help those who cant afford renting kiosks to bring their own certified food trucks & beverages.		To create job opportunities & improve economy.

Table 15 Summary of the thesis recommendations for developing green channels in arid region. Recommendations were developed for Jeddah City, Saudi Arabia (Source: author)

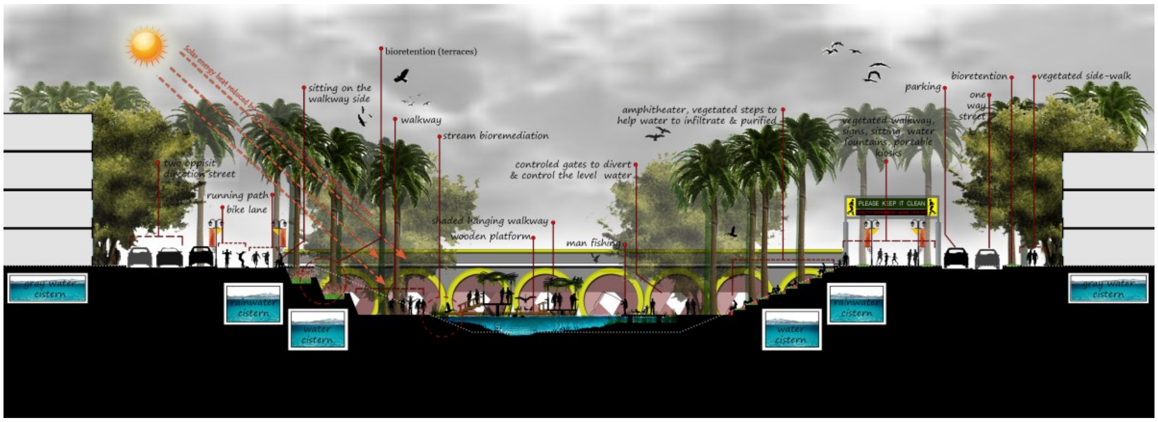

Figure 71 An envision of possible design and activates for A-7 – scenario 1 (Source: author)

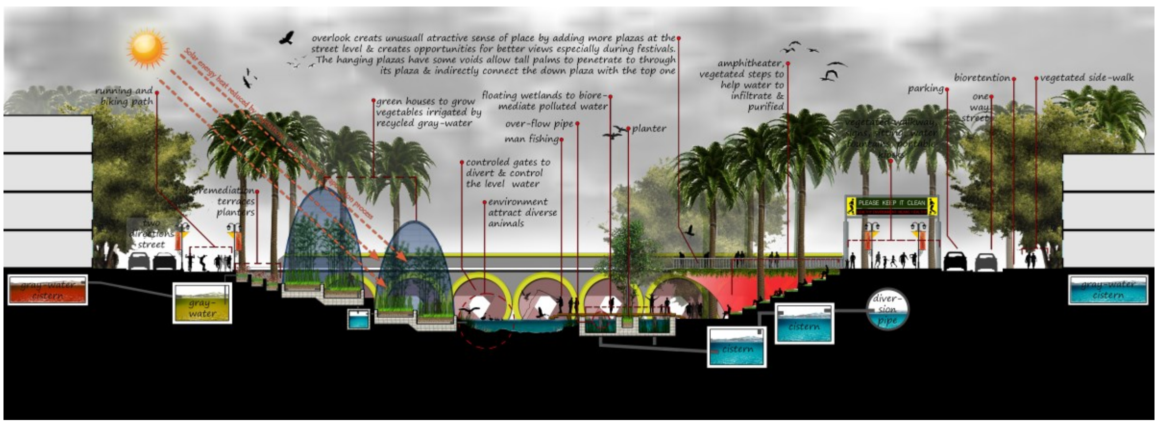

Figure 72 An envision of possible design and activates for A-7 – scenario 2 (Source: author)

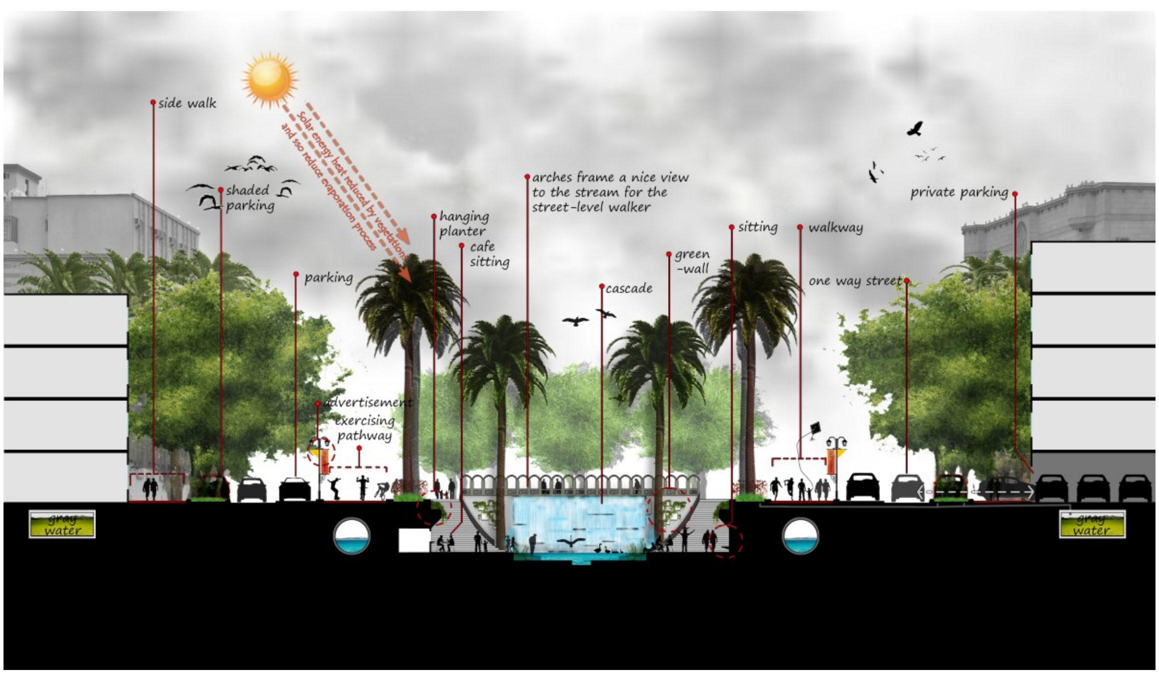

Figure 73 An envision of possible design and activates for A-1 – scenario 1 (Source: author)

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